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Gymnosperm fossils from the Gangapur Formation (Early Cretaceous) of Adilabad District, Telangana, India

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ABSTRACT

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The present paper deals with the diversity of gymnosperms during the sedimentation of Gangapur Formation (Early Cretaceous) in Pranhita-Godavari Graben and their palaeoenvironmental importance. Plant fossils were collected from Ralpet, Nowgaon and Rampur localities, near Sirpur-Kaghaznagar town, and also from Butarmal Nala near Asifabad in Adilabad District, Telangana. A new species of *Elatocladus* (*E. andhrensis*) is also described. The floral diversity and palaeoenvironment of the Gangapur Formation is discussed on the basis of macro- and micro- plant fossil evidences drawn from the present study and also from earlier studies. Dominance of conifers in the floral assemblage indicates prevalence of upland flora with warm and humid conditions during the time of deposition of Gangapur Formation.

Key-words: Gymnosperm fossils, conifers, palaeoenvironment, Gangapur Formation, Early Cretaceous, Pranhita-Godavari Graben, Telangana, India.

INTRODUCTION

King (1881) described outcrops, exposed around the Gangapur village, as "Gangapur beds" as the lower part of Kota Group. The Gangapur Formation was instituted by Kutty (1969), who identified the type section, and was named after the village Gangapur (Lat. 19°16'N; Long. 79°26'E) in Adilabad district, Telangana, India. He also identified the lower contact of Gangapur Formation with underlying beds at two places, one in a stream section about 1.6 km to the west of Paikasigudem and other in the Gangapur cliff. This formation extends from north of Nowgaon (Lat. 19°20'N; Long. 79°24'E) to the west of Gangapur (Lat. 19°16'N; Long. 79°26'E) and in the east up to Dharmaram and Paikasigudem (Kutty 1969). Subsequently, the geology of the Gangapur Formation, along with other formations in the Pranhita-Godavari Graben, has been studied by Sen Gupta (1970, 2003), Rudra (1982), Bandyopadhyay and Rudra (1985), Raiverman (1986), Kutty et al. (1987), Lakshminarayana and Murthi (1990), Biswas et al. (1994), Lakshminarayana (1995, 1996, 2002) and Biswas (2003).

The sedimentation of the Gangapur Formation

took place during the Early Cretaceous after renewed rift activity (Biswas 2003). The formation is characterized by coarse ferruginous sandstone with many pebble bands succeeded by an alternating sequence of sandstones and mudstones or silty mudstones. It unconformably overlies the Kota Formation which includes limestone, sandstone, siltstone, claystone and conglomerates. Although both the Gangapur and Chikiala formations are known to overlie the Kota Formation, the relationship between the Gangapur and Chikiala formations is not clear. There are neither floral nor faunal fossil evidences from the Chikiala Formation, while the Gangapur Formation yielded well preserved Early Cretaceous flora. Currently, two opinions exist on the relation of these formations; while some workers believe that the Chikiala Formation is younger than the Gangapur Formation (Raiverman et al. 1985, Lakshminarayana 1996), the others believe that they are of same age, i.e. Early Cretaceous (Rudra 1982, Kutty et al. 1987). The authors agree with the second opinion as no distinct fossils were known from the Chikiala Formation. These Upper Gondwana sequences are covered by the Deccan Traps. The generalized stratigraphic sequence of Pranhita-Godavari Graben is given in Table 1.

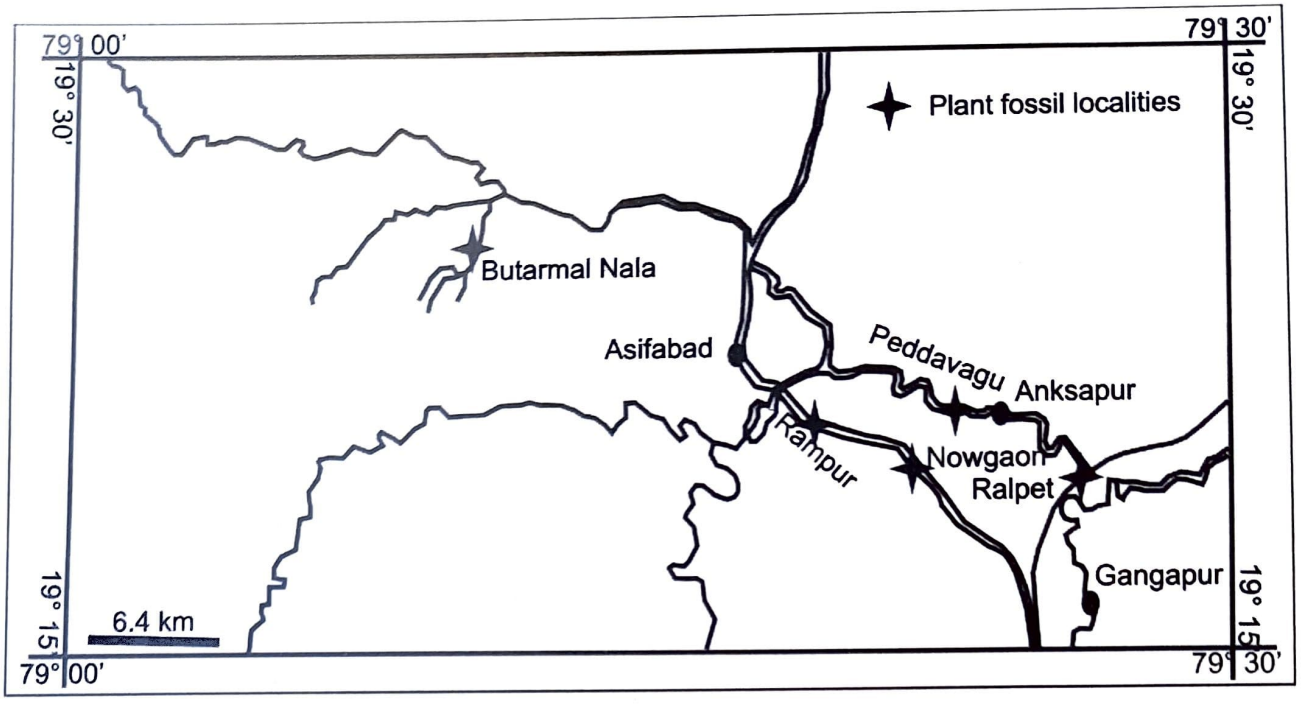
Plant megafossils from the Gangapur Formation have been studied by Bose et al. (1982), Ramakrishna and Muralidhara Rao (1986, 1991), Muralidhara Rao and Ramakrishna (1988), Lakshminarayana and Kutumba Rao (1988), Sukh-Dev and Rajanikanth (1988) and Rajanikanth (1996). Palynological studies from the Gangapur sediments have been carried out by Rajeshwar Rao and Ramanujam (1979), Ramanujam and Rajeshwar Rao (1979, 1980), Bose et al. (1982), Rajeshwar Rao et al. (1983), Prabhakar (1987), Ramakrishna and Ramanujam (1987) and Ramakrishna et al. (1985, 1986). The present paper describes gymnosperm megafossils and evaluates their diversity and ecology.

