Late Cretaceous palm stem *Palmoxylon lametaei* sp. nov. from Bhisi Village, Maharashtra, India

Debi Dutta[1,*], Krishna Ambwani[1], and Emilio Estrada-Ruiz[2,]**

[1] Geology Department, Lucknow University, Lucknow-226007, India.
[2] Unidad Académica en Ciencias de la Tierra, Universidad Autónoma de Guerrero, Ex Hacienda de San Juan Bautista, 40323 Taxco El Viejo, Guerrero, Mexico.
** debi_dutta@yahoo.com, ** emilkgrama@yahoo.com .*

ABSTRACT

A new fossil palm trunk Palmoxylon lametaei sp. nov. is described from the Lameta Formation (Upper Cretaceous) of Bhisi area of Nand inland basin, Nagpur District, Maharashtra, India. The stem is well preserved revealing all the anatomical features identifiable to the modern arecoid palm (Phoenix). The fossil plant is characterized by the presence of cortical, dermal, sub-dermal and central zones with profuse roots in the bark region, indicating a basal part of the stem. Presence of fibrous and diminutive bundles only in the outer part of the stem is significant while a gradual transformation from compact to lacunar condition of ground tissue from outer to inner part of the stem suggests that the plants thrived under aquatic environment.

Key words: Arecaceae, Palmoxylon, Lameta Formation, Upper Cretaceous, India.

RESUMEN

Un nuevo estípite de palmera fósil Palmoxylon lametaei sp. nov. se describe para la Formación Lameta (Cretácico Superior) dentro del área de Bhisi de la cuenca Nand, Distrito Nagpur, Maharashtra, India. El tallo está bien preservado y revela todas las características anatómicas para la identificación con palmas modernas (Phoenix). La planta fósil se caracteriza por la presencia de corteza, una zona dermal, zona subdermal y central, con raíces abundantes en la región de la corteza, lo que indica una parte basal del tallo. La presencia de haces fibrosos y haces diminutos sólo en la parte externa del tallo es significativa, mientras que una transformación gradual del tejido parenquimatoso de compacto a lagunar desde el interior del tallo, sugiere que las plantas prosperaron en un ambiente acuático.

Palabras clave: Arecaceae, Palmoxylon, Formación Lameta, Cretácico Superior, India.

INTRODUCTION

The palms are a very diverse group, which thrives in tropical regions. Although palms are especially diverse in tropical forest they have large ecological amplitude that extends from temperate environments (*e. g., Chamaerops*) to deserts (*e. g., Phoenix*) and from sea level to high altitudes (*e. g., Trachycarpus*). In a light gradient they occupy various zones in the canopy, from the dark under story to more rich light environments. Some plants reach up to 80 m in height. In this regard, the fossil records of palms present a variety of forms.

Fossil palms have been collected at different locations around the world and as early as in the Cretaceous (Harley, 2006). The town of Bishi, India is very important because a diversity of palms and dicots has been collected there (Dutta *et al.*, 2007).

A phoenicoid fossil palm stem belonging to the family *Arecaceae*, has been recovered from the sediments of Lameta Formation exposed at Bhisi village in Chandrapur District, Maharashtra, India. Upper Cretaceous angiosperm woods belonging to families Sapindaceae and Lecythadaceae have also been reported from Polgaon and Rajulwari of Nand Dongargaon inland basin by Kar *et al.* (2004). Recently, Dutta *et al.* (2007) reported a fossil palm stem (*Palmoxylon bhisiensis*) from the Bhisi area. The present investigation adds yet another fossil palm wood, *Palmoxylon lametaei* sp. nov. that shows affinities with the extant genus (*Phoenix*) from the same locality (Figure 1). Occurrence of fossil palm stems and other dicot woods in the Lameta sediments reflect evolution and establishment of angiosperm plants during the Late Cretaceous which, however, appeared to a large extent during the Deccan Intertrappean phase.

