EARLY EOCENE ARECOID PALM WOOD, *PALMOXYLON VASTANENSIS* N. SP. FROM VASTAN LIGNITE, GUJARAT, INDIA: ITS PALAEOENVIRONMENTAL IMPLICATIONS

M. PRASAD¹, H. SINGH¹, S. K. SINGH¹, DEBI MUKHERJEE² and EMILIO ESTRADA RUIZ³

1. BIRBAL SAHNI INSTITUTE OF PALAEOBOTANY, 53, UNIVERSITY ROAD, LUCKNOW: 226007, INDIA.
2. CENTRE OF ADVANCE STUDY IN GEOLOGY, LUCKNOW UNIVERSITY, LUCKNOW, 226007, U.P. INDIA.
3. UNITED ACADEMICAEN CIENCIASDELA TIERRAUNIVERSIDAD AUTONOMADE GUERRERO EX HACIENDA DE SAN JUAN BAUSTINA, 40323, TAXCO EL VIEJO, MEXICO.

Corresponding author: E-mails: ¹mahesh_bsip@yahoo.com, ² Debi_Dutta@Yahoo.com

ABSTRACT

A new species of fossil palm wood, *Palmoxylon vastanensis* is reported and described from the Vastan Lignite Mine, Surat, Gujarat, India. The fossil wood is characterized by highly lacunar ground tissue with very large air spaces indicating that plants were growing in an aquatic or the marshy environment. A detailed anatomical study revealed its affinities with the extant arecoid taxa belonging to the family Arecaceae. Among them, it closely resembles *Areca catechu* as both fossil and living species possess similar anatomical features such as highly lacunar ground tissue, reniform, dorsal sclerenchymatous sheath of the fibrovascular bundles with the frequency of 30-35 per cm². Based on the anatomical characters of the fossil and present day ecology of its modern equivalent, the palaeoenvironmental implications have been discussed.

Keywords: *Palmoxylon vastanensis* n. sp., Arecaceae, anatomy, palaeoenvironment, Vastan Lignite, Lower Eocene, Gujarat, India

INTRODUCTION

The subsurface beds of the Lower Cambay Shale exposed in an opencast lignite mine at Vastan in the southern part of the basin, include a large number of different types of fossils such as foraminifers, ostracods, molluscs, fishes and mammals reported by several workers (e.g. Garg et al., 2008; Bajpai et al., 2005; Punekar and Saraswati, 2010; Rana et al., 2004). The Palaeogene sediments in the Cambay Basin are exposed in the form of the strips along the Saurashtra coast and to the east of the Gulf of Cambay (Fig.1). The Vastan opencast lignite mine is situated about 29 km NE of Surat. The lignite, together with the associated sediments containing pollen assemblage, was reported by Samant and Tapaswi (2000, 2001); Samant and Bajpai (2001); Rana et al. (2004). The marine ostracods from these sediments were recovered by Bhandari et al. (2005). Evidence of marine fish remains and mammalian fossils was reported by Sahni et al. (2004); Nolf et al. (2006); Rana et al. (2005a,b), while Rose et al. (2006) provided information related

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Fig. 1. Geological map of the area showing site of palm wood occurrence. Inset shows position of the study area in India.
to depositional environment and sedimentation in the Palaeogene lignite-rich succession at Surat, Gujarat. Later, these views were also supported by Tom McCann (2010) and Kishor et al. (2011).

It has been observed by one of the authors (H. Singh) that occurrence of plant megafossils (especially leaves) was restricted in the uppermost thin layer of lignite in contact with the shale bed (Fig.2). A few fragmentary wood specimens were found associated with the sandy shale bed. In addition, reports of microfossils from the Vastan lignites have been published by Tripathi and Srivastava (2006); Samant and Tapaswi (2008); Guleria et al. (2008): Mandal and Guleria (2006); Garg et al. (2008). Recently, Singh et al. (2010) reported the occurrence of plant megafossils (fruits) referable to Ziziphus, Combretum, Terminalia and Lagerstromia belonging to the dicotyledonous families Rhamnaceae, Combretaceae and Lythraceae.

GEOLOGICAL SETTING

The vastan lignite mine is situated about 29 km north east of Surat town (Lat 21° 25’ 47”N Long. 73° 37’ 30”) in Gujarat, western India. The shale referable to the Cambay Shale Formation is variable in thickness (20-145m), consisting of lignite bands of various thicknesses alternating with carbonaceous and grey shales (Fig.2). There are two main lignite seams in this mine; lignite seam-1 lies at the top and lignite seam-2 at the bottom of the mine (Rana et al., 2008). The Cambay Formation overlies the Palaeocene-Lower Eocene Vagadkhol Formation and is overlain by the upper Eocene Nummulitic limestone and marl which denotes the Amravati Formation (Sudhakar and Basu, 1973) (Table 1). The foraminifer, Nummulites burdigalensis occurs as an indicator of Shallow Benthic Zone of middle Ypresian (Early Eocene) age, about 18-20 m above the rodent-bearing horizon (Sahni et al., 2006); Berggren and Pearson, 2006. The succession, in turn, is overlain by the recent alluvium. According to Sahni et al. (2006) the sediments of lower half of the Vastan lignite mine were deposited in an estuarine to lagoonal environment, whereas those of the upper half were deposited under the shallow marine conditions.

MATERIAL AND METHODS

The material was collected by one of the authors (HS) from the sediments of Lignite seam 1 exposed at the Vastan Lignite Mine. It is a small piece, black in colour measuring 4x2 cm in size, apparently showing fibrovascular bundles scattered in the matrix. The specimen was cut into thin sections (TS and LS). To observe the anatomical characters, these sections were ground to thin slices and polished by standard method for preparation of permanent slides. The important characters were studied under low and high magnifications under the optical microscope and the photomicrographs for important anatomical features were prepared.

SYSTEMATIC DESCRIPTION

Family Arecaceae Schultz, 1832
Genus Palmoxylon Schenk, 1882
Type species: Palmoxylon blanfordi Schenk, 1882
Palmoxylon vastanensis n. sp.
(Pl. I, figs.a-k; Pl. II, figs.a-c)
Type specimen (Holotype): Palmoxylon vastanensis n. sp; BSIP Museum No.39901.
Type locality: Vastan lignite mine, Gujarat, India.
Horizon and Age: Cambay Shale Formation; Lower Eocene.
Parts available: Sub-Dermal and Central zones.
Derivation of name: The specific name is based on the locality, Vastan, from where the specimen was recovered.
Diagnosis: Wood blackish in colour; comprising sub-dermal and central size 4x2.6cm, fibro-vascular bundles in sub-dermal zone irregularly oriented with one metaxylem vessel and one metaxylem vessel; comprising sub-dermal and central size 4x2.6cm, fibro-vascular bundles in sub-dermal zone irregularly oriented with one metaxylem vessel sometimes two may be present; size of the bundles ranges from 440x500-700-800µm; dorsal schelencymatous sheath reifferm; cells of this sheath generally not preserved. A layer of tabular parenchyma present around the fibrous part of the bundle; auricular lobes round, auricular sinus absent; diminutive fibrovascular bundles rare, fibrous bundles absent, leaf-trace bundles rare. Fibrovascular bundles of central zone irregularly dispersed in ground tissue, bigger in size as compared to sub-dermal zone; 1000x900-1200x1000µm; the schelencymatous sheath reifferm, cells of this sheath partly preserved; frequency of the fibrovascular bundles is 30-35 cm² and the f/v ratio varies 4/1-5/1; tabular parenchyma present; stegmata absent. Ground tissue highly lacunar; cells rod to cylindrical and variously shaped forming large air spaces; secretory cells present in the ground tissue; diminutive fibro-
vascular bundles rare; leaf-trace bundles present.

Description: The silicified specimen is black in colour due to association of lignite beds; it measures 4cm in length and 2.6cm broad. The fibrovascular bundles are irregularly dispersed throughout the specimen as seen in cross section (Pl. I, fig.a). Based on the consistency, orientation of the fibrovascular bundles and the nature of ground tissue, anatomically it is divisible into sub-dermal and central zones, while the outermost part (dermal zone) is missing. The distinction between sub-dermal and central zones can be made by the concentration of the fibro-vascular per cm²; ground tissue being highly lacunar with larger air spaces in the central zone (Pl. I, figs. f-k; Pl. II, figs a,b).

Sub-dermal Zone: The fibro-vascular bundles in this zone are sparsely placed. Their size varies from 440x500 to 700x800µm, generally round to oval in shape having reniform dorsal fibrous sheath; bundles generally with one metaxylem vessel, rarely two vessels can be present (Pl. I, figs.b,d,g). The cells of fibrous sheath generally are decayed off possibly due to unsuitable ecological conditions for its preservation; however, the outer most layer (tabular parenchyma) are present around fibrous part, these cells are cylindrical, oval to elongated in shape, their size varies from 200-250µm. Radiating parenchyma around vascular part of the bundles are present (Pl. I, fig.e,f). The frequency of fibro-vascular bundles varies from 35-40 per cm²; the f/v ratio ranges from 4/1 to 6/1. Phloem cells are not rare; leaf trace bundles present. At places, secretory glands (50 x100-410x250µm size) (Pl. I, fig. k). Leaf-trace bundles are sometimes present in this zone. At places, secretory glands are also present in this zone (Pl. I, fig.i; Pl. II, fig.a).

Diminutive Fibro-vascular Bundles: These are small-sized fibrovascular bundles, rarely seen in this zone, irregularly arranged in the ground tissue, measuring less than 250-300µm in size. Their structure is almost similar to that of normal, fibro-vascular bundles (Pl. I, fig.c).

Leaf-Trace Bundles: Leaf trace bundles are very rarely seen in the stem and can be distinguished by protruded vascular part with many smaller xylem vessels. They are slightly larger in size than the normal fibro-vascular bundles and extend from 1 to 1.4mm (Pl. I, fig.a).

Central Zone: This zone is about 2cm thick having larger fibro-vascular bundles as compared to the sub-dermal zone, they measure1000x900-1200x1000µm with a layer of peripherally elongated tabular parenchyma ( Pl.I, figs.d,g). The sclerenchymatous sheath of the fibro-vascular bundles is reniform; the cells of this part are disintegrated to reveal their exact nature (Pl. II, fig.a). However, a few sclerenchymatous cells can be observed, they are polygonal in shape with larger lumen and thin cell wall. The auricular sinus is indistinct; each fibro-vascular bundle has generally one metaxylem vessel, rarely two may be present. The frequency of fibro-vascular bundles vary from 30-35 per cm². The fibro-vascular ratio ranges 4/1-5/1. The fibrous bundles and stegmata are absent in this zone; are absent. Radiating parenchyma present around the vascular part of the bundles and anastomoses with the parenchyma cells of the ground tissue (Pl.I, figs.e,g,h). The ground tissue is highly lacunar with very large air spaces formed by union of cylindrical parenchyma of various shapes (50 x100-410x250µm size) (Pl. I, fig. k). Leaf-trace bundles are sometimes present in this zone. At places, secretory glands are also present in this zone (Pl. I, fig.i; Pl. II, fig.a).

Ground Tissue: The ground tissue in the present fossil is highly lacunar throughout providing spongy nature to the stem, distinctly consisting of the cells of variable shapes and sizes (100x300 µm). These cells provide the ground matrix with small to very large air spaces. The spongy nature of the ground tissue gradually increases from sub-dermal to central zone (Pl. I, figs.1-3; Pl. II, fig b).

Vessel Elements: The number of the xylem vessels in the sub-dermal and central zones is generally one, rarely two per fibro-vascular bundle, they are round to oval in shape and...
EXPLANATION OF PLATE I

(a). Cross section of *Palmoxylon vastanensis* n. sp. Showing general distribution of the fibrovascular bundles. (b) Fibrovascular bundles of sub-dermal zone with small xylem vessel. (c) Diminutive fibrovascular bundle of subdermal zone. (d) Fibrovascular bundle showing elongated tabular parenchyma around the fibrous sheath. (e, f) Part of fibrovascular bundle showing radiating parenchyma around vascular region. (g) Fibrovascular bundle of central zone shows radiating parenchyma and two xylem vessels. (h, i) Part of fibrovascular bundles showing spongy nature of ground tissue in sub-dermal zone and secretory canal. (k) Ground tissue of central zone showing large air spaces.
extruded. Their size ranges from 150-230µm; due to poor preservation the sculpture of these vessels is not seen (Pl. I, figs. d-g; Pl. II, fig.c).

**COMPARISON WITH INDIAN FOSSIL PALMS**

The present fossil palm possesses a distinct lacunar ground tissue with very large air spaces throughout (sub-dermal and central parts). Different species of *Palmoxylon* having reniform dorsal sclerenchymatous sheath and lacunar ground tissue, have been taken into account (Table 2) viz. *P. superbum* Rao and Menon (1964), *P. blanfordi* trabeculosum deccanense, *Palmoxylon hislopi* Lakhanpal (1939), Sahni (1964); Mahabale and Kulkarni (1972), *P. trabeculosum* (Sahni, 1964). *P. jammuensis* Sahni (1931, 1964), *P. bhanfordi* Schenk (1982), Sahni (1964), *P. parthasarathyi* Rao and Menon (1964), *P. fiestmentali* Rao and Achutan (1969), *P. superbum* Trivedi and Verma (1971), *P. parapaniensis* Lakhanpal et al. (1979), *P. livistonoides* Prakash and Ambwani (1980) and *P. dilacunosum* Ambwani (1984). Further, on close observation, it was found that Palmoxylon parapiansis, *P. livistonoides* and *P. dilacunosum* having highly lacunar ground tissue and a number of characters such as fibrovascular bundles/cm², presence/absence of fibrous bundles and stegmata were considered. *Palmoxylon parapiansis* has greater number of fibrovascular bundles both in outer and inner zones, whereas in *P. vastanensis* these are very large with radiating parenchyma. *P. livistonoides* has greater number of fibrovascular bundles in dermal and sub-dermal zones with higher f/v ratio, fibrous bundles and stegmata are present while they are absent in the present species. The ground tissue is compact in dermal zone and lacunar in sub-dermal zone, thus can not be fully compared with the present species. Lastly, *P. dilacunosum* though has very large air spaces in ground tissue but is compact in the dermal zone, the number of fibrovascular bundles, f/v ratio and presence of fibrous bundles with stegmata does not match with the present species. Considering the above fact, the present fossil reveals characters of difference from above-mentioned species.

**Table 2: Comparison of Palmoxylon vastanensis with other known species of Palmoxylon.**

<table>
<thead>
<tr>
<th>Species</th>
<th>Stenzel’s Classification</th>
<th>No of FVB/cm²</th>
<th>F/V Ratio</th>
<th>Fibrous bundles &amp; Stegmata</th>
<th>Ground Tissue</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>P. decanense</em></td>
<td>Reniformia</td>
<td>D. 200-270</td>
<td>D. 10/1</td>
<td>Fibrous bundles absent; stegmata present</td>
<td>Slightly lacunar to highly lacunar</td>
</tr>
<tr>
<td><em>P. chihndowarensis</em></td>
<td>Reniformia</td>
<td>D. 297-625</td>
<td>D. 4.5/1-8/1</td>
<td>Both absent</td>
<td>Compact to highly lacunar, air spaces small</td>
</tr>
<tr>
<td><em>P. eocenum</em></td>
<td>Reniformia</td>
<td>D. 300-366</td>
<td>D. 6.5/1-10.5/1</td>
<td>Fibrous bundles present; stegmata absent</td>
<td>Lacunar throughout; cells Y shape</td>
</tr>
<tr>
<td><em>P. parthasarathi</em></td>
<td>Reniformia</td>
<td>D. 350-380</td>
<td>D. 0.2/1-0.6/1</td>
<td>Fibrous bundles present; stegmata absent</td>
<td>Highly lacunar</td>
</tr>
<tr>
<td><em>P. khalsa</em></td>
<td>Reniformia</td>
<td>NA</td>
<td>1/1-2/1</td>
<td>Absent</td>
<td>Lacunar, cells rod-like</td>
</tr>
<tr>
<td><em>P. trabeculosum</em></td>
<td>Reniformia</td>
<td>Very small</td>
<td>2/1-4/1</td>
<td>Both present</td>
<td>Lacunar, cells isodiametric</td>
</tr>
<tr>
<td><em>P. blanfordi</em></td>
<td>Reniformia / Complanata</td>
<td>Usually 14</td>
<td>2/1-3/1</td>
<td>Absent</td>
<td>Lacunar, cells stellate, radiating</td>
</tr>
<tr>
<td><em>P. kamalam</em></td>
<td>Complanata</td>
<td>Usually 70</td>
<td>1.5/1-2/1</td>
<td>Absent</td>
<td>Lacunar, cells trabecular</td>
</tr>
<tr>
<td><em>P. wadiai</em></td>
<td>Reniformia</td>
<td>SD. 30</td>
<td>3/1-4/1</td>
<td>Absent</td>
<td>Lacunar, air spaces small</td>
</tr>
<tr>
<td><em>P. jammuensis</em></td>
<td>Lunaria</td>
<td>10-12</td>
<td>12/1-16/1</td>
<td>Both present</td>
<td>Slightly lacunar</td>
</tr>
<tr>
<td><em>P. casalata</em></td>
<td>Lunaria</td>
<td>D. 32-41</td>
<td>D. 12/1-15/1</td>
<td>Absent</td>
<td>Very Lacunar</td>
</tr>
<tr>
<td><em>P. sclerodermum</em></td>
<td>Cordata</td>
<td>C. 22</td>
<td>8/1</td>
<td>Absent</td>
<td>Very lacunar; cells shape vary</td>
</tr>
<tr>
<td><em>P. superbum</em></td>
<td>Cordata</td>
<td>D. 100-130</td>
<td>D. 9/1-12/1</td>
<td>Both present</td>
<td>Extremely lacunar</td>
</tr>
<tr>
<td><em>P. parapaniensis</em></td>
<td>Reniform-Lunate</td>
<td>O. 85-112</td>
<td>O. 1/1-5/1</td>
<td>Both present</td>
<td>Highly lacunar Throughout, cells Y-shape, oval</td>
</tr>
<tr>
<td><em>P. livistonoides</em></td>
<td>Reniformia</td>
<td>D. 130-140</td>
<td>D. 1/1-6/1</td>
<td>Both present</td>
<td>Compact- lacunar</td>
</tr>
<tr>
<td><em>P. dilacunosum</em></td>
<td>Reniformia</td>
<td>D. 160-170</td>
<td>D. 4/1-6/1</td>
<td>Both present</td>
<td>Compact to Highly lacunar</td>
</tr>
</tbody>
</table>

**EARLY EOCENE AREOCID PALM WOOD, PALMOXYLON VASTANENSIS N. SP.** 119
Comparative anatomy of P. vatsanensis n. sp. with other Palmaceae

<table>
<thead>
<tr>
<th>Species</th>
<th>Shape</th>
<th>SD. 35-40C: 30-35</th>
<th>SD. 4/1-6/1C: 4/1-5/1</th>
<th>Both Absent</th>
<th>Lacunar with very big air spaces</th>
</tr>
</thead>
<tbody>
<tr>
<td>P. lacanumum (Unger)</td>
<td>Reniform</td>
<td>120</td>
<td>1/5-1/11</td>
<td>Steg mata, absent tabular parenchyma</td>
<td>Lacunar, radiating parenchyma</td>
</tr>
<tr>
<td>Stenzel, 1904</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>P. vasculorum (Schenk)</td>
<td>Reniform</td>
<td>70</td>
<td>1/5</td>
<td>Tabular parenchyma, steg mata absent</td>
<td>Slightly lacunar</td>
</tr>
<tr>
<td>Stenzel, 1904</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>P. smithi</td>
<td>Reniform</td>
<td>10-20</td>
<td>1-1.5/1 - 1/1</td>
<td>Fibrous bundles present; steg mata absent</td>
<td>Generally compact to slightly lacunar</td>
</tr>
<tr>
<td>Tidwell et al., 1970</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>P. pristina</td>
<td>Reniform</td>
<td>30-40</td>
<td>1.7/1 - 2.7/1</td>
<td>Both present</td>
<td>Ground tissue compact</td>
</tr>
<tr>
<td>Tidwell et al., 1970</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>P. enochii</td>
<td>Reniform</td>
<td>17-34</td>
<td>6/1-7/1</td>
<td>Both absent</td>
<td>Lacunar cells rod to triangular forim air spaces</td>
</tr>
<tr>
<td>Emilio &amp; Cevallos Ferriz, 2009</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Areca catechu</td>
<td>Reniform</td>
<td>26-40</td>
<td>6/1-8/1</td>
<td>Both present</td>
<td>Lacunar, cells rod shape to triangular</td>
</tr>
<tr>
<td>Linn.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Loxocos rupicola</td>
<td>Reniform</td>
<td>35-45</td>
<td>5/1-7/1</td>
<td>Both absent</td>
<td>Highly lacunar</td>
</tr>
<tr>
<td>H. Wendl. &amp; Drude</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Oredoxa/Roystoea regia</td>
<td>Reniform</td>
<td>30-35</td>
<td>7/1—9/1</td>
<td>Both absent</td>
<td>Hig Highly lacunar, cells ribon shaped</td>
</tr>
<tr>
<td>Cook</td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

(D: dermal zone, SD: Sub-dermal zone, C: central zone, I: inner zone, O: outer zone).

**Comparison with foreign fossil palms**

Cretaceous palm woods described from abroad with lacunar ground tissue by Tidwell (1970) are *Palmoxylon simperi* and *P. pristina* (Table 2); both the species belong to Reniformia group, possess fibro-vascular bundles with one to two xylem vessels and show presence of fibrous bundles as well as steg mata; the f/v ratio varies from 1/1 -1.5/1 but the ground tissue is compact to slightly spongy in nature. The above characters do not fully agree with the anatomical characters of the present specimen. Further, comparison with *P. enochii* Emilio et al. (2009), though, show Reniform-type of dorsal sclerenchymatous sheath, the frequency of the fibrovascular bundles ranges from 17-34 per cm². The f/v ratio is slightly higher being 6/1-7/1 while the fibrous bundles and steg mata are present. Ground tissue is lacunar with moderately bigger air spaces; however, it can be compared with the present species only in having nearly similar frequency of the fibrovascular bundles and lacunar ground tissue. *Palmoxylon vastanensis* was also compared with *P. lacanumum* (Unger) Stenzel (1904) and *P. vasculorum* (Schenk) Stenzel (1904). These species show similarity to some extent because of lacunar ground tissue and reniform dorsal sclerenchymatous sheath but differ from the present species in containing higher number of fibro-vascular bundles per cm² and lower f/v ratio. In view of the distinctions of the present fossil palm wood from the above-mentioned fossil species, it is preferred to describe it as a new species.

**Affinities with extant palms**

The present fossil palm wood has been compared with the modern palms having highly lacunar ground tissue, reniform dorsal sclerenchymatous sheath of the fibrovascular bundles, their frequency per cm², fibrovascular ratio, presence and absence of fibrous bundles and steg mata as well as other cellular details. Of the known anatomy of different genera (as mentioned by Tomlinson, 1961), *Areca catechu* Linn. *Oredoxa* (Roystoea) regia Cook. and *Loxocos rupicola* H. Wendl. and Drude show anatomical similarities with *Palmoxylon vastanensis* (Table 2). Out of the above mentioned taxa, anatomical characters of *Areca catechu* show closest resemblance to the fossil as both have highly lacunar ground tissue, fibrovascular bundles with one metaxyem vessel, dorsal sclerenchymatous sheath being reniform, secondarily enlarged ground tissue parenchyma with elongated, cylindrical and rod-shaped cells forming very large air spaces and marked by absence of fibrous bundles. However, steg mata are present in *Areca catechu*. It has been observed that the frequency of fibrovascular bundles and presence of radiating parenchyma around the vascular part both in *Areca catechu* and *Palmoxylon vastanensis* is almost similar (Pl. I, fig.k; PL. II, figs d,e). *Oredoxa* (Roystoea) regia also shows anatomical similarity to certain extent; the frequency of fibrovascular bundles ranges from 30 to 35 per cm², absence of fibrous bundle and steg mata are recorded both in fossil and living specimens; though the ground tissue is highly lacunar and the parenchyma cells are secondarily expanded, they are ribbon shaped. The fibrovascular ratio is much higher and presence of two metaxylem vessels are generally seen in *Oredoxa* (Roystoea) regia (Pl. II, figs.h.i). Lastly, *Loxocos rupicola* has reniform type of dorsal sclerenchymatous sheath; the frequency of the fibrovascular bundles is slightly higher (35-45 per cm²) while the fibrovascular ratio is 5/1-7/1(5/1-6/1 in fossil); Fibrous bundles and steg mata are absent both in fossil and the living species; whereas the ground tissue parenchyma cells are transversely expanded and the air spaces are smaller in the living species, the cells form triangular to polygonal and sometimes rectangular air spaces; absence of radiating parenchyma in *Loxocos rupicola* adds a point of difference between the living and fossil forms (Pl. II, figs.f.g).

**Palaeoenvironment**

The fossil remains of palm are among the safest guides to climatic conditions in the past. It is evident that the temperature by itself is not the main factor governing the distribution of plants of this family. Apart from a few “desert” species such as *Phoenix sylvestris* and *P. decylefera* which form the prominent exceptions, the existing members of this group demand high temperature and relatively high humidity throughout the year. The area drained by upper Narbada and Godavari rivers (between 18°N and 23°N), from which at least several species of *Palmoxylon* and fruits have been reported, is by no means rich in plant fossils. The climate in this area during the Intertropical period would, therefore, seem to have been more humid than at present and comparable to Sri Lanka or parts of...
EARLY EOCENE ARECOID PALM WOOD, PALMOXYLON VASTANENSIS N. SP.

EXPLANATION OF PLATE II

(a) Leaf trace bundle with protruded xylem part with many small vessels. (b) Lacunar ground tissue of the central zone showing the large air spaces and cylindrical cells. (c) Longitudinal section of *Palmoxylon vastanensis* n. sp., showing degraded xylem vessel sculpture and air spaces in lateral view. (d) Cross section of *Areca catechu* to show the fibrovascular bundle with a vessel. (e) Ground tissue of the same showing cylindrical parenchyma cells and large air spaces. (f,g) Cross section of *Loxococos rupicola* showing single vessel in the fibro-vascular bundle, rod-shaped parenchyma cells and irregular air spaces. (h,i) Cross section of stem of *Oreodoxa (Roystonea) regia* Cook. to show fibrovascular bundle with two metaxylem vessels and ribbon-shaped parenchyma cells anastomosing to form large air spaces.

Bengal and Assam. The family Arecaceae containing almost unique group of plants known as palms is a large group both in genera (250) and approximately 2000 species; it differs from any other dicot plants and at the same time is very natural one with a most distinctive appearance. Its geographical range is also distinct, being rigidly limited by tropical climatic conditions (Fig.4). They are one of the most exclusive large tropical families. Such climatic limitation is never absolute in family of any size and to Arecaceae, having representation in subtropical and even in the warm temperate regions. However, the tropical character of the family is emphasized.

The more humid and warm conditions during Pre-Eocene period (especially in the Deccan Intertrappean (Trap Country) which became drier later on, are further indicated by the fact that abundance of the genus *Palmoxylon* known in the area; it is now poor in palms. A little west in Rajasthan (Kapurdi) it indicated much higher rainfall and a moist climate in contrast to the desertic and scrub forests of the present day. However, it became drier and warmer after the Mioocene in the northern and western India including Vastan. The present report of the plant megafossil (Palm) belonging to monocotyledons constitutes a first report from the Vastan Lignite Mine.
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Fig. 4. General latitudinal distribution of family Arecaceaein the world (shaded area).


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