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# Fossil wood of *Dipterocarpus* from Nagri Formation (Middle Siwalik) of India: palaeoclimatic and phytogeographical significance

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## ABSTRACT

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The paper reports the occurrence of fossil wood of *Dipterocarpus* (Dipterocarpaceae) from sandstone of Nagri Formation (Middle Siwalik), Saharanpur District, Uttar Pradesh, India. Present distribution of nearest living relatives (NLRs) of the fossil wood in the evergreen forests of Indo–Malaysian region indicates prevalence of tropical moist conditions in the Himalayan foot–hills in the Miocene in contrast to present day drier and cooler climate.

**Key–words**—*Dipterocarpus*, Nagri Formation, Middle Siwalik, Upper Miocene, Uttar Pradesh.

## भारत के नगरी शैलसमूह (मध्य शिवालिक) से प्राप्त *डिप्टेरोकार्पस* की जीवाश्म काष्ठः पुराजलवायवी एवं पादपभौगोलीय महत्ता

रश्मि श्रीवास्तव, रत्नेश सिंह चंदेल एवं शैलेंद्र सिंह

## सारांश

यह शोध–पत्र भारत में उत्तर प्रदेश के सहारनपुर जिले के नागरी शैलसमूह (मध्य शिवालिक) के बलुआपत्थर से प्राप्त डिप्टेरोकार्पस (डिप्टेरोकार्पेसी) की जीवाश्म काष्ठ की प्राप्ति प्रस्तुत करता है। भारत–मलेशिया अंचल के सदाहरित वनों में जीवाश्म काष्ठ के निकटतम जीवित संबंधी (एन.एल.आर.) पादपों का वितरण मध्यनूतन काल में हिमालय की तलहटी की वर्तमान शुष्कतर और शीतलतर जलवायु के विपरीत उष्णकटिबंधीय आर्द्र स्थितियों की व्यापकता इंगित करता है।

**सूचक शब्द**–*डिप्टेरोकार्पस,* नगरी शैलसमूह, मध्य शिवालिक, ऊपरी मध्यनूतन, उत्तर प्रदेश।

## INTRODUCTION

THE northern edge of the Indian Plate was folded, faulted, and uplifted due to collision of the Indian and Asian plates resulting in the buckling down of crust to receive sediments from the raised portion. The Siwalik sedimentation took place in the elongated foreland basin developed in front of the rising Himalayas during the middle Miocene to upper Pleistocene with the deposition of continental fresh water molassic sediments with a thickness of more than 5000 m of clastic sediments exposed all along the Himalayan foot–hills. Broadly, the warm and humid climate has prevailed during

