A fossil pandanaceous stem *Pandanaceoxylon kulkarnii* gen. et sp. nov. from Deccan Intertrappean beds of Wardha district, Maharashtra

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Pandanaceoxylon kulkarnii gen. et sp. nov., a fossil stem showing close affinity with the genus *Pandanus* of the family Pandanaceae has been described from the Deccan Intertrappean beds of Nawargaon in Wardha District, Maharashtra. This is the first record of pandanaceous stem from the Deccan Intertrappean exposures of India.

***Key-words**—Pandanaceoxylon*, Compound vascular bundle, Deccan Intertrappean beds, Nawargaon, Maharashtra.

INTRODUCTION

PANDANACEAE has a very meagre fossil record. Guleria and Lakhanpal (1984) reported *Pandanus* leaves from the Eocene sediments of Kutch. Bonde (1990) reported pandanaceous fruit *Pandanusocarpon umariense* from the Deccan Intertrappean beds of Umaria. A pandanaceous stem has been described for the first time in the present communication.

Order—Pandanales

Family— Pandanaceae

Genus—*Pandanaceoxylon* gen. nov.

Pandanaceoxylon kulkarnii gen. et sp. nov.

(Pl. 1, Figs 1-8, Pl. 2, Figs 9-16; Text-figs 1-83)

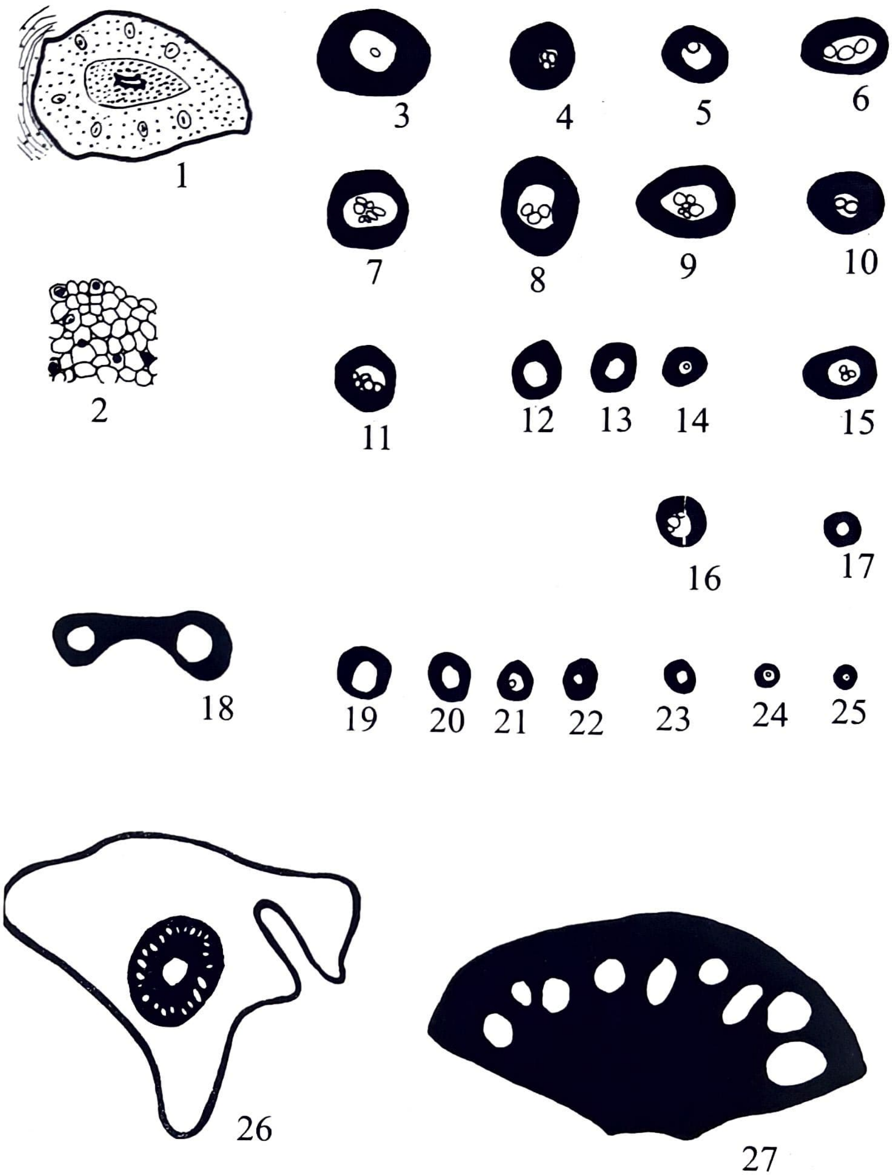
The present description is based upon the study of monocotyledonous stem with leaf sheaths and roots. Externally the rhizome is ensheathed by leaf bases and bears adventitious roots at places. The specimen is reddish brown externally as well as internally.

Structure of the stem

Internally the stem structure shows cortex enclosing the vascular cylinder (Text-fig.1). Cortex—The cortex measures 5 to 6 mm in radial extent. Surrounding the cortex, there are 3-5 leaf sheaths. There is no clear differentiation of cortex into inner, middle and outer zones. However, the cells of the outer and inner zones are compactly arranged as compared to the middle one. In the middle zone, cells are larger with larger lumen.