MATERIAL AND METHOD

Plant fossils were collected from the ongoing quarries located at Nowgaon (Lat. 19°18'N; Long. 79°23'E), Ralpet (Lat. 19°18'N; Long. 79°25'E) and Rampur (Lat. 19°19'N; Long. 79°22'E), about 7 km south of Sirpur-Kaghaznagar (Lat. 19°21'N; Long. 79°28'E), Adilabad District, Telangana. The exposed quarry sections are about 10-12 metres thick and are characterized by coarse ferruginous sandstone with many pebble bands succeeded by an alternating sequence of sandstones and mudstones or silty mudstone. Fossil plant specimens were also collected from the mudstone sequences exposed on the banks of Peddavagu (Lat. 19°21'N; Long. 79°25'E) situated about 10 km south-east of Asifabad and Butarmal Nala (Lat. 19°27'N; Long. 79°13'E) about 13 km west-northwest of Asifabad (Lat. 19°21'N; Long. 79°17'E) in Adilabad District, Telangana (Text-figure 1). The fossil plant material is preserved as impressions on pinkish-gray mudstones. Despite

Table 1. Upper Gondwana stratigraphic succession in Pranhita-Godavari Graben (modified after Kutty et al. 1987, Lakshminarayana 1996 and Sen Gupta 2003).

Formation	Lithology	Age
Deccan Traps		
Gangapur/Chikiala	Coarse ferruginous sandstone, grey-white-pinkish mudstone and silty mudstone/shale	Early Cretaceous
----------	----------Unconformity----------	----------
Kota	**Upper:** Sandstone, siltstone and claystone **Middle:** Limestone **Lower:** Conglomeratic sandstone, siltstone and trough cross stratified sandstone	?Jurassic
Dharmaram	Coarse sandstone and red clays	Late late Triassic
Maleri	Red clays, fine-medium sandstone and lime pellet rocks	Early late Triassic
Bhimaram	Ferruginous/calcareous sandstone, minor red clays	Late middle Triassic
Yerrapalli	Red and violet clays with sandstone and lime pellet rocks	Early middle Triassic



Text-figure 1. Map showing the fossil localities

the preservation limitation, most morphological details are still preserved, including venation pattern, in maximum number of specimens. Plant fossils were studied under an Olympus SZH 10 stereo dissecting microscope. All specimens were photographed with Canon SX 150 IS digital camera using either polarized light or low angle lighting to reveal surface details.

Comparison was made with Indian Early Cretaceous floras reported by Feistmantel (1879), Sahni (1928), Baksi (1968), Bose and Kasat (1972), Bose and Sukh-Dev (1972), Maheshwari and Kumaran (1976), Bose and Banerji (1981, 1984), Bose et al. (1982), Sukh-Dev and Rajanikanth (1988) and also with type material available in the repository of the Birbal Sahni Institute of Palaeobotany, Lucknow. The flora was also compared with species known from Antarctica (Halle 1913, Cantrill & Hunter 2005). The specimens here described are lodged in the museum of the Birbal Sahni Institute of Palaeobotany, Lucknow.

SYSTEMATIC PALAEOBOTANY

Division: Spermatophyta

Order: Cycadales

Genus: *Taeniopteris* Brongniart 1828

Taeniopteris kutchensis Bose & Banerji 1984

Plate 1, figure 5

Description: Leaf simple, strap shaped, maximum available size 4 cm long and about 1 cm wide, lamina thin, margin entire. Midrib prominent, 0.75-1 mm wide, longitudinally striated. Secondary veins arising at an angle of 80°-90°, mostly simple, rarely once forked soon after emergence from midrib, slightly curving upward and then running parallel up to the margins. Density of secondary veins less than 16 per cm.

Specimens examined: BSIP Specimen Nos. 40219-40221.

Localities: Ralpet, Rampur and Peddavagu (near Anksapur), Adilabad District, Telangana.

Remarks: The species is reported for the first time from the Gangapur Formation and so far it was known only from the Bhuj Formation of Kutch (Bose & Banerji 1984). Although specimens are fragmentary and only central region

of the leaf is recovered, the nature of venation pattern supports assignment of the specimens to this species. In gross morphology, specimens may look like *T. spatulata*, however, they can be easily distinguished from the latter by the absence of frequent bifurcation of secondary veins and their lesser density.

