



EARLY CRETACEOUS FLORAL DIVERSITY AND ECOLOGY IN THE PRANHITA-GODAVARI BASIN, EAST COAST OF INDIA

C.H. CHINNAPPA¹, A. RAJANIKANTH¹ and Y.V. RAO²

¹BIRBAL SAHNI INSTITUTE OF PALAEOSCIENCES, 53 UNIVERSITY ROAD, LUCKNOW, 226007, INDIA

²DEPARTMENT OF BOTANY, ANDHRA UNIVERSITY, VISAKHAPATNAM, 530003, INDIA

chinnabsip@gmail.com; rajanikanth.annamraju@gmail.com; raoyechuri@yahoo.com

ABSTRACT

Abundant plant fossils have been recovered from the Early Cretaceous (Berriasian-Aptian) fluvial sediments of the Gangapur Formation, Pranhita-Godavari Basin, east coast of India. The flora consists of ferns and gymnosperms. The fern components in the collection include *Cladophlebis*, *Contiopteris* and *Gleichenia*. The gymnosperms are represented by *Elatocladus*, *Harrisiohyllum*, *Pachypteris*, *Pagiophyllum*, *Pityospermum*, *Ptilophyllum*, *Taeniopteris*, *Taxites* and *Torreyites*. Three floral assemblages have been identified based on the relative association of various floral elements. First assemblage is principally composed of *Elatocladus*, along with *Torreyites*, *Taxites* and *Harrisiohyllum*. Second assemblage includes *Cladophlebis*, *Gleichenia*, *Pachypteris*, *Taeniopteris* and *Pityospermum*. Third assemblage mainly constitutes *Ptilophyllum* along with *Pagiophyllum*. These three assemblages are interpreted as representing three communities, occupying three subenvironments within the river floodplain. Away from the river channel is probably occupied by first assemblage, the riverbanks by second assemblage and the openland/lowland area was by the third assemblage. Analysis of flora from present and previous studies highlighted the conifer dominance, both in abundance and diversity. Comparison of this floral assemblage with other Early Cretaceous floras of India and adjoining Gondwanan continents showed that the flora is more closely comparable with the Satpura Basin and Western Australian floras than the other Early Cretaceous floras of India, Southern Australia and Antarctica. The total flora with well diverse foliages and spores belonging to bryophytes, pteridophytes and gymnosperms from the Early Cretaceous of the PG Basin suggests prevalence of warm and humid climatic conditions during the time of deposition.

Keywords: Pranhita-Godavari Basin, east coast, Early Cretaceous, floral diversity, palaeo-ecology

INTRODUCTION

The Pranhita-Godavari (PG) Basin is one of the largest Gondwana basins in India and it embodies almost a complete succession from Permian to Cretaceous. Interestingly, the exposed Lower Cretaceous rocks in the basin are about 525m (that includes both the Gangapur and Chikiala formations) in thickness and contain rich micro- and macrofossils. These sediments are exposed in and around the village of Gangapur (19° 16' N; 79° 26' E) in the Adilabad district, Telangana, India (Fig. 1). Historically, these Early Cretaceous outcrops were referred as "Gangapur beds" and placed under the Kota Group (King, 1881). However, based on lithological distinctions, Kutty (1969) separated these Early Cretaceous sediments from the Kota Group and created a new lithostratigraphic unit and named it as the Gangapur Formation after the village Gangapur. Known outcrops of this formation extend from north of Nowgaon (19° 20' N; 79° 24' E) to the west of Gangapur (19° 16' N; 79° 26' E) and in the east up to Dharmaram and Paikasigudem (Kutty, 1969).

Knowledge on plant megafossils from Early Cretaceous sediments of the PG Basin have been known through the studies of previous workers (see Chinnappa *et al.*, 2014 and references therein). However, all previous studies are based on less sample size (in most cases the sample size is one or two and yet in some studies it is maximum of 10 specimens). Moreover, these studies emphasised the biostratigraphic utility of the flora rather than floral diversity, vegetation dynamics or their ecological preferences. Recent field excursion by the authors to the Lower Cretaceous successions of the PG Basin has resulted in the collection of a large number of plant fossils. These fossils helped to understand the floral diversity and their community structure. Attempt has been made to bring out the depositional history and

palaeoecological preferences of the flora. The paper also throws some light on the phytogeographic relationship of the flora with other Gondwana flora.

