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Dipterocarpaceous macrofossils from Churia Group of Arjun Khola area, western Nepal and their phytogeographical and palaeoclimatical implications

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ABSTRACT

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Investigation of plant megafossils collected from Churia Group of western Nepal revealed the presence of fossil wood, leaves and a fruit of a phytogeographically important genus, *Dipterocarpus* Gaertn. f. of the family Dipterocarpaceae. These have been described under the form species, *Dipterocarpoxylon siwalicus* Prakash, *Dipterocarpus suraikholaensis* Prasad and Pandey, and three new species namely *Dipterocarpus nepalensis* n. sp., *D. miocenicus* and *D. churiensis*. The analysis of present day distribution of extant species of *Dipterocarpus* comparable to the fossil remains indicates that they do not grow in the sub–himalayan zone of India and Nepal; instead they are presently distributed in the evergreen forests of South–east Asian region (Myanmar, Malaya, Java, Borneo, etc.). This suggests that after rise of Himalaya, drier conditions prevailed so that such species could no longer survive there. Based on the present and past distribution of the comparable extant species of *Dipterocarpus,* the phytogeography as well as migration of this genus has been discussed. The finding of dipterocarps in the Siwalik sediments of Himalayan foot hills of Nepal suggests that they have migrated from the South–east Asian region during early Miocene and later on became locally extinct due to prevailing of unfavourable condition. An attempt has also been made to categorize the already known species of *Dipterocarpoxylon* having almost similar anatomical features.

Key–words—Plant macrofossils, *Dipterocarpus, Dipterocarpoxylon* (Dipterocarpaceae), Churia Group (Upper Miocene), Arjunkhola, Western Nepal, Palaeoclimate, Phytogeography.

पश्चिमी नेपाल में अर्जुन खोला क्षेत्र के चुरिया समूह से प्राप्त डिप्टेरोकार्पेसीय गुरूजीवाश्मों एवं उनके पादपभौगोलीय व पुराजलवायु संबंधी निहितार्थ

महेश प्रसाद एवं सोमलता गौतम

सारांश

पश्चिमी नेपाल के चुरिया समूह से संगृहीत पादप गुरूजीवाश्मों पर अन्वेषण से डिप्टेरोकार्पेसी कुटुंब के पादपभौगोलीय रूप से महत्वपूर्ण वंश, *डिप्टेरोकार्पस* गेर्टन की काष्ठ, पत्तियों एवं फल के जीवाश्मों की विद्यमानता का पता चला है। इन सभी को रूप अधीन प्रजाति, *डिप्टेरोकार्पोक्सीलॉन सिवालिकस* प्रकाश, *डिप्टेरोकार्पस नेपालेन्सिस* नई प्रजाति *डी. सुरईखोलेन्सिस* प्रसाद एवं पांडेय, *डी मायोसेनिकस* नई प्रजाति एवं *डी. चुरिएन्सिस* नई प्रजाति के अंतर्गत वर्णित की गई हैं। जीवाश्म अवशेषों का *डिप्टेरोकार्पस* के तुलनीय रूपों का मौजूदा वितरण का विश्लेषण इंगित करता है कि कुटुंब की समस्त निहित जाति भारत और नेपाल के उप हिमालयी मंडल में नहीं उगती, वे वर्तमान रूप में दक्षिण–पूर्व एशियाई मंडल (म्याँमार, मलाया, जावा, बोर्नियो, इत्यादि) के सदाहरित वनों में वितरित हैं। यह जताता है कि हिमलयोत्थानोपरांत, शुष्कतर स्थिति व्याप्त थी जिसकी वजह से ऐसी आर्द्र प्रिय जाति वहाँ नहीं बच सकीं। *डिप्टेरोकार्पस* की तुल्य विहित जाति के मौजूदा एवं गत वितरण के आधार पर पादप भूगोल के साथ–साथ इस वंश के विस्थापन के पथ की भी चर्चा की गई है। नेपाल में हिमालयी गिरिपादों के शिवालिक अवसादों में डिप्टेरोकार्पों की प्राप्ति सुझाती है कि प्रारंभिक मध्यनूतन के दरम्यान ये दक्षिण–पूर्व एशियाई अंचल से विस्थापित हुए हैं तथा तत्पश्चात् अनुकूल स्थिति के विद्यमान होने की वजह से विलुप्त हो गए। लगभग सदृश शरीर रचना संबंधी लक्षणों वाले *डिप्टेरोकार्पोक्सीलॉन* की पहले से ही विख्यात जाति को वर्गीकृत करने का भी प्रयास किया गया है।

सूचक शब्द—पादप गुरूजीवाश्म, *डिप्टेरोकार्पस, डिप्टेरोकार्पोक्सीलॉन* (डिप्टेरोकार्पेसी), चुरिया समूह (मध्य–नूतन), अर्जुनखोला, पश्चिमी नेपाल, पुराजलवायु, पादप भूगोल।

INTRODUCTION

AN extensive area of southern Nepal in the foot–hills of Himalaya is covered with the deposits of sandstones, grits, conglomerates, pseudoconglomerates, clays and silts. These are known as Churia (Siwalik) beds and contain within them a rich and varied assemblage of flora and fauna. The flora abound angiospermous leaf, fruit and seed impressions and carbonised woods exposed at a number of localities such as Koilabas (Prasad *et al.,* 1999; Prasad & Dwivedi, 2008), Surai Khola (Prasad & Awasthi, 1996), Tinau Khola, Binai Khola and Butwal (Konomatsu & Awasthi, 1999), Arjun Khola (Prasad & Khare, 2004; Prasad, 2007), and Surkhet area (Prasad & Pradhan, 1998). The present investigation is, however, based on a collection of various plant megafossils from the Churia beds of Arjun Khola, western Nepal.

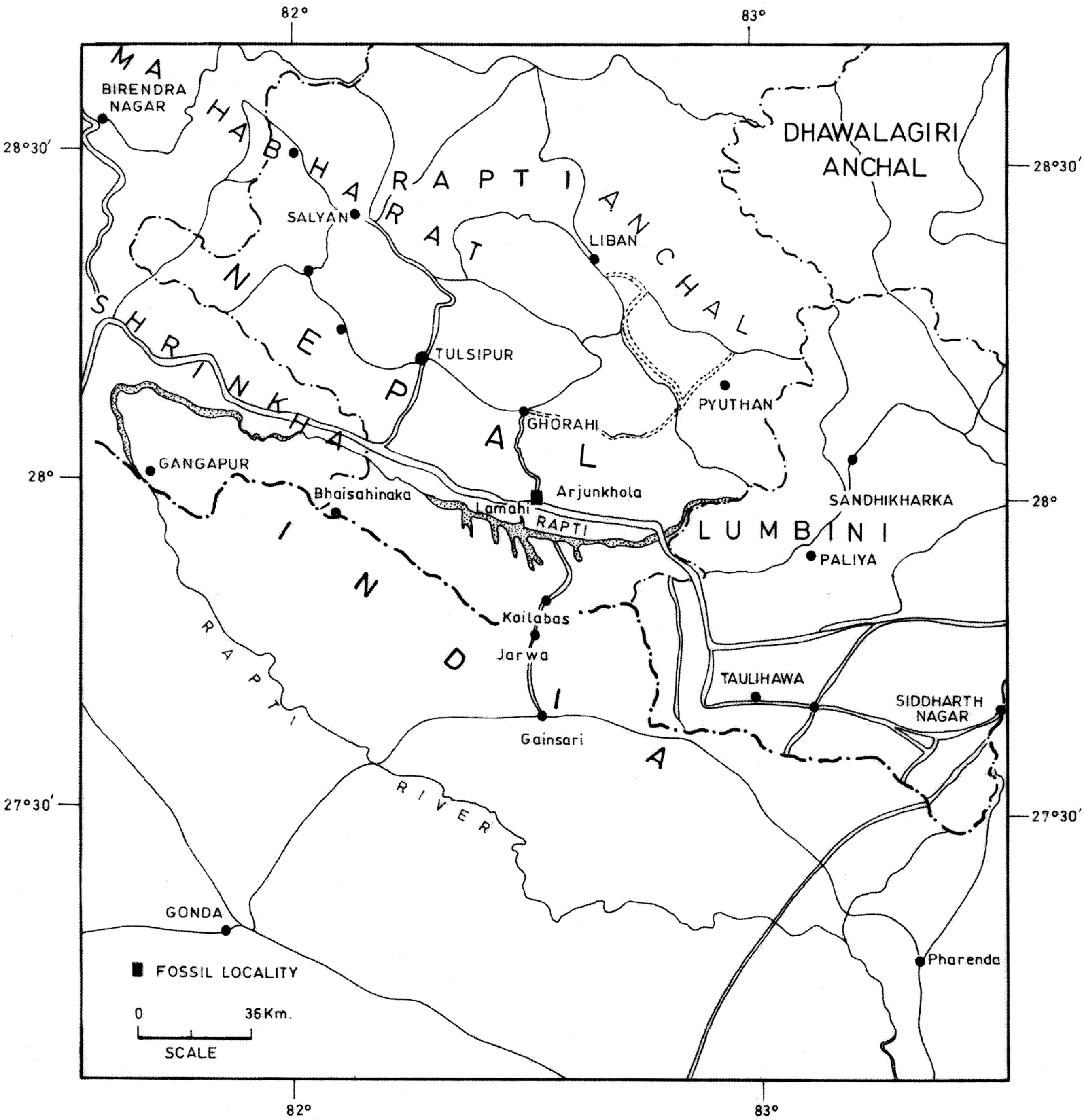

Fig. 1—Map showing the study area.

The fossil locality, Arjun Khola (27°53'2.8" N: 82°30'31.4" E) lies in the Dang District of Rapti Anchal, western Nepal and easily approachable by hard surfaced road originating from Mahendra Highway about 3 km west of Lamhi, a famous town of Deokhuri Valley (Fig. 1). A well developed Churia sequence belonging to Lower and Middle Churia Group exposed in Arjun Khola area all along the Arjun River and the road leading to Ghorai covering a distance of 15 km. The sediments consist of clays, shales, sandstones and siltstones. The shales containing well preserved leaf and fruit impressions are generally thinly bedded and splintery in nature. A large number of well preserved plant megafossils comprising carbonised to semi–silicified woods, leaf, fruit, seed and flower impressions have been collected from different profiles of this sequence. Although a rich collection of a variety of plant megafossils has been made mainly from the Lower and Middle Churia sediments of Arjun Khola sequence, only few of them have been described so far. Prasad and Khare (2004) have done the morphological and cuticular study of two leaf impressions resembling the extant taxa, *Sterculia coccinia* (Sterculiaceae) and *Diospyros toposia* Ham. (Ebenaceae) collected from profile 6 of Middle Churia Formation of Arjun Khola. Recently, Prasad (2007) described fossil wood and leaf impressions of tropical evergreen species, *Chrysophyllum roxburghii* G. Don (Sapotaceae) from the Arjun Khola sequence, western Nepal.

Further study on the plant megafossils from the Arjun Khola sequence revealed the presence of fossil wood, leaf and fruit impressions similar to the extant species, *Dipterocarpus indicus* Bedd., *D. alatus* Roxb. and *D. bourdillonii* Br. of the family Dipterocarpaceae which have been described and discussed in the present investigation.

GEOLOGICAL SETUP

The Churia Group is delimited on the South by the Main Frontal Thrust (MFT) and on the North by Main Boundary Thrust (MBT). It consists of basically of fluvial deposits of Neogene age (23 million years to1.6 million years old). This extends all along the Himalayas forming the southernmost hill range with width of 8–50 km. The general dip of the beds of the Churia Formation trends north wards with varying angles and the overall strike is East West. The study area of Arjun Khola falls in the Dang Section of western Nepal. An almost complete and uninterrupted sequence of the Churia Group is well exposed all along the road from Arjun Khola to Ghorai ranging in age from Middle Miocene–Middle Pleistocene (Figs 2, 3).

The detail lithology and stratigraphy of the Churia Group have been studied by Gleinnie and Ziegler (1964), Sharma (1980), Kumar and Gupta (1981), Chaudhuri (1983), Tokuoka *et al.* (1986), Corvinus (1990) and Appel *et al.* (1991). Gleinnie and Ziegler (1964) classified the Churia Group

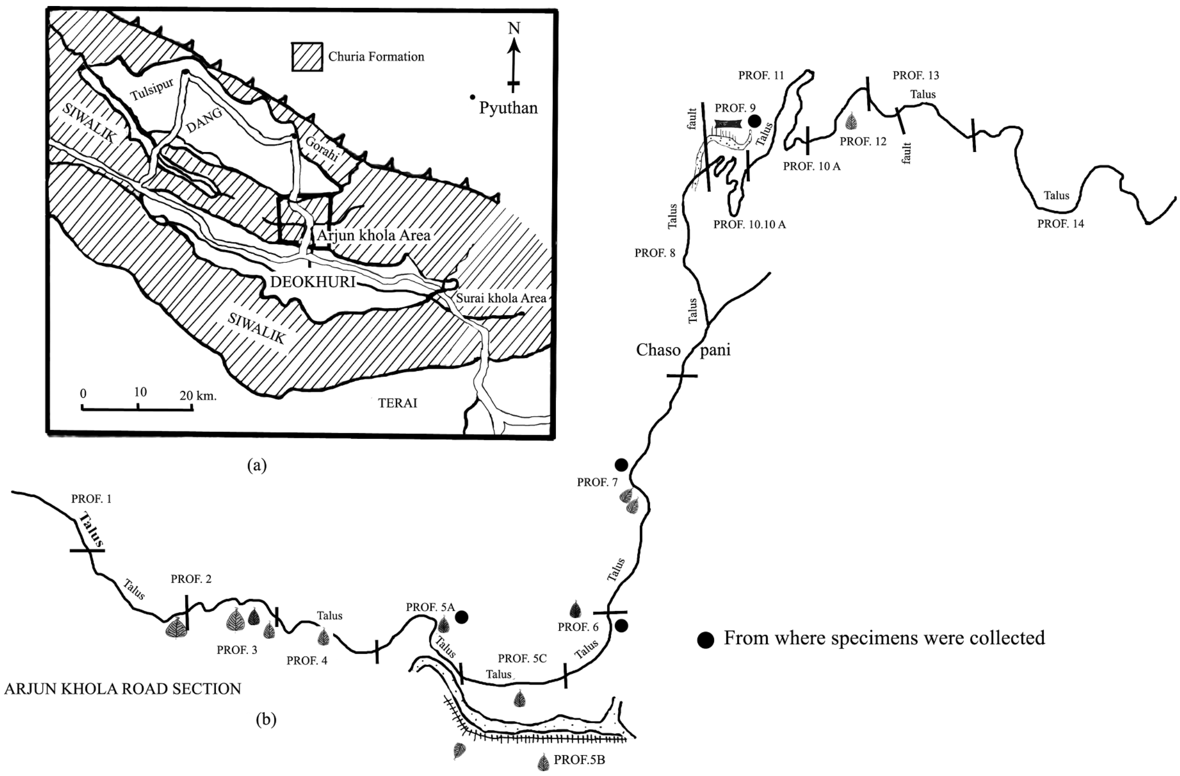

Fig. 2—(a) Map showing Churia Formation (Siwalik) in Nepal. (b) 14 profiles of Arjun Khola sequence, western Nepal showing fossil sites.