***Taeniopteris spatulata* McClelland 1850**

Plate 1, figures 6, 9

Description: Leaf simple, linear-spatulate, 1.5-2.5 cm long and 0.5-0.8 cm wide, margin entire, base and apex not known. Midrib distinct, 1 mm wide, faintly striated along longitudinal direction. Secondary veins arising at an angle of 80°-95°, simple or once forked, majority are once forked near the midrib and running to the leaf margins. Density of secondary veins 20-22 per cm.

Specimens examined: BSIP Specimen Nos. 40222-40225.

Localities: Rampur, Butarmal Nala and Peddavagu (near Anksapur), Adilabad District, Telangana.

Remarks: The specimens are incomplete. Among the four specimens, two are preserved with sub-apical portion (BSIP 40222, 40223), one with apical portion (BSIP 40225) and the other (BSIP 40224) with central region of the leaf. Although they represent various parts of the leaf, their venation pattern strongly indicates same affinity. The venation pattern of the specimens resembles *T. spatulata* from the Rajmahal Formation described by Bose and Banerji (1981).

***Taeniopteris* sp.**

Plate 1, figures 7, 8

Description: Leaf simple, linear, 2-3 cm long and 4-5 mm wide, margin entire, base and apex not known. Midrib prominent, 1-2 mm wide. Secondary veins arising at an angle of 100°-110°, mostly simple, sometimes dichotomizing soon after the emergence and extending to the margins. Density of secondary veins more than 20 per cm.

Specimens examined: BSIP Specimen Nos. 40226-40228.

Localities: Rampur, Nowgaon and Peddavagu (near Anksapur), Adilabad District, Telangana.

Remarks: The maximum range of the secondary vein divergence in all the known species of *Taeniopteris* is 80°-90° and they run either horizontal to the midrib or towards the apical region. However, in the present specimens the secondary vein divergence angle ranges from 100°-110° and it runs towards the base. The specimens therefore could not be assigned to any known species due to lack of more details. The secondary vein divergence angle of *Taeniopteris* sp., here described, resembles *Taeniopteris* sp. from Latady Basin, Antarctica (Cantrill & Hunter 2005).

Order: Bennettitales

Genus: *Ptilophyllum* Morris in Grant 1840

***Ptilophyllum cutchense* Morris in Grant 1840**

Plate 1, figure 1

Description: Pinnate leaf, 5 cm long and 1 cm wide, lamina linear-lanceolate, rachis 1 mm wide, longitudinally striated and concealed by pinnae base. Pinnae attached on the upper surface of the rachis by whole base, arising at an angle of 60°-70°, linear-lanceolate, 4-6 mm long 1-2 mm wide, margin entire, apex obtuse-bluntly acute. Veins arise from base of the pinnae, 4-5 in number, parallel and mostly unforked or rarely once forked.

Specimens examined: BSIP Specimen Nos. 40229-40232.

→

Plate 1

Bar = 1 cm (unless otherwise mentioned)

1. *Ptilophyllum cutchense*, BSIP specimen no. 40229. 2. *Ptilophyllum rarinervis*, BSIP specimen no. 40236. 3. *Ptilophyllum* cf. *P. distans*, BSIP specimen no. 40237. 4. *Ptilophyllum acutifolium*, BSIP specimen no. 40235. 5. *Taeniopteris kutchensis*, BSIP specimen no. 40221. 6. *Taeniopteris spatulata*, BSIP specimen no. 40222. 7. *Taeniopteris* sp., BSIP specimen no.40226. 8. *Taeniopteris* sp., BSIP specimen no.40227. 9. *Taeniopteris spatulata*, BSIP specimen no. 40224.