GEOLOGY

The PG Basin is a large intra-cratonic Gondwana basin trending NW-SE, located in the eastern part of Peninsular India. The thickness of the sediment in the basin is ~3000 m deposited from the Late Carboniferous/Early Permian to the Cretaceous (Biswas, 2003). The Gondwana sedimentation seems to have occurred on block-faulted Proterozoic basins that evolved due to repeated sagging along SW and NE faults. A thick, almost uninterrupted succession of Permo-Triassic and partly Jurassic and Cretaceous sediments of mainly continental origin overlie the Proterozoic sediments. The geologic formations can be divided into Lower and Upper Gondwana. The status of Upper Gondwana in the PG Basin has undergone considerable change from time to time. Hughes (1877) considered the Maleri and Kota formations as a single unit and together named them as Kota-Maleri beds. King (1881) considered the suggestions earlier made by Blanford (1878) and separated them into two different formations, namely, Maleri and Kota based on faunal, lithologic and stratigraphic grounds. While the Maleri Formation holds a Triassic fauna, the Kota Formation had a Jurassic fauna. Simultaneously, King (1881) treated the Gangapur Formation as the lower part of the 'Kota Group'. Kutty (1969), however, identified the contact of the Gangapur beds with the underlying strata at two places, one in a stream section about 1.6 km to the west of Paikasigudem and the other in the Gangapur cliff, and he erected the Gangapur Formation (Fig. 1). Subsequently, the lithology and stratigraphy of the Gangapur Formation, along with other formations in the PG Basin, were extensively

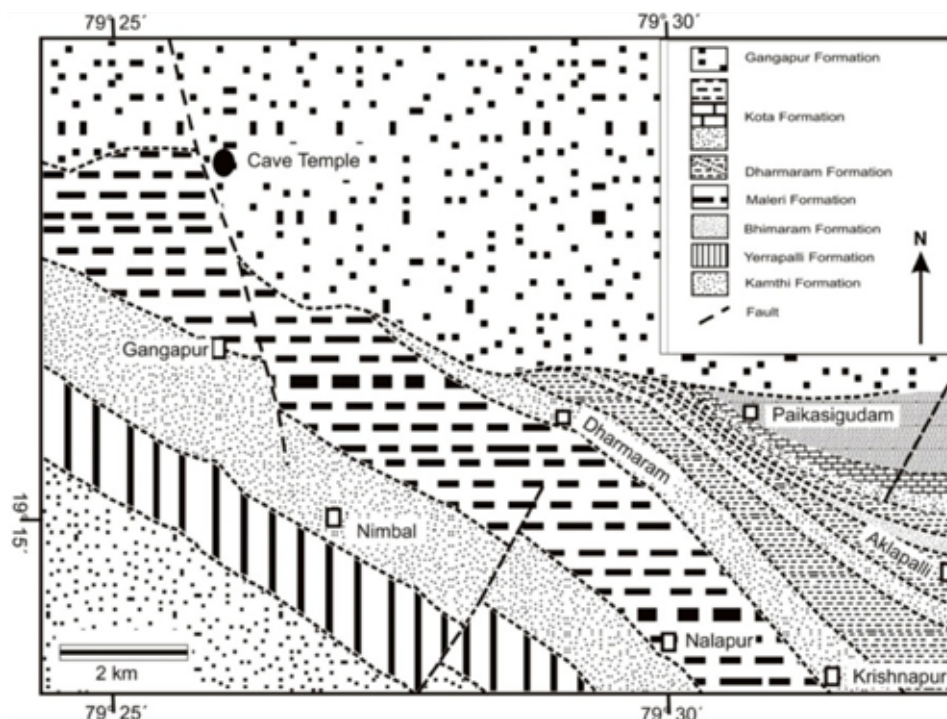


Fig.1. Geologic map of the PG Basin around the Gangapur village (after Kutty, 1969).

Table 1: Lithostratigraphy and ages of various lithostratigraphic units in the PG Basin (data from Kutty *et al.*, 1987, Lakshminarayana, 1996 and Sen Gupta, 2003).