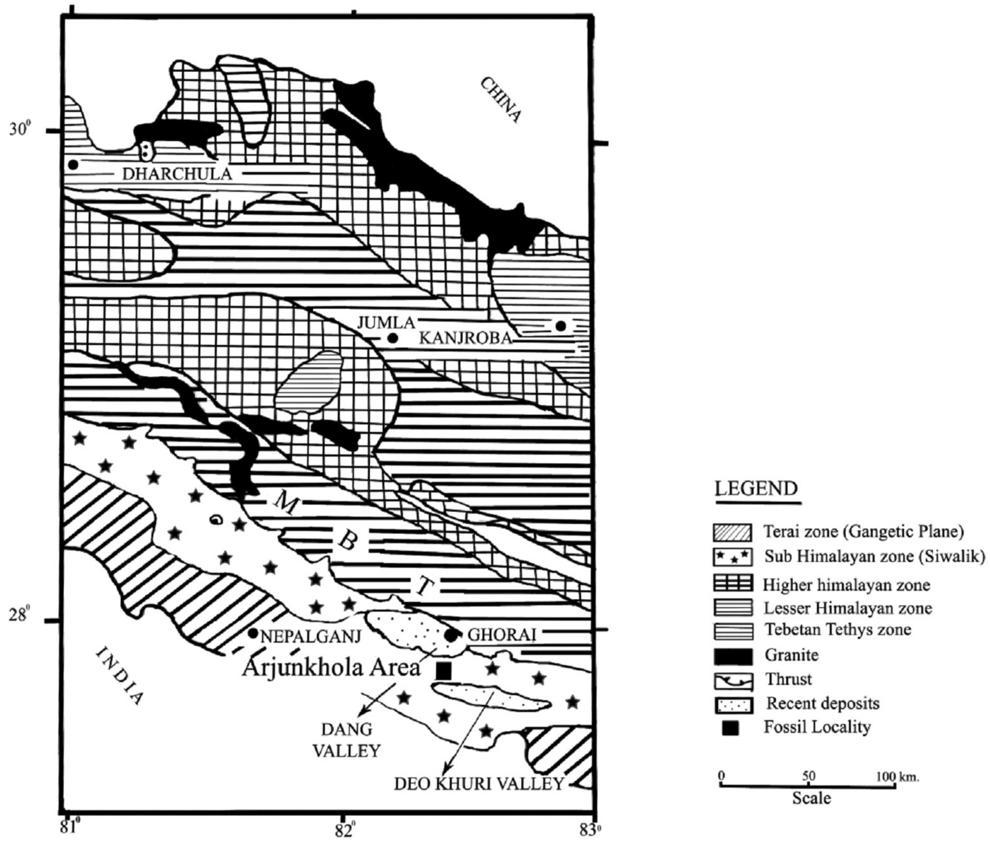

Fig. 3—Geological map showing Siwalik outcrop around fossil locality (after Upreti & Yoshida, 2005).

into two formations (1) Lower Churia Formation (Sandstone facies) and (2) Upper Churia Formation (Conglomerate facies). The sandstone facies very often contain plant fossils associated with group of palaeosols which developed during brief successive pause in sedimentation. However, a lithostratigraphical classification (Lower, Middle and Upper Formation) of the Churia Group in western Nepal Himalaya has been suggested by Chaudhuri (1983). The lower Churia Formation with an average thickness of about 1800 m is composed of fine grained green chlorite, biotite, muscovite and well bedded indurate sandstones and siltstones). The Middle Churia Formation is about 2000 m thick succession of dominantly arenaceous rocks with intercalation of clay beds while the Upper Churia Formation consist of up to 2500 m thick succession and characterized by fine grained, poorly indurate sandy clays in the lower part and boulder conglomerate in the upper part of the succession.

The Arjun Khola sequences mostly consist of molasses sediments of the Lower and Middle Churia Formation. The whole sequence is divided into 14 profiles on the basis of their lithological characters (Fig. 4a, b, c, d). There are more than 30 fossiliferous beds of mainly shales. Siltstones and few fine grained sandstones yielding a variety of well preserved leaf, fruit and flower impressions. The Lower Churia Formation comprises an alternation of sandstone and mudstone beds of almost same thickness while in the Middle Churia Formation the thickness of sandstone beds is greater than the mudstone beds.

MATERIAL AND METHOD

The specimens of semi–petrified fossil wood and leaf and fruit impressions were collected from Churia section exposed on Arjun Khola to Ghorai Road in Deokhuri District of western Nepal. The wood was collected from near profile 9 and fruit was from profile 6 while leaf impressions were collected from profile 5, 6 and 7 of Middle Churia Formation of Arjun Khola sequence (Fig. 4a, b, c, d). The fossil wood is small in size and brown in colour. It was sliced into thin pieces in different planes (TS, TLS, RLS) and then thin sections were prepared by grinding on disk using different grades of Carborundum grit. The wood sections were studied under a high power microscope and identified with the help of Xylarium at BSIP, Lucknow. The leaf and fruit impressions, preserved on purple/ grey shale were studied morphologically with the help of either hand lens or low power microscope with reflected light. The identification of leaf and fruit samples has been carried out at Central National Herbarium, Howrah, West

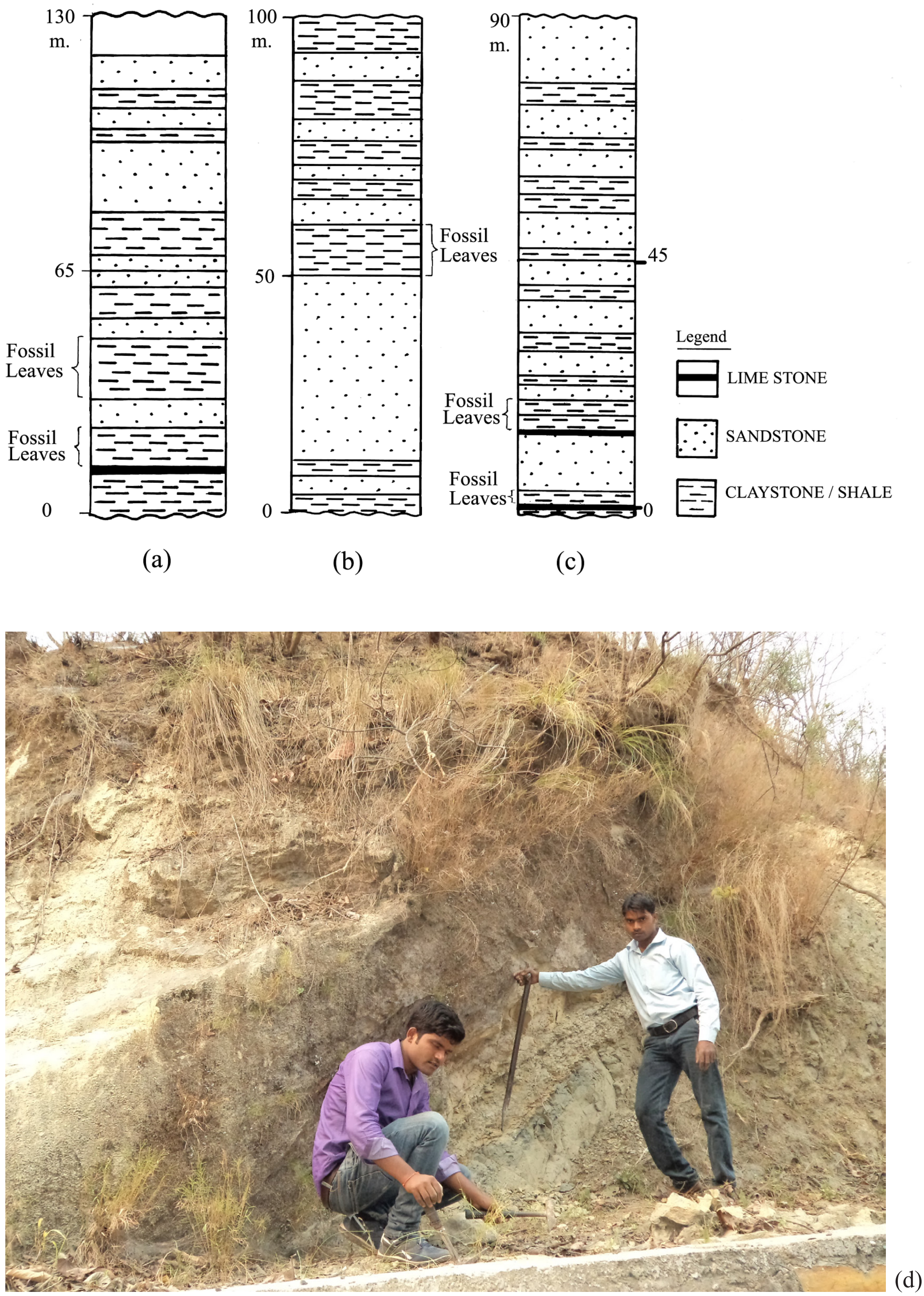

Fig. 4—(a) Litholog of profile 5A indicating occurrence of fossil leaves (*D. nepalensis* n. sp. and *D. suraikholaensis* Prasad & Pandey). (b) Litholog of profile 6 indicating occurrence of fossil leaves (*D. miocenicus* n. sp.). (c) Litholog of profile 7 indicating occurrence of fossil fruit (*D. churiensis* n. sp.). (d) Well exposed fossiliferous beds exposed in the section of profile 6 from where fossil leaf, *Dipterocarpus miocenicus* n. sp. and fruit *D. churiensis* n. sp. were collected.

Bengal. For the description of fossil leaves the terminology given by Hickey, 1973; Dilcher, 1974 and Ash *et al*., 1999 has been followed. All the fossil specimens and slides have been deposited in the Museum (Conservatory) of BSIP, Lucknow.

SYSTEMATICS OF FOSSIL WOOD

MALVALES Dumart

DIPTEROCARPACEAE Blume

DIPTEROCARPOXYLON Holden emend. DenBerger, 1927

Dipterocarpoxylon siwalicus Prakash, 1975

(Pl. 1.1–3)

1927 *Dipterocarpoxylon* Holden emend. DenBerger, p. 495
1975 *Dipterocarpoxylon siwalicus* Prakash, p. 193; Plate 1, Figs 1–3.

Description—

Wood—Diffuse–porous.

Growth rings—Indistinct.

Vessels—Mostly large, t.d. 150–230 µm, r.d. 165–395 µm, solitary, oval to sometimes elliptic due to pressure during fossilization, 6–8 per sq. mm, tyloses present, vessel members 180–570 µm long with truncate to tailed ends, perforations simple, intervessel pits not seen (Pl. 1.1).

Vasicentric trachieds—present, paratracheal, slightly bigger than neighboring parenchyma cells in cross section (Pl. 1.1).

Parenchyma—Mostly apotracheal, diffuse and diffuse aggregate and surrounding the gum canal, paratracheal parenchyma scanty, present around vessels, parenchyma cells also found around gum duct (Pl. 1.1).

Xylem rays—1–5 (6) seriate, 5–12 rays per mm, rays heterocellular, sheath cells generally present on the both flanks of the rays (Pl. 1.2, 3).

Fibres—Libriform, thick walled, nonseptate, interfibre pits could not be seen.

Gum canals—Vertical, solitary or in pairs, sometimes in short tangential bands of 2–4, uniformly distributed, small, 45–70 µm in diameter, round to oval in shape (Pl. 1.1).

Repository—Birbal Sahni Institute of Palaeobotany, Lucknow Museum No. 39880 (Figured specimen).

Horizon & Age—Middle Churia Formation, Upper Miocene.

Locality—Masotkhola (27º55'44.8" N: 82º20'8.1" E) near profile 9, Arjun Khola Sequence, Dang District, Rapti Anchal, western Nepal.

Number of specimen—1.

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

Fossil record and comparison–A large number of fossil woods belonging to the extant genus *Dipterocarpus* Gaertn.f. are known from Tertiary sediment of India and abroad (Tables 1, 2). Those most similar to the present fossil wood, mainly in the shape, size and distribution of vessels and in having 1–6 seriate xylem rays, are *Dipterocarpoxylon chowdhurii* Ghosh (1956) from Assam, *D. siwalicus* Prakash, 1975 from Siwalik of Nalagarh, Himachal Pradesh, *D. malvii* Ghosh & Ghosh (1959) from Kutch, *D. schenkii* Felix (Schweitzer, 1958) from the Tertiary of Java, *D. anisopteroides* (Schweitzer, 1958) from Tertiary of western Java and *D. javanicum* (Hofman) Schweitzer (1958) from Tertiary of western java (Table 2). Except *D. siwalicus* Prakash, the remaining fossil woods differ in possessing larger gum canals and slightly abundant parenchyma. Comparative study suggests that the present fossil wood shows closest affinity with *D. siwalicus* Prakash in shape, size and distribution of vessel and parenchyma nature of xylem rays and gum canals. The fibres in both of them are thick walled and non septate. The present fossil wood has been assigned under the same species *D. siwalicus* Prakash. Both *D. siwalicus* Prakash and the present fossil wood show affinity with the same modern wood *Dipterocarpus indicus* Bedd.

SYSTEMATICS OF FOSSIL LEAVES

MALVALES Dumart

DIPTEROCARPACEAE Blume

DIPTEROCARPUS Gaertn.f.

Dipterocarpus nepalensis n. sp.