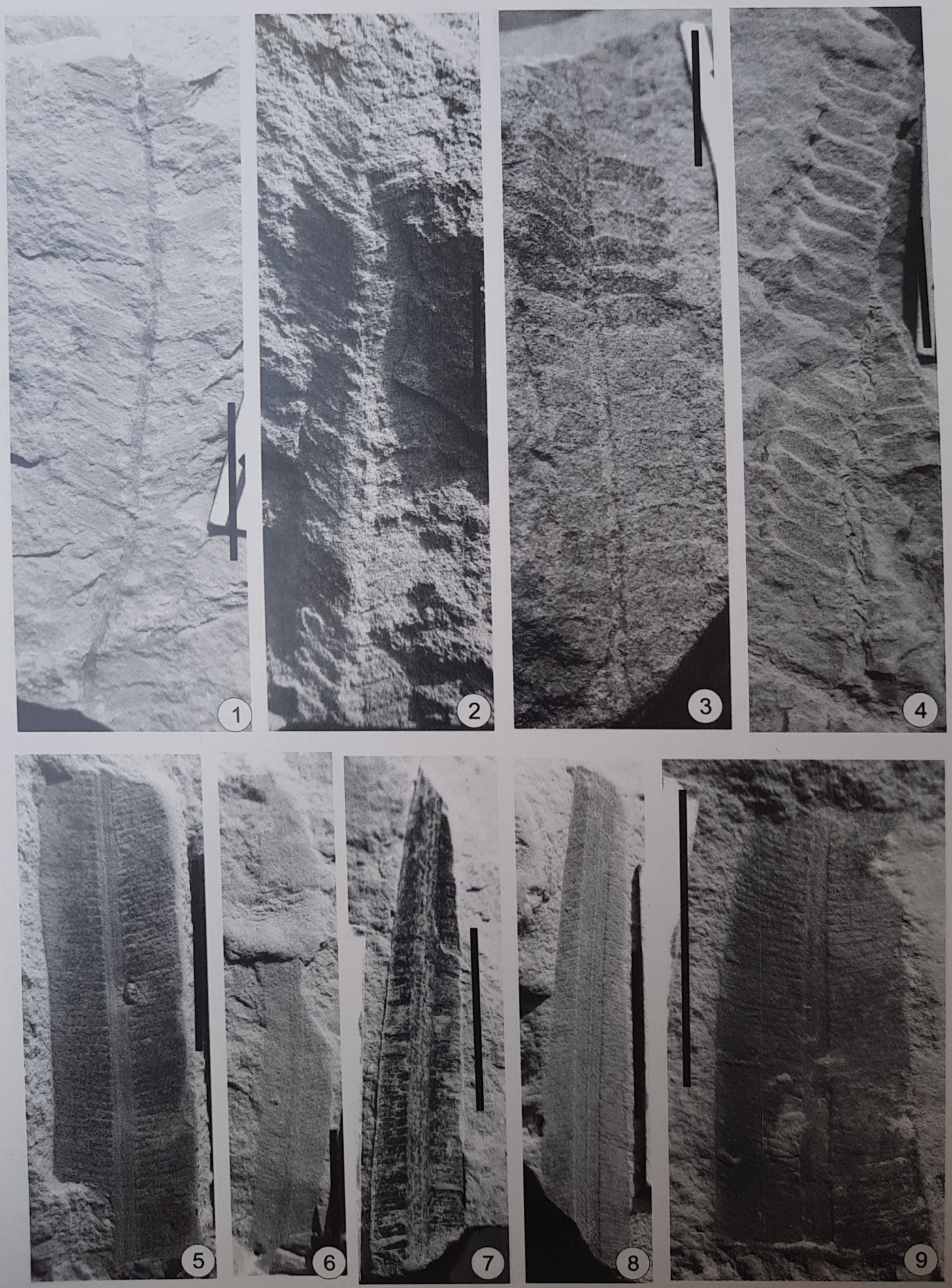


Plate 1

Localities: Rampur and Nowgaon, Adilabad District, Telangana.

Remarks: Early reports of *P. cutchense* from the Gangapur Formation were by Bose et al. (1982) and Sukh-Dev and Rajanikanth (1988). The specimens described by Sukh-Dev and Rajanikanth (1988) have comparatively longer pinnae (4-15 mm), while the specimens described by Bose et al. (1982) come closer to the present specimen.

***Ptilophyllum acutifolium* Morris in Grant 1840**

Plate 1, figure 4

Description: Pinnate leaf, 1-1.5 cm long and 1 cm wide, lamina linear-lanceolate, rachis 1 mm wide, longitudinally striated and concealed by pinnae base. Pinnae attached on the upper surface of the rachis by whole base, arising at an angle of 50°-70°, alternate-subopposite, linear-lanceolate, straight, 5-6 mm long and 1 mm wide, margin entire, acroscopic margin slightly round and basiscopic margin slightly decurrent or expanded, apex acute. Veins arising from base of the pinnae, 3-5 in number, parallel, forked or unforked.

Specimens examined: BSIP Specimen Nos. 40233-40235.

Localities: Rampur and Peddavagu (near Anksapur), Adilabad District, Telangana.

Remarks: On the basis of decurrent basiscopic margin and characteristic venation, the presently studied material is treated under the genus *Ptilophyllum*. The acute apex clearly indicates their affinity to *P. acutifolium*. The venation pattern is reasonably well preserved. The specimens described by Bose et al. (1982) and Sukh-Dev and Rajanikanth (1988) from the Gangapur Formation slightly differ from the present specimens in having longer pinnae (3-15 mm). The species shows an apparent resemblance with the specimens of *P. acutifolium* from Raghavapuram Formation described by Baksi (1968).

***Ptilophyllum rarinervis* (Feistmantel) Bose & Kasat 1972**

Plate 1, figure 2

Description: Pinnate leaf, 5 cm long and 1 cm wide, lamina linear-lanceolate, tapering towards apex, rachis slender, less than 1 mm wide, concealed by pinnae base. Pinnae attached on the upper surface of the rachis by whole base, pinnae bases of opposite sides touching each other, arising at an angle of 55°-60°, alternate-subopposite, falcate, linear-lanceolate, 4-6 mm long and less than 1 mm wide, margin entire, acroscopic margin slightly round, basiscopic margin straight, apex bluntly acute. Veins arise from base of the pinnae, 2-3 in number, three veins are common, parallel and once or twice forked.

Specimens examined: BSIP Specimen No. 40236.

Localities: Butarmal Nala, Adilabad District, Telangana.

Remarks: This species, being reported for the first time from the Gangapur Formation, is a rare species. The species was, for the first time, identified by Feistmantel (1879) under *Otozamites rarinervis*. Later, Bose and Kasat (1972) transferred it to *Ptilophyllum*. This species is distinguished from all other species of *Ptilophyllum* by few veins, i.e. 2-3 per pinnae. So far only four specimens have been collected, one each from Vemavaram and Onthea and two from Raghavapuram (Bose & Kasat 1972, Mahabale & Satyanarayana 1979). Recently, Chinnappa et al. (2014) added two

→

Plate 2

Bar = 1 cm (unless otherwise mentioned)

1. *Elatocladus sehoraensis*, BSIP specimen no. 40207. 2. *Elatocladus confertus*, BSIP specimen no. 40199. 3. *Elatocladus* cf. *E. bosei*, BSIP specimen no. 40211. 4. Strobili of *Elatocladus andhrensis* sp. nov., BSIP specimen no. 40214. 5. *Elatocladus andhrensis* sp. nov., BSIP specimen no. 40214. 6. *Pagiophyllum rewaensis*, BSIP specimen no. 40242. 7. *Elatocladus andhrensis* sp. nov., BSIP specimen no.40121. 8. *Elatocladus andhrensis* sp. nov., portion enlarged to show foliage nature, BSIP specimen no.40121. 9. *Pagiophyllum marwarensis* BSIP specimen no.40240.