	Formation	Lithology	Age
Deccan Traps			
Upper Gondwana	Gangapur/Chikiala	Coarse ferruginous sandstone, greywhite-pinkish mudstone and silty mudstone/shale	Early Cretaceous
	-----Unconformity-----		
	Kota	Upper: Sandstone, siltstone and claystone Middle: Limestone Lower: Sandstone with pebbles of banded chert	?Jurassic
	Dharmaram	Coarse sandstone and red clays	Late Late Triassic
	Maleri	Red clays, fine-medium sandstone and limestone	Early Late Triassic
	Bhimaram	Ferruginous/calcareous sandstone, minor red clays	Late Middle Triassic
Lower Gondwana	Yerrapalli	Red and violet clays with sandstone and limestone	Early Middle Triassic
	Kamthi	Upper: Coarse grained, ferruginous sandstone with quartz pebbles Middle: Siltstone Lower: Purple colored argillaceous sandstone interbedded with sandstone	Late Late Permian-? Early Triassic
	-----Unconformity-----		
	Kundaram/Barren Measure ('Ironstone shale'/'Infra Kamthi')	White-light yellow feldspathic sandstone, ferruginous shale, ironstone and clay/coal bands	Late Early Permian-Late Permian
	Barakar	Upper: Feldspathic sandstone, shale and carbonaceous shale Lower: Feldspathic sandstone, siltstone and coal laminae	Late Early Permian
	Talchir	Diamictite, rhythmite, tillite, greenish shale and sandstone	Early Early Permian
-----Unconformity-----			
Proterozoic		Igneous and metamorphic rocks	Precambrian

studied by many workers (Sen Gupta, 1970, 2003; Rudra, 1982; Bandopadhyaya and Rudra, 1985; Raiverman, 1986; Kutty *et al.*, 1987; Lakshminarayana and Murthi, 1990; Biswas 1992, 2003; Biswas *et al.*, 1994, Lakshminarayana, 1995, 1996, 2002).

The sedimentation of the Gangapur Formation took place during the Early Cretaceous after the renewed rift activity (Biswas, 2003). The formation is characterised by coarse, ferruginous sandstone with many pebble bands succeeded by

an alternating succession of sandstone and mudstone or silty mudstone facies. It unconformably overlies the Kota Formation which is composed of limestone, sandstone, siltstone, claystone and conglomerate. The Upper Gondwana units are in turn covered by the Deccan Traps. Stratigraphic nomenclature for the PG Basin has been variously given in literature. The classification given by Kutty *et al.* (1987), Lakshminarayana (1996) and Sen Gupta (2003) is adopted here; the generalised lithostratigraphic succession of the PG Basin is given in Table 1.

MATERIALS AND METHODS

Plant fossils were collected from the active quarries (RLQ 1 and RLQ 2) located at Ralpet (19° 18' N; 79° 25' E), about 7 km south of Sirpur-Kaghnagar (19° 21' N; 79° 28' E), Adilabad District, Telangana (Fig. 2). The quarry sections consist of approximately 8-12m of strata, which are characterised by coarse, ferruginous sandstone with many pebble bands succeeded by an alternating succession of sandstone and mudstone or silty mudstone facies (Fig. 3B, C). The plant fossils were preserved in pinkish-grey coloured mudstone. Fossil plant specimens were also collected from the mudstone succession exposed on the banks of Butarmal Nala (19° 27' N; 79° 13' E) about 13 km West North West of Asifabad (19° 21' N; 79° 17' E) Adilabad District, Telangana (Fig. 2). The fossil plant material is preserved as impressions in grey to buff colored silty mudstone (Fig. 3A). Despite the lack of whole leaf and cuticle, important morphological features, such as venation pattern, are well

preserved to help determine the taxonomic affinities of the fossil material. Plant fossils were studied under an Olympus SZH 10 stereo dissecting microscope. The morphological definitions employed here are after Ellis *et al.* (2009). All specimens were photographed with a Canon SX 150 IS digital camera using either polarised light or low angle lighting to reveal surface details. The material here described is lodged with the Birbal Sahni Institute of Palaeosciences (BSIP) fossil repository and has been assigned the registered Birbal Sahni Institute of Palaeosciences specimen numbers.