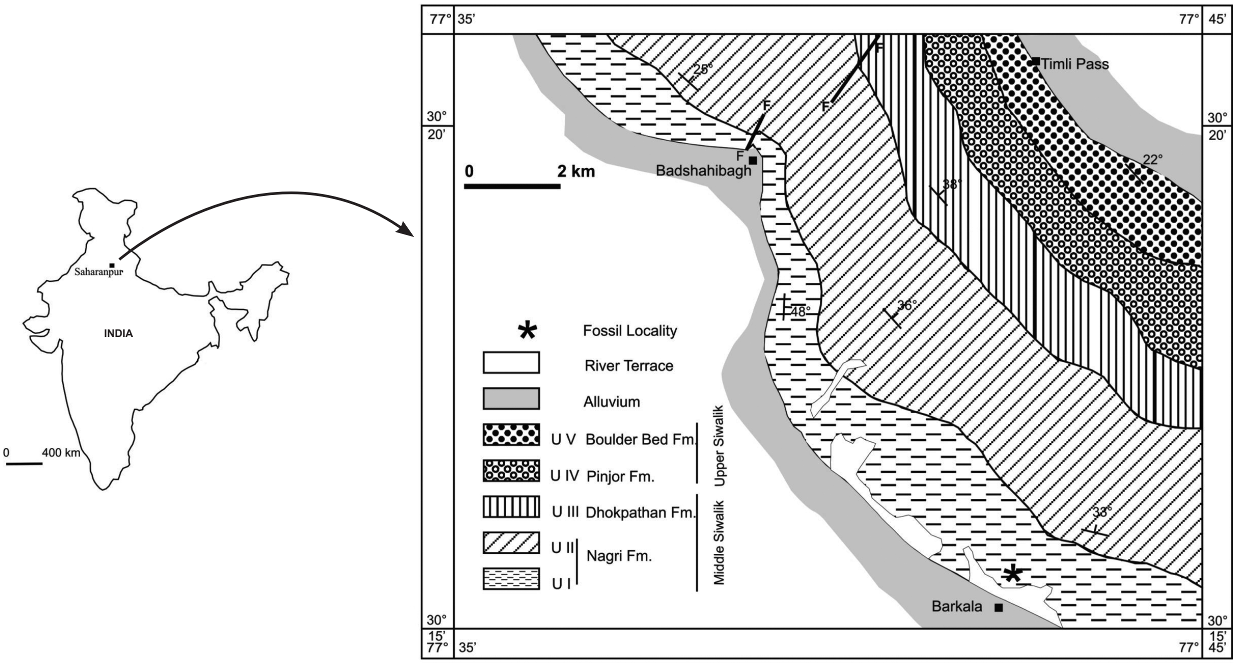


Fig. 1—Geological map of Barkala area showing fossil locality (modified after Singh *et al*., 2011).

the major part of Siwalik sedimentation, in which flora and fauna proliferated. The Siwalik Group is subdivided into: (a) Lower Siwalik Subgroup comprising an upward–coarsening mudrock–sandstone succession; (b) Middle Siwalik Subgroup consisting mainly of sandstones, and (c) Upper Siwalik Subgroup consisting of conglomerates, sandstones and mudrocks (Kumar *et al*., 2003).

The rocks of Siwalik Group are widely known for their embedded remains of vertebrate fossils (Verma, 1989; Nanda, 2002; Srivastava & Patnaik, 2002). A large number of plant fossils are also recorded by various workers (Awasthi, 1992; Guleria *et al*., 2002, 2005; Prasad, 2008 and references therein). Well preserved permineralised woods of *Dipterocarpoxylon arcotense* Awasthi were recovered from Nagri Formation (Middle Siwalik Subgroup) of Saharanpur District, Uttar Pradesh, India is being described in the present communication.

## GEOLOGY OF THE AREA

In the study area, rocks of Middle and Upper Siwalik Subgroup are exposed. During the course of mapping, five separate lithostratigraphic units were identified on the basis of lithofacies association, grain size characters and sand: clay: conglomerate ratio (Fig. 2). Based on field characters, three distinct units have been identified within the Middle Siwalik Subgroup. Amongst them, Unit–I and Unit–II correspond to two identified members of Nagri Formation while Unit–III corresponds to the Dhokpathan Formation. Unit–IV and Unit–V of Upper Siwalik Subgroup correspond to Pinjor and Boulder Bed formations respectively.

Unit–I is characterised by massive dark greyish green coloured, fine– to medium–grained indurated sandstone with interspersed gritty sandstone and clay/ mudstone. Unit–II is a fine–grained trough and tabular cross bedded sandstone unit with intermittent clay/ mudstone bands which appear in repeated cycles. Intraformational conglomerate horizon is interspersed at the base of each cycle by a fining upward sequence. Unit–III is represented by fine– to coarse–grained multiple storied grey to brown coloured sandstone with pebble and mudstone/ clay bands. Unit–IV consists of banded grey coloured medium– to coarse–grained sandstone separated by polymictic conglomerate beds. Unit–V consists of polymictic boulder and pebble unit with disoriented clasts with minor sandstone lenses.

## MATERIAL AND METHOD

The material for the present study was collected by two of us (S. S. and R. S. C.). Two logs of silicified wood varying 29–35 cm in diameter were collected from about 1 km NNE of Barkala Village (30°15'10" N: 77°42'30" E) in Sarbar Rao within sandstone of Nagri Formation (Unit–I) of Middle Siwalik Subgroup (Figs 1, 2). Thin sections of the fossil woods were prepared in three planes, i.e. transverse, tangential longitudinal and radial longitudinal by standard techniques for the study of anatomical characters. The sections were studied under high–power Olympus (BX 50) Microscope and photographed with an attached DP 20 Digital Camera. Wood descriptions and measurements were taken in accordance with IAWA recommendations (IAWA Committee, 1989). Identifications were made by comparing

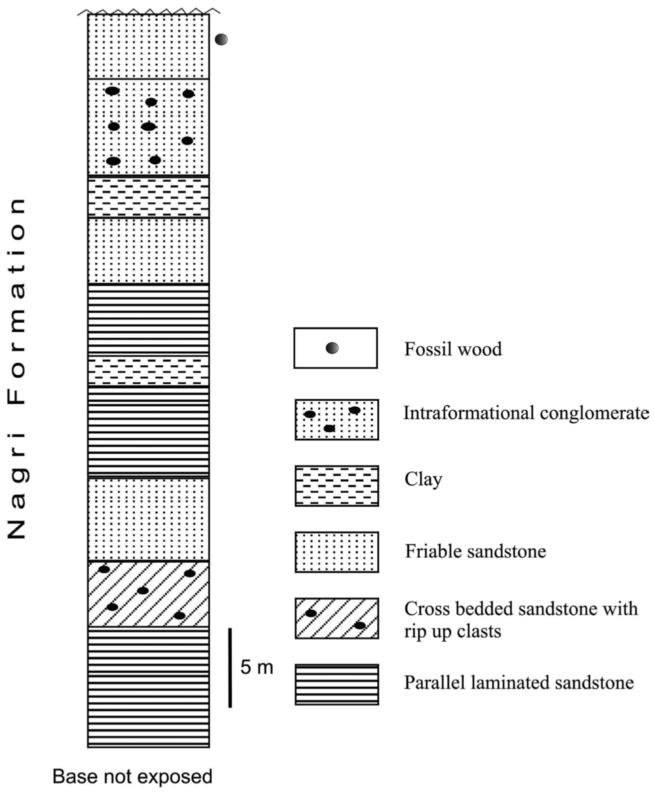


Fig. 2—Lithocoloumns of measured sections of Unit – I, exposed at NNE of Barkala Village (fossil locality).

the anatomical characters with modern wood slides available at the Birbal Sahni Institute of Palaeobotany (BSIP), Lucknow and the Forest Research Institute, Dehradun. The type slides are housed in the Museum of the Birbal Sahni Institute of Palaeobotany, Lucknow and figured specimen in Geological Survey of India, Northern Region, Lucknow.

## SYSTEMATICS

**Order—MALVALES**

**Family—DIPTEROCARPACEAE**

**Subfamily—DIPTEROCARPOIDEAE**

**Genus—DIPTEROCARPOXYLON** Holden emend Den Berger, 1927

***Dipterocarpoxylon arcotense*** Awasthi, 1980

(Pl. 1.1–7)

The description is based on two well preserved pieces of petrified wood showing all the xylotomical details.

*Description—Wood* diffuse porous (Pl. 1.1). *Growth rings* not seen. *Vessels* small to large, mostly medium to large, tangential diameter 100–272 (mostly 150–200) µm, radial diameter 100–364 (mostly 120–280) µm, predominantly solitary, rarely in pairs, circular to oval, evenly distributed, 7–13 per sq mm, heavily tylosed (Pl. 1.1, 2); vessel members truncate with oblique ends, 193–885 µm in height; perforations simple; intervessel pits could not be observed due to tylosed vessels and rare occurrence of paired or radial multiples of vessels. *Tracheids* vasicentric occurring in the immediate vicinity of vessels intermingled with paratracheal parenchyma, recognizable in longitudinal sections in having bordered pits, pits 6–7 µm in diameter (Pl. 1.3). *Axial parenchyma* both paratracheal and apotracheal; paratracheal vasicentric, 1–4 seriate sheath round the vessels, sometimes confluent connecting a few adjacent vessels; apotracheal sparse, few cells dispersed among the fibres, sometimes forming short tangential uniseriate lines, also in the form of short tangential bands enclosing gum canals (Pl. 1.1, 2); cells 22–40 µm in diameter and 77–180 µm in length. *Rays* 1–8 (mostly 3–6) seriate; uniseriate rays made up of either upright or both procumbent and upright cells, about 16–32 µm in width and 3–9 cells or 224–370 µm in height (Pl. 1.4, 5); multiseriate rays made up of procumbent cells in the central portion with 1 to several marginal rows of upright cells at one or both the ends (Pl. 1.4, 6 ), 69–200 µm in width and 8–40 cells or 320–1346 µm in height; sheath cells present occasionally on one or both the flanks (Pl. 1.4, 5); ray to ray fusion observed; ray tissue heterogeneous (Pl. 1.7); vessel ray pits preserved at few places, many per cell; procumbent cells 22–37 µm in tangential height and 34–88 µm in radial length; upright cells 38–58.8 µm in tangential height and 24–40.80 µm in radial length. *Fibres* angular in cross section, nonseptate, 12–18 µm in diameter. *Gum canals* normal, vertical, embedded in parenchymatous tissue; solitary or in short tangential rows of 2–5 or more (Pl. 1.1, 2), small to large, almost of the same size of the vessels, tangential diameter 60–205 µm, radial diameter 85–298 µm; frequency quite high.

*Figured Specimen*—Specimen No. BSIP 40127.

*Horizon*—Nagri Formation of Middle Siwalik Subgroup.

*Locality*— Barkala Village, Saharanpur District, Uttar Pradesh.

*Age*—Late Miocene.

*Affinities*—The diagnostic features of the permineralized wood are: almost solitary tylosed vessels, vasicentric tracheids, scattered vertical gum canals which are solitary or in groups of 2–5, paratracheal parenchyma vasicentric, apotracheal parenchyma as few diffuse to diffuse–in aggregate cells among fibres and in the form of short tangential bands encircling gum canals, 1–7 (mostly 3–5) seriate distinctly heterocellular rays with uniseriate extensions. A combination of all these characters indicates that the fossil belongs to genus *Dipterocarpus* Gaertn. f. of the family Dipterocarpaceae. Thin sections of a large number of extant woods of *Dipterocarpus* available at the Xylaria of Forest Research Institute, Dehradun and Birbal Sahni Institute of Palaeobotany, Lucknow were examined carefully, besides searching the computerised wood databases [insidewood.lib.ncsu.edu] and published descriptions and illustrations of many species of *Dipterocarpus* for comparison (Pearson & Brown, 1932; Chowdhury & Ghosh, 1958; Metcalfe & Chalk, 1950; Kribs, 1959; Hayashi *et al*., 1973; Miles, 1978; Ilic, 1991; Negi & Raturi, 1992; Gupta, 2007). From the survey of wood slides and literature it was found that the fossil shows close resemblance with the wood structure of *Dipterocarpus gracilis* Blume (*D. pilosus* Roxb.) and *D. tuberculatus* Roxb. in having 1–7 seriate rays and size of gum canals is up to the size of vessels.

A number of fossil woods showing resemblance with *Dipterocarpus* are described from various Neogene sediments of India under the organ genus *Dipterocarpoxylon* Holden emend Den Berger (1927) while a few woods were described directly under the modern genus *Dipterocaprus*. They are listed in a table along with their modern counterparts (Fig. 3). The present wood was compared with all the known species. The nearest comparable species are: *Dipterocarpoxylon arcotense* Awasthi, *D. nalagarhense* Prakash and *D. premacrocarpum* Prakash where gum canals are large up to the size of vessels. However, *D. premacrocarpum* differs in having narrower rays (1–5 seriate) while in *D. nalagarhense* rays are broad (up to 10 seriate). The present fossil wood shows nearest resemblance with *Dipterocarpoxylon arcotense* and hence it is placed in the same species. Besides woods, fossil leaves of *Dipterocarpus* are also reported from the Neogene exposures of India (Lakhanpal & Guleria, 1987; Prasad, 1994; Antal & Prasad, 1996; Guleria *et al.*, 2000). Besides India, dipterocarpaceous remains were also reported from the Cenozoic sediments of South and Southeast Asia, Africa and China (Bancroft, 1935; Schweitzer, 1958; Prakash, 1965a–b; Lemoigne, 1978; Muller, 1981; Srivastava & Kagemori, 2001; Mandang & Kagemori, 2004; Songtham *et al.*, 2005; Wang *et al.*, 2006; Shi & Li, 2010; Feng *et al*., 2013).

The genus *Dipterocarpus* Gaertn. f. includes about 69 species which are mainly confined to the Indo–Malaysian region with maximum development in Borneo, Malaysian Peninsula and Sumatra (Mabberley, 2005). The genus ranges in its distribution from India in the west to Philippines in the east. In India, it is found in Assam, the Andamans and the Western Ghats (Chowdhury & Ghosh, 1958). *Dipterocarpus gracilis* with which the fossil shows nearest resemblance is a large tree found in lowland semi–evergreen and evergreen forests of Bangladesh, India (Andaman and Nicobar Islands, Arunachal Pradesh, Assam and Tripura, Western Ghats) and South east Asia (Indonesia, Peninsular Malaysia, Myanmar and Thailand) (Negi & Raturi, 1992), while *D. tuberculatus* Roxb. is also a large tree distributed in Myanmar, south Vietnam (Cochin–China) and Chittagong hill tract of Bangladesh (Chowdhury & Ghosh, 1958).

## DISCUSSION

The family Dipterocarpaceae holds important distinction of being the most dominant large trees forming canopy as well as understorey of lowland equatorial forests of Asia, Africa and South America. Dipterocarpaceae includes three sub families: Dipterocarpoideae in Asia, Pakaraimoideae, endemic in South America and Monotoideae in Africa and South America (Maguire & Ashton, 1977). However, status of Pakaraimoideae and Monotoideae varies with authors (Maury, 1978; Maury–Lechon & Curtet, 1998; Kostermans, 1989; Londoño *et al.*, 1995). They excluded these last two subfamilies from Dipterocarpaceae and formally described them in a family Monotaceae (including taxa namely *Monotes, Marquesia* and *Pakaraimea*).

The family Dipterocarpaceae (Order Malvales) consists of 16 genera and about 680 species distributed in tropical belt of three continents of Asia, Africa and South America (Maury–Lechon & Curtet, 1998; Mabberly, 2005). Amongst them more than 450 species (about 92%) are spread in the equatorial forests of Indo–Malaysian region. The area is limited northward by Himalayan foot hills to the extreme southwest up to Seychelles (only one species). The eastern border to New Guinea and Sundaland delimits the southern most parts. No dipterocarps are recorded from Australia as Wallace's line seems to be the main phytogeographic boundary in southeast Asia which might be due to continental drift instead of climatic difference (Maury–Lechon & Curtet, 1998).

Asian dipterocarps received considerable attention due to economically important timber species distributed in a wide range of climatic zones of tropical Asia. All dipterocarps are arborescent, resinous and are the main constituents of tropical rain forests of Asia (Ashton, 1982, 1988; Aiba & Kitayama, 1999). Considering modern distribution of the family and high concentration of the species as well as earlier oldest fossil record from Oligocene (Muller, 1981), its origin was

**PLATE 1**

*Dipterocarpoxylon arcotense* Awasthi, 1980 ⟶

1. Transverse section of the fossil showing solitary, tylosed vessels and vertical gum canals in short tangential rows (marked by arrows).
2. Another transverse section showing tylosed solitary vessels, distribution of parenchyma and scattered gum canals embedded in parenchymatous tissue (marked by arrows).
3. Vasicentric tracheids showing pits on tangential walls (marked by arrows).
4. Tangential longitudinal section showing heterocellular multiseriate rays.
5. Tangential longitudinal section magnified showing sheath cells on the flanks of a multiseriate ray (marked by arrows).
6. Tangential longitudinal section magnified showing long uniseriate extension (marked by arrows).
7. Radial longitudinal section showing heterocellular ray tissue.