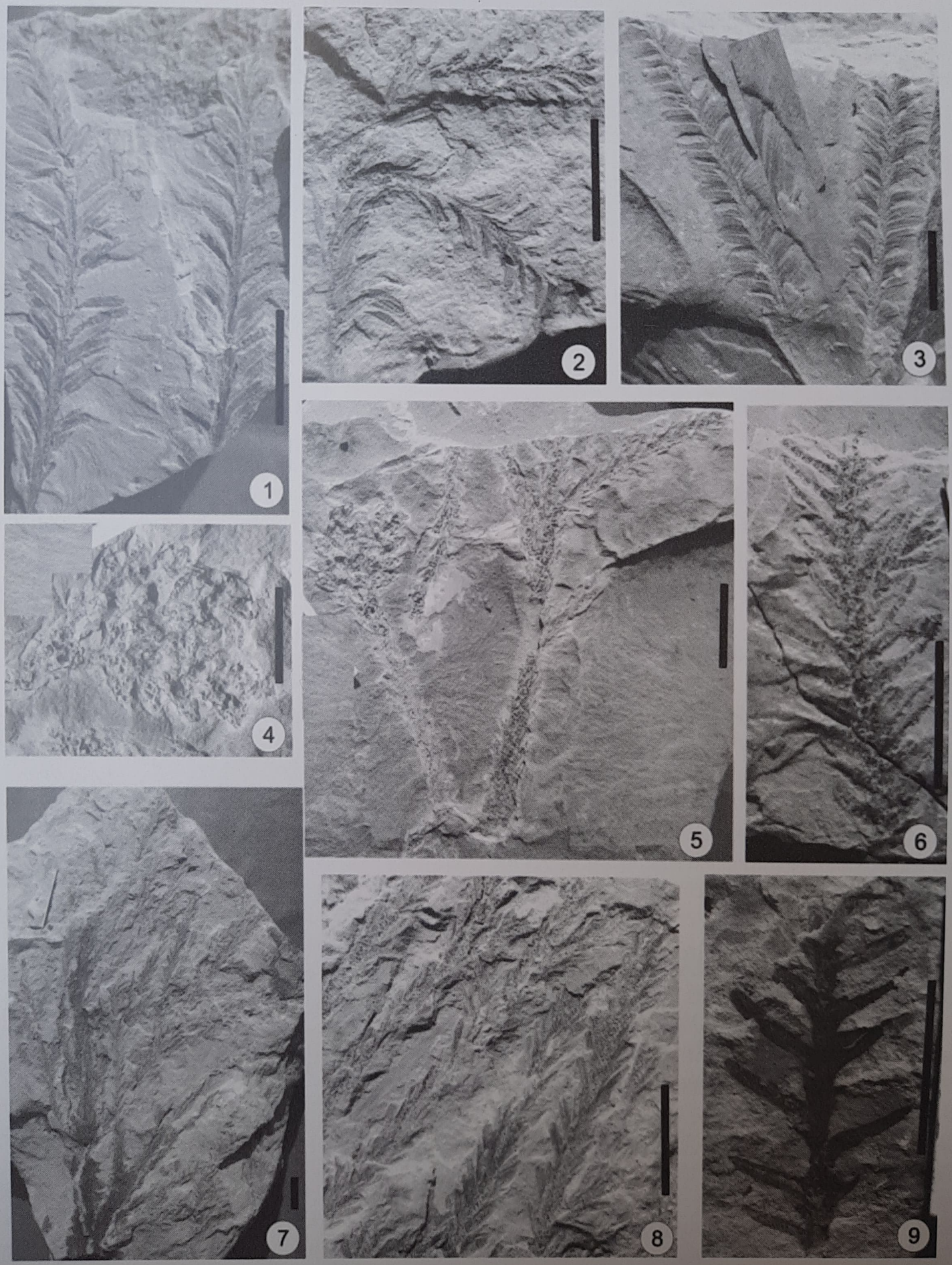


Plate 2

more specimens from Vemavaram. The present specimen exactly resembles with the specimens described by Bose and Kasat (1972).

Ptilophyllum cf. *P. distans* (Feistmantel) Jacob & Jacob 1954

Plate 1, figure 3

Description: Pinnate leaf, 4 cm long and 1 cm wide, lamina linear-lanceolate, rachis 1 mm wide, longitudinally striated and concealed by pinnae base. Pinnae attached on the upper surface of the rachis by whole base, arising at an angle of 80°-90°, alternate-subopposite, falcate, at places turn back, linear-lanceolate, 4-5 mm long and less than 1 mm wide, margin entire, acroscopic margin slightly round or auriculate, basiscopic margin slightly decurrent and concealed by acroscopic margin of the pinnae below, apex acute-apiculate. Veins arising from base of the pinnae, 4-6 in number, parallel and unforked.

Specimens examined: BSIP Specimen No. 40237.

Localities: Butarmal Nala, Adilabad District, Telangana.

Remarks: One specimen from the present collection shows gross morphological similarity with *P. distans* (Feistmantel) Jacob & Jacob (1954). The specimen closely resembles *P. distans* from Gangapur Formation described by Sukh-Dev and Rajanikanth (1988) in external features. As the specimen lacks cuticular details, it is considered here as a comparative form.

Order: Coniferales

Genus: *Elatocladus* Halle 1913

Elatocladus confertus (Oldham & Morris) Halle 1913

Plate 2, figure 2

Description: Vegetative shoots 2-9 cm long, central axis 1-1.5 mm wide, shoots irregularly branched, arising at an angle of 30°-50°. Leaves spirally borne, attached by whole base, arising at an angle of 50°-70°, spreading laterally, swept back, linear-lanceolate or oblong shape, 3-5 mm long and 0.8-1 mm wide, base slightly twisted, margin entire, apex acute-subacute. Midrib distinct, running from base to apex.

Specimens examined: BSIP Specimen Nos. 40194-40206 and 40241.