SYSTEMATIC PALAEOBOTANY

Class **Filicopsida** Pichi-Sermolli, 1958

Order **Filicales** Engler & Prantl, 1898-1902

Family **Osmundaceae** Berchtold & Presl, 1820

Genus **Cladophlebis** Brongniart, 1849

Cladophlebis kathiawarensis Roy, 1968

(Pl. I, fig. 1; Pl. II, fig. 1)

Material: Single partial leaf.

Description: Frond pinnate. Rachilla prominent, about 1 mm wide, uniform throughout the length. Pinnules sub-opposite to alternate, obovate to triangular, up to 10 mm long and 4 mm wide at base, gradually reducing towards the apex. Pinnule base asymmetrical; acroscopic base margin slightly auriculate to straight and basispic base margin decurrent and margins entire to slightly dentate. The pinnule margins at basal $\frac{3}{4}$ of the pinnule are less dentate, mostly appear like entire-undulate, but

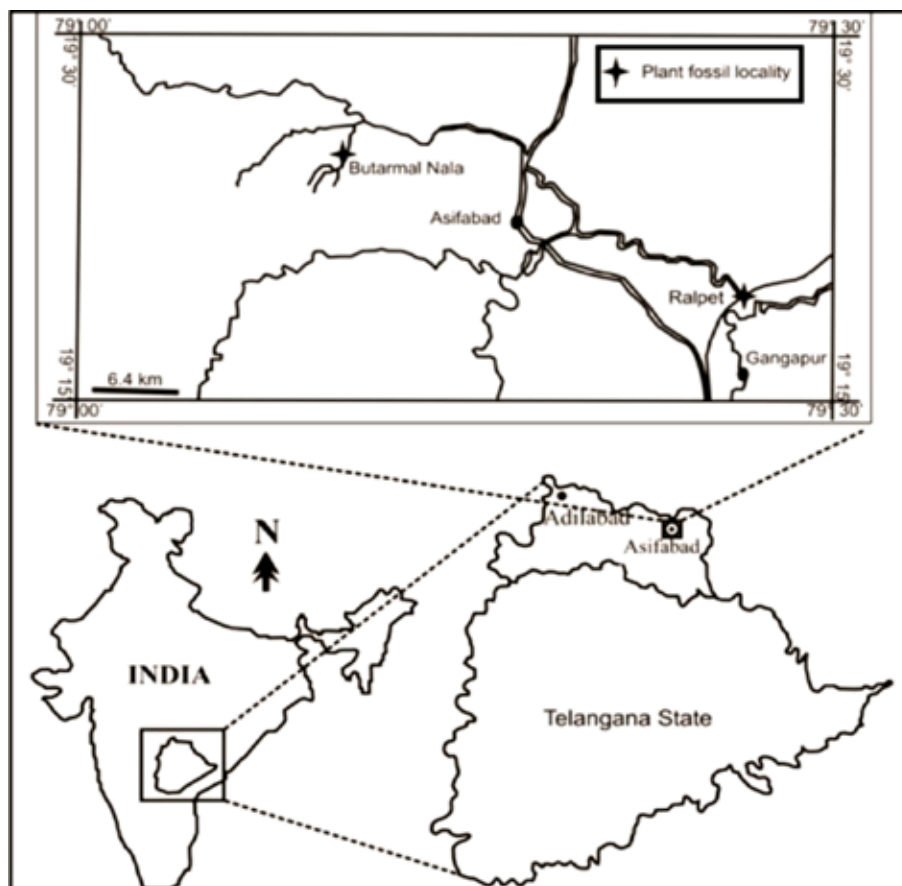


Fig. 2. Locality map of the Asifabad area, Adilabad district, Telangana, showing fossil collection sites.