Vascular bundles in the cortex

The diminutive vascular bundles are distributed throughout the cortex. In addition, the larger bundles are present mostly in the outer and inner parts. Middle part is occupied by the smaller bundles (Pl. 1, figs 5, 6). The bundles are arranged more or less in radial rows. The larger bundles are collateral while the smaller ones are concentric and hadrocentric or centrophloic. The larger bundles are oval to round in cross section with an average size of 210x188 μm. Each vascular bundle is surrounded by 4 to 5 layered fibrous sheath having thickness of 32 to 48 μm (Text figs 3-25, Pl. 2, figs 9-11). Fibre cells—These are sclerenchymatous, somewhat thicker than the surrounding parenchyma cells. They are polygonal in shape with 4 μm lumen diameter. The vascular tissue has ill-preserved phloem enclose in the arms of 'V' or 'Y' or crescent shaped xylem. Metaxylem elements are round to oval in cross section, 36 μm in diameter, protoxylem elements are round to angular in shape, 24 μm in diameter (Text-figs 3-16), phloem tissue consists of thin walled compactly arranged cells. Phloem patch is 40 μm in thickness and phloem cells are 5 μm in diameter.



Text-figs 1-27. *Pandanaceoxylon kulkarnii* gen. et sp. nov. 1. Cross section of the stem showing the arrangement of vascular bundles, endodermoid layer and leaf sheath x1.6. 2. Ground parenchyma cells. Note thin sac like cells with black contents x100. 3-11, 15-16. Collateral vascular bundles of cortical region x50. 18. Fusion bundles x50. 12-14, 17, 19-25. Diminutive vascular bundles of cortical region x50. 26. Cross section of the root showing invaginated epiblema and steler part x50. 27. Sector of the root showing the steler arc part and metaxylem elements x200.

PLATE 1

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1. Original specimen showing the roots and leaf sheath (scars) x0.9
2. Original specimen showing the roots and leaf sheath (scars) x0.6
3. Original specimen showing the roots and leaf sheath (scars) x0.45
4. Bud (shoot-tip) in longitudinal section with ensheathing leaves x7.5. Note the tristichos arrangement of leaves
5. Cross section of the stem showing cortex and five leaf sheaths x4.5. Note the distribution of vascular bundles in the cortex
6. The same cross section showing the cortex and central vascular zone x3.75
7. Cross section of the leaf sheath showing large collateral vascular bundles and smaller diminutive bundles x102
8. Cross section of the root showing the central select part x100

