

First report of fossil wood from Khadsalia Lignite Mine, Saurashtra, Gujarat, India and its significance

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ABSTRACT

A fossil wood collected from the Eocene beds of Khadsalia Lignite Mine, Gujrat, India has been described here for the first time. The fossil wood shows close affinity with the extant genus, *Diospyros* Linn. of family Ebenaceae and characterized by 1-2 seriate, close, concentric, tangential lines at nearly regular interval and 1-2 seriate heterogeneous xylem rays. The present finding indicates the existence of tropical evergreen vegetation under a very humid climatic condition which has been responsible for the formation of lignite in the Khadsalia area in western India.

Key-words: Anatomy, *Diospyros*, Eocene, Fossil wood, Gujarat, Khadsalia Lignite Mine, Phytogeography.

INTRODUCTION

The subsurface Bhavnagar Lignite deposits are associated with the Tertiary age group of Lignite deposits in Saurashtra Basin, Gujarat. Khadsalia open-cast Lignite Mine is a the part of Bhavnagar Lignite deposit and is situated in Bhavnagar District, Saurashtra State Gujarat. Khadsalia Clay Formation is exposed at Khadsalia village (21°26' 43":72°07' 30"E; Fig. 1). The exploration of the Lignite Mine was taken up by Gujarat Mineral Development Corporation (GMDC). This open-cast Lignite Mine is explored in Lakhanka-Khadsalia Block about 25 km SSE of the main Bhavnagar town (Fig. 1).

A rich assemblage of both fossil flora and fauna have been documented from Early Eocene subsurface beds of the Cambay Shale Formation well exposed in the open-cast lignite mines at Vastan, Vagadkhola and Tarkeshwer in the Gujrat State, India (Bajpai et al. 2005, Rana et al. 2008, Rose et al. 2009, Kumar et al. 2011, Singh et al. 2010, 2014, 2015, Smith et al. 2016). The floral assemblage comprises plant fossils dominated by leaves, fruits, seed, carbonised and

petrified woods, mangrove roots, spores and pollen grains. Khadsalia Lignite Mine in Saurashtra Basin is little known from a palaeontological point of view. The coal petrological, geochemical and palynofacies studies of Khadsalia Lignite Mine sequences have been carried out earlier (Thakur et al. 2010, Singh et al. 2017). Moreover, Samant (2000) reported a variety of palynotaxa from the same lignite mine. Keeping in view of the meager work on plant fossils, the present paper emphasizes on the fossil wood obtained from the sedimentary succession of the open-cast Khadsalia Lignite Mine. The anatomical study of the fossil wood suggests its close resemblance to the extant genus *Diospyros* Linn. of family Ebenaceae.

General Geology

The Bhavnagar subsurface lignite deposit, associated with the Tertiary sedimentary deposit of the Saurashtra Basin, Gujarat is a part of the Saurashtra Peninsula in Bhavnagar District. It is bounded by sea except in the NE, where Khadsalia locality is flanked mostly by alluvium and sometimes by fluvial sedimentary plains. The Saurashtra Peninsula is bound by N-S