(Pl. 1.4, 5)

Diagnosis—Leaf elliptic to oblong; size 12–22 x 9.5 cm; base obtuse, margin entire; venation pinnate, craspedodromous to eucamptodromous; primary vein prominent, stout; secondary veins about 15 pairs visible, 0.9 to 1.8 cm apart, alternate to sub–opposite, angle of divergence acute, 55–70º,

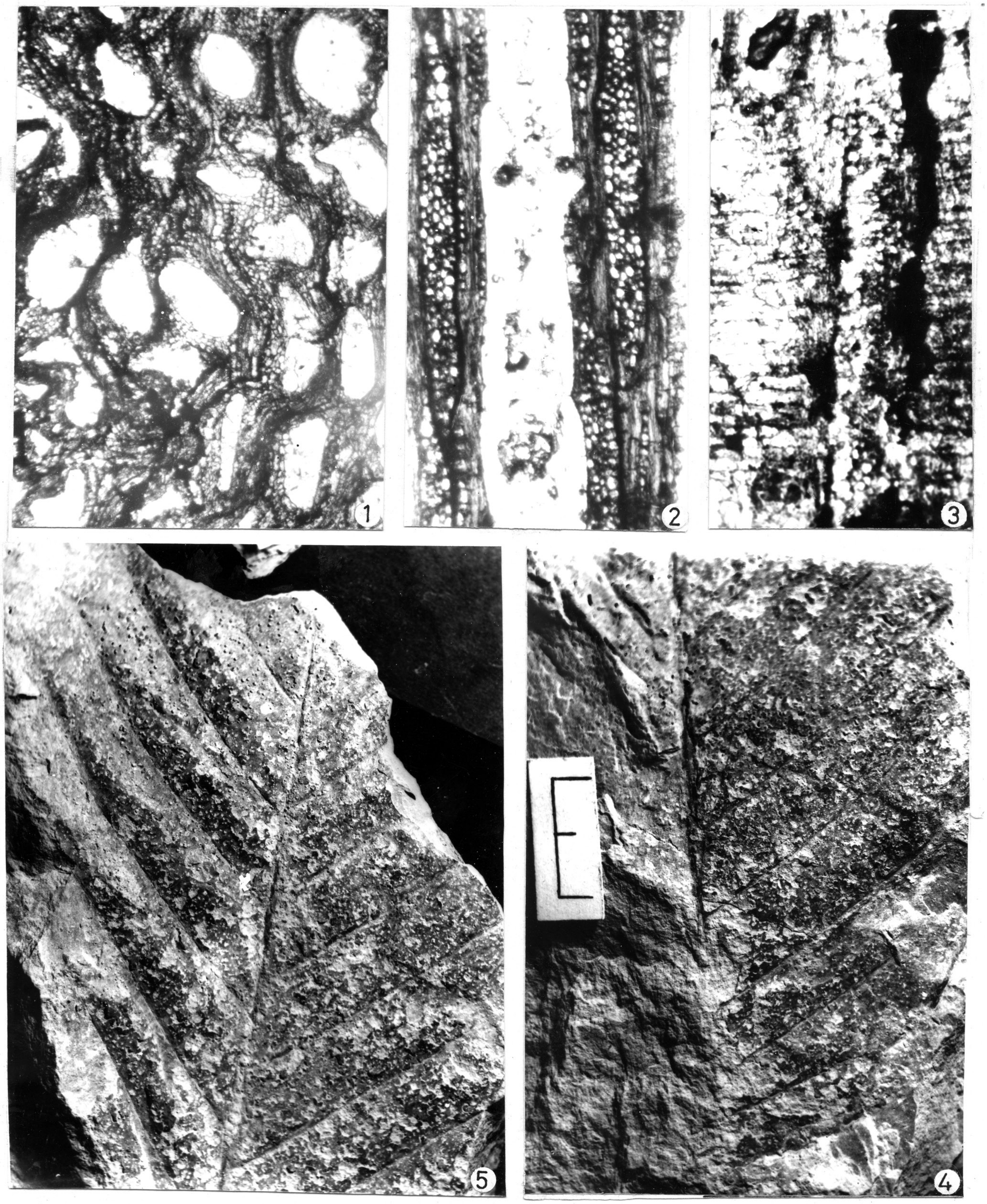

PLATE 1

Dipterocarpoxylon siwalicus Prakash

1. Cross section of the fossil wood showing nature of vessels, parenchyma and gum canals. x 60 (BSIP Museum Slide No. 39880–I).
2. Tangential longitudinal section of the fossil wood showing brand heterogeneous xylem rays with sheath cells at the both flanks of the rays. x 90 (BSIP Museum Slide No. 39880–II).
3. Radial longitudinal section of the fossil woods showing heterocellular xylem rays. x 90 (BSIP Museum Slide No. 39880–III).

Dipterocarpus nepalensis n. sp.

4, 5. Fossil leaves showing shape size and venation pattern (Basal and Apical part) x 1 (BSIP Museum Specimen No. 39881a, b, Holotype).

lower pair of secondary arise with greater angle, run almost straightly and curved near the margin; tertiary veins fine, angle of origin, RR to AO, percurrent, straight to sinuous, oblique, predominantly alternate and close.

Description—Leaf simple, symmetrical, elliptic to oblong; preserved size 22.0 x 9.0 cm and 12.0 x 9.5 cm; apex indistinct; base obtuse; margin seemingly entire; texture thick chartaceous; petiole not preserved; venation pinnate, craspedodromous to eucamptodromous; primary vein single, prominent, stout, almost straight; secondary veins about 15 pairs visible, 0.9 to 1.8 cm apart, alternate to sub–opposite, angle of divergence acute, 55–70º, lower pair of secondary arise with greater angle, run almost straight and curved near the margin, unbranched; tertiary veins fine, angle of origin, RR to AO, percurrent, straight to sinuous, branched, oblique in relation to midvein, predominantly alternate and close.

Repository—Birbal Sahni Institute of Palaeobotany, Lucknow Museum No. 39881 (Figured specimen).

Horizon & Age—Middle Churia Formation, Upper Miocene.

Locality—Profile 7 (27º55'29.7" N: 82º30'57.9" E), Arjun Khola Sequence, Dang District, Rapti Anchal, western Nepal.

Number of specimen—2.

Etymology—After the name of country 'Nepal'.

Affinity—The diagnostic features of the present fossil leaves are symmetrical, elliptic to oblong shape, obtuse shape, chartaceous texture, craspedodromous to eucamptodromous venation, acute angle of divergence of secondary veins and its curvature near the margin and closely placed, percurrent, straight sinuous tertiary veins correspond closely to the extant leaves of the genus *Dipterocarpus* Gaertn.f. of the family Dipterocarpaceae. A critical analysis of herbarium sheets of all the available species of this genus has been carried out in order to infer its specific affinities and found that the extant leaves of *D. indicus* Bedd. (Syn. *D. turbinatus* Dyer; C.N.H. Herbarium Sheet No. 69353) show the closest resemblance to the present fossil leaves. Several fossil leaves showing affinity with *Dipterocarpus* Gaertn. f. have been reported from the Tertiary sediments of both India and abroad. They include *Dipterocarpus antiquus* Heer and *D. tabuanus* and *D. nordenskioldi* (Geyler, 1887); *Phyllites dipterocarpoides* (Crie, 1888) from Pliocene of Java. *D. siwalicus* Lakhanpal & Guleria from different parts of Siwalik, viz. Jwalamukhi (Lakhanpal & Guleria, 1987), Koilabas (Prasad, 1990), Surai Khola (Awasthi & Prasad, 1990), Kathgodam (Prasad, 1994), Surkhet Valley (Prasad & Pradhan, 1998), Bhutan (Prasad & Tripathi, 2000), West Bengal (Antal & Prasad, 1996) and Kasauli Formation (Guleria *et al*., 2000). *D. koilabasensis* (Prasad *et al.*, 1999) from Siwalik of Koilabas, western Nepal. A detailed comparison of the present fossil leaves with the above known species indicates that it does not show similarity with any of them. The present fossil leaves differ from most of them in being large elliptic to oblong shape and acute angle of divergence and course of secondary veins. Therefore, these have been assigned to a new specific name *Dipterocarpus nepalensis*.

Dipterocarpus suraikholaensis Prasad & Pandey

(Pl. 2.1)

2008 *Dipterocarpus suraikholaensis* Prasad & Pandey, p. 22; Pl. 3, Fig. 1

Description—Leaf simple, symmetrical, elliptic; preserved size 14.5 x 8.0 cm; apex slightly broken; base indistinct; seemingly obtuse; margin entire to slightly undulated; texture coriaceous; petiole not reserved; venation pinnate, craspedodromous to eucamptodromous; primary vein single, prominent, stout, straight; secondary veins more than 16 pairs visible, 0.6 to 1.0 cm, mostly alternate, angle of divergence (55–60º), acute, moderate, unbranched, straight to uniformly curved up; tertiary veins fine, angle of origin usually RR, percurrent, straight, some times branched, oblique in relation to midveins, predominantly alternate and close.

Repository—Birbal Sahni Institute of Palaeobotany, Lucknow Museum No. 39882 (Figured specimen).

Horizon & Age—Middle Churia Formation, Upper Miocene.

Locality—Profile 5A (27º54'50.6" N: 82º31'00.4" E), Arjun Khola Sequence, Dang District, Rapti Anchal, western Nepal.

Number of specimen—1.

Affinity—The combination of symmetric, elliptic shape, obtuse base, slightly undulated margin, coriaceous texture, craspedodromous to eucamptodromous venation, and narrow acute angle of divergence of secondary veins with straight to uniformly curved course and RR, percurrent tertiary veins suggest that the fossil leaf is consistent with the features seen in the extant leaves of *Dipterocarpus* Gaertn. f. of the family Dipterocarpaceae. A critical examination of a large member of herbarium sheets of several extant species of this genus has been carried out and greatest similarities were found with the *Dipterocarpus alatus* Roxb. (C.N.H. Herbarium Sheet No. 50655).

Of all the known fossil species of the genus *Dipterocarpus* Gaertn. f. (mentioned earlier in the text) *D. suraikholaensis* Prasad & Pandey (2008) is very similar to the present fossil leaf in shape, size and venation pattern hence it has been described under the same species, *D. suraikholaensis* Prasad & Pandey.

Dipterocarpus miocenicus n. sp.

(Pls 3.1; 4.1)

Diagnosis—Leaf symmetrical, ovate, size 16.0 x 9.0 and 15.0 x 11.0 cm; acute; margin entire to undulated; venation craspedodromous; primary vein stout, straight; secondary

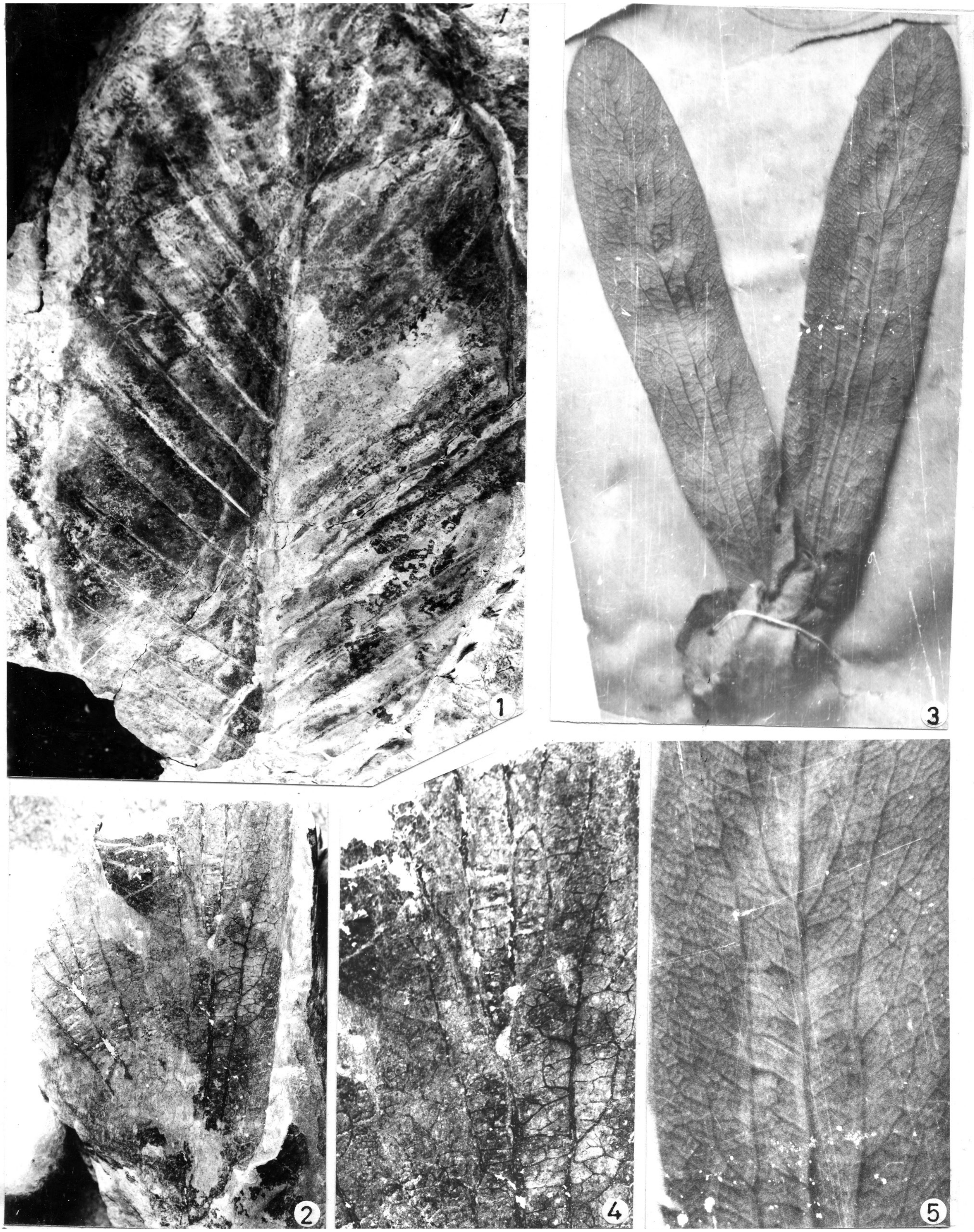

PLATE 2

Dipterocarpus suraikholaensis Prasad & Pandey

1. A fossil leaf showing shape, size and venation pattern. x 1 (BSIP Museum Specimen No. 39882).

Dipterocarpus churiensis n. sp.