MATERIALS AND METHODS

The fossil material was collected by one of the authors (Debi Dutta) from the Lameta Formation sediments exposed at Bhisi village in Chandrapur District, Maharashtra. It is a

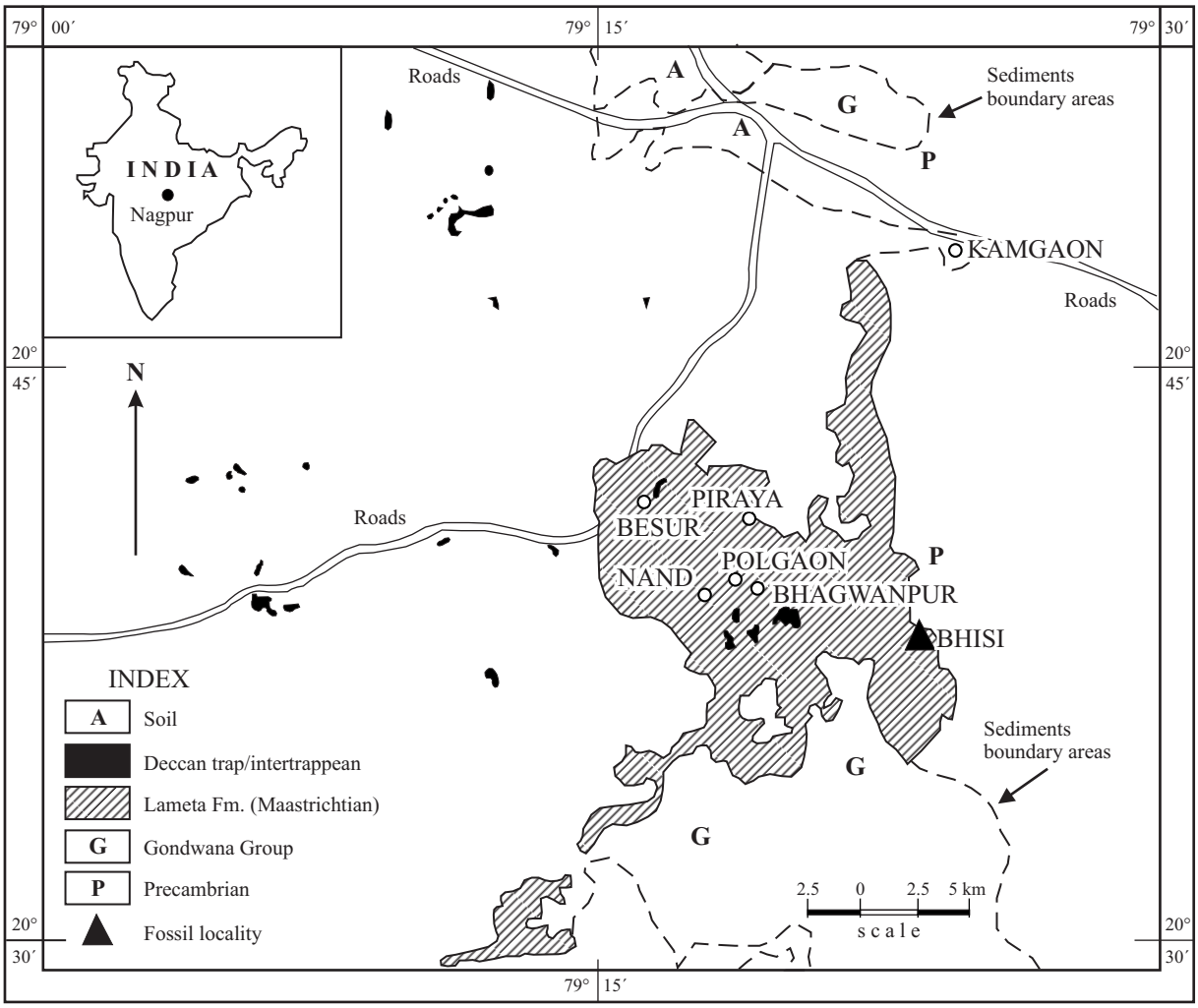


Figure 1. Map showing location from where the specimen was collected (after Mohabey, 1996).

small sample containing roots on the bark area implying to be a basal part of the stem. The specimen was cut into thin sections: transverse section (TS) and longitudinal section (LS). These sections were ground and polished by standard method for preparation of permanent slides to observe the anatomical characters. The important characters were studied under low and high magnifications and the photomicrographs for important anatomical features were prepared.