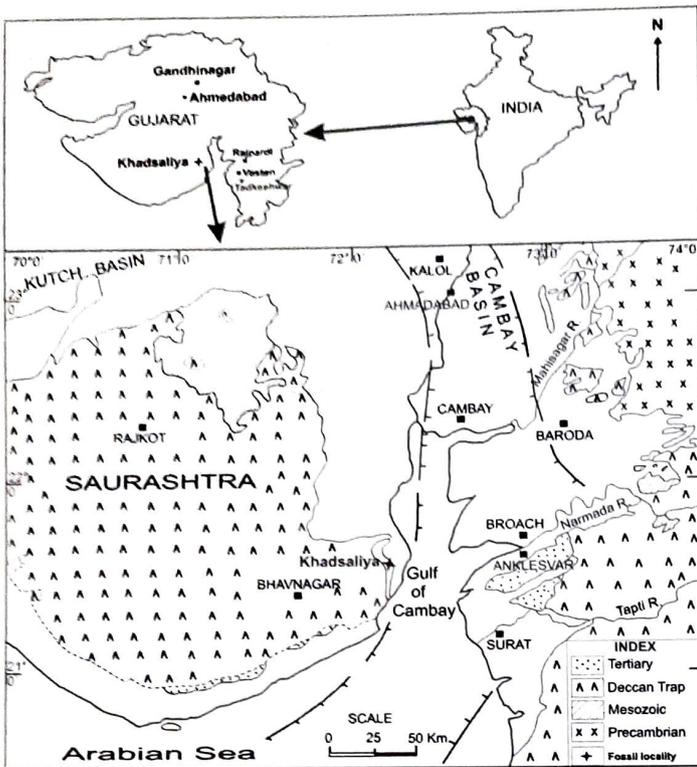


Fig. 1. Location and geological map of the Khadsalia area (Bhavnagar), Gujarat, India. (Source: GMDC).

trending Cambay fault in the eastern part, the extension of Narmada geofracture in the south, E-W trending gulf

of Kutch fault in the north and the major WNW-ESE fault (an extension of the West Coast Fault System in the Arabian Sea) in the west. The NE-SW trend continues across the Cambay Graben into Saurashtra as a southwesterly plunging arch. Saurashtra region is the horst surrounded rift graben and the central, southern and northern Saurashtra exhibits distinct volcano-tectonic characteristics (Biswas and Deshpande, 1983). On the eastern part of Saurashtra, a sharp contact of alluvium with basalt is observed in the N-S direction, extending from the west of Nal Sarovar to Bhavnagar. About 65% of Saurashtra Peninsula is covered by basaltic lava flows (Deccan Trap), overlying the Mesozoic sediments in north and underlying the Tertiary-Quaternary sediments at coastal fringe. The Deccan trap provides the basement for the deposition of Tertiary sediments that are exposed at some places (Fig. 1) Geological succession of the study area is shown in Table 1. Lignite in the region occurs in Khadsalia Clays Formation (Eocene), which is not exposed at the surface. This green to greenish grey clay sequence, overlying the supratrappean (Lower Eocene) and Deccan Traps (Cretaceous-Eocene) holds the Lignite deposits together with carbonaceous clay.

Table 1. Geological succession of the Khadsalia lignite mine, Gujarat (Modified after Srivastava 1963, GHCL 2008, Thakur et al. 2010).

Formation	Lithology	Age
	Alluvial, coastal dune, sand, mud flats, soil	Recent
----- Unconformity -----		
Lakhanka Formation	Agate, Conglomerate, ferruginous sandstone and intercalation of clays	Pleistocene to Recent
----- Unconformity -----		
Gaj Formation	Variegated sandstone, marl conglomerate Limestone and gypsious clays	Lower Miocene
----- Unconformity -----		
Khadsalia clays	Grey to Greenish-grey clays including with carbonaceous clay and Lignite	Eocene
----- Unconformity -----		
Supratrapean	Laterite, lithomarge, bentonite	Lower Eocene
----- Unconformity -----		
Deccan Trap	Basaltic lava flows with intrusive dykes	Cretaceous to Eocene

Table 2. List of fossil woods belonging to the family Ebenaceae from different parts of India and abroad.

Fossil Taxa	Locality	Epoch/Period
<i>Ebenoxylon ebeniodes</i> Schenk 1883, Kaiser 1890.	Libyan desert near Regenfeld	Upper Cretaceous
<i>E. diosyroides</i> Felix 1882, Kaiser 1890.	Argentina	Tertiary
<i>E. speciosum</i> Platen 1908	California	Tertiary
<i>E. tenax</i> Beck 1866, Kaiser 1890, Schonfeld 1947	Sanoxy	Oligocene
<i>E. tunetanum</i> Fliche 1856, Edwards 1931	Tunisia (Ain Cherichera)	Pliocene
<i>Ebenoxylon</i> sp. Fliche 1856	Myteline (Orthymnos)	Tertiary
<i>E. boreale</i> Platen 1908	Alaska	Tertiary (Oligocene)
<i>E. knollii</i> Hofmann 1944, Greguss 1956	Prambachtrichen Darno Bergos (Com Heves)	Oligocene
<i>E. hofmannae</i> Greguss 1956	Darno bergos, Hngary	Oligocene
<i>Diospyroxylon</i> sp. cf. <i>D. ebenaster</i> Greguss 1987	Hungary	Miocene
<i>Diospyroxylon</i> Greguss 1967	Hungary	Miocene
<i>Diospyros</i> sp. Slijper 1932	Limberg, Netherland	Pliocene
<i>Diospyros</i> and <i>Maba</i> Navale 1968	Neyveli Lignite Mine, Tamilnadu, South India	Miocene
<i>Diospyros washingtonia</i> Prakash & Barghoom 1961	Columbia Basalt	Miocene
<i>Ebenoxylon arcotense</i> Awasthi 1970, 1984	Cuddalore Sandstone & Neyveli Lignite Mine, South India	Mio-Pliocene
<i>E. karticherriense</i> Prakash & Tripathi 1970	Tippam Sandstone, Assam, India	Upper Miocene
<i>E. indicum</i> Ghosh & Kazmi 1958	Assam, India	Mio-Pliocene
<i>E. miocenecum</i> Prakash 1978, Antal et al. 1996	Upper Kalagarh (Uttarakhand); W. Bengal, India	Miocene
<i>E. Siwalicus</i> Prakash 1981	Kalagarh, (Uttarakhand)	Miocene (Lower Siwalik)
<i>E. obliquiporosum</i> Awasthi & Ahuja 1982	Varkala Beds, Kerala	Mio-Pliocene
<i>E. deccanense</i> Trivedi & Srivastava 1982	Deccan Intertrappean, Madhya Pradesh, India	Early Tertiary
<i>E. mahagoaense</i> Chitleyee & Patil 1972	Deccan Intertrappean, Madhya Pradesh, India	Early Eocene
<i>E. kalagarhesnsis</i> Prasad 1989	Kalagarh, (Uttarakhand) India	Middle Miocene
<i>E. candoleana</i> Prasad 1993	Kalagarh, (Uttarakhand) India	Middle Miocene
<i>E. neyveliensis</i> Mukherjee and Prasad 2013	Neyveli Lignite Mine, South India	Miocene
<i>E. cambayense</i> Singh et al. 2015	Vastan Lignite Mine, western India	Early Eocene

MATERIAL AND METHODS

The fossil Locality, Khadsalia Lignite Mine (21°26'43":72°07'30"E) is situated at Bhavnagar District, Saurashtra State of Gujarat, India (Fig. 1). The fossil woods were collected from the base of lignite seam (lower seam) of the lignite mine (Fig. 2). Thin sections were prepared from two pieces of carbonized woods measuring 8 x 3 cm and 10 x 3.5 cm. The slides were prepared by the standard methods of cutting,

grinding and polishing using different grades of carborandum powder and finally mounted in Canada balsam. Microscopic study has been carried out under High power Microscope and photographs were taken using DS-20 digital camera attached to the Microscope. According to the recommendation of IAWA Committee (1989) anatomical description of the fossil wood has been done. All the figured slides and specimens are kept in the repository of Birbal Sahni Institute of Palaeosciences, Lucknow.