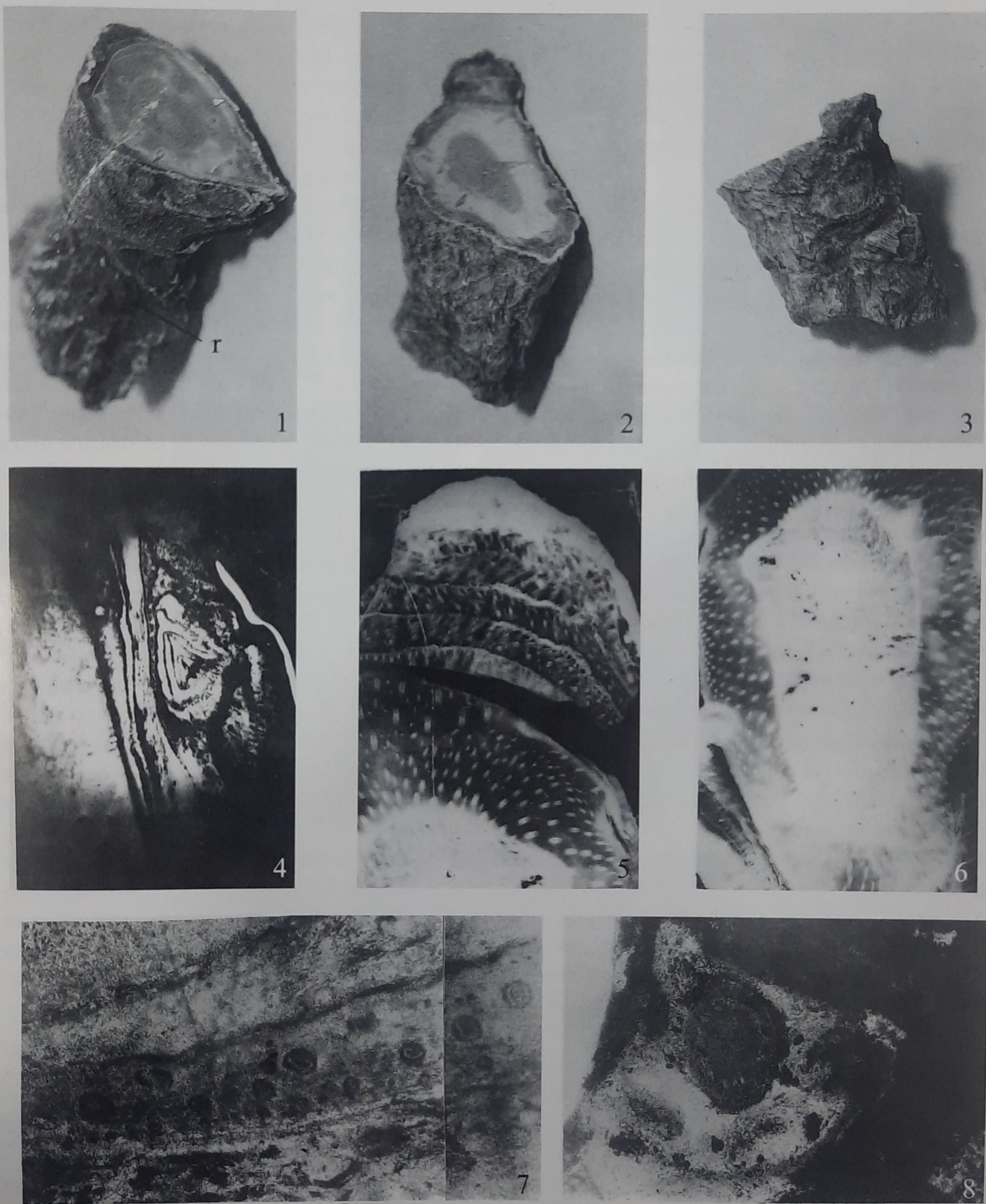


PLATE 1

The smaller bundles are also round in shape in cross section (Text-figs 17, 19-25) varying in diameter from 50-80 μm. Each has 4-5 layered fibrous sheath enclosing the vascular tissue. The vascular tissue has well preserved one or two xylem vessel elements surrounded by a patch of phloem tissue or phloem tissue is in the center and is surrounded by a ring of xylem elements.

The ground parenchyma of the cortex consists mainly of small, oval to polygonal angular, thin walled, loosely arranged cells. The cells are 80x48 μm in size. Scattered in the ground parenchyma are found sac like cells of 16-18 μm diameter filled with black contents. Their walls are slightly thicker than the ground parenchyma cells (Text-fig. 2). This is prominent feature of the cortex. Vascular cylinder—It is delimited from the cortex by the endodermoid layer and varies in diameter from 1.7 to 1.9 cm in various sections (Text-fig. 1, Pl. 1, fig. 6). Fibrovascular bundles are distributed in the ground parenchyma. Fibre bundles are absent. Vascular cylinder can be broadly distinguished into peripheral and central vascular zones. The vascular bundles are small and compactly arranged in the peripheral zones (Pl. 2, fig.14). The fibrous sheath enclosing vascular tissue is more developed on dorsal side than on the ventral and lateral sides.

Peripheral vascular zone—It extends radially to 3-4 mm in different sections. On an average 10-13 fibrovascular bundles are found per sq mm. The bundles are oval to round in cross section (Text-figs 52-60, Pl. 2, fig.12). Oval vascular bundles are 192x112 μm in size whereas round vascular bundles are 128 μm in diameter. The fibrous sheath is 3-4 layered and 32 μm in thickness. The fibres are thick walled, hexagonal in cross section with a lumen diameter of 4 μm and wall thickness 2 μm, xylem consists of 4-8 round or angular vessels arranged mostly in a single crescentic row (Text-figs 53-60). Metaxylem elements are towards the periphery of the crescent and protoxylem towards centre. (reverse is true for certain bundles). The largest metaxylem vessel is 32 μm in diameter and smallest protoxylem vessel is 16 μm in diameter Protoxylem shows spiral lateral wall pitting (Pl. 2, fig.16). Some of the bundles are concentric, with vessels arranged in a circular ring enclosing phloem. The phloem patch is 50x32 μm in size and is enclosed in xylem arc. The phloem tissue is not preserved. Compound vascular bundles are present (Text-figs 61-65; Pl. 2, fig.13). Their number is than that of the central vascular zone. Two to three vascular bundles are fused by their lateral and dorsal caps. Two to three distinct conducting strands are enclosed by a common bundle sheath. There is no continuity of vascular tissue between different strands within the compound bundles.

Central vascular zone—The distribution of fibrovascular bundles in this zone is 4-8 per sq mm. The fibrovascular bundles are oval to round in shape (Text-figs 66-80; Pl. 2, fig.15). Round vascular bundles are 176 μm in diameter while oval vascular bundles are 240x160 μm in diameter. Fibrous sheath on the dorsal side of the bundles is 2-4 layered and 64 μm thick. Fibre cells are thick walled, polygonal in shape and with lumen diameter of 4-8 μm. On the ventral side, fibrous sheath is 2-3 layered and 20 μm in thickness. The fibres are thick walled and polygonal with 3 μm lumen diameter. On the lateral side, fibrous sheath is 1-2 layered and 24 μm in thickness. The xylem has 4-10 vessels arranged either in crescentic or V shaped fashion (Text-figs 66-79). The metaxylem elements are generally towards the periphery of xylem arc and protoxylem towards the centre.