Localities: Ralpet, Rampur, Nowgaon, Butarmal Nala and Peddavagu (near Anksapur), Adilabad District, Telangana.

Remarks: The present collection and previous reports indicate that *Elatocladus confertus* is very common in Gangapur Formation. The specimens recovered lack cuticle. However, presence of well preserved foliar and branching characters (wherever preserved) provide sufficient features to identify them at species level. The specimens, here described, show close similarity with the specimens from the Gangapur Formation described by Bose et al. (1982), but slightly differ in having smaller leaves. *E. confertus* described here resembles very closely to specimens from Kutch (Bose & Banerji 1984). In their external morphology, the specimens also resemble with *E. confertus* figured by Halle (1913) from Graham Land and by Sahni (1928) from India.

Elatocladus sehoraensis Maheshwari & Kumaran 1976

Plate 2, figure 1

Description: Vegetative shoot 4 cm long, central axis 1 mm wide, shoots irregularly branched, arising at an angle of 60°-70°. Leaves spirally borne, attached by whole base, arising at an angle of 40°-60°, spreading laterally, linear-lanceolate shape, 5-6 mm long and 1 mm wide, base twisted, margin entire, apex bluntly acute-obtuse. Midrib distinct, running from base to apex.

Specimens examined: BSIP Specimen Nos. 40207-40209.

Localities: Ralpet and Butarmal Nala, Adilabad District, Telangana.

Remarks: The specimens here described closely resemble with the specimens from the Jabalpur Formation described by Maheshwari

and Kumaran (1976) in gross morphology. The species is being reported for the first time from the Gangapur Formation.

Elatocladus cf. *E. bosei* Maheshwari & Kumaran 1976

Plate 2, figure 3

Description: Twig slender, maximum available length is 4 cm, stem 1-1.5 mm wide. Leaves spirally borne, attached by whole base, arising at an angle of 70°-80°, spreading in horizontal plane, linear-lanceolate, 3-5 mm long and 0.8-1 mm wide, base constricted, margin entire, apex obtusely pointed. Midrib distinct, traverse from base to apex.

Specimens examined: BSIP Specimen Nos. 40210-40211.

Localities: Ralpet and Butarmal Nala, Adilabad District, Telangana.

Remarks: The specimens from the Gangapur Formation are comparable to *E. bosei* of the Jabalpur Formation described by Maheshwari and Kumaran (1976) and *E. chawadensis* from the Bhuj Formation of Kutch, described by Bose and Banerji (1984) in their external morphology, but slightly differ from the latter in their smaller leaf size. However, both of these species were erected after their cuticle structure which is absent in the present specimens. Hence, based on their gross morphology, the specimens are only compared with *E. bosei*. It is recorded for the first time from the Gangapur Formation.

Elatocladus andhrensis Chinnappa, Rajanikanth & Y. V. Rao, sp. nov.

Plate 2, figures 4-5, 7-8

Diagnosis: Shoots irregularly branched, branch angle 40°-50°, axis 1-3 mm wide, robust, leaves spirally arranged, attached by whole base, 30°-50°, face forward, oblong, 2-3 mm x 1 mm in size, base never twisted, margin entire, apex subacute, midvein prominent, traverses from base to apex, strobilus 1 cm x 0.5 cm in size consisting of 8-10 oval bodies

Description: Vegetative shoots irregularly branched at an angle of 40°-50°, largest specimens 15 cm long, axis 1-3 mm wide, robust. Leaves spirally borne, attached by whole base, arising at an angle of 30°-50°, spreading forward, oblong in shape, small in size, i.e. 2-3 mm long and less than 1 mm wide, base never twisted, margin entire, apex acute-subacute. Single prominent midvein passes through the leaf from base to apex. The fertile shoot laterally emerging from the vegetative shoot at an angle of 30°-40°, terminated by aggregate of probable male cones, 1 cm long and 0.5 cm wide and consist 8-10 oval bodies.

Holotype: BSIP Specimen No. 40212.

Specimens examined: BSIP Specimen Nos. 40212-40218.

Localities: Ralpet, Nowgaon and Peddavagu (near Anksapur), Adilabad District, Telangana.

Etymology: The specific epithet refers to Andhra University, Visakhapatnam, Andhra Pradesh.

Remarks and comparison: The specimens of *E. andhrensis* possess well branching pattern and strobili/cones. The previous reports of this kind from the Gangapur Formation are by Bose et al. (1982) and Sukh-Dev and Rajanikanth (1988) under *E. confertus* and by Pal et al. (1988) as *E. heterophylla*. The present specimens differ from the earlier ones in leaf nature and smaller leaf size. The cone in *E. heterophylla* Pal et al. (1988) is 2.3 cm long and 0.7 cm wide and consists of 13-14 oval bodies, whereas it is 1 cm long and 0.5 cm wide and contains 8-10 oval bodies in the present species. The isolated specimens of *Conites sripermaturensis*, probable female cones of *E. plana* Feistmantel (Sahni 1928), are different from the attached cones of present specimens. The present species also resembles *E. confertus* from Kutch described by Bose and Banerji (1984) in external morphology. However, it is easily distinguishable from the latter by their small size of leaves, i.e. 2-3 mm, divergence angle, i.e. 30°-50°, forward spreading and absence of swept back. The leaf divergence

angle in *E. andhrensis* resembles *Elatocladus* sp. B from the Gangapur Formation described by Sukh-Dev and Rajanikanth (1988) and *E. sherensis* from Jabalpur Formation described by Prakash (2013). However, it differs in other features such as leaf size and their nature. The solitary specimens of *Stachyotaxus sampathkumaranii* (Rao 1950, 1964) differ from those of *Elatocladus* by lenticular leaf shape and its phyllotaxy. *Elatocladus andhrensis* is primarily distinguished from all other known species of *Elatocladus* based on small size of leaves and narrow divergence of leaf angle and in having strobili/cone.