GEOLOGIC SETTING STRATIGRAPHY

The Lameta Formation (Late Cretaceous) is localized around Nand-Dongargaon overlain by the Deccan volcanic rocks, and comprises basal, red and green, silty, non-laminated clays, generally resting on the Precambrian schists with a pronounced unconformity over the Kamthi Formation. Here, the clays generally attain up to 6 m thickness associated with less frequently occurring sandstones of vertical and lateral accretion types. Packets of grey and yellow marls are also locally present in the clays and shales interbedded with thin limestones and marlites; these sediments are partially exposed at Bhisi village (Figure 2). The Lameta Formation conventionally has been considered to be a fluvio-lacustrine deposit (Hislop, 1869; Medlicott and Blanford, 1894; von Huene and Matley, 1933). Based on detailed lithofaces analysis, its deposition took place possibly in marine environment, as was postulated by Sahni, 1984; Jain and Sahni, 1985. Mohabey *et al.*, 1993; Mohabey and Udhoji, 1996; Hansen *et al.*, 1996 and Mohabey 1996, 2001. They suggested a deposition in alluvial-limnic environments under semiarid climate with seasonal fluctuations. The Lameta Formation sediments of Nand-Dongargaon have been known for their rich assemblage of fragmentary dinosaur bones represented by *Titanosaurus indicus*, *T. blanfordi*, *Laptosaurus madagascariensis*, *Antarctosaurus septentrionalis* (Hislop, 1869; Lydekker, 1879; Matley, 1921; von Huene and Matley 1933; Berman and Jain, 1982). As regards the age of the Lameta Formation at Bhisi inland basin, Mohabey (1984, 1990); Mohabey and Mathur (1989), Sahni (1984); Vianey-Liaud *et al.* (1987); Prasad *et al.* (1988) and Prasad and Khajuria (1995) assessed to be Late Cretaceous (Maastrichtian).

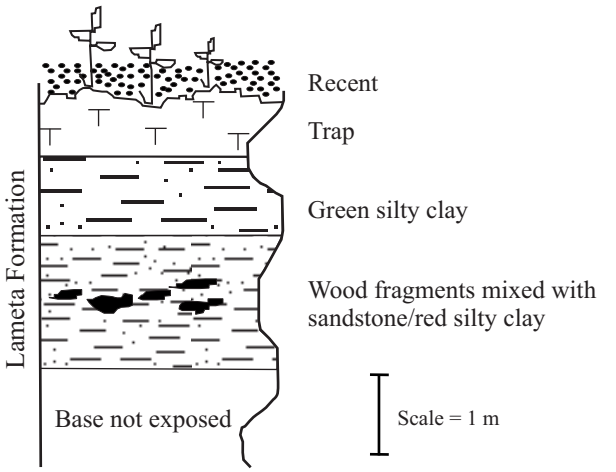


Figure 2. Details of the lithology of the area and location of fossil palm stem.

SYSTEMATIC PALEOBOTANY

Family Arecaceae Schultz Sch. 1832
Genus *Palmoxylon* Schenk 1882

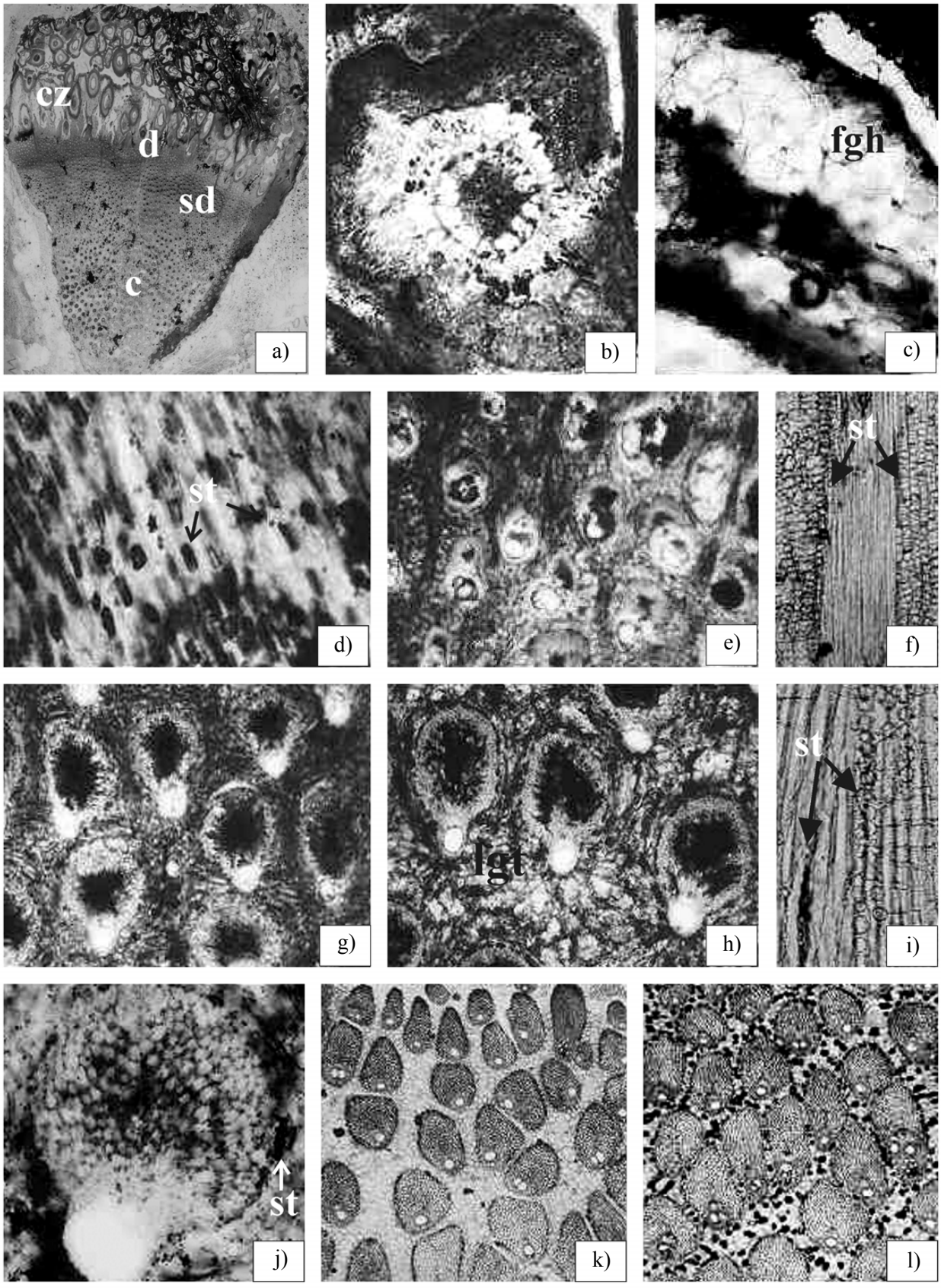
Type species. *Palmoxylon blanfordi* Schenk 1882.

***Palmoxylon lametaei* new species**
(Figures 3a-3h and 3j)

Diagnosis. Fossil palm stem divisible in dermal, sub-dermal and central lacunar zones, covered with outermost cortex with roots; stem measures 8 cm high and 6 cm wide, fibrovascular bundles with single metaxylem vessel and prominent dorsal sclerenchymatous sheath present; shape generally reniform sometimes lunate. The size of the fibrovascular bundles ranges from 700 to 1600 μm, the fibrovascular ratio ranges 1/3-3/4 and the frequency ranges from 15 to 25 per cm^2. Fibrous and diminutive bundles are present throughout the length of the stem. Ground tissue becomes lacunar towards inner part of the stem. Scabrate type stegmata are present in the fibrous sheath of the bundles.

Description. *Cortical zone*. This zone consists of profuse roots compactly arranged in the bark tissue (Figures 3a-3c). The younger roots show central ring of vascular part, whereas the mature ones have inner cortex composed of arenchymatous tissue with larger air spaces. The bark cells are elongated in nature encompassing fibrous bundles, small fibrovascular and leaf trace bundles. Sometimes radiating parenchyma may also be seen in this zone. Fungal infection can be observed within the roots infested by fungal hyphae. No fertile stages were observed to know the type of fungi growing in it. Stegmata (scabrate type) can be observed in the stellar part of root. The central core of the root is generally composed of compact parenchyma cells (Figures 3a-3c).

Dermal zone. This zone is about one centimeter in thickness composed of closely placed fibrovascular bundles within the compact ground tissue. Each fibrovascular bundle usually contains one circular metaxylem vessel. The shape of these fibrovascular bundles is generally oval to slightly elongated; sometimes it may be triangular (Figures 3a, 3e). The dorsal sclerenchymatous part is usually reniform to lunate consisting cells of wider lumen. Sometimes an incipient ventral sclerenchymatous sheath can also be observed around the vascular part of the bundles (Figures 3e, 3j). The stegmata can be seen around the outer part of the sclerenchymatous sheath of the fibrovascular bundles. The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size of the fibrovascular bundles varies from 700 to 1000 μm and the frequency ranges from 20 to 25 per cm^2. The fibrovascular ratio of the bundle varies from 1/2 to 2/3. The metaxylem vessel is very small, circular, measuring 100 μm in diameter and 200 to 250 μm long. Very rarely fibrous bundles can be observed in this zone.