PLATE 2 →

9. Cross section of the stem showing the distribution of vascular bundles in the cortex x30
10. The same magnified showing large vascular bundles x150. Note the tannin-sac like cells containing black contents throughout the cortex
11. The same magnified showing smaller bundles x150
12. Fibrovascular bundles in the central zone x96
13. Compound vascular bundles x199
14. Cross section of the stem showing the peripheral zone of central vascular zone x30
15. Cross section of the stem showing the peripheral and central zone of the central vascular zone x30
16. Protoxylem elements showing the spiral lateral wall pitting x399

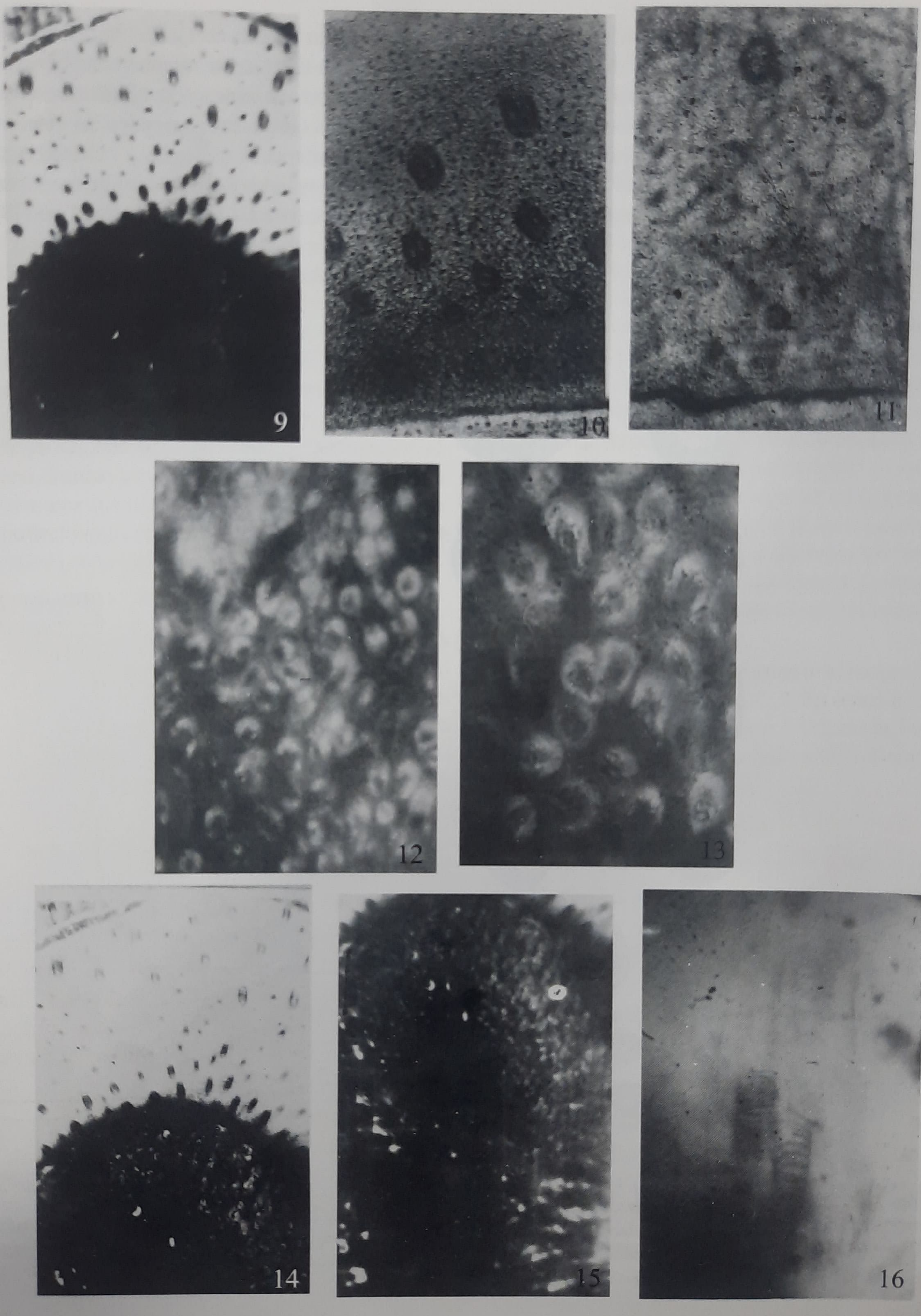
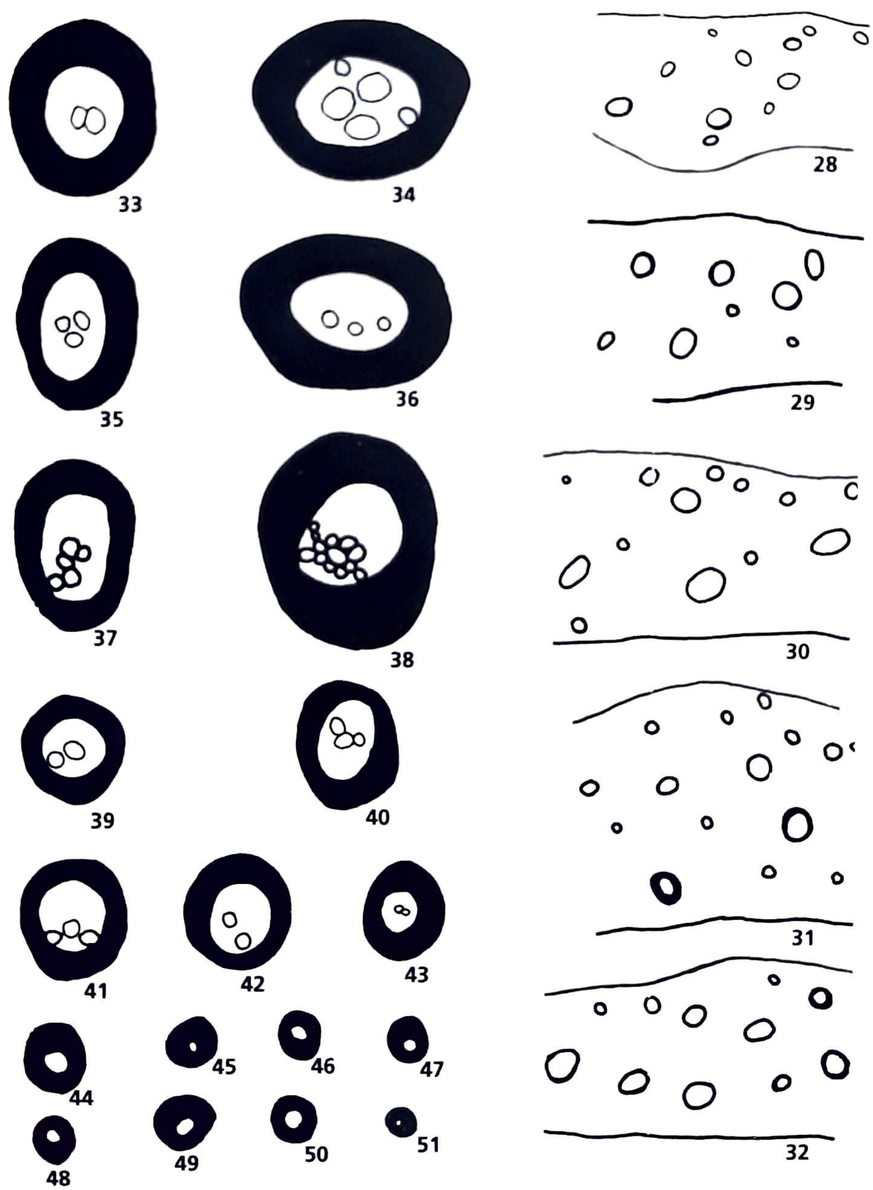


PLATE 2

Metaxylem elements are 32 μm in diameter and protoxylem elements are 16 μm in diameter. Both metaxylem and protoxylem elements are generally round but sometimes angular. The phloem is 80 x 32 μm in size and is included in the xylem arms. The tissue is not well preserved. Compound vascular bundles are bi and tripolar appearing together within a continuous fibrous sheath (Text-figs 81-83). Obliquely running vascular bundles are quite common in both the vascular zones. Compound vascular bundles are more or less restricted to a region just within the conjested peripheral zone. Conjunctive parenchyma— It consists of oval to circular cells throughout vascular region. These are thin walled. Scattered in the conjunctive parenchyma are found sac like cells filled with black contents.



Text-figs 28-51. 28. Outermost leaf sheath x50. Showing large and small vascular bundles. 29-31. Intermediate leaf sheaths showing large and small bundles x50. 32. Innermost leaf sheath showing large and small vascular bundles x50. 33-43. Large collateral vascular bundles in the leaf sheaths x200. 44-51. Small concentric vascular bundles in the leaf sheaths x200.

Structure of the root

Many roots are cut in various planes (Text-fig. 1; Pl. 1, figs.1, 2). They are oval to round in shape. Some roots are compressed and their epiblema is invaginated (Text-fig. 26, Pl.1, fig. 8). They are 1 to 1.5 mm in diameter. Epiblema is single layered, it is made up of longitudinally elongated cells having 28x20 μm size. Hypodermis is represented by brown band, cells are not seen. Outer cortex is not preserved, middle cortex is with air cavities delimited by 1 to 2 layered parenchyma. Inner cortical cells are compactly arranged. Endodermis and pericycle are not clear. Vascular region— Vascular bundles are radial, xylem is exarch with 23-24 arcs (Text-fig. 26, Pl. 1, fig. 8). Each arc has one metaxylem and 1-2 protoxylem elements. Metaxylem elements are 40 μm in diameter, phloem arcs alternate with the xylem arcs. In the centre parenchymatous pith is seen. It has outer cells more compactly arranged than the inner ones.

Leaf sheaths

Externally, the rhizome is surrounded by 3-5 arcs of leaf sheaths (Text-figs 28-32, Pl.1, fig. 5). The leaf sheath of innermost arc is about 990 μm in thickness. The leaf sheaths of second, third and fourth arcs are nearly uniform in thickness and measure about 1260 μm. The leaf sheath of the outermost arc is about 1080 μm in thickness.