Genus: *Pagiophyllum* Heer 1881

Pagiophyllum marwarensis Bose and Sukh-Dev 1972

Plate 2, figure 9

Description: Leafy axes 1-2 cm long, bearing spirally inserted leaves, arising at an angle of 50°-60°, spread laterally or forward. Leaves arising from rhomboidal leaf base cushion, 3-5 mm long and 1-1.5 mm broad, margin entire, base decurrent, apex pointed or acute.

Specimen examined: BSIP Specimen Nos. 40238-40239.

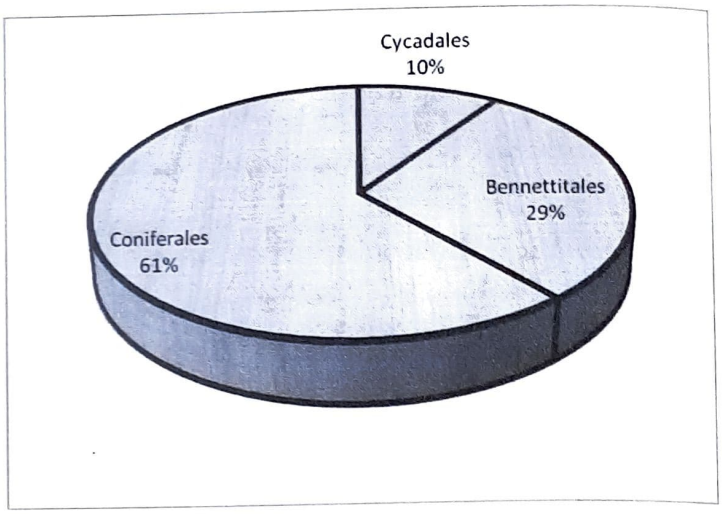
Localities: Rampur, Adilabad District, Telangana.

Remarks: The present specimen resembles *P. marwarensis* from Jabalpur Formation described by Bose and Sukh-Dev (1972) and from Gangapur Formation described by Bose et al. (1982) in gross morphological features.

Pagiophyllum rewaensis Bose & Sukh-Dev 1972

Plate 2, figure 6

Description: Leafy axes 25 mm long, bearing spirally inserted leaves, arising at an angle of 60°-70°, spread forward. Leaves small and narrow with distinct keel, 3-5 mm long and less than 1 mm broad, broad at base and narrowing towards the apex, apical portion of the leaf slightly curved, margin entire, base slightly decurrent, apex acute.



Text-figure 2. Diversity of various gymnosperm taxa in the Gangapur Formation

Specimens examined: BSIP Specimen No. 40240.

Localities: Peddavagu (near Anksapur), Adilabad District, Telangana.

Remarks: The present specimen resembles *P. rewaensis* from Jabalpur Formation described by Bose and Sukh-Dev (1972) in gross morphological features. However, the leaves in holotype are 9 mm long and 2 mm wide, but their range is mentioned as 2.5 x 1.5-10 x 2 mm (Bose & Sukh-Dev 1972). The leaf size in the present specimen fits within the range given by the authors. The species is new to the Gangapur Formation.

DISCUSSION

The Gangapur Formation holds good diversity of plant megafossils in the form of gymnosperms showing quantitative and qualitative abundance (Table 2, Text-figure 2). These are represented by pteridosperms, cycadophytes and conifers. Conifers are dominant and include nine genera, viz. *Elatocladus* (9 species), *Pagiophyllum* (6 species), *Araucarites* (3 species), *Brachyphyllum* (2 species) and *Allocladus, Arthrotaxites*, *Coniferocaulon*, *Conites* and *Torreytites* each represented by single species. The genus *Elatocladus* is comparatively rich and more common in Gangapur Formation and is recovered in great number from all the localities. A new species of *Elatocladus (E.*

Table 2. Distribution pattern of plant taxa in Gangapur Formation; Ak: Anksapur, Bn: Butarmal Nala, Ck: Chirakunta, Gp: Gangapur, Kn: Kondapalli, Kt: Kattarala, Ma: Moar, Nw: Nowgaon, Rl: Ralpet, Rm: Rampur; +: present, -: absent, *: added in this study.