2. A fossil fruit wing showing shape and size. x 1 (BSIP Museum Specimen No. 39884, Holotype).
3. A modern fruit wing showing similar shape and size. x 2.
4. A part of fossil fruit wing magnified to show the internal details. x 2.5.
5. A part of modern fruit wing magnified to show similar details. x 2.5.

PLATE 3

Dipterocarpus miocenicus n. sp.

1. A fossil leaf showing shape, size and venation pattern. x 1 (BSIP Museum Specimen No. 39883, Holotype).

veins 11 pairs visible, 1.0–1.8 cm. apart, upper secondaries closely placed, alternate to opposite, angle of divergence less than 50º, curved near the margin, tertiary veins fine, angle of origin usually RR, percurrent, almost straight, branched, predominantly alternate and close.

Description—Leaf simple, symmetrical, ovate, preserved size 16.0 x 9.0 and 15.0 x 11.0 cm; apex slightly broken, acute; base indistinct; margin entire to undulated; petiole not preserved; venation craspedodromous; primary vein single, prominent, stout, straight; secondary veins 11 pairs visible, 1.0–1.8 cm. apart, upper secondaries closely placed, alternate to opposite, angle of divergence less than 50º, narrow acute, run straightly and curved near the margin, unbranched; tertiary veins fine, angle of origin usually RR, percurrent, almost

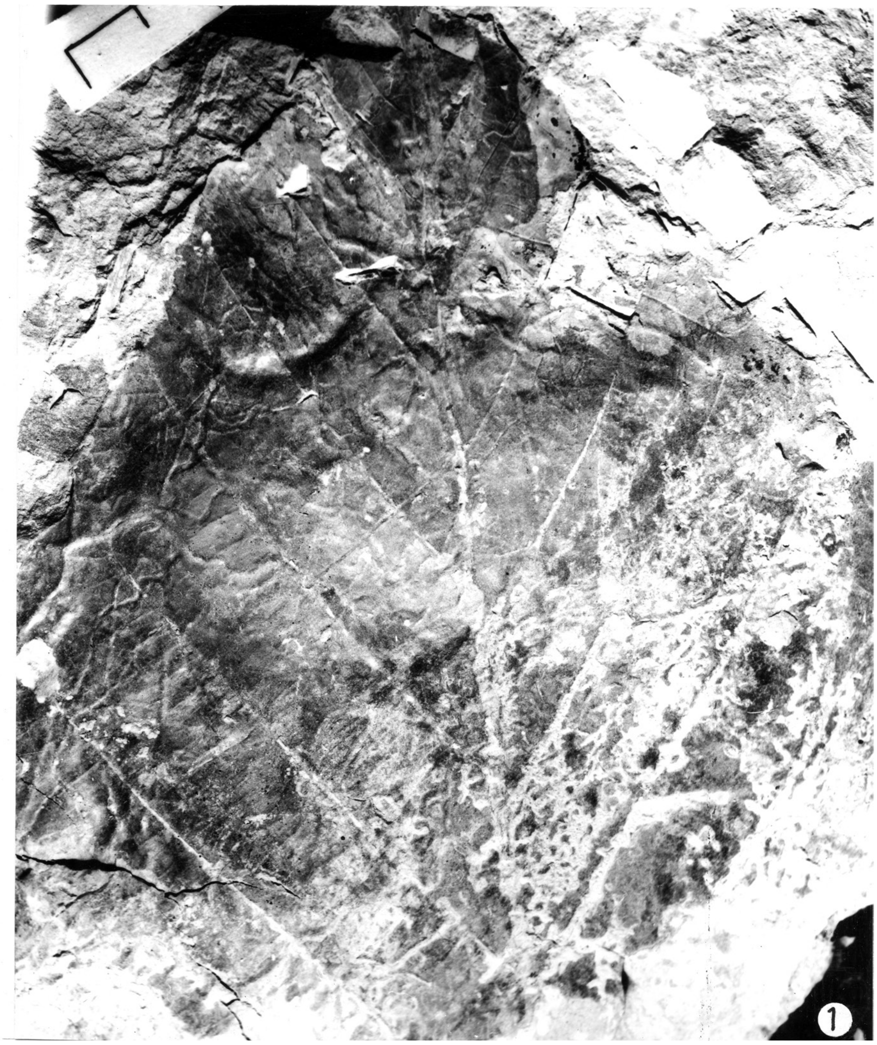

PLATE 4

1. *Dipterocarpus miocenicus* n. sp.–A fossil leaf showing apical part. x 1 (BSIP Museum Specimen No. 39883A, Holotype).

straight, sometimes branched, oblique in relation to mid vein, predominantly alternate and close.

Repository—Birbal Sahni Institute of Palaeobotany, Lucknow Museum No. 39883. (Holotype).

Horizon & Age—Middle Churia Formation, Upper Miocene.

Locality—Profile 6 (27º55'24.5" N: 82º31'01.3" E), Arjun Khola Sequence, Dang District, Rapti Anchal, western Nepal.

Number of specimen—2.

Etymology—After the Miocene age of sediments.

Affinity—The characteristic features of this species are ovate shape, seemingly acute base, entire to undulated margin, craspedodromous type of venation, closely placed apical secondaries, with narrow acute angle of divergence and its marked curvature near the margin and RR, percurrent, usually straight and branched tertiary veins. These features are found commonly in the extant leaves of the genus *Dipterocarpus* Gaertn. f. of the family Dipterocarpaceae. After going through of all the available extant species of *Dipterocarpus* Gaertn.f. it was observed that the fossil *Dipterocarpus miocenicus* leaves show closest similarity with the leaves of extant species *Dipterocarpus bourdillonii* (C.N.H. Herbarium Sheet Nos. 50051, 50768, 50651) in almost all the morphological characters. On comparison of this fossil species with the earlier known species (Table 2 and described in this text) it has been observed that these do not show similarity with any of them. *Dipterocarpus miocenicus* leaves differ mainly in being wide, ovate shape and angle of divergence of secondary veins. The secondaries are arising at very narrow acute angle and run almost straightly towards margin. The differences support its recognition as a new species.

SYSTEMATICS OF FOSSIL FRUIT WING

Dipterocarpus churiensis n. sp.

(Pl. 2.2, 4)

Diagnosis—Two wings joined at base; linear to lanceolate with three parallel primaries, size 6.0 x 2.0 cm; secondary veins arising from primaries at acute angle, opposite to alternate, tertiary veins percurrent, straight to slightly convex or nearly sinuous, quaternary veins fine, random reticulate.

Description—Wing or fruiting calyx two, joined at base, linear to lanceolate with three prominent longitudinal primaries (one middle and two laterals), running parallel, apical portion broken, preserved size of a wing 6 cm in length and 2 cm in width. Venation distinct, secondary veins arising from primaries at acute angle, opposite to alternate, tertiary veins opposite to alternate, percurrent, straight to slightly convex or nearly sinuous, quaternary veins fine, random reticulate.

Repository—Birbal Sahni Institute of Palaeobotany, Lucknow Museum No. 39884 (Holotype).

Horizon & Age—Middle Churia Formation, Upper Miocene.

Locality—Profile 6 (27º55'24.5" N: 82º31'01.3" E), Arjun Khola Sequence, Dang District, Rapti Anchal, western Nepal.

Number of specimen—1

Etymology—After Churia Formation to which fossil locality belongs.

Affinity—Two linear to lanceolate lobes with prominent primaries, acute angle of secondary veins, prominent straight to slightly convex and mainly sinuous tertiary veins and random reticulate quaternary veins of the fruit wing directly indicate its resemblance with the fruiting calyx lobes of the winged fruit of the genus Dipterocarpaceae. A survey of the herbarium sheets of a number of families and genera at Central National Herbarium, Howrah, West Bengal shows that winged fruit with persistent perianth lobes are also found in the genera, *Abelia* R. Brown (Caprifoliaceae), *Ancistrocladus* Wall. (Ancistrocladaceae), *Astronium* jacq. (Anacardiaceae), and *Porana* Burman (Convolvulaceae) but the present fossil differs from them because of its larger size. In order to find out its specific affinity, the available herbarium sheets of all the available species of this genus have been examined and we concluded that the fruit wing of the *Dipterocarpus bourdillonii* Br. (C.N.H. Herbarium Sheet No. 50051, Pl. 2 figs 3, 5) show closest affinity with the present fossil. So far, only one fruiting calyx resembling with the genus *Dipterocarpus* Gaertn. f. is known from the Middle Miocene of Fugian, China under the form species *D. zhangae* (Shi & Li, 2010) This can be differentiated from present fossil in having different shape, size and venation pattern. The basal part is also tapering gradually towards the base. Further it is oblanceolate in shape with longer size (13.35 x 2.25 cm). Feng *et al*. (2013) described a fossil winged fruit resembling a dipterocarpaceous genus *Shorea* Roxb. ex Gaertner from the Late Eocene of Maoning Basin, Guengdong Province South China under the form species, *Shorea maomingensis* Feng, Kedrul et Jin. This fruit is entirely different from the present fossil fruit in being presence of 9–18 primary (parallel) veins arising independently at the base.

PHYTOGEOGRAPHICAL AND PALAEOCLIMATICAL IMPLICATIONS

The present study on the plant fossils from Siwalik sediments of Arjun Khola area revealed the presence of fossil wood, leaf and fruit impressions belonging to the genus, *Dipterocarpus* Gaertn. f. which is important from phytogeographical point of view. The Dipterocarpaceae is a family of 17 genera approximately 500 species of mainly low land rain forests. It belongs specially to tropical Asia and about 350 species distributed in South–East Asia (India, Sri Lanka, Myanmar, Malaya, Philippines, Mollucca, Celebes and New Guinea. Besides, there are two genera, *Monotes* and *Marquesia* which are distributed in tropical Africa. At present, the Dipterocarpaceae has its maximum in number of species in Myanmar and Malaya peninsula. In the Indo–Malayan region the dipterocarps forests are characteristic of low altitudes growing in moisture region of well drained plains. The majority of species usually occur below 2000 feet.

Dipterocarpus Gaertn. f., with 69 extant species (Mabberley, 1997) is the third largest and most diverse genus among the family Dipterocarpaceae. The most species of this genus are centered round Borneo, Sumatra and the Malaya peninsula and the greatest diversity of *Dipterocarpus* species occurs in Borneo with many endemic to the Islands. The genus extends from the distribution centre eastwards to the Philippines into Siam, Indo–China, Myanmar, Bangladesh and further westwards to the Eastern Ghats to Travancore in South India and Sri Lanka. The extant species, *Dipterocarpus indicus* Bedd. (Syn. *D. turbinatus* Gaertn.f.) with which fossil wood and one of the leaves resembles closely is a large evergreen to semi–evergreen tree Indigenous with the area from India (Arunachal Pradesh, Assam, Manipur, Meghalaya, Tripura, Andaman Island and Nicobar Islands) Bangladesh, Myanmar, Thailand, Cambodia and Laos to Vietnam, Malaya peninsulas. The extant comparable species, *D. alatus* Roxb. of the fossil leaf is a evergreen to mixed deciduous tree commonly found to grow in Thailand, Cambodia Laos to Vietnam, Philippines and Malaya peninsula all along the banks of Dongani River and in Myanmar. All the three modern comparable species, i.e. *Dipterocarpus indicus* Bedd., *D. alatus* Roxb. and *D. bourdillonii* Br. of fossils do not grow now in the Siwalik region (Himalayan foot hills) but they are presently found to grow in the evergreen forests of South and Northeast parts of India and South–east Asian region. The

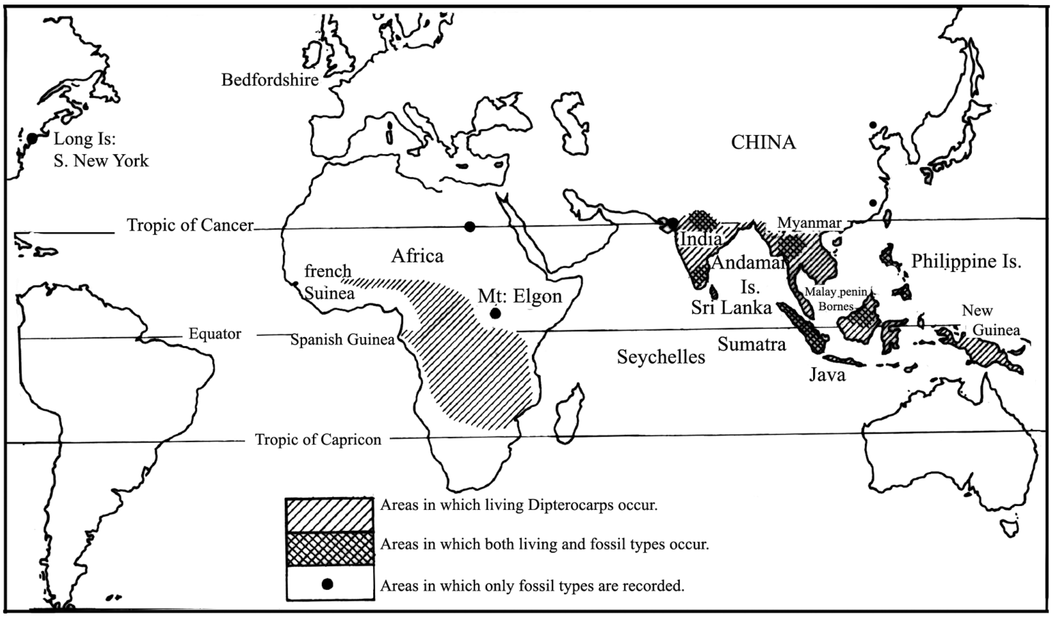

Fig. 5—Map showing present and past distribution of Dipterocarps in India and abroad.

presence of these dipterocarps in the Himalayan foot hills of Nepal during Miocene times indicates that the evergreen forest was flourishing there under warm humid condition as compared to mixed deciduous type of forest at present with reduced precipitation. Further, the finding of dipterocarps in the Siwalik sediments of Himalayan foot hills of Nepal suggests that they have migrated from the South–east Asian region during early Miocene and later on became extinct due to prevailing of unfavourable condition most probably due to uplift of Himalaya. Similarly the extant species, *D. bourdilioni* Br. with which one of the fossil leaves and fossil fruit wing show closest affinity is a species of large tree endemic to Western Ghats especially in the state of Kerala with one or two occurrences extending into Karnataka and Tamil Nadu in low land evergreen forests (Ashton, 1998).

From phytogeographical point of view, Dipterocarpaceae may be regarded as an important family. The present and past distribution of the family indicates that it is pan tropical and specially belongs to tropical Asia except that two genera *Marquesia* and *Monotes* which are distributed in the Africa regions. The fossil record suggests that Dipterocarpaceae originated during the early Middle Oligocene (Merril, 1923; Muller, 1970). Lakhanpal (1974) further envisaged that the family originated in western Malaysia, where about two third of all dipterocarps species occur today (Desch, 1957). This region is also quite rich in the fossil record (Lakhanpal, 1974; Bande & Prakash, 1986). From western Malaysia dipterocarps spread eastward to Philippines and northward through Myanmar to India. The possible time of the South–west migration was Early Miocene when the land connections between Malaya, Myanmar and eastern India were established. The abundance of dipterocarps such as *Dipterocarpus, Anisoptera, Isoptera, Shorea, Hopea, Dryobalanops* in eastern India as well as in southern India during Miocene–Pliocene times indicates that they spread from eastern India to south west to Sri Lanka via Himalayan foot–hills where they are still flourishing. The occurrence of dipterocarpaceous remains (fossil woods, leaves, fruits and impressions) in the Himalayan foot–hills (Prasad, 2008; Table–6) and the Tertiary beds of Africa (Bancroft, 1933; Chiarugi, 1933) suggest that from eastern India the dipterocarps also spread westward into Africa most probably via Arabia (Lakhanpal, 1970; Seward, 1935).

There are two conflicting hypotheses for the explanation of origin and phytogeography of the Asian dipterocarps (Merril, 1923; Ashton, 1982). One hypothesis says that the dipterocarps originated on the Eurasian Plate possibly in the Malaysian region and migrated westward and towards south Asia/ India and Africa during the late Cenozoic. This hypothesis is mainly based on assumption that highest modern species diversity might reflect area of origin of dipterocarps (Lakhanpal, 1970; Sasaki, 2006). The other hypothesis suggested that the dipterocarps originated in Gondwana (Croijat, 1952; Ashton, 1982) and reach Asia by rafting on the Indian Plate (Dayanandan *et al.,* 1999; Decuousso *et al.,* 2004). Moreover, the fossil resin chemistry and palynological data from 50 Ma old sediments suggest that the Asian dipterocarps migrated from India into Asia as the land connection between the Indian and the Asian Plate was established at ca. 50 Myrs ago (Scotese *et al.*, 1988; Rowly, 1996; Dutta *et al.*, 2011). Conti *et al.* (2002) also opined that many of the Angiosperms did not originate in the South–east Asian region but dispersed into the area from western Gondwana land. This view is strongly supported by the earliest record of fossil dipterocarps from Oligocene sediments

Table 1—Fossil records of *Dipterocarpus* Gaertn. f. from Tertiary sediments of India and abroad.

Fossil Taxa	Horizon/Age	Locality	Reference
Dipterocarpoxylon acrotense Awasthi	Cuddalore Series, Mio–Pliocene	Murattandichavade Near Pondicherry, South India	Awasthi, 1980
D. bolpurense Ghosh & Roy	Upper Miocene Tipam Series, Upper Miocene Namsang Bed, Upper Miocene–Pliocene	Santiniketan, Birbhum District, West Bengal Bisalgarh, near Agartala, Tripura Deomali, Arunachal Pradesh	Ghosh & Roy, 1979 Mehrotra & Bhattacharyya, 2002 Awasthi & Mehrotra, 1993
D. kalagarhensis Trivedi & Ahuja	Lower Siwalik, Middle Miocene	Kalagarh, U.P.	Trivedi & Ahuja, 1980
D. malavii Ghosh & Ghosh	Pliocene	Mothala District, Kachchh	Ghosh & Ghosh, 1959
D. malavii Ghosh & Ghosh	Kankavati Series, Pliocene	Kutch, Gujarat	Guleria, 1983
D. malavii Ghosh & Ghosh	Lower Lalgarh Formation	Silai River section, West Bengal	Bera & Banerjee, 1990
D. kalaicharparense Eyde	Middle Tertiary Tippam Series, Upper Miocene	Garo Hills Meghalaya Namchik River beds, Tirap District, Arunachal Pradesh	Eyde, 1963 Awasthi & Mehrotra, 1997
D. kalaicharparense Eyde	Tippam Series, Upper Miocene	Jairampur, Jirap Distt., Arunachal Pradesh	Awasthi & Mehrotra, 1997
D. nalagarhense Prakash	L. Siwalik, Middle Miocene	Khokhra, near Nalagarh, Himachal Pradesh	Prakash, 1975
D. nungarhense Trivedi & Ahuja	Lower Siwalik, Middle Miocene	Nungarh Nala, Kalagarh, U.P.	Trivedi & Ahuja, 1980
D. parabaudii Prakash	Lower–Middle Siwalik, Middle Mio–Pliocene	Kalagarh, U.P.	Prakash, 1978
D. parabaudii Prakash	Lower Siwalik, Middle Miocene	Laxmi River Section, Bhutan	Prasad & Tripathi, 2000
D. pondicherriense Awasthi	Cuddalore Series, Miocene–Pliocene	Pondichery, South India	Awasthi, 1974
D. pondicherriense Awasthi	Kankavati Series, Pliocene	Kutch, Gujarat	Guleria, 1983
D. premacrocarpum Prakash	Lower Siwalik, Middle Miocene	Khokhra, near Nalagarh, Himachal Pradesh	Prakash, 1975
D. siwalicus Prakash	Lower Siwalik, Middle Miocene	Khokhra, near Nalagarh, Himachal Pradesh	Prakash, 1975
D. surengei Prakash	Lower Middle Siwalik, Middle Miocene–Pliocene	Kalagarh U.P., Pauri Garhwal	Prakash, 1981
Dipterocarpoxylon sp. Rawat	Middle Siwalik Series, Upper Miocene–Pliocene	Mohand, U.P.	Rawat, 1964
Dipterocarpoxylon cuddalorense Navale	Cuddalore Series Mio–Pliocene	Near Pondicherry, South India	Navale, 1963
Fossil wood cf. *Dipterocarpus* sp. Navale	Miocene	Neyveli Lignite deposits, South India	Navale, 1963

Fossil wood cf. *Dipterocarpus* sp. Navale	Miocene	Neyveli Lignite deposits, South India	Navale, 1974
Fossil wood cf *Dipterocarpus turbinatus* Guleria	Mar Formation, Plio–Pleistocene	Bikaner, Rajasthan	Guleria, 1996
Fossil wood cf. *Dipterocarpus* sp. Guleria	Shumar Formation	Jaisalmer District, Rajasthan	Guleria, 1986
Fossil wood cf. *Dipterocarpus* sp. Antal *et al.*	Lower Siwalik, Middle Miocene	Oodlabari, Darjeeling District, West Bengal	Antal *et al.*, 1999
Fossil wood cf. *Dipterocarpus* sp. Prasad & Khare	Middle Siwalik, Mio–Pliocene	Haridwar, U.P.	Prasad & Khare, 1994
Dipterocarpus siwalicus Lakhanpal & Guleria	Lower Siwalik, Middle–Miocene	Balugoloa near Jawalamukhi, H.P.	Lakhanpal & Guleria, 1987
Dipterocarpus siwalicus Lakhanpal & Guleria	Middle Siwalik, Mio–Pliocene	Oodlabari, Darjeeling District, West Bengal	Antal & Prasad, 1996
	Lower Siwalik, Middle–Miocene	Balia River Section, Kathgodam, U.P.	Prasad, 1994
	Lower Siwalik, Middle–Miocene	Koilabas, Nepal	Prasad, 1990
	Lower Siwalik, Middle–Miocene	Suraikhola, Nepal	Awasthi & Prasad, 1990
	Lower Siwalik, Middle–Miocene	Laxmi River Section, Bhutan	Prasad & Tripathi, 2000
	Middle Siwalik Series, Mio–Pliocene	Surkhet area, Far western Nepal	Prasad & Pradhan, 1998
Dipterocarpus koilabasensis Prasad *et al.*	Lower Siwalik, Middle–Miocene	Koilabas, Nepal	Prasad *et al.,* 1999
Dipterocarpoxylon goepperti Krausel	Tertiary	Western Java	Schweitzer, 1958
D. krauseli (DenBerger) Edwards	Pliocene	Western Java	Schweitzer, 1958
D. schenki (Felix) Schweitzer	Tertiary	Western Java	Schweitzer, 1958
D. resiniferum Schweitzer	Pliocene	Western Java	Schweitzer, 1958
D. porosum Krausel	Upper Cretaceuos	England	Schweitzer, 1958
D. javanicum (Hofman) Schweitzer	Tertiary	Western Java	Schweitzer, 1958
D. gracile Schweitzer	Pliocene	Western Java	Schweitzer, 1958
D. perforatum Schweitzer	Quaternary	Sumatra	Schweitzer, 1958
D. anisopteroides Schweitzer	Pliocene	Western Java	Schweitzer, 1958

Dipterocarpoxylon sp. Schweitzer	Tertiary	Java & Sumatra	Schweitzer, 1958
Dipterocarpus antiqus Heer,	Tertiary	Sumatra	Heer, 1883
D. atavinus Heer	Tertiary	Sumatra	Heer, 1883
Phyllites dipterocarpoides Crie	Pliocene	Western Java	Crie, 1888
Dipterocarpus nordenskioldi Geyler	Tertiary	Sumatra	Krausel, 1929
Dipterocarpus labuanus Krausel	Tertiary	Sumatra	Krausel, 1929
Dipterocarpaciophyllum sumatrense Krausel	Tertiary	Sumatra	Krausel, 1929
Dipterocarpus Verbekianus (fruit) Heer	Tertiary	Sumatra	Heer, 1874
Pollen of *Dipterocarpus* and *Dryobalanops*	Tertiary and Quaternary	N.W. Borneo	Muller, 1964
Dipterocarpoxylon tertiarum Prakash,	Mio–Pliocene	Myanmar	Prakash, 1973
D. chowdhurii Prakash,	Mio–Pliocene	Myanmar	Prakash, 1973
Dipterocarpoxylon africanum Bancraft	Tertiary	Near Mount Elgon, East Africa	Bancraft, 1933
Dipterocarpoxylon africanum Schweitzer	Plio–Plistocene	Somali and East Africa	Schweitzer, 1958
Dipterocarpophyllum humei	Nubian Sandstone, Tertiary	Egypt	Schweitzer, 1958
D. zeraibense Schweitzer	Nubian Sandstone, Tertiary	Egypt	Schweitzer, 1958
D. scevelianum	Tertiary	East Africa	Chiarugi, 1933
D. giubense	Tertiary	East Africa	Chiarugi, 1933
D. somalense	Plio–Pleistocene	East Africa	Chiarugi, 1933

(34–24 Ma) of Borneo, a centre of presently high diversity of dipterocarps with more than 280 species (Muller, 1981). According to Morley (2000) the dipterocarps originated within the Late Cretaceous rain forest of Africa or South America before they split. Like the rain forest, the Dipterocarpaceae probably also experienced widespread expansion under the climatic optimum from the Palaeocene to the Middle Eocene. The diversification and dispersal of the dipterocarps in Africa and South America are rarely documented in the fossil record (Ashton, 1982) perhaps due to the unfavourable depositional environment. The earliest fossil record of this family is based on resin and pollen grain from early Eocene of western India. (Dutta *et al*., 2011) indicates the wide spread existence of the Asian sub family Dipterocarpoideae in the early Eocene extremely equatorial climate of the Indian Plate prior to the early Eocene collision of India with Asia (Morley, 2000; Copley *et al*., 2010). Due to climatic change during the Late Eocene and Oligocene the diversification of dipterocarps decreases across the Indian sub continent. (Morley, 2000). The occurrence of fossil leaves of *Dipterocarpus* in the early Miocene sediments of North west India (Guleria *et al*., 2000) indicates the continuity of this family from Oligocene. In the Middle Miocene climate became warmer and moister due to uplift of the Himalaya (Morley, 2000) and became suitable for a drastic increase in their species diversity and became a dominant group in the forests of the Indian sub continent as evidenced by geological distribution and diversification during Miocene period (Prasad, 2008; Guleria, 1992). On increasing aridity and seasonality after Late Miocene and Pliocene the climatic conditions became unsuitable for the growth of dipterocarps and thus started towards their gradual disappearance along with the other moist loving species of

Angiosperms form the most part of India (Except South and North–east India) (Morley, 2000; Prasad, 2008). The record of the most of the species in our findings also supports this view.

REASSESSMENT ON THE STATUS OF *DIPTEROCARPOXYLON* SPECIES

Several fossil woods have now been referred to the form genus *Dipterocarpoxylon* Holden emend. Denberger, 1927. In 1916, Holden instituted the form genus *Diptercarpoxylon* for the petrified woods showing affinity with family Dipterocarpaceae. He coined the named *Dipterocarpoxylon burmense* for a wood specimen collected from Tertiary sediment of Burma. However, on the basis of mainly two facts, first the presence of exclusively uniseriate rays and secondly the doubtful occurrence of gum canals, this fossil wood do not shows resemblance with any typical Asiatic members of Dipterocarpaceae. It is supposed to belong instead to the genus *Gluta* Linn. of the family Anacardiaceae and consequently kept under the form genus *Glutoxylon* Chowdhury (Chowdhury, 1952). In 1929, DenBerger emended the generic diagnosis of *Dipterocarpoxylon* Holden to restrict the usage of this form genus for the fossil woods of Dipterocarpaceae comprising only two anatomically similar genera *Dipterocarpus* Gaertn.f. and *Anisoptera* Korth. Out of 32 species *Dipterocarpoxylon* listed in Table 3 only two, i.e. *Dipterocarpoxylon performatum* (Schweitzer, 1958) and *Dipterocarpoxylon anisopteroides* (Schweitzer, 1958) have been assigned to the fossil woods of the genus *Anisoptera* Korth. Ghosh and Kazmi 1958 further instituted the form genus *Anisopteroxylon* to assign the fossil woods of the genus *Anisoptera* Korth. as they have separated these two genera anatomically. Thus, the form genus *Dipterocarpoxylon* Holden emend. DenBerger became restricted for the fossil wood of only the genus *Dipterocarpus* Gaertn. f.