Sub-dermal zone. The fibrovascular bundles in this zone are slightly bigger and sparsely placed. The size varies from 1000 to 1200 μm, they are generally oval in shape consisting of fibrous sheath with 1–2 metaxylem vessels (Figures 3g, 3h). The fibrous sheath cells are thick walled with small lumen in the inner part while the outer sclerenchymatous cells have larger lumen. The sclerenchymatous sheath is sagittate to reniform in shape. The frequency ranges from 15 to 20 per cm^2 and fibro-vascular ratio is more than 2/3 in the bundle. A few phloem cells can be seen preserved between the fibrous and the vascular parts. The fibrous and diminutive bundles are observed in this zone. The ground tissue parenchyma consists of variable shapes, where the elongated cells provide spongy nature to the ground tissue (Figure 3g).

Central zone. The central zone is about 2 cm in thickness having comparatively larger fibrovascular bundles with a prominent thick walled sclerenchymatous sheath and sclereids (Figure 3h). The fibrous sheath is generally reniform to lunate in shape. The parenchymatous cells around vascular part become radially elongated (Figure 3h). The fibro-vascular ratio is more than 3/4. Size of these bundles ranges from 1000 to 1600 μm while their frequency in this zone is about 15 bundles per cm^2. The sclerenchymatous cells are generally bigger in size as compared to those dermal and sub-dermal zones. Stegmata are frequently seen around the fibrous sheath. Leaf- trace bundles are absent in this zone. The ground parenchyma is loosely arranged providing lacunar condition in this zone (Figure 3h).

Diminutive bundles. These are small size fibrovascular bundles irregularly arranged in the ground tissue of sub-dermal zone measuring less than 250 μm in size. Their structure is almost similar to that of fibrovascular bundles (Figure 3f).

Ground tissue. The ground tissue in the present palm stem shows gradual transformation from compact to lacunar condition from the outer side towards the inner side of the stem. It is compact in the dermal zone which develops very small air spaces in the sub-dermal zone, while in the central zone different types of parenchymatous cells provide larger air spaces. This anatomical feature of the plants represents aquatic ecology of the area (Figures 3e, 3g, 3h).

Etymology. The specific name of the present palm stem is based on the Lameta Formation from where the sample has been collected.

Type. Holotype B.S.I.P. Museum slide nos. 13391 and 13392.

Measurements. The specimen measures 8 cm in length and 6 cm broad bearing outer cortical zone (3 cm thick) consisting of compactly emerging roots of different stages, which represent basal part of the stem. Anatomically it is divisible into cortical, dermal, sub-dermal and central zones depending on the consistency, orientation of the fibrovascular bundles and the nature of ground tissue (Figure 3a).

Locality. Bhisi village, Chandrapur District, Maharashtra, India.

Horizon and age. Lameta Formation (Late Cretaceous, Maastrichtian).

DISCUSSION

The anatomical characteristics of the present fossil palm, viz. i) compact ground tissue, ii) closely placed fibrovascular bundles with extruded xylem vessel and reticulate thickenings, iii) bark containing roots with conducting zone divisible into two parts, iv) regularly dispersed fibrovascular bundles, v) presence of fibrous bundles in sub-dermal zone, and vi) lacunar ground parenchyma in the central part of the stem show affinities with the extant genus *Phoenix* of the family *Arecaceae* (Figures 3i, 3k, 3l). For detail anatomical comparison of the present fossil species with the extant species of *Phoenix*, only three species (*Phoenix dectylefera*, *P. cannariensis* and *P. paludosa*) were available. Out of above species *Phoenix paludosa* shows anatomical resemblance to *Palmoxylon lametaei*. However, *P. dectylefera* differs the present fossil in having Veginata-type dorsal sclerenchymatous sheath, the F/V ratio and the frequency of the fibrovascular bundles is higher, the ground tissue is compact (Table 1), whereas *P. cannariensis* has *Complanata*-type bundle sheath with higher F/V ratio, the number of the fibrovascular bundles in the dermal zone is less as compared to the present fossil species, the ground tissue in *P. cannariensis* is compact throughout the stem and the tabular parenchyma are prominent with stegmata (Table 1). Whereas *Phoenix paludosa* shows close resemblance to the fossil stem in having *Reniformia*-type fibrous sheath of the fibrovascular

Figure. 3. a: Transversal section (TS) of *Palmoxylon lametaei* showing bark with roots, dermal, subdermal and central zones ×0.5. b: (TS) enlargement of the root showing cortex and central conducting zone ×20. c: Longitudinal section (LS) part of the root showing fungal infection ×150. d: (LS) part of the root magnified to show stegmata ×60. e: (TS) cross section of the stem showing dermal zone with regular orientation of the fibrovascular bundles ×100. f: (LS) *Palmoxylon lametaei* showing stegmata ×250. g: (TS) subdermal zone showing partially lacunar ground tissue ×100. h: (TS) inner zone showing lacunar ground parenchyma ×100. i: (LS) *Phoenix paludosa* showing stegmata ×250. j: (TS) vascular bundles enlarged to show sclerenchymatous and single metaxylem vessel ×200. k: (TS) of *Phoenix paludosa* showing dermal zone with fibrovascular bundles having 1-2 metaxylem vessels and compact ground tissue ×100. l: (TS) *Phoenix paludosa* showing sub-dermal and inner zone with lacunar ground tissue ×100. Abbreviations: cz – cortical zone; d – dermal; sd – subdermal; c – central; st – stegmata; lgt – lacunar ground tissue; fgh – fungal hyphae.

Table 1. Comparative anatomical features of modern species of *Phoenix*. D: dermal zone, SD: sub-dermal zone, C: cortical zone. I: inner zone, O: outer zone.

***Phoenix* species**	**Stenzel's classification**	**Fibrous bundles/ stegmata**	**F/V ratio**	**Distribution of fibro vascular bundles/cm^2**	**Ground tissue**	**Special characters**	**Age**
Phoenix dectylefera L.	Veginata	Both present	D. 2/3 SD. 3/1 C. 3/1	D. 30 SD. 25 C. 20	Compact	Tannin cells present, tabular parenchyma not prominent	Extant
Phoenix cannariensis Hort.	Complanata	Both present	D. 4/1 SD. 3/1 C. 2/1–3/1	D. 40 SD. 35 C. 30	Compact	Tabular parenchyma prominent with stegmata	Extant
Phoenix paludosa Roxb.	Reniformia	Stegmata present	D. 1/2–1/3 SD. 1/2 C. 1/2	D. 10–20 SD. 20 C. 15–20	Compact in dermal and sub-dermal zones, lacunar in central zone	Diminutive fibro-vascular bundles present	Extant

bundles, presence of stegmata, the F/V ratio being almost same as in the fossil and the frequency of the fibrovascular bundles in dermal, sub-dermal and central zones also matches; presence of diminutive bundles are present both in fossil and the extant species while the ground tissue shows the similarity in both being compact in dermal and sub–dermal zones and lacunar in central zone. Thus, it can be very well visualized that during the Late Cretaceous time, species similar to *Phoenix paludosa* must have been growing at the place of fossilization and represented by *Palmoxylon lametaei* (Table 1).