These leaf sheaths are adpressed with each other in such a way that adaxial epidermis of one (outer) leaf sheath is touching the abaxial epidermis of the next leaf (inner). Hence separate epidermal layers are not clearly seen, instead a dark line represents the adpressed epidermis of adjacent leaf sheaths. Internal structure in all the leaf sheaths appears to be almost similar. The vascular bundles are irregularly distributed in the mesophyll tissue (Text-figs 28-32, Pl.1, fig. 7). The innermost leaf sheath appears to be comparatively immature, as it prossesses compactly arranged mesopyll whereas in the outermost leaf sheath the mesophyll appears to be lacunose suggesting that it is comparatively mature leaf sheath. Vascular bundles of innermost leaf sheath are better preserved so that their structure could be studied. Two types of vascular bundles are present, very small diminutive vascular bundles are present at the abaxial surface and large bundles are present towards the adaxial surface. Diminutive vascular bundles are round in shape having diameter of 72 to 108 μm. They are concentric (Text-figs 44-51). Large vascular bundles are also round in shape having a diameter of 198 μm and are collateral (Text-figs 33-43). Each vascular bundle is surrounded by sclerenchymatous sheath, red or brown in colour. It is 24 μm in thickness in diminutive vascular bundles while it is 40 μm in thickness in larger vascular bundles. In the collateral vascular bundles 2-3 metaxylem elements and 1-2 protoxylem elements are present (Text-figs 33-43). Xylem elements are arranged in an arc shaped manner. Mesophyll tissue is compactly arranged with parenchymatous cells. There is no differentiation into palisade and spongy tissue. Mesophyll cells are round to oval in shape. Some black contents are present in sac like cells. They are dispersed in the mesophyll. Such structures are also seen in the cross section of stem. In the remaining leaf sheaths diminutive vascular bundles are very few. Other anatomical characters are the same.

Bud – Bud (shoot-tip) is present at the peripheral part of rhizome (Pl. 1, fig. 4). It is cut in longitudinal plane. It is triangular in shape, 2 to 3 mm in height and 3 to 5 mm in diameter. It shows tristichous arrangement of leaves.

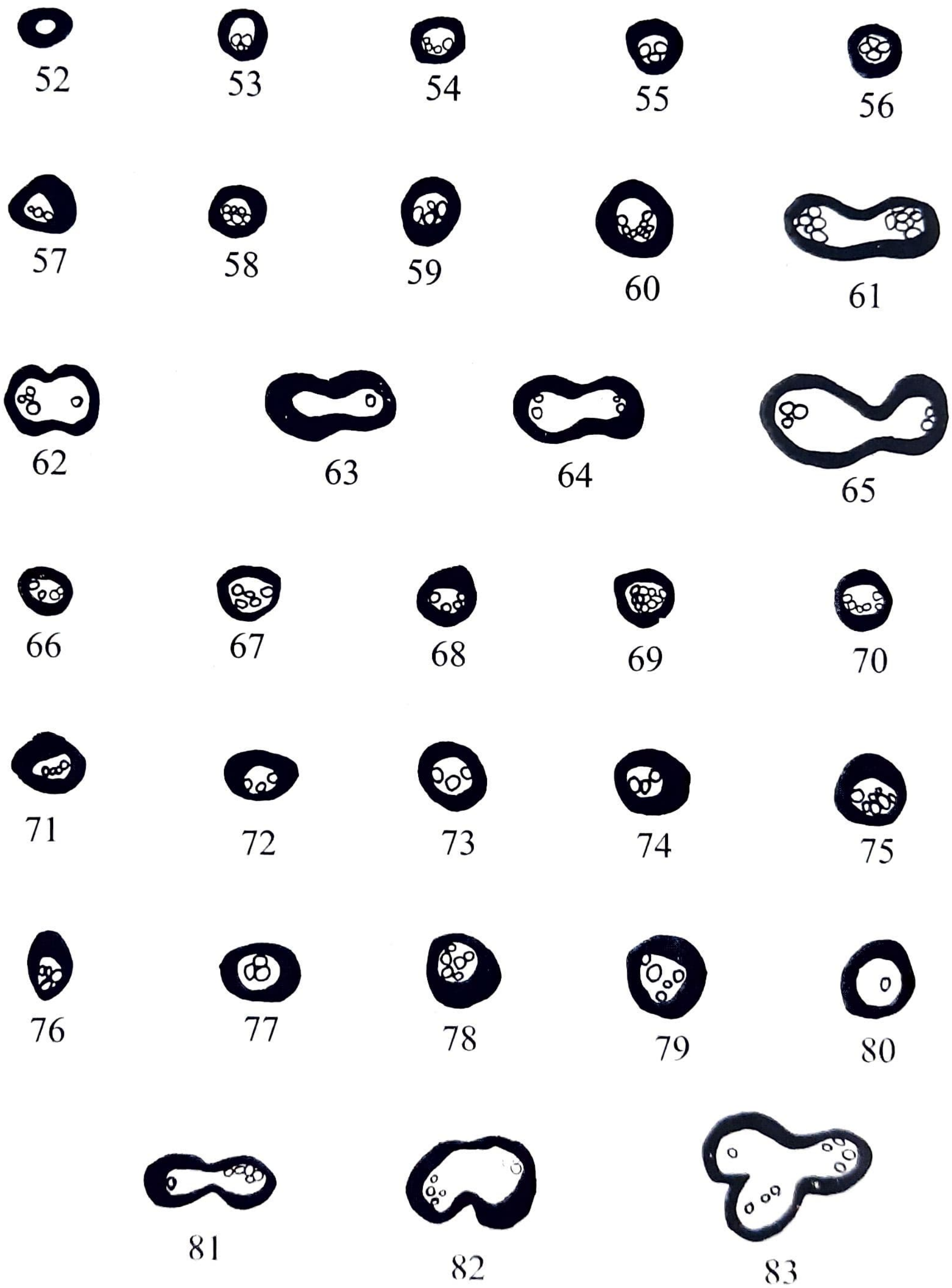
Comparison with Extant Taxa

1. Tristichous arrangement of leaves is seen in bud.
2. There is clear differentiation of cortex and vascular cylinder.
3. Endodermoid layer delimits cortex from vascular cylinder.
4. Three types of vascular bundles are seen in the stem, namely concentric, collateral and compound.
5. Vascular bundles are distributed in ground parenchyma.
6. Collateral bundles are bipolar to tripolar.
7. Compound vascular bundles have elements arranged in 'V' or 'U' shape .
8. Vascular bundles have 4-8 metaxylem elements.
9. In the root—a) Single layered epiblema is seen.

b) Middle cortex with air cavities delimited by 1-2 rows of parenchyma cells. c) Xylem arcs 23-24. d) Each arc has one metaxylem and 1-2 protoxylem elements.

10. 3 to 5 arcs of leaf sheath are present around the stem. Mesophyll is parenchymatous. Tannin sacs are found in mesophyll. Small diminutive bundles are concentric while larger bundles are collateral.

The survey of monocotyledonous families with respect to the occurrence of tristichous arrangement of



Text-figs 52-83. 52-60. Fibrovascular bundles from the peripheral region of vascular zone. Note the crescent shaped arrangement of xylem elements x100. 61-65. Bipolar compound vascular bundles from the peripheral region of vascular zone x100. 66-80. Fibrovascular bundles from the central region of vascular zone. Note the sclerenchymatous bundles sheath and arrangement of xylem elements in 'V' or crescent manner x60. 81, 82. Bipolar compound vascular bundles from the central region of vascular zone x100. 83. Tripolar compound vascular bundle from the central region of vascular zone x100.

leaves and presence of compound vascular bundles in addition to the above mentioned diagnostic characters shows that the present fossil belongs to the family Pandanaceae. (Warburg 1900; Soleredar and Meyer 1928; Cheadle and Uhl 1948a,b; Metcalfe 1960, 1963; Tomlinson 1961, 1970; Zimmermann *et al.* 1972, 1974). The most distinctive diagnostic feature is the presence of compound (bi or tripolar) bundles, i.e. vascular bundles with two or three discrete vascular strands restricted to certain regions of the stem. In addition to Pandanaceae, compound vascular bundles are also present in the members of the family Arecaceae, Cyclanthaceae and Araceae. In the family Araceae and Arecaceae only two vascular bundles are fused with each other whereas in the present fossil specimen sometimes more than two vascular bundles are fused with each other to form compound vascular bundles. In the members of Cyclanthaceae, the vascular bundles of the stem have either dorsal or ventral sclerenchyma sheath, rarely both may be absent. On the other hand, in the present fossil the vascular bundles have both these sheaths and these are well developed. Therefore, the present fossil shows close resemblance with the family Pandanaceae.

Family Pandanaceae has three genera, *Pandanus, Freycinetia* and *Sararanga.* Stem anatomy is essentially the same in all three and reflects the homogeneity of the family. The variations in stem structure among the three genera of Pandanaceae has not been investigated in sufficient details to indicate whether there are variations in diagnostic features of stem anatomy at the generic level.

Vessels are present in metaxylem of stem of *Pandanus* and *Freycinetia,* the elements are often very long and with oblique scalariform perforation plates while vessels are absent in the adult stem of *Sararanga,* the metaxylem trachieds are very long, tapering and without definite end wall. The only additional feature in *Freycinetia* is presence of multipolar compound bundles. In present fossil, multipolar compound bundles are not seen. The present fossil shows close affinity with the genus *Pandanus* in following respects :

1. Tristichous arrangement of leaves.
2. Leaf sheath and adventitious roots surround the stem.
3. The stem cortex is delimited from vascular cylinder by an endodermoid layer.
4. The vascular cylinder is divisible into peripheral and central zones.
5. In the outer peripheral zone vascular bundles are somewhat smaller and compactly arranged whereas in the central zone they are larger and sparsely arranged.
6. Vascular bundles are of three types : concentric, collateral and compound.
7. Compound, bipolar to tripolar vascular bundles are present in vascular cylinder, more prominently in peripheral zone.
8. The collateral vascular bundles are with 'V' or 'U' shaped xylem.
9. The ground tissue of cortex and vascular cylinder has large sacs with coloured contents (Tannin sacs).

Present fossil shows some resemblance with the stem structure of two extant species of *Pandanus,* viz., *P. tectorius* and *P. odoratissimus*. Presence of endodermis and simple bipolar compound bundles are characteristic features of *P. tectorius* but it has vascular bundles with single metaxylem whereas in the present fossil they are 4-8. In *P. odoratissimus* 4-6 metaxylem elements are present and simple bipolar compound vascular bundles are also present but it lacks clearly, differentiated endodermis. So the present fossil does not show exact resemblance with the above two species of *Pandanus.*

Comparison with the Fossil Specimens

Amongst the fossil monocots described so far, *Cyclanthodendron sahnii* Rode (Sahni and Surange, 1953) shows some resemblance with the present fossil. However, it differs from *C. sahnii* in the following features :

1. In *Cyclanthodendron,* leaves appear to be 2 ranked whereas in the present fossil they are 3 ranked.
2. Fibre bundles are present in stem and leaf sheaths of *Cyclanthodendron* whereas they are absent in the present fossil.

3. In *Cyclanthodendron* stem cortex, the bigger bundles are situated in the middle and the smaller bundles are placed in the outer as well as inner part of cortex, whereas in the present fossil, larger bundles are present mostly in outer and inner parts, middle part is occupied by smaller bundles.
4. In *Cyclanthodendron,* the central vascular zone is demarcated from the cortex by the crowding of the small bundles at the margins, whereas in the present fossil central vascular zone is delimited from the cortex by the endodermoid layer.
5. In *Cyclanthodendron,* lobed bundles are present in subdermal and central region. A big bundle gives out branches to its right and left and these remain attached to the parent bundle for some distance and make the big bundle look like a compound bundle. Therefore the attached bundles are the branches of the same bundle. Whereas compound vascular bundles are found in the present fossil. Two to three distinct conducting strands are enclosed by a common bundle sheath.

Nambudiri and Tidwell (1978) observed that *Viracarpon* fruit, which shows many similarities with extant *Pandanus* should be treated as an extinct genus of the family Pandanaceae. Bande and Awasthi (1986) reinvestigated it with the help of number of well preserved specimens and suggested that the affinities of this infructiscence are not close with any of the Cyclanthaceae, Araceae and Pandanceae families. Similarly Bonde (1985) showed the affinity of *Tricoccites trigonum* to that of *Pandanus* of Panadanaceae. Biradar and Bonde (1988) reconstructed the whole *Cyclanthodendron* plant and suggested that probably the pseudostem of *Musocaulon indicum* at maturity produces *Tricoccites trigonum* fruits. So its affinity with *Pandanus* is still doubtful.

So far no fossil wood of *Pandanus* has been reported and the present report forms the first record of the occurrence of pandanaceous wood from the Deccan Intertrappean Beds of India. It is designated as a new genus *Pandanaceoxylon kulkarnii* gen. et sp. nov. The specific epithet is after Prof. A.R. Kulkarni who has made significant contributions to the study of monocotyledonous wood anatomy.

Generic Diagnosis

***Pandanaceoxylon* gen. nov.**

The vascular bundles in outer and inner region of cortex are larger than those in the middle. The xylem elements in the vascular bundles are arranged in 'V' or 'U' shaped manner. Compound vascular bundles present. The vascular cylinder delimited from cortex by endodermoid layer.

The vascular cylinder is divisible into outer and inner zones with more closely distributed vascular bundles in the outer zone and comparatively sparsely arranged in the central vascular zone. Vessels with spiral thickening. Bi-tripolar compound vascular bundles present. In the root, air cavities present in middle cortex. Stele has 23-24 radial arcs of xylem. Each arc has one metaxylem and 1-2-protoxylem elements. Shoot buds are located at the periphery of rhizome. They show tristichous arrangement of leaves. Tannin sacs are present in the ground tissue of stem, root and leaf sheaths.

Specific Diagnosis

***Pandanaceoxylon kulkarnii* sp. nov.**

Cortex measures 5 to 6 mm in diameter, large vascular bundles are 210x188 μm with 4 to 5 layered or 32 to 48 μm thick fibrous sheath, metaxylem elements 36 μm in diameter and protoxylem 24 μm in diameter. Phloem patch is 40 μm in width and phloem cells are 5 μm in diameter. Smaller bundles are 50 to 80 μm. The ground parenchymatous cells are 80x48 μm in size. Vascular cylinder is 1.7 to 1.9 cm in diameter. The vascular bundles in the peripheral zone are 192 x 112 μm in size with 3-4 layered or 32 μm in thick fibrous sheath. Metaxylem elements are 32 μm in diameter and protoxylem elements are 16 μm in diameter. The phloem is 50 x 32 μm in size. Vascular bundles in the central zone are 240 x 160 μm in size with 2-4 layered and 64 μm thick fibrous sheath on dorsal side, 2-3 layered and 20 μm on the ventral side and 1-2 layered and 24 μm on the lateral sides. Metaxylem elements is 32 μm and protoxylem elements is 16 μm diameter, phloem patch is 80x32 μm in size, root is 1 to 1.5 mm in diameter. Epiblema with longitudinally elongated cells with 28x20 μm size.

Metaxylem elements are 40 μm in diameter. The leaf sheaths of innermost whorl are 990 μm in radial width. Those of 2nd, 3rd and 4th whorls are about 1260 μm in width and those of outermost are 1080 μm diminutive vascular bundles 72 to 1080 μm in diameter with 24 μm thick fibrous sheath, larger vascular bundles are 198 μm in diameter with 40 μm thick fibrous sheath. Tannin sacs in ground tissue of stem, root and leaves are 16-48 μm in diameter.

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