Some of the *Dipterocarpoxylon* species enumerated here show marked difference in their anatomical features. The anatomical features of two fossil woods, *Dipterocarpoxylon indicum* Ramanujam 1956 and *D. cuddalorense* Navale (1963) described from Tertiary sediments of south India have been critically evaluated and revised their affinity (Awasthi 1965). Accordingly *Dipterocarpoxylon indicum* Ramanujam is a fossil wood of *Dryobalanops* Gaertn. f. of the same family and *D. cuddalorense* Navale is of the genus *Terminalia* Linn. of the family Combretaceae. Likewise, the fossil wood of *Dipterocarpoxylon holdenii* Gupta 1935 known from the Tertiary of Burma is characterized by banded parenchyma and the absence of gum canals and showing its affinity among the family Fabaceae (Prakash, 1973).

An attempt has been made to analyze the anatomical features (xylem rays, vessels, gum canals, parenchyma, fibre, etc.) of all the species of *Dipterocarpoxylon* Holden emend. DenBerger in order to categorize these species in the some distinct groups. The xylem rays are the most distinguishable features considered during the identification of fossil woods. *Dipterocarpoxylon pondicherriense* Awasthi, *D. parabaudii* Prakash, *D. premacrocarpum* Prakash, *D. kalaicherparense* Eyde, *D. krauselii* Schweitzer, *D. gracile* Schweitzer and *D. africanum* Schweitzer possess 1–5 (mostly 3–4) seriate heterogeneous xylem rays and the vessels are medium to large sized (225–370 µm) except in *D. kalaicharparense* where the vessels are small to medium (68–225 µm). The gum canals are usually small to medium sized in almost all the above species. In the second group, there are about 12 species which are with 1–6 (3–5) seriate xylem rays. These are *Dipterocarpoxylon chowdhurii* Ghosh, *D. tertiarum* Guleria, *D. siwalicus* Prakash, *D. kalagarhensis* Yadav, *D. arcotense* Awasthi, *D. jammuense* Guleria & Srivastava, *D. nungarhense* Prakash, *D. malvaii* Ghosh & Ghosh, *D. Schenkii* Schweitzer, *D. somalense* Chiarugi, *Dipterocarpoxylon* sp. Antal & Prasad and *Dipterocarpoxylon* sp. Prasad & Khare. Of these two species *D. somalense* Chiarugi and *Dipterocarpoxylon* sp. Antal & Prasad possess medium sized vessel (100–180 µm) while the remaining species have small to large vessels (80–300 µm). In these species, the gum canals are small to medium sized (45–180 µm) except *Dipterocarpoxylon arcotense* Awasthi which possesses medium to large canals, usually bigger than the vessels.

Dipterocarpoxylon tertiarum Prakash and *D. porosum* Schweitzer can be categorize separately as these possess 1–9 and 1–7 heterogeneous xylem rays respectively and the vessels in both of them are larger (30–315 µm).

Of these, only four species *Dipterocarpoxylon surengei* Prakash, *D. nalagarhensis* Prakash, *D. geoppertii* Schweitzer and *D. javanicum* Schweitzer are possessing 1–8 (mostly 5–7) seriate xylem rays along with usually medium sized (105–300 µm) vessels.

The gum canals are mostly small to medium sized in all of them except in the fossil wood of *D. surengei* Prakash where the gum canals are bigger than vessels thus this can be treated as distinct group from them. Similarly *Dipterocarpoxylon bolpurense* Mehrotra & Bhattacharyya, *D. resiniferum* Schweitzer and *D. giubense* Chiarugi are characterized by the presence of 1–4 seriate heterogeneous xylem rays along with usually medium to large sized vessels and small to medium sized gum canals. Lastly *Dipterocarpoxylon scevelianum* Chiarugi has very thin 1–3 seriate heterogeneous xylem rays with medium sized vessels and gum canals. It is entirely different from the already known species of *Dipterocarpoxylon*. Further, it may not be belongs to the genus *Dipterocarpus* Gaertn.f.

Parenchyma is another distinguishing anatomical characters utilized in the identification of fossil woods. Both, paratracheal and apotracheal parenchyma are found in the almost all species of *Dipterocarpoxylon* (Holden) DenBerger. Paratracheal parenchyma are generally scanty to vasicentric while the apotracheal parenchyma are diffuse and diffuse in aggregate and around the either solitary or short tangential

Table 2—Comparative chart showing the anatomical features of different *Dipterocarpoxylon* species known from Tertiary sediments of India and abroad.

Name of the Taxa	Wood	Growth rings	Vessels	Parenchyma	Vasicentric tracheids	Rays	Fibres	Gum cannal
Dipterocarpoxylon pondicherriense Awasthi, 1974	Diffuse porous	Absent	Medium to large, t.d. 120–370 µm, r.d. 150–345 µm, exclusively solitary, 3–8 vessels per sq. mm, tylosed, vessel members, 300–750 µm in length, pits 6–10 µm	Paratracheal and apotracheal, paratracheal parenchyma occasionally aliform, apotracheal parenchyma associated with gum canals	Present, 16–56 µm in diameter, paratracheal	1–5 (mostly 3–4), heterogeneous, 10–50 cells in height	Angular to hexa gonal, 16–38 µm in diameter, non septate, thick walled	Frequent, vertical, solitary or in pairs as well as short tangential rows of 3–8, circular, upto 120 µm in diameter
D. tertiarum Prakash, 1965, Prakash, 1973,	Diffuse porous	Absent	Exclusively solitary medium to large 3–5 per sq. mm, tylosed, t.d. 135–315 µm, r.d. 150–420 µm, vessel members 150–600 µm, pits about 8 µm, alternate and bordered	Apotracheal and paratracheal, apotracheal diffuse to diffuse in aggregate and around gum canals, paratracheal parenchyma around the vessels	Present, Sparse, paratracheal	1–9 (mostly 5–7 seriate), heterogeneous,10–80 cells in height	Thick walled, non septate	Abundant, vertical, single or paired, sometimes in short tangential rows, 70–120 µm in diameter
D. chowdhurii Ghosh, 1956, Prakash, 1973,	Diffuse porous	Absent	Large to medium sized, almost always solitary, occasionally in pairs, 6–8 per sq. mm, tylosed, t.d. 165–225, r.d. 240–375 µm, vessel members 255–675 µm long, pit pairs 6–8 µm in diameter, bordered and alternate with linear apertures.	Mostly apotracheal, diffuse and in irregular broken lines and around gum canals, paratracheal parenchyma scanty, 16–30 µm in diameter, 76–150 µm	Present around the vessel	1–6 (mostly 4–5 seriate), 90–2250 µm in length, 6–9 rays per mm, heterogeneous	Libriform, thick walled, 12–20 µm in diameter, 960–1120 µm in length	Abundant, solitary and often in pairs and in tangential rows of 2–5, 80–160 µm in diameter
D. tertiarum Prakash, 1965, Guleria, 1996,	Diffuse porous	Absent	Small to large, t.d. 100–300 µm, r.d. 150–400 µm, tylosed, exclusively solitary, vessel member 250–700 µm long	Paratracheal and apotacheal, paratracheal 1–3 cells thick around the vessels, sometimes aliform, apotracheal parenchyma abundant, diffuse to diffuse in aggregate, 20–36 µm in diameter	Present in the vicinity of vessel,	1–6 (mostly 4–5 seriate), 5–60 cell in height, 4–6 per mm, heterogeneous	Thick walled, non septate	Frequent, vertical, solitary or in pairs, 70–130 µm in diameter
Dipterocarpus sp. Antal, Prasad & Khare, 1999	Diffuse porous	Absent	Small to medium, t.d. 120–180 µm, r.d. 160–210 µm, mostly solitary, 25–30 per sq. mm, tylosed, vessel members 150–600 µm long, pits 4–6 µm in diameter	Paratracheal and apotracheal, abundant diffuse to diffuse in aggregate and around the gum canals, paratracheal scanty to vasicentric	Present, paratracheal	1–6 (mostly 4) seriate, 3–35 cells in height, up to 1100 µm in length, heterogeneous	Angular, thick walled, non septate	Vertical, solitary or in pairs and sometimes in short tangential rows of 2–4, 65–110 µm in diameter
D. kalagarhensis Yadav, 1989	Diffuse porous	Absent	Medium to large, mostly solitary, tylosed, t.d. 116–224 µm, r.d. 184–320 µm, vessel members 240–480 µm long, pits bordered	Paratracheal scanty, apotracheal parenchyma abundant, diffuse and diffuse in aggregate, terminal, in uniseriate lines and surrounding gum canals, 18–74 µm in diameter, 68–240 µm in length	Sparse, associated with vessels, 75–40 µm	1–6 (4–5 seriate), 5–40 cells in height, 120–1540 µm in length, heterogeneous	Polygonal, 24–35 µm, thick walled.	Vertical, abundant single or usually in pairs, 88–180 µm in diameter

D. arcotense Awasthi, 1980, Prasad, 1993	Diffuse porous	Indistinct	Small to large, t. d. 78–208 µm, r.d. 104–234 µm, exclusively solitary, tylosed, vessel members 200–700 µm, pits 4–8 µm, vestured, alternate	Paratracheal and apotracheal, paratracheal scanty to vasicentric, forming 1–4 seriate, sheath, apotracheal quit abundant, diffuse and diffuse in aggregate, often forming 1–2 seriate sheath around gum canals, 20–30 µm in diameter	Sparse, around vessels	1–6 (mostly 4–5 seriate), 3–33 cells in height, 180–840 µm in length, 6–9 rays per mm, heterogeneous	Aligned in radial rows, angular, 18–24 µm, non septate	Normal, vertical, in pairs as well as in short tangential rows of 2–7, larger than vessels, 130–260 µm in diameter.
D. parabaudii Prakash, 1978	Diffuse porous	Absent	Medium to large, t.d. 165–330 µm, r.d. 135–405 µm, solitary, tylosed, vessel members 270–570 µm long	Paratracheal and apotracheal, paratracheal quit scanty around the vessels, apotracheal parenchyma usually in thick layers of cells around the gum canals, some times diffuse and diffuse in aggregated, 20–28 µm in diameter	Scanty, paratracheal	1–5 (usually 3–4 seriate), 8–53 cells in height, 375–1425 µm in length,7–9 per mm, heterogeneous	Libriform, non septate, 12–16 µm in diameter, 795–1245 µm in length	Abundant, vertical solitary in pairs or tangential rows of 3–5, 75–165 µm in diameter
D. surengei Prakash, 1981	Diffuse porous	Absent	Mostly large, t.d. 128–290 µm, r.d. 128–352, solitary, 4–6 per sq. mm, tylosed, vessel members 320–640 µm long	Apotracheal parenchyma abundant, diffuse and diffuse in aggregate, some times, forming short tangential lines and also around gum canals, paratracheal parenchyma scanty, around the vessels, 16–20 µm in diameter, 48–248 µm in height	Sparse, paratracheal	1–8 (mostly 5–7 seriate), 160–1620 µm high, heterogeneous	Libriform, thick walled, non septate, 800–1200 µm long, 12–24 µm in diameter	Large, vertical, bigger than vessels, single or in pairs and short tangential rows of 3–5, 240–440 µm in diameter
D. bolpurense Ghosh & Roy, Mehrotra & Bhattacharyya, 2002	Diffuse porous	Absent	Medium to large, t.d. 100–250 µm, r.d. 150–330 µm, exclusively solitary, 5–11, sq. per mm, tylosed, vessel members 180–440 µm in height, pits about 10 µm in diameter	Paratracheal and apotracheal, paratracheal scanty to vasicentric, apotracheal diffuse and in short tangential bands enclosing the vessels	Paratracheal, around vessel	1–4 seriate, 4–6 per mm, 15–20 cells or 500–1100 µm in height, heterogeneous	Thick walled, 12–18 µm in diameter, non sepate	Gum canals normal, vertical, scattered and in group of 2–4, t.d. 80–110 µm, smaller than vessels
D. jammuense Guleria & Srivastava, 2001	Diffuse porous	Not seen	Small to large, t.d. 80–260 µm, r.d. 100–360 µm, almost solitary, 3–9 per sq. mm, vessel members 140–600 µm long	Paratracheal and apotracheal, paratracheal vasicentric, apotracheal scanty, only a few diffuse cells, also forming sheath around gum canals	Intermingled with parenchymatous cells around the vessel	1–6 (mostly 3–5 seriate), 5–9 ray per mm, 5–45 cells or 200–1260 µm high, heterogeneous	Semi libriform, non septate, pitted	Vertical, solitary or in tangential group of 2–4 (rarely 5), smaller than vessels, 65–80 µm in diameter
D. siwalicus Prakash, 1975	Diffuse porous	Absent	Mostly large, t.d. 160–240 µm, r.d. 180–400 µm, always solitary, 5–7 per sq. mm, tylosed, vessel members 160–500 µm long	Mostly apotracheal as diffuse, solitary cells, sometimes diffues and diffuse in aggregate, paratracheal parenchyma scanty	Sparse, paratracheal	1–5 (rarely 6 seriate), 7–14 per mm, heterogeneous	Thick walled, non septate	Abundant, vertical, 40–68 µm in diameter, solitary or pairs and in tangential rows of 3–6
D. nalagarhense Prakash, 1975	Diffuse porous	Absent	Large to medium sized, t.d. 105–255 µm, r.d. 150–360 µm, mostly solitary, 4–6 per sq. mm, tylosed, vessel members 210–525 µm in length	Mostly apotracheal as diffuse to diffuse in aggregate forming short, 1–2 seriate lines, and also surrounding the gum canals	Sparse, associated with vessels	1–8 seriate, 225–1425 µm high, 4–7 rays per mm, heterogeneous	Thick walled, non septate	Vertical, single or in pairs, occasionally in short tangential rows of 3–4 (5), t.d. 90–200 µm