Gymnosperm taxa	Fossil localities									
Cycadales/Pentoxylales	**Nw**	**Kn**	**Rl**	**Kt**	**Bn**	**Ma**	**Ck**	**Ak**	**Gp**	**Rm**
Cycadites sp.	-	-	-	-	-	-	+	-	-	-
Taeniopteris kutchensis Bose & Banerji	-	-	*	-	-	-	-	*	-	*
Taeniopteris spatulata McClelland	+	-	+	+	+	-	-	*	-	*
Taeniopteris sp.	*	-	-	-	-	-	-	*	-	*
Bennettitales										
? *Anomozamites* sp.	+	-	-	-	-	-	-	-	-	-
Cycadolepis sp.	-	-	-	-	-	-	+	-	-	-
Dictyozamites gondwanensis Sukh-Dev & Rajanikanth	-	-	-	-	+	-	-	-	-	-
Nilssonia sp.	-	-	+	+	-	-	-	-	-	-
Otozamites sp.	-	-	+	+	-	-	-	-	+	-
Pterophyllum medlicottianum Oldham & Morris	-	-	+	-	-	-	-	-	-	-
Ptilophyllum acutifolium Morris	+	+	+	-	-	-	-	+	-	*
Ptilophyllum cutchense Morris	+	-	+	-	-	-	-	-	-	*
Ptilophyllum distans (Feistmantel) Jacob & Jacob	-	-	-	-	+	-	-	-	-	-
Ptilophyllum horridum Roy	-	-	-	-	+	-	-	-	-	-
Ptilophyllum rarinervis (Feistmantel) Bose & Kasat	-	-	-	-	*	-	-	-	-	-
Ptilophyllum sp.	-	-	+	+	+	-	-	-	-	-
Coniferales										
Allocladus bansaensis Sukh-Dev & Zeba-Bano	+	-	+	-	-	-	-	-	-	-
Araucarites cutchensis Feistmantel	+	-	+	-	+	-	-	-	-	-
Araucarites minutus Bose & Maheshwari	+	-	-	-	+	-	-	-	-	-
Araucarites sp.	-	-	+	+	-	-	-	-	-	-
Arthrotaxites feistmantelii Sahni	+	-	-	-	-	-	-	-	-	-
Brachyphyllum sehoraensis Bose & Maheshwari	-	-	-	-	+	-	-	-	-	-
Brachyphyllum sp.	-	-	-	-	+	-	-	-	-	-
Coniferocaulon rajmahalense Gupta	+	-	-	-	-	-	-	-	-	-
Conites sripermaturensis Sahni	-	-	-	+	-	-	-	-	-	-
Elatocladus andhrensis sp. nov.	*	-	*	-	-	-	-	*	-	-
Elatocladus bosei Maheshwari & Kumaran	-	-	*	-	*	-	-	-	-	-
Elatocladus confertus Seward & Sahni	+	-	+	+	+	-	+	*	+	*
Elatocladus heterophylla Halle	-	+	-	-	-	-	-	-	-	-
Elatocladus jabalpurensis (Feistmantel) Sahni	+	-	-	+	-	-	-	+	-	-
Elatocladus kingianus Bose et al.	-	-	+	+	-	-	-	-	+	-
Elatocladus plana (Feistmantel) Seward	-	-	+	+	-	-	-	-	-	-
Elatocladus sehoraensis Maheshwari & Kumaran	-	-	*	-	*	-	-	-	-	-
Elatocladus sp.	+	-	+	-	+	-	-	-	-	-
Pagiophyllum burmense Sahni	-	-	+	+	-	-	-	-	-	-
Pagiophyllum marwarensis Bose & Sukh-Dev	+	-	-	-	+	+	+	-	-	*
Pagiophyllum peregrinum Lindley & Hutton	-	-	+	-	-	-	-	-	-	-
Pagiophyllum rewaensis Bose & Sukh-Dev	-	-	-	-	-	-	-	*	-	-
Pagiophyllum spinosum Sukh-Dev & Rajanikanth	-	-	+	-	-	-	-	-	-	-
Pagiophyllum sp.	-	-	+	-	-	-	-	-	-	-
Torreyites sitholeyi Ganju	-	-	-	+	-	-	-	-	-	-

andhrensis), with in situ strobili, has also been recorded. The cycadophytes include Cycadales and Bennettitales. The former is less diversified than the latter. Cycadales includes two genera, viz. *Taeniopteris* (with three species) and *Cycadites* sp. The Bennettitales shows taxonomically good diversification, but numerically less. It includes five genera, viz. *Ptilophyllum* (with six species)

and *Pterophyllum, Otozamites*, *Dictyozamites* and *Anomozamites* each with single species. Ginkgoales are not recovered. The palynological studies also indicate more or less similar scenario, where the pollen spectrum is dominated by conifers followed by cycadophytes (Rajeshwara Rao et al. 1983, Prabhakar 1987, Ramanujam & Rajeshwara Rao 1979, 1980, Bose et al. 1982). Good preservation of spores and pollen indicates that the flora was growing around the depositional site and there was not much of long distance transport (Rajeshwara Rao et al. 1983).

The abundance of conifers and nature of bennettitalean leaves in the presently studied assemblage closely resemble the flora of Jabalpur Formation of Sehora area. The relative presence or absence of some taxa in both Gangapur and Jabalpur formations can be attributed to taphonomic constraints (Spicer 1991) or local floral variations. Concerted efforts are needed to fully understand floral variations and local anomalies. The Gymnosperm flora from the coeval litho-units of East Coast basins of India shows co-dominance of cycadophytes and conifers and relative abundance of *Dictyozamites,* whereas the latter is scarcely represented in Gangapur flora.

The overall composition of palaeobotanical data indicates upland vegetation dominated by conifers. The less abundance and diversity of cycadophytes, scarcity of broad leaf members (e.g. *Dictyozamites*, *Ginkgo*) and presence of conifers with narrow and scaly leaves indicate that the plants were under physiological stress conditions. This is substantiated by presence of sunken stomata, confinement of stomata to lower side of leaf and presence of papillae (Bose et al. 1982, Sukh-Dev & Rajanikanth 1988). On the contrary, presence of *Classopollis* pollen indicates brackish environment (Rajeshwar Rao et al. 1983, Prabhakar 1987, Rajanikanth 1996). However, it is important to notice that *Classopollis* like pollen are produced by members of both Araucariaceae and Cheirolepidiaceae families (Kendall 1949, Couper 1955, Venkatachala 1966, Srivastava 1976). These members are also adapt to xeric environments and can tolerate hot and dry climates (Alvin 1982, Archangelsky & Taylor 1986, Watson 1988, Zhou et al. 2000, Van der Ham et al. 2003, Kunzmann et al. 2004, Yang et al. 2009, Mendes et al. 2010, Du et al. 2013). Hence, the inference that the conifer dominated flora of Gangapur Formation existed under warm and humid conditions seems justified. Further, non-recovery of marine phytoplankton and doubtful recovery of marine algae (Rajanikanth 1989) suggest that marine/ marginal marine/brackish environments are unlikely. Palaeobotanical, sedimentological and heavy mineral studies indicate fresh water (fluvial) environment (Sukh-Dev & Rajanikanth 1988, Prabhakar 1987, Ramamohanarao et al. 2003). Poor sorting and random orientation of plant fragments in clay beds of Gangapur Formation may reflect frequent floods in the basin (Lakshminarayana 2002).

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