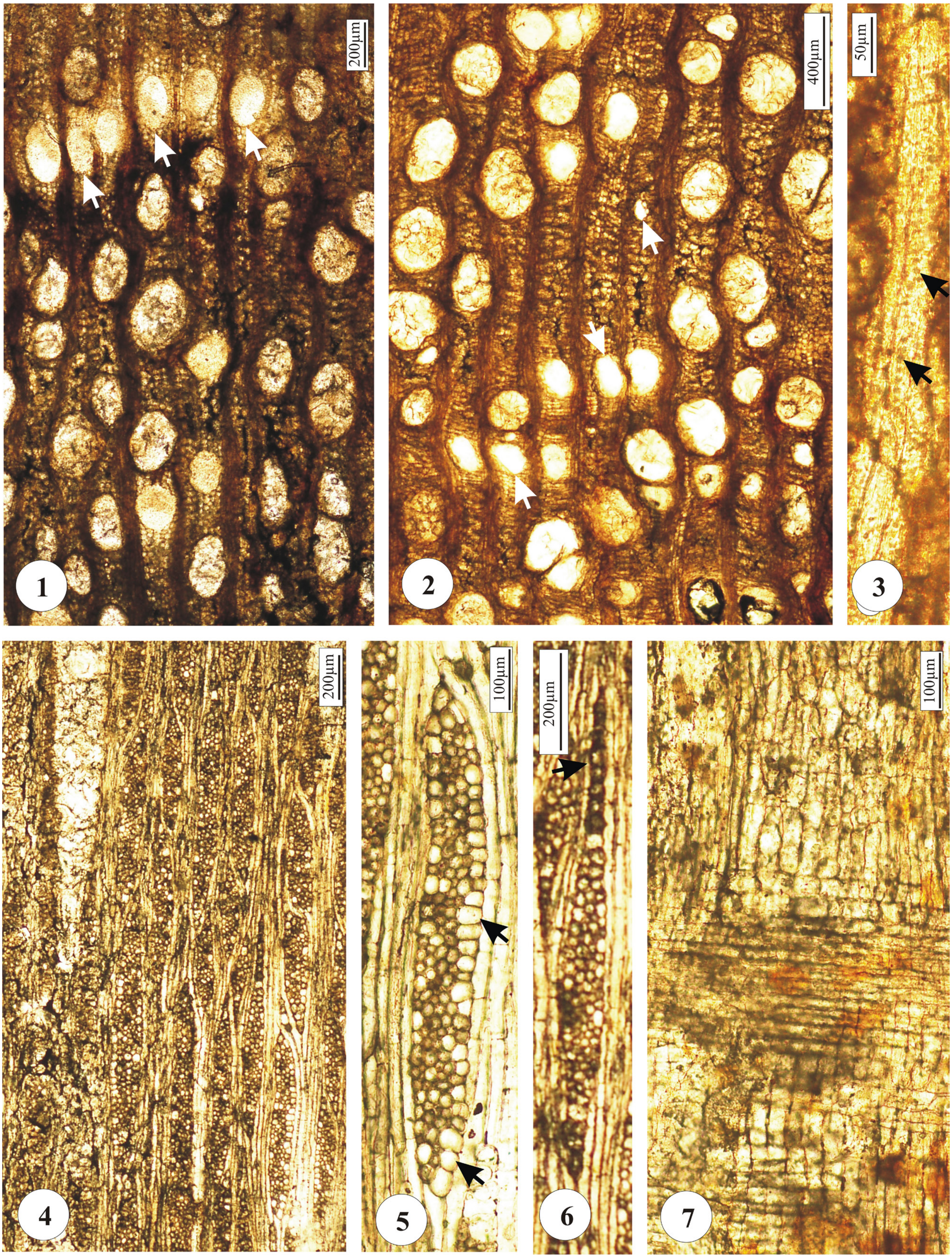


**PLATE 1**

| S.N. | Fossil Species | Nearest living relative | Horizon and age; Locality | Reference |
|---|---|---|---|---|
| 1. | *Dipterocarpoxylon arcotense* Awasthi | *Dipterocarpus tuberculatus* | Cuddalore Sandstone, Miocene–Pliocene, near Pondicherry; Lower Siwalik, Middle Miocene; Kalagarh, Uttarakhand | Awasthi, 1980; Prasad, 1993 |
| 2. | *D. bolpurense* Ghosh & Roy | *Dipterocarpus* spp. | Santiniketan, Upper Miocene, West Bengal; Deomali, Upper Miocene–Pliocene, Arunachal Pradesh; Tipam Group, Upper Miocene, Tripura | Ghosh & Roy, 1979; Awasthi & Mehrotra, 1993; Mehrotra & Bhattacharyya, 2002 |
| 3. | *D. chowdhurii* Ghosh | *D. bourdillonii* | Tipam Sandstones/Group, Upper Miocene, Assam | Ghosh, 1956; Prakash *et al*., 1994 |
| 4. | *D. jammuense* Guleria *et al.* | *D. lowii* | Middle Siwalik, Middle Pliocene; Jammu; Middle Siwalik, Upper Miocene, Dehradun, Uttarakhand | Guleria *et al*., 2002; Guleria *et al.,* 2005; Shukla *et al.,* 2013 |
| 5. | *D. kalagarhensis* Yadav | *D. obtusifolius* | Lower Siwalik Middle Miocene, Kalagarh, Uttarakhand; Late Pliocene–Early Pleistocene, West Bengal; Middle Siwalik, Middle Pliocene; J&K | Yadav, 1989; Bera & Banerjee, 2001; Guleria *et al*., 2002 |
| 6. | *D. kalaicharparensis* Eyde | *D. dyeri* | Garo Hills, Middle Tertiary, Kalaicharpara, Meghalaya; Tipam Group Upper Miocene, Tirap, Arunachal Pradesh | Eyde, 1963; Awasthi & Mehrotra, 1997 |
| 7. | *D. malavii* Ghosh & Ghosh | *D. dyeri* | Kankavati, Pliocene, Kutch, Gujarat; Late Pliocene–Early Pleistocene, West Bengal, Warkalli Formation, Miocene, Kerala | Ghosh & Ghosh, 1959; Guleria, 1983; Bera & Banerjee, 2001; Srivastava, 2001 |
| 8 | *D. nalagarhense* Prakash | *D. dyeri* | Lower Siwalik, Middle Miocene, Nalagarh, Himachal Pradesh | Prakash, 1975 |
| 9. | *D. nungarhense* Trivedi & Ahuja | *D. indicus* | Lower–Middle Siwalik, Middle Miocene, Kalagarh, Uttarakhand | Trivedi & Ahuja, 1980 |
| 10. | *D. parabaudii* Prakash | *D. baudii* | Lower–Middle Siwalik, Middle Miocene, Kalagarh, Uttarakhand | Prakash, 1978 |
| 11. | *D. pondicherriense* Awasthi | *D. indicus* | Cuddalore Sandstone, Miocene Pliocene, near Pondicherry; Kankawati, Pliocene, Kutch, Gujarat | Awasthi, 1974; Guleria, 1983 |
| 12. | *D. premacrocarpum* Prakash | *D. macrocarpus* | Lower Siwalik, Middle Miocene, Nalagarh, Himachal Pradesh; Tipam Sandstones, Miocene, Cachar, Assam; Tipam Group, Late Miocene Early Pliocene, Mamit, Mizoram | Prakash, 1975; Prakash *et al*., 1994; Tiwari & Mehrotra, 2000 |
| 13. | *D. sivalicus* Prakash | *D. indicus* | Lower Siwalik, Middle Miocene, Nalagarh, Himachal Pradesh | Prakash, 1975 |
| 14. | *Dipterocarpoxylon* sp. | *Dipterocarpus* spp. | Warkalli Formation, Miocene, Thiruvananthapuram, Kerala | Srivastava, 2001 |
| 15. | *D. surangei* Prakash | *D. tuberculatus* | Lower–Middle Siwalik, Middle Miocene, Kalagarh, Uttarakhand | Prakash, 1981 |
| 16. | *D. tertiarum* Guleria | *D. turbinatus* | Mar Formation Pliocene Plestocene, Bikaner, Rajasthan | Guleria, 1996 |
| 17. | *Dipterocarpus* wood | *Dipterocarpus* spp. | Middle Siwalik, Miocene Pliocene, Hardwar Uttarakhand; Middle Siwalik, Miocene Pliocene, Darjeeling, West Bengal | Prasad & Khare, 1994; Antal *et al.,* 1999 |

Fig. 3—Table showing various species of fossil woods of *Dipterocarpus* described from Tertiary sediments of India.

postulated in Western Malaysia during late Mesozoic to early Tertiary. The family later migrated to India during the Neogene when the land connections were established between the two landmasses (Merrill, 1923; Lakhanpal, 1974; Awasthi, 1996; Sasaki, 2006). According to another view dipterocarps originated in Gondwanaland (Croizat, 1964; Aubreville, 1976; Ashton, 1982; Ducousso *et al*., 2004; Dutta *et al*., 2011b) and dispersed from India to Southeast Asia after the establishment of land connection between the Indian and Asian plates during the middle Eocene (49–41 Ma). Recently the oldest fossil records of the family (dipterocarpaceous pollen, wood and amber) are reported from the early Eocene sediments of western India (Dutta *et al*., 2009, 2011a–b; Rust *et al*., 2010; Beimforde *et al*., 2011). However, identification of the dipterocarpaceous wood, the only megafossil reported so far from the Palaeogene is doubted by Shukla *et al*. (2013). Presence of dipterocarpaceous remains in the Palaeogene sediments of India can be explained by the second theory. Not only the dipterocarps but much of the vegetation present in Southeast Asia is not indigenous, as many genera were introduced from India and migrated to other countries after the establishment of land connections, thus supporting 'Out of India' hypothesis.

Today, the distribution of Dipterocarpaceae in India is restricted to the evergreen to semi–evergreen to deciduous forest of Assam, Western Ghats and Andamans (Chowdhury & Ghosh, 1958; Santapau & Henry, 1973; Prasad *et al*., 2009). The megafossil records of the family are reported from all the Neogene exposures of India (Lakhanpal *et al.*, 1976; Srivastava, 1991; Srivastava & Guleria, 2006; Shukla *et al*., 2013) with a single record of dipterocarpaceous wood from the Palaeogene sediments of western India (Rust *et al*., 2010). This indicates a more or less warm and humid climate with CMMT (cold month mean temperature) not less than 18º C and dry season not exceeding four months (Ashton, 1988) supporting the luxuriant vegetation during the Neogene Period. This is in contrast to the dry deciduous to moist deciduous forests occurring today in the area suggesting changes in the climatic condition. The climate change was initially gradual but later became more intensified due to the Himalayan uplift, a factor for establishment of monsoon regime (Boos & Kuang, 2010). The main factor for monsoon initiation and intensification is attributed to uplift of Tibetan Plateau (An *et al.*, 2001; Zachos *et al.*, 2001; Zheng *et al*., 2004) at the beginning of late Oligocene (Srivastava *et al*., 2012) to early Miocene (Clift *et al*., 2008). Increasing aridity and seasonality due to uplift of Himalaya and periodic glaciations during post Pliocene demonstrate a reduction of dipterocarps along with other evergreen and moist deciduous elements in Indian subcontinent as well as other parts of Asia due to climatic shift.

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