D. premacrocarpum Prakash 1975	Diffuse porous	Absent	Large to medium, t.d. 150–270 µm, r.d. 180–230 µm, solitary, 4–6 per sq. mm, tylosed, vessel members 150–600 µm in length	Mostly apotracheal as diffuse cells, some times forming short lines and also enclosing gum canals	Sparse, paratracheal	1–5 seriate, 6–10 rays per mm, 225–1575 µm in height, heterogeneous	Thick walled, non septate	Vertical, solitary or in tangential rows of 3, t.d. 135–225 µm
D. nungarhense Trivedi & Ahuja, 1980	Diffuse porous	Absent	Medium to large, t.d. 110–175µm, r.d. 198–308 µm, 8–15 per sq. mm, usually solitary, vessel members 800–1848 µm	Paratracheal and apotracheal, paratracheal parenchyma vasicentric to confluent, apotracheal parenchyma diffuse and around the gum canals	Intermingled with parenchyma around vessels	1–6 (mostly 3–5) seriate heterogeneous 13–22 cells or 492–792 µm high	Thick walled, non septate	Vertical, single or in pairs and in short tangential rows of 3, t.d. 57–88 µm, r.d. 132–154 µm
Dipterocarpoxylon sp. Prasad & Khare, 1994	Diffuse porous	Indistinct	Small to large, t.d. 80–210 µm, paired or in radial multiples of 2–3, 10–20 per sq. mm, tylosed, vessel members 170–800 µm, pit pairs 4–8 µm	Paratracheal and apotracheal, paratracheal scanty to vasicentric, apotracheal quite abundant, diffuse to diffuse in aggregate, 1–2 seriate short lines, also enclosing the gum canals	Present	1–6 (mostly 3–4 seriate), 3–46 cells or 105–1200 µm in height, heterogeneous	Thick walled, non septate, 16–20 µm in diameter	Normal, vertical solitary, paired or in tangential rows of 2–6, 75–105 µm in diameter
D. malvaii Ghosh & Ghosh, 1959; Guleria, 1983	Diffuse porous	Absent	Small to large, t.d. 94–240 µm, r.d. 160–360 µm, exclusively solitary, 6–7 per sq. mm, tyloses absent, gummy deposits present, vessel members 240–440 µm, pits vestured, 4–6 µm in diameter	Paratracheal and apotracheal, paratracheal parenchyma sparse, intermingled with vasicentric parenchyma, apotracheal parenchyma diffuse and associated with gum canals, sometimes enclosing neighbouring gum canals form 3–6 seriate bands	Present	1–6 (mostly 4–5 seriate), 12–75 cells or 325–1920 µm in height, heterogeneous, sheath cells occasionally present	Thick walled, non septate with fibre tracheids	Abundant, diffuse scanty, or in pairs, usually 3–11 gum canal in a row, t.d. 64–144 µm, r.d. 96–160 µm, 4–7 per sq. mm
D. kalaicharparense Eyde, 1963	Diffuse porous	Indistinct	Mostly large, t.d. 68–225 µm, r.d. 255–300 µm, 5–7 per sq. mm, tyloses absent, some times with dark content, vessel members 300–675 µm in length.	Paratracheal and aprotracheal, paratracheal scanty to vasicentric, apotracheal parenchyma aggregate and short confluent bands enclosing gum canals	Not distinguishable	1–5 (mostly 3–4 seriate), 7–43 cells or 375–1500 µm in height	Thick walled, non septate	solitary, paired or in short tangential rows
D. cuddalorense Navale, 1963	Diffuse porous	Indistinct	Large, solitary or in group of two, tylosed, vessel members medium in length	Paratracheal vasicentric, few layers around the vessels, apotracheal parenchyma diffuse and associated with the gum canals	–	Mostly uniseriate, 6–15 cells high, heterogeneous	Thick walled, non septate	Solitary, sometimes in group, smaller than vessels
D. goeppertii Krausel; Schweitzer,1958	Diffuse porous	Absent	Mostly solitary, very large in size, 7–8 per sq. mm, tylosed, mostly 300 µm in diameter	Paratracheal and apotracheal, paratracheal vasicentric associated with vessels, apotracheal diffuse and diffuse in aggregate and enclosing the gum canals	Present	1–8 (mostly 6–7 seriate), 3–45 cells in height ± homogeneous	Thick walled, non septate	Solitary, small, 50–80 µm in diameter
D. krauselii DenBerger; Schweitzer,1958	Diffuse porous	Absent	Mostly solitary, very large, t.d. 150–300 µm, r.d. 200–425 µm	Paratracheal and apotracheal, paratracheal sparse, apotracheal diffuse to diffuse in aggregate and enclosing the gum canals with thick bands of parenchyma	Present	1–5 (mostly 3–4 seriate), 4–85 cells in height, ± homogeneous	Thick walled, non septate	2–3 gum canals in group, small, 75–100 µm in diameter
D. porosum Krausel; Schweitzer,1958	Diffuse porous	Absent	Very large, solitary and in multiple of 2–3, 6–7 per sq. mm, t.d. 250–300 µm, r.d. 400–600 µm	Paratracheal parenchyma sparse and vasicentric, apotracheal parenchyma diffuse and diffuse in aggregate and enclosing the gum canals with thick boundaries	Present	1–7 (mostly 6–7) seriate, 7–50 cells in height, heterogeneous	Thick walled, non septate	Small, 65–80 µm in diameter

D. schenkii Felix Schweitzer, 1958	Diffuse porous	Absent	Large, solitary or in 2–3 multiples, t.d. 125–250 µm, r.d. 300–600 µm, 4–7 per sq. mm	Apotracheal parenchyma in short bands enclosing the gum canals and diffuse and diffuse in aggregate, paratracheal sparse, vasicentric	Present	1–6 (mostly 5–6) seriate, 30–50 cells in height, heterogeneous	Thick walled, non septate	80–110 µm in diameter
D. resiniferum Schweitzer, 1958	Diffuse porous	Absent	Medium to large, solitary and multiples of 2–3, t.d. 150–300 µm, 5–6 per sq. mm	Paratracheal parenchyma sparse and vasicentric apotracheal parenchyma in bands enclosing the gum canals		1–4 seriate, 40–50 cells in height, homogeneous (heterogeneous)	Thick walled, non septate	2–7 gum canal in tangential line, 100–125 µm in diameter
D. javanicum (Hofman) Schweitzer, 1958	Diffuse porous	Absent	Large, solitary and in radial multiples of 2–3, 3–6 per sq, mm, t.d. 150–230 µm, r.d. 200–300 µm	Paratracheal parenchyma sparse, apotracheal parenchyma abundant diffuse and diffuse in aggregate, and enclosing the gum canals	Present	1–8 (mostly 6–7) seriate, ± homogeneous	Thick walled, non septate	Small, 60–100 µm in diameter, solitary or in group
D. gracile Schweitzer, 1958	Diffuse porous	Absent	Medium to large, solitary or in multiples, t.d. 100–150 µm, r.d. 150–225 µm	Paratracheal parenchyma sparse, apotracheal parenchyma sometimes diffuse and diffuse in aggregate and enclosing the gum canals forming short tangential bands	Present	1–5 seriate, upto 40 cells in height, homogeneous	Thick walled, non septate	Small, 60–75 µm in diameter, usually solitary
D. perforatum Schweitzer, 1958	Diffuse porous	Absent	Vessel, small to medium, mostly solitary or in radial multiples of 2–3, t.d. 100–200 µm, r.d. 150–250 µm, 13–20 per sq. mm	Paratracheal parenchyma sparse, apotracheal parenchyma also sparse found usually enclosing the gum canals	Present	1–4 seriate, 5–50 cells in height, homogeneous	Thick walled, non septate	Gum canals small, few, 50–110 µm in diameter
D. anisopteroides Schweitzer, 1958	Diffuse porous	Absent	Medium to large, usually solitary, round, in multiples, 5–10 per sq. mm, t.d. 150–200 µm, r.d. 175–300 µm	Paratracheal parenchyma sparse, apotracheal parenchyma abundant, diffuse and diffuse in aggregate forming 1–3 seriate interrupted lines and enclosing the gum canals	Present	1–6 (mostly 5) seriate, 4–65 cells in height, homogeneous	Thick walled, non septate	Small, mostly solitary, 60 µm in diameter
D. scevelianum Chiarugi,1933	Diffuse porous	Distinct	Medium to large, solitary or in multiples of 2–4, 16–17 per sq. mm, t.d. 120–200 µm, r.d. 220–260 µm	Paratracheal parenchyma sparse, around vessels, apotracheal parenchyma diffuse and diffuse in aggregate forming 1–3 seriate metatracheal bands, also enclosing the gum canals	Present	1–3 seriate, 12–20 cell in height, heterogeneous	Thick walled, non septate	Medium, mostly solitary, 100–150 µm in diameter
D. somalense Chiarugi,1933	Diffuse porous	Distinct	Mostly medium to large, solitary or in radial multiples of 2–3, t.d. 100–140 µm, r.d. up to 230 µm	Paratracheal parenchyma sparse, around vessels, apotracheal parenchyma diffuse and diffuse in aggregate forming 1–3 seriate metatracheal bands	Present	Usually 6 seriate, 7–25 cells in height, heterogeneous	Thick walled, non septate	Small to medium sized, solitary, 45–120 µm in diameter
D. giubense Chiarugi,1933	Diffuse porous	Distinct	Solitary or in radial multiples of, 2–4, 12–14 per sq. mm, t.d. generally 50–140 µm, r.d. 60–240 µm	Paratracheal parenchyma sparse, vasicentric and apotracheal parenchyma usually in metatracheal bands	Present	1–4 seriate, 8–25 cells in height, heterogeneous	Thick walled, non septate	Solitary, frequent, t.d. 80–160 µm
D. africanum Bancraft,1933; Schweitzer,1958	Diffuse porous	Distinct	Solitary or in radial multiples of 2–4, tylosed	Paratracheal parenchyma sparse, around the vessels, apotracheal parenchyma diffuse and diffuse in aggregate, sometimes 2–4 cells wide metatracheal bands, also enclosing the gum canals	Present	1–5 (mostly 3) seriate, heterogeneous	Thick walled, non septate	Solitary or in frequent Series of 2–6

Table 3—Present day distribution and forest types of the modern comparable species of *Dipterocarpus* Gaertn. f.

Fossil taxa	Modern comparable species	Forest type	Distribution
Dipterocarpoxylon siwalicus Prakash *Dipterocarpus nepalensis* n. sp.	*Dipterocarpus indicus* Bedd. *Syn.* *D. turbinatus* Gaertn.	Evergreen	North east India, Andaman, Myanmar, Malaya peninsula
Dipterocarpus miocenicus n. sp. *D. churiensis* n. sp.	*D. bourdillonii* Br.	Evergreen	South India
Dipterocarpus suraikholaensis Prasad & Pandey	*D. alatus* Roxb. *Syn.* *D. costatus* Gaertn. *D. incans* Roxb.	Evergreen to mixed deciduous	North east India, Myanmar, Malaya peninsula

rows of gum canals. Similarily the nature and distribution of vasicentric tracheids, fibres and pits are uniform throughout the genus *Dipterocarpoxylon.*

CONCLUSIONS

The present investigation on the plant fossils from Siwalik sediments of Arjun Khola area revealed the presence of fossil wood, leaf and fruit impressions belonging to the genus, *Dipterocarpus* Gaertn.f. of the family Dipterocarpaceae.

We recognize three groups among the previously described *Dipterocarpoxylon* species distinguished by their anatomical features like vessels, rays and gum canals.

All the three modern species comparable to these fossils i.e. *Dipterocarpus indicus* Bedd., *D. bourdillonii* Br, and *D. alatus* Roxb. do not grow now in the Siwalik region (Himalayan foot hills) but they are presently found to grow in other parts of India and South–east Asian region.

The presence of these evergreen dipterocarps in the Himalayan foot hills of Nepal during Miocene times indicates that the evergreen forest was flourishing there as compared to mixed deciduous type of forest at present.

The record of these dipterocarps from Siwalik sediments of Himalayan foot hills of Nepal suggests that they have migrated from the South–east Asian region during early Miocene and later on became extinct due to prevailing of unfavourable conditions most probably due to uplift of Himalaya.

The abundance of dipterocarps such as *Dipterocarpus, Anisoptera, Isoptera, Shorea, Hopea, Dryobalanops* in eastern India as well as in southern India during Miocene–Pliocene times indicates that they spread from eastern India to south west to Sri Lanka via Himalayan foot–hills where they are still flourishing.

The fossil records suggest that the family Dipterocarpaceae originated during the early Middle Oligocene (Merril, 1923; Muller, 1970) in western Malaysia where 2/3 of all dipterocarps species occur today. From western Malaysia, dipterocarps spread eastward to the Philippines and northward through Burma to India. The possible time for the South–west migration was early Miocene (about 22 Ma) when land connection between Malaya, Burma and eastern India was established.

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REFERENCES

Antal JS & Prasad M 1996. Dipterocarpaceous fossil leaves from Ghish River section in Himalayan foot–hills near Oodlabari, Darjeeling District, West Bengal. Palaeobotanist 43: 73–77.

Antal JS, Prasad M & Khare EG 1999. In situ fossil woods of *Dipterocarpus* Gaertn. in the Himalayan foot hills of Darjeeling District, West Bengal, India. Biological Memoirs 25: 25–28.

Appel E, Rosler W & Corvinus G 1991. Magnetostratigraphy of Mio–Plistocene Surai Khola Siwalik in west Nepal. Geology Journal of International 105: 191–198.

Ash AW, Ellis B, Hickey LJ, Johnson K, Wilf P & Wing SL 1999. Manual of Leaf Architecture: Morphological Description and Categorization of Dicotyledonous and Net–Veined Monocotyledonous Angiosperms. An informal publication prepared by the Leaf Architecture Working Group (LAWG), Privately published and distributed. Smithsonian Institution, Washington.

Ashton PS 1982. Dipterocarpaceae, in Flora Malesiana, Series 1 Spermatophyta ed. C.G.G.J. Van Steenis), Martinus Nijhoff Publication, 1: 237–289.

Ashton PS 1998. *Dipterocarpus bourdillonii*. The IUCN Red list of thretened species. Version 2015.

Awasthi N 1965. Thesis on “Further studies on the fossil woods from the Cuddalore Series of south India. University of Lucknow, Lucknow.

Awasthi N 1974. Occurrence of some dipterocarpaceous woods in the Cuddalore Series near Pondicherry.Palaeobotanist 21(3): 339–351.

Awasthi N 1980. The new *Dipterocarpus* woods from the Cuddalore Series near Pondicherry. Palaeobotanist 26(3): 248–256.