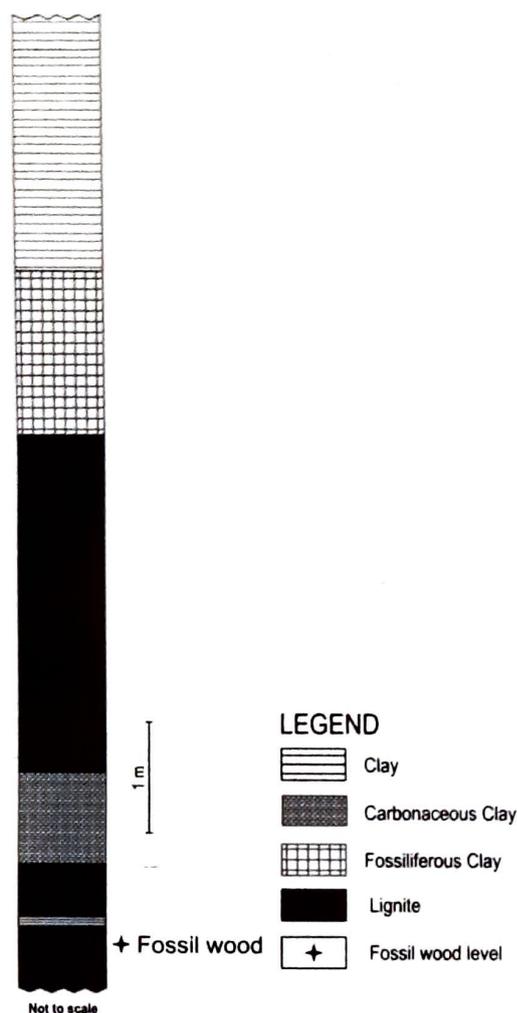


Fig. 2. Litholog of Khadsalia Lignite Mine showing the occurrence of fossil wood in the outcrop.

SYTEMATIC DESCRIPTION

Order Ericales

Family Ebenaceae Hiern, 1873

Genus *Ebenoxylon* Felix, 1882

Ebenoxylon eocenica sp. nov.

(Pl. 1, figs. 1-6)

Description: Wood diffuse porous, Growth rings indistinct, Vessels small to medium size, t. d. 85-130 μm ; r. d. 110-196 μm ; usually solitary, sometime in multiples of 2-5, 4-6 vessels per sq. mm., vessels are often filled with dark contents, circular to oval when solitary, while those in radial multiples are generally flattened at the base of contact (Pl. 1, figs. 1-2); vessels 140-430 μm in length with usually truncate to tailed end, perforations simple; inter-vessel pits small to medium, 4-6 μm in diameter, alternate, circular to oval

in shape; bordered pits alternate with linear to lenticular apertures (Pl. 1, fig. 6). Parenchyma apotracheal and paratracheal; paratracheal parenchyma scanty, associated with the vessels; apotracheal parenchyma 1-2 seriate, regular to irregular concentric slightly wavy lines, about 12-15 lines/mm (Pl. 1, figs. 1-2); parenchyma cells thin walled, 10-12 μm in diameter and 45-190 μm in length. Xylem rays fine, 1-2 seriate, 18-32 μm in width and 105-850 μm in length and 3-12 celled (Pl. 1, figs. 3-4); ray tissues heterogeneous, rays composed of both upright and procumbent cells; ray cells thin walled, tangential height of procumbent cells 18-28 μm and 20-70 μm in radial length; tangential height of upright cells 35-75 μm and radial length 16-30 μm . Ray cells profusely crytalliferous in nature (Pl. 1, fig. 5). Fibres aligned in radial rows, polygonal, semilbriform, moderately thick walled, nonseptate; 12-14 μm in diameter, 140-450 μm in length.

Specimen: Museum no. BSIP 41178.

Horizon & Age: Cambay Shale Formation, Eocene.

Locality: Khadsalia Lignite Mine, Saurashtra, Gujrat, India.

Etymology: After the 'Eocene' Epoch.

Modern affinity: The diagnostic features of the fossil wood such as 1-2 seriate, close, concentric, tangential lines at nearly regular interval and 1-2 seriate, heterogeneous xylem rays are found in the modern woods of the families Apocyanaceae, Ebenaceae, Rubiaceae and Sapotaceae (Pearson & Brown 1932, Metcalfe & Chalk 1950). Further, the presence of small to medium size vessels with small pits, upright cells and non septate fibres collectively indicate its affinity with the genus *Diospyros* Linn. of the family Ebenaceae. The extant taxa of other families differ from the present fossil either in vessel size or in the distribution of parenchyma and comparatively thick xylem rays. On critical examination of thin sections of available species of the genus *Diospyros* Linn. and the published anatomical details of some more species of this genus (Kanehira 1924, Desch 1959, Kribs 1959, Normand 1960, Miles 1978, Ilic 1991), it was found that the fossil wood shows closest affinity with *D. macrophylla* Blume (BSIP Xylarium slide no. 2210).