The majority of palm woods has been described from the different Deccan Intertrappean sediments of India viz: *Palmoxylon hislopi* (Rode, 1933), *P. dakshinense* and *P. chhindwarensis* (Prakash, 1960), *P. eocenicum* (Prakash, 1962), *P. deccanensis* (Sahni, 1964), *P. wadai* (Sahni, 1931), *P. kamalam* (Rode, 1933; Shukla, 1939; Sahni, 1964; Mahabale and Kulkarni, 1973), *P. blanfordi* (Schenk, 1882; Sahni, 1931, 1964), *P. parthasarathyi* (Rao and Menon, 1964), *P. superbum* (Trivedi and Verma, 1971) *P. parapaniensis* (Lakhanpal *et al.*, 1979), *P. livistonoides* (Prakash and Ambwani, 1980), *P. dilacunosum* (Ambwani, 1984) and *P. bhisiensis* (Dutta *et al.*, 2007). The above species anatomically differ from the present specimen in one or other characters, hence could not be fully compared. As *Palmoxylon lametaei* sp. nov. shows lacunar ground tissue, it is closely comparable to *P. blanfordi*, *P. livistonoides*, and *P. bhisiensis*. Anatomically, *Palmoxylon lametaei* sp. nov. differs from *P. blanfordi* as the later possesses only central part and has stellate cells in the ground tissue, while the F/V ratio is higher (Table 2). *P. livistonoides* also differs as it has only dermal and subdermal zones, more number of fibrovascular bundles and F/V ratio whereas stegmata are absent (Table, 2). On the other hand, based on the lacunar ground tissue *P. bishiensis* is demarcated into an outer and inner zones and highly stretched parenchyma cells; it also shows higher number of vascular bundles in both the zones (Table, 2). From the Olmos Formation (Upper Cretaceous, upper Campanian-lower Maastrichtian) of Mexico, Estrada-Ruiz and Cevallos-Ferriz (2009) described a fossil palm with ground tissue lacunar, but differs from a new species in the number of fibrotraqueids, metaxylem and the types cell of the ground tissue. The above differences favor to assign the present fossil stem a new species.

Recovery of pollen grains belonging to *Arecaceae* such as *Palmaepollenites* and *Palmidites* from the dinosaurian coprolites of Lameta Formation was made by Mohabey (1996), Mohabey and Samant (2003), Ambwani *et al.* (2003) and Kar *et al.* (2004); as well as occurrence of palm-like seed resembling *Phoenix* Ambwani and Dutta (2005) corroborate the fact that the palms were quite established during the Late Cretaceous time. At the same time, development of some other angiosperms such as grasses and plants referable to Capparidaceae can not be ruled out either (Prasad *et al.*, 2005; Dutta *et al.*, 2007).

The Lameta Formation developed a flora similar to a wet forest, and the new species, *Palmoxylon lameteai* and other as *Palmadites*, *Phoenix*, further support the presence of a humid environment. Also Lameta Formation is one of the richest and most diverse stratigraphic units in India and not only of dicotyledonous plants, but also for monocotyledons, as evidenced by the presence of several palms collected.

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Table 2. Characters comparison of *Palmoxylon lametaei* with other species of *Palmoxylon.* D: dermal zone, SD: sub-dermal zone, C: cortical zone. I: inner zone, O: outer zone.