Awasthi N & Mehrotra RC 1993. Further contribution to the Neogene flora of North–east India and significance of the occurrence of African element. Geophytology 23(1): 81–92

Awasthi N & Mehrotra RC 1997. Some fossil dicotyledonous woods from the Neogene of Arunachal Pradesh, India. Palaeontographica 245: 109–121.

Awasthi N & Prasad M 1990. Siwalik plant fossils from Surai Khola area, western Nepal. Palaeobotanist 38: 298–318.

Bancroft H 1933. A contribution to the geological history of the Dipterocarpaceae. Geol. Foren Forhandl. 55(1): 59–100.

Bande MB & Prakash U 1986. The Tertiary flora of Southeast Asia with remarks on palaeoenvironment and phytogeography of the Indo–Malayan region. Review of Palaeobotany and Palynology 49: 205–233.

Bera S & Banerjee M 1990. A new species of *Palmoxylon* and accretionary structure in the petrified woods from lateritic sediments in the western part of Bengal Basin, India. Indian Journal of Earth Science 17(1): 78–89.

Chaudhuri RS 1983. Provenance of the Siwalik sediments of Nepal Himalaya. Contemporary Geoscience Research in Himalaya 2: 85–90.

Chiarugi A 1933. Legni fossili della Somalia Italiana. VI Fossil dal Pliocene dal Plistocene. Palaeontographica 32: 97–167.

Chowdhury KA 1952. Some more fossil woods of *Glutoxylon* from South–east Asia. Annals of Botany, London 56(63): 373–378.

Conti E, Eriksson T, Schonenberger J, Systsma KJ & Baum DA 2002. Early Tertiary out of india dispersal of Crypteroniaceae: evidence from phylogeny and molecular dating. Evolution 56: 1931–1942.

Copley A, Aquae JP & Royer JY 2010. India–Asia collision and the Cenozoic slow down of the Indian Plate: implication for the forces driving plate motions. Journal of Geophysical Research 115: B0310.

Corvinus G 1990. Lith and biostratigraphy of the Siwalik succession in Surai Khola area, Nepal. Palaeobotanist 38: 293–297.

Crie MI 1888. Recherches sur la flore Pliocene de Java; Slg. Geol. Reichsmus. Leiden Beitr. Geol. Ost. Asien., **5** Leiden.

Croizat L 1952. Manual of Phytogeography. D.W. Junk B.V. Publisher. The Hague.

Dayanandan S, Astho PS, Willians SM & Primack RB 1999. Phylogeny of tropical tree family Dipterocarpaceae based on nucleotide sequences of the chloroplast *rbcL* gene. American Journal of Botany 86: 1182–1190. St. Louis.

Decousso M, Bena G, Bourgeous C, Buyck B, Eyssarther G, Vincelette M, Rabevohitra R, Randrihasipara L, Dreyus B & Prin Y 2004. The last common ancestor of Sarcolaenaceae and Asin dipterocarps trees was ectomycorhizal before the India–Madagascar separation about 88 million years ago. Molecular Ecology 13: 231–236.

DenBerger LG 1927. Unterscheidungsmerkmale von rezenten und fossilen Dipterocarpaceen gattumgen. Bull. Jard. Bot. Buiterzorkg 3(8): 495–498.

Desch HE 1957. Mannual of Malayan Timbers. I. Malayan Forest Record 15: 1–328.

Dilcher DL 1974. Approaches to identification of angiosperm leaf remains. Botanical Review 40: 1–157.

Dutta S, Tripathi SM, Mallik M, Mathews RP, Greenwood PF, Rao MR & Summons RE 2011. Eocene out–of–India dispersal of Asian Dipterocarps. Review of Palaeobotany & Palynology 166: 63–68. Amsterdam.

Eyde R H 1963. A *Shoreoxylon* and two others Tertiary woods from the Garo Hills, Assam. Palaeobotanist 11(12): 115–121.

Feng X, Tang B, Korul TM & Jin J 2013. Winged fruits and associate leaves of *Shorea* (Dipterocarpaceae) from the Late Eocene of South China and their phytogeographic and palaeoclimatic implications. American Journal of Botany 100(3): 574–581.

Geyler H Th 1887. Uber fossile pflanzer von Labuan. Vega–Exped. Vetenskapliga Arbeten 4: 475–507.

Ghosh PK & Roy SK 1979. *Dipterocarpoxylon bolpurense* sp.nov., a fossil wood of Dipterocarpaceae from the Tertiary of West Bengal, India. Current Science 48(1): 495–496.

Ghosh SS 1956. On a fossil wood belonging to the genus *Dipterocarpus*. Science & Culture. 21: 691–692.

Ghosh SS & Ghosh AK 1959. *Dipterocarpoxylon malvai* sp.nov.–a new fossil record from the Pliocene of Kutch. Science & Culture 25: 328–332.

Ghosh SS & Kazmi MH 1958. *Anisopteroxylon bengalensis* gen. et n. sp. New fossil wood from microlithic site of West Bengal. Science & Culture 23(9): 485–487.

Gleinnie KW & Ziegler MA 1964. The Siwalik Formation in Nepal. 22nd International Geological Congress 15: 82–95.

Guleria JS 1983. Some fossil woods from the Tertiary of Kachchk, western India. Palaeobotanist 31(2): 109–128.

Guleria JS 1986. Fossil woods from the Tertiary sediments near Jaisalmer, Rajastan and their bearing on the age of Shumar Formation. Spec. Indian Geophytological Conf. Pune (Abstract No.108).

Guleria JS 1992. Neogene Vegetation of peninsular India. Palaeobotanist 40: 285–311.

Guleria JS 1996. Occurrence of *Dipterocarpus* in the Mar Formation in Bikaner, Rajasthan, western India. Palaeobotanist 43(2): 49–53.

Guleria JS & Srivastava R 2001. Fossil dicotyledonous woods from the Deccan Intertrappean beds of Kachchh, Gujarat, western India Palaeontographica 257B: 17–33.

Guleria JS, Srivastava R & Prasad M 2000. Some fossil leaves from the Kasauli Formation of Himachal Pradesh, North West India. Himalayan Geology 21(1, 2): 43–52.

Gupta KM 1935. A review of the genus *Dipterocarpoxylon* of Holden with description of a new species *D. holdenii* from the Irrawady system of Burma. Proceeding of Indian Academy Science 1(10): 633–639.

Heer O 1874. Nachtrage zur Miocene flora Gronlands. K. stensk. Vetensk. Akad. Handl. 13(2): 1–29.

Heer O 1983. Beitrage zur fossilen flora von Sumatra. Neues. Denkshr.allg. Schewetz.Gesell. fur Gasammt. Naturw. 28: 1–22.

Hickey LJ 1973. Classification of architecture of dicotyledonous leaves. American Journal of Botany 60: 17–33.

Holden R 1916. A fossil wood from Burma. Record of Geological Survey of India. 47: 67–272.

Konomatsu M & Awasthi N 1999. Plant fossils from Arung Khola and Binai Khola formations of Churia Group (Siwalik) west central Nepal and their palaeoecological and phytogeographical significance. Palaeobotanist 48: 63–181.

Krausel R 1929. Fossil pflangen aus dem Tertiar von Sud. Sumatra. Verb. Geol. mijnb. Geroot. Ned. Geol. Surv. 9(1): 1–44.

Kumar R & Gupta VJ 1981. Stratigraphy of Nepal Himalaya. Contemporary Geological Science Research in Himalaya: 161–176.

Lakhanpal RN 1970. Tertiary flora of India and their bearing on the historical geology of the region. Taxon 19(5): 675–694.

Lakhanpal RN 1974. Geological history of the Dipterocarpaceae: *In:* Lakhanpal RN *et al.* (Editors)—Symposium on Phytogeography of Angiosperm. Birbal Sahni Institute of Palaeobotany, Lucknow Special Publication 1: 30–39.

Lakhanpal RN & Guleria JS 1987. Fossil leaves of *Dipterocarpus* from the Lower Siwalik beds near Jawalamukhi, Himachal Pradesh. Palaeobotanist 35: 258–262.

Mabberley DJ 1997. *The Plant Book. A portable Dictionary of the vascular plants*. 2nd Edition, Cambridge University Press, Cambridge.

Mehrotra RC & Bhattacharyya A 2002. Wood of *Dipterocarpus* from a new locality of the Champa Nagar Formation of Tripura, India. Palaeobotanist 51: 123–127.

Merril ED 1923. Distribution of the Dipterocarpaceae. Philippinnes Journal of Science 23**:** 1–32.

Morley RJ 2000. Origin and evolution of tropical rain forests. John Wiley and Sons. Chichester, U.K.

Muller J 1964. A palynological contribution to history of the Mangrore vegetation of Borneo. *In*: Cranwell CM (Editor)–Ancient Pacific Flora: the pollen story: University of Hawaii Press Honolulu: 33–42.

Muller J 1970. Palynological evidences on early differentiation of angiosperms. Biological Review 45: 415–450.

Muller J 1981. Fossil pollen records of extant angiosperms. Botanical review 47: 1–142

Navale GKB 1963. Some silicified dipterocarpaceous woods from Tertiary beds of the Cuddalore Series near Pondicherry, India. Palaeobotanist 11(1, 2): 66–81.

Navale GKB 1974. Botanical resolution of some microstructure of Neyveli lignite, south India. Palaeobotanist 21(3): 359–364.

Prasad M 1990. Some leaf impressions from the Lower Siwalik sediments of Koilabas, Nepal. Palaeobotanist 37: 299–305.

Prasad M 1993. Siwalik (Middle Miocene) woods from the Kalagarh area in the Himalayan foot hills and their bearing on palaeoclimate and phytogeography. Review of Palaeobotany and Palynology 76(1): 49–82.

Prasad M 1994. Siwalik (Middle Miocene) leaf impressions from the foot–hills of the Himalaya, India. Tertiary Research 15: 53–90.

Prasad M 2007. Fossil wood and leaf of the genus *Chrysophyllum* Linn. from Churia (Siwalik) Group of Himalayan foot–hills of western Nepal and its significance. Phytomorphology 57: 177–184.

Prasad M 2008. Angiospermous fossil leaves from the Siwalik foreland basin and its palaeoclimatic implications. Palaeobotanist 57: 177–215.

Prasad M, Antal JS, Tripathi PP & Panday VK 1999. Further contribution to the Siwalik flora from the Koilabas area, western Nepal. Palaeobotanist 48: 49–95.

Prasad M & Awasthi N 1996. Contribution to the Siwalik flora from Surai Khola sequence, western Nepal and its palaeoecological and phytogeographical implications. Palaeobotanist 43: 1–42.

Prasad M & Dwivedi HD 2008. Some plant megafossils from the Sub–himalayan zone (Middle Miocene) of western Nepal. Journal of Palaeontological Society of India 53: 51–64.

Prasad M & Khare EG 1994. Occurrence of *Dipterocarpus* Gaertn. in the Siwalik sediments of Hardwar, Uttar Pradesh. Biological Memoirs 20(1): 51–54.

Prasad M & Khare EG 2004. Cuticular studies on the fossil leaves from Churia (Siwalik) sediments of Arjun Khola sequence, western Nepal. Palaeobotanist 53: 105–112.

Prasad M & Pandey SM 2008. Plant diversity and climate during Siwalik (Miocene–Pliocene) in the Himalayan foot–hills of western Nepal. Palaeontographica 278B: 13–70.

Prasad M & Pradhan UMS 1998. Studies on plant fossils from the Siwalik sediments of Far eastern Nepal. Palaeobotanist 48: 99–109.

Prasad M & Tripathi PP 2000. Plant megafossils from the Siwalik sediments of Bhutan and their climatic significance. Biological Memoirs 26: 6–19.

Prakash U 1973. Fossil woods from the Tertiary of Burma. Palaeobotanist 20(1): 48–70.

Prakash U 1975. Fossil woods from the Siwalik beds of Himachal Pradesh, India. Palaeobotanist 22: 192–210.

Prakash U 1978. Fossil woods from the Lower Siwalik beds of Uttar Pradesh India. Palaeobotanist 25: 376–392.

Prakash U 1981. Further occurrence of fossil woods from the Lower Siwalik, Uttar Pradesh, India. Palaeobotanist 28–29: 374–388.

Ramanujam CJK 1956. Fossil woods of Dipterocarpaceae from the Tertiary of South Arcot District, Madras. Palaeobotanist 4: 45–56.

Rawat MS 1964. A new record of *Dipterocarpoxylon* from Siwalik Formation of Uttar Pradesh. Science & Culture 30: 337–338.

Rowley DB 1996. Age of initiation of collision between India and Asia: a review of stratigraphic data. Earth and Planatary Science Letters 145: 1–13.

Sasaki S 2006. Ecology and Physiology of Dipterocarpaceae. *In*: Susuki K *et al*. (Editors)–Plantation Technology in Tropical Forest Science: Springer: 3–22.

Scotese CR, Gahagan LM & Larson RL 1988. Plate tectonic reconstructions of the Cretaceous and Cenozoic ocean basin. Tectonophysics 155: 27–48.

Seward AC 1935. Leaves of dicotyledons from the Nubian Sandstone of Egypt: 1–21. Ministry of Finance Survey Department, Egypt.

Sharma CK 1980. *Geology of Nepal.* Kathmandu, Nepal.

Shi G & Li H 2010. A fossil fruit wing of *Dipterocarpus* from the Middle Miocene of Fujian, China and its palaeoclimatic significance. Review of Palaeobotany and Palynology 162: 599–606.

Schweitzer HJ 1958. Die fossilen Dipterocarpaceen Holzer. Palaeontographica 150B: 1–66.

Tokuoka T, Takayasu K, Yoshida M & Hisotomi K 1986. The Churia (Siwalik) Group of the Arung Khola area, west central Nepal. Memoirs of the Faculty of Science, Shimane University 20: 135–210.

Trivedi BS & Ahuja M 1980. *Dipterocarpoxylon nungarhensis* n. sp. from Kalagarh (Bijnore District), India. Palaeobotanist 26(3): 221–225

Upreti BN & Yoshida M 2005. Guide book for Himalayan Trekers, Series No. 1 Geology and natural hazards along the Kaligandak Valley, Nepal. Department of Geology, Tri Chand Campus, Tribhuwan University, Kathmandu.

Yadav RR 1989. Some more fossil woods from the Lower Siwalik sediments of Kalagarh, Uttar Pradesh and Nalagarh, Himachal Pradesh. Palaeobotanist 37: 52–62.