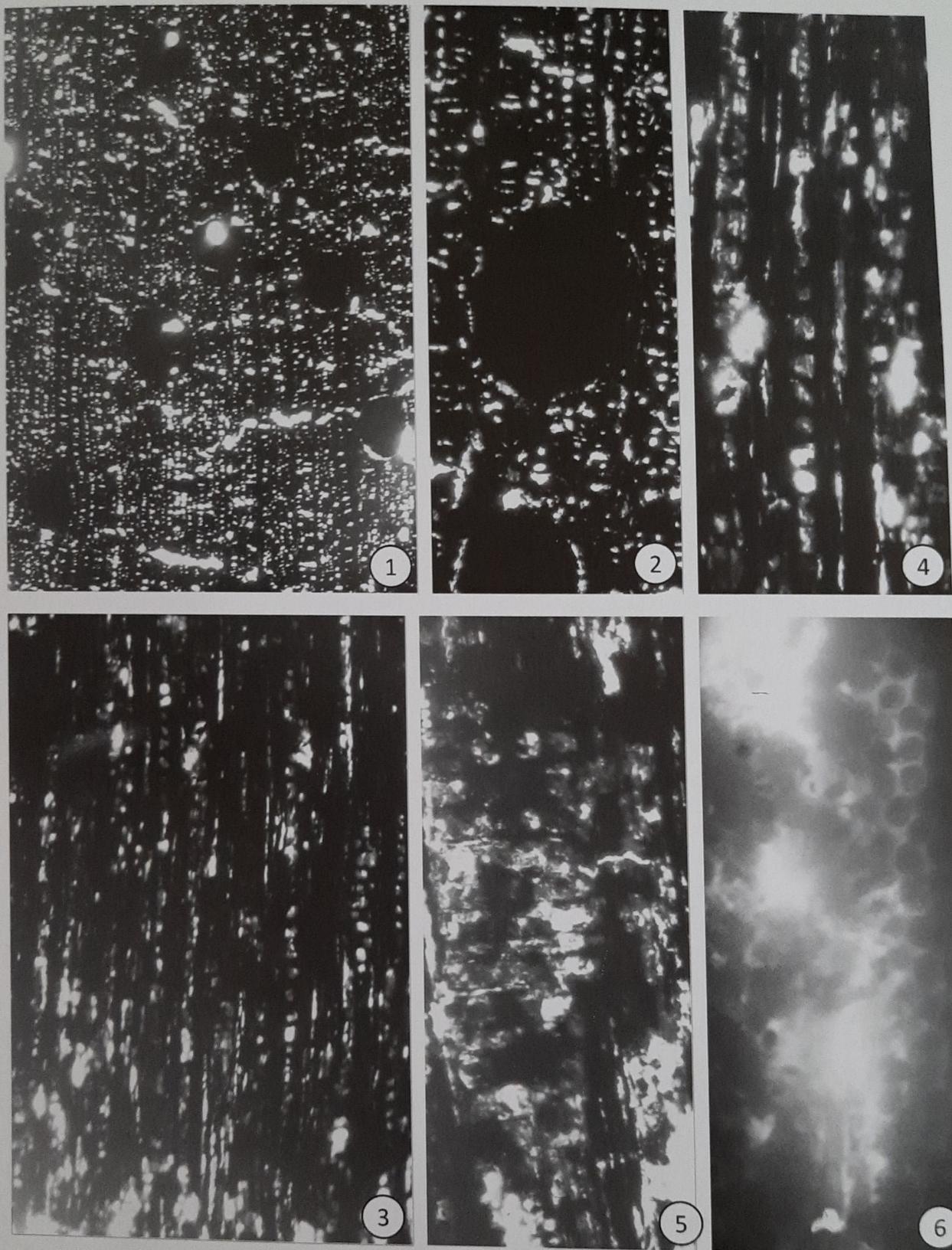


PLATE 1

1. *Ebenoxylon eocenica* sp. nov. – Showing cross section of the wood in low power showing shape, size and distribution of vessels and parenchyma. x50. Slide no. BSIP/41178-I.
2. *E. eocenica* sp. nov. – Cross section magnified to show the distribution pattern of parenchyma and vessels filled with very dark resinous matter. x120. Slide no. BSIP/41178-I.
3. *E. eocenica* sp. nov. – Tangential longitudinal section showing mostly uniseriate xylem rays and the nature of fibres and parenchyma strands. x80. Slide no. BSIP/41178-II.
4. *E. eocenica* sp. nov. – A part of tangential longitudinal section magnified to show the details of xylem rays cells. x120 Slide no. BSIP/41178-II.
5. *E. eocenica* sp. nov. – Radial longitudinal section showing heterocellular xylem rays. x120. Slide no. BSIP/41178-III.
6. *E. eocenica* sp. nov. – Magnified inter-vessel pit pairs. X550. Slide no. BSIP/41178-II.

Fossil record and comparison: Fossil woods resembling the genus *Diospyros* Linn. are described under the form genus *Ebenoxylon* Felix 1882. Several species of this genus have been recorded from the Tertiary sediments of India and abroad. Out of which 12 species are known from the Indian subcontinent, (Table 2). The present fossil wood has been compared with all the above known Indian species as well as available species of other countries. It was found that the present fossil wood is entirely different from them in one or more characters. However, it shows similarity with the fossil wood *Ebenoxylon kalagarhensis* Prasad (1989) described from Middle Miocene of Kalagarh area, Uttarakhand. Both the fossil woods from Khadsalia and Kalagarh possess 1-2 seriate concentric lines of apotracheal parenchyma, 1-2 seriate, heterogeneous xylem rays and small to medium bordered pits but differ from *E. kalagarhensis* in the size of vessels which are comparatively larger in size. The fossil wood *Ebenoxylon arcotense* (Awasthi) Awasthi 1984 described from the Tertiary sediments of South India is also different from the present fossil wood as it bears vessels of comparatively larger size (140-250 μm) and the xylem rays are composed of

oval to circular cells (procumbent cells) as compared to predominantly upright cells (elongated cells). The fossil wood, *Ebenoxylon cambayense* Singh et al. (2015) described from Cambay Shale Formation of Vastan Lignite Mine also differs in possessing regular concentric bands of apotracheal parenchyma and mostly uniseriate xylem rays. The remaining other species can be differentiated in having different size and frequency of the vessels and nature of parenchyma bands. The rays in remaining species are either homogeneous or have only few upright cells. In view of the noted differences the present fossil wood is attributed to a new species as *Ebenoxylons eocenica*.

DISCUSSION AND CONCLUSION

The present investigation on the carbonised woods collected from the Eocene sediments of Khadsalia Lignite deposits, western India revealed the occurrence of a new taxon *Ebenoxylon eocenica* of family Ebenaceae. This is the first report of the taxon from this fossil locality. It resembles the modern taxon *Diospyros macrophylla* Blume which is a member of evergreen forests of Java. It indicates the prevalence of warm and humid climate in the Khadsalia area during the Eocene period.

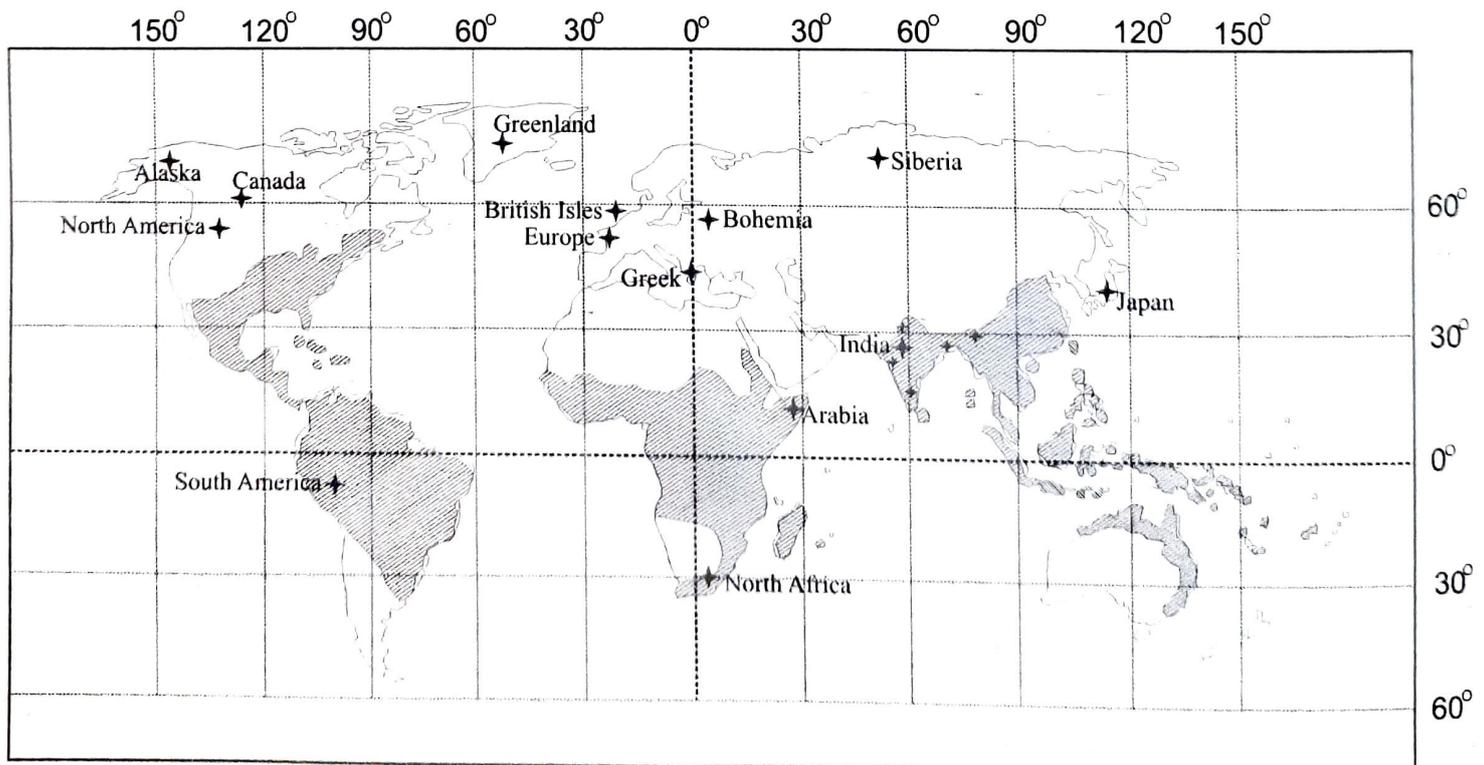


Fig. 3. Map showing the present and past global distribution of the genus *Diospyros* Linn.

Diospyros Linn. is a well known genus of family Ebenaceae that comprises about 470 species and distributed in tropical and subtropical region of the world with greater diversity in the Indo-Malayan region. The genus is also widely distributed (Fig. 3). Based on fossil wood about 27 form species have been reported from Pliocene to late Cretaceous deposits from different parts of the world (Kaiser 1890, Platen 1908, Prakash & Barghoom 1961, Slijper 1932, Prakash & Tripathi 1970, Awasthi 1970, Chitale & Patil 1972, Prakash 1978, 1981, Trivedi & Srivastava 1982, Prasad 1989, 1993, Navale 1968). *Ebenoxylon ebenoides* described from Late Cretaceous of Libyan desert is the oldest record of the genus (Kaiser 1890). In India, the oldest record of this family also dates back to Late Cretaceous. Two fossil woods *Ebenoxylon mahagaoense* (Chitale & Patil 1972) and *E. deccanensis* (Trivedi & Srivastava 1982) have been reported from the Late Cretaceous of India. Based on fossil leaves, more than 75 form species have been reported from different parts of the world (India, Japan, Panama, Africa, Bohemia, Canada, Europe, England, Greek, and Greenland etc.). Out of these about 12 form species have been described from the Indian subcontinent (Prasad et al. 2015). The earliest record of fossil leaf *Diospyrophyllum provectum* Linn. cf. *Diospyros* goes back to Upper Cretaceous of Bohemia (Velenovsky 1884). Thus, from the past and present distribution of *Diospyros* Linn., it is evident that this genus is cosmopolitan.

The extant species, *Diospyros macrophylla* Blume presently grows in the South East Asia (Backer & Bakhuizen Von Den Brink, 1965). Thus, the occurrence of this Malayan representative in Khadsalia area (India) suggests that some of the flora of south eastern region might have been migrated to Khadsalia area and fossilized during the Eocene.

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