Fossil species	Stenzel's classification	Fibrous bundles/ stegmata	F/V Ratio	Distribution of fibro vascular bundles/cm^2	Ground tissue	Any special character	Locality
Palmoxylon blanfordi (Schenk, 1882)	Reniformia	Absent	D. NA SD. NA C. 2-3/1	D. NA SD. NA C. 14	Lacunar with small air spaces	Stellate cells present	Deccan Intertrappean series
P. mathuri (Sahni, 1931)	Reniformia	Fibrous bundles present / stegmata absent	D. 2/3 SD. 2/3 C. NA	D. 300-400 SD. NA C. 400-500	Trabecular with large air spaces	Ground tissue trabecular and low fibrovascular ratio	Lackhapur, Kutch, Gujarat
P. caudatum (Sahni, 1931)	Lunaria	Absent	D. 20/1 SD. 12/-15/1 C. NA	D. 32-41 SD. 36-38 C. NA	Very lacunar	Vascular bundles with extruded xylem	Burma (Tertiary)
P. hislopi (Sahni,1931)	Lunaria	Absent	D. NA SD. 5-8/1 C. NA	D. NA SD. 65-104 C. NA	Lacunar, cells thin walled	Stellate cells present	Deccan Intertrappean Chhindwara District, M.P.
P. sinosum (Sahni,1943)	Reniformia	Absent	D. NA SD.3-4/1 C. NA	21-30	Lacunar	Ground parenchyma isodimetric	Minbu (Burma)
P. prismaticum (Sahni,1964)	Cordata	Both present	D. 5-6/1 SD. --- C. 4.5-5/1	D. 71-85 SD.37-41 C. 30-34	Compact in dermal, lacunar in SD and C zones	Palisade cells and roots present	Unknown
P. intertrappeum (Sahni, 1964)	Cordata	Fibrous bundles present / stegmata absent	D. 32/1 SD. --- C. --	D. 140 SD. C.---	Compact in dermal, lacunar in SD central zones	Palisade cells present	Deccan Intertrappean M.P.
P. geometricum (Shani, 1964)	Cordata	Absent	D. NA SD. NA C. 8/1	D. NA SD. NA C. 22	Thin walled lacunar	Regular geo-metrical forms of the cells, Y or V shaped	Sind, Pakistan (Tertiary?)
P. khalsa (Shani, 1964)	Reniformia	Absent	NA	NA	Lacunar, cells branched	Rod like parenchyma present	Unknown
P. deccanense (Shani, 1964)	Reniformia	Absent	D. NA SD. 8/1-15/1 C. NA	D. NA SD. 28-45 C. NA	Lacunar	Rod like and Y-shaped cells present	Deccan Inter-trappean series Maragour, Wardha District, M.P
P. kamalam, (Sahni,1964)	Complanata	Absent	D. NA SD. 1.51-2/1 C. NA	D. NA SD. 70 C. NA	Lacunar cells thin walled elongated	-------	Deccan Intertrappean, Chhindwara District, M.P.
P. parthasarathyi (Rao and Menon, 1964)	Reniformia	Fibrous bundles present / stegmata absent	D. 0.2/1- 0.8/1 SD. 0.2/1-0.6/1 C. 0.3/1-0.4/1	D. 350-380 SD. 90-110 C. 60-66	Highly lacunar	-------	Mohgaon Kalan Chhindwara District, M.P.
P. superbum (Trivedi and Verma, 1971)	Cordata	Both present; stegmata spherical	D. 9/1 -12/1 SD. 10/1-17/1 C. 1.5/1- 2/1	D. 100-130 SD. 60-70 C. 40-45	Extremely lacunar	-------	Keria, Chhindwara District, M.P.
P. parapaniensis (Lakhnpal et al., 1979)	Reniformia-Lunaria	Both present	O. 1/1-1/5 I. 1/3- 1/5	O. 85-112 I. 35-40	Highly lacunar, cells Y shaped forming circular to oval air spaces	Diminutive fibro-vascular bundles present	Parapani Mandla District M.P
P. livistonoides, (Prakash and Ambwani,1980)	Reniformia	Fibrous bundles present / stegmata absent	D. 1/1-6/1 SD.3/1-7/1 C. NA	D. 240-800 SD. 400-800 C. NA	D. Compact SD. Slightly lacunar C. NA	Roots present in bark region	Nawargaon, Wardha District, Maharashtra

Continues...

Table 2 (continued). Characters comparison of *Palmoxylon lametaei* with other species of *Palmoxylon.*

Fossil species	Stenzel's classification	Fibrous bundles/ stegmata	F/V ratio	Distribution of fibro vascular bundles/cm^2	Ground tissue	Special characters	Locality
P. shahpuraensis (Ambwani, 1983)	Cordata to Reniformia	Fibrous bundle absent: stegmata: present	D. 4/1-6/1 SD. 2/1-4/1 C. 1/1-2/1	D. 140-150 SD. 65-70 C. 40-45	D. Compact; SD. cells with small air spaces; C. cells with bigger inter-cellular spaces	-------	Ghugua, Mandla District, M..P.
P. dilacunosum (Ambwani, 1984)	Cordata to Reniformia	Fibrous bundles present: stegmata absent	D. 4/1-6/1 SD. 2/3-3/1 C. 1/1-2/1	D.160-170 SD. 120-130 C. 65-70	D. Compact and scanty; SD. Slightly lacunar; C.Highly lacunar	Extra large air spaces in central zone	Mandla district, M.P.
P. bhisiensis (Dutta *et al.*, 2007)	Reniformia	Both present	O. 5/1-6/1 I. 5/1	O. 40-60 I. 30-35	large lacunar spaces	Lacunar, cells stretched, ribbon shaped	Bhisi, (Upper Cretaceous) Nagpur District, M.S
P. enochii (Estrada-Ruiz and Cevallos-Ferriz, 2009)	Reniformia	-------	-------	17-34	Lacunar cells with small air spaces	Aerenchyma of different shapes	Mexico, (Upper Cretaceous)
P. lametaei sp. nov.	Reniformia to Lunaria	Both present	D. 1/2-1/3 SD.2/3 C. 3/4	D. 20-25 SD.15-20 C. 15	D. compact, lacunar in SD and C zones	Radiating parenchyma in between fibro-vascular bundles	Bhisi, (Upper Cretaceous) Nagpur District, M.S.

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