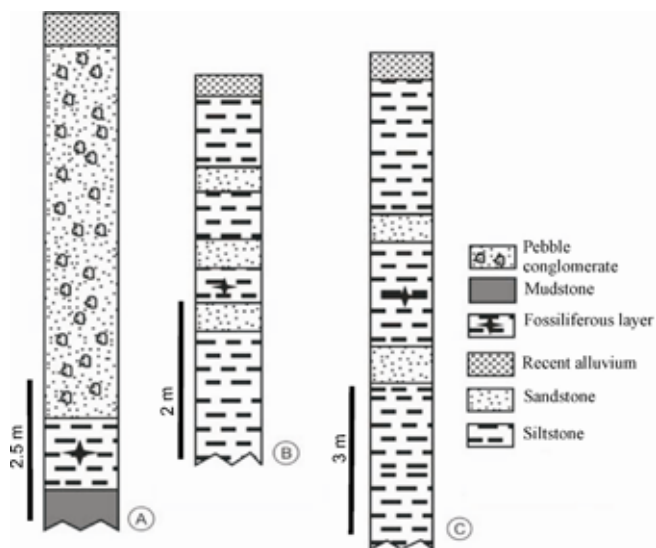


Fig. 3. Lithostratigraphic columns of strata exposed at BNS (A), RLQ 2 (B) and RLQ 1 (C).

towards the apex the margins are strongly dentate. Adjacent pinnule bases non-contiguous. Pinnules arise at an angle of 60° from rachilla. Midrib prominent, runs straight at most part of the pinnule but, near the apex it takes a slightly zigzag path. Secondary veins emerging at an angle of about 45° - 60° , usually once forked at central part of the pinnule.

Specimen: BSIP Museum No. 40587

Locality: RLQ 2

Horizon and age: Ralpet bed (Gangapur Formation), Early Cretaceous.

Comments: Single fragmentary specimen with well preserved pinnules. Venation pattern is marked clearly. Unfortunately, none of the pinnule have apices preserved. The characteristic shape of the pinnule, however, indicates that the apex is possibly bluntly acute.

Comparison: The pinnules of the present specimen best fit with *C. kathiawarensis* in having consistently once forked and distally placed secondary veins, hence the specimen is included under this taxon. The pinnule shape and margins with dentition shows some similarities with *C. kakadbhitisensis* Mehra and Verma (1982), *C. oblonga* (Halle) Rees and Cleal (2004), *C. antarctica* (Halle) Rees and Cleal (2004), *C. denticulata* (Brongniart) Harris (1961) and *C. indica* (Oldham & Morris) Sahni and Rao (1933). However, all the above-mentioned species can easily be distinguished from *C. kathiawarensis* in one or other characters such as pinnule size, secondary vein concentration and their divergence angle. *C. denticulata* and *C. indica* differs in having twice forked lateral veins. *C. oblonga* and *C. antarctica* differ in high lateral vein concentration and/or their less divergence angle. *C. kakadbhitisensis* differs in its large pinnule size (50-70 x 30-40 mm) and secondary veins disappearing at apical part of the pinnule.

Cladophlebis sp. A
(Pl. I, fig. 4; Pl. II, fig. 4)

Material: Two fragmentary pinnae.

Description: Frond pinnate. Rachilla prominent, less than 1 mm wide. Pinnules alternate, ovate to triangular, up to 2 mm long and 1 mm wide at base, gradually reducing in size towards the pinna apex. Pinnule base asymmetrical; acroscopic base margin slightly expanded and basiscopic base margin constricted, apex bluntly acute to obtuse and margins entire. Adjacent pinnule bases contiguous. Pinnules arise at an angle of 40° - 60° from rachilla. Midrib prominent at proximal end of the pinnule and near distal end it is thin; secondary veins emerging at an angle of about 50° , usually once forked about centre of pinnule.

Specimen: BSIP Museum No. 40588, 40589

Locality: RLQ 2

Horizon and age: Ralpet bed (Gangapur Formation), Early Cretaceous.

Comments: Fragmentary specimens preserved only part of the ultimate pinnae with three pairs of pinnules. Midrib is prominent, preserved up to $\frac{3}{4}$ of the pinnule only; at apices, midrib is not clear. The poor preservation of midrib at terminal parts makes it difficult to determine its nature, i.e. whether simple or forked. Lateral veins can be observed only in the lowermost pinnule, present on right side of the pinnae rachis/rachilla, here again only two lateral veins are clear and they fork at the centre of pinnule.

Comparison: *Cladophlebis* sp. A described here shows some similarities with *C. sahnii* Vishnu-Mittre (1959) described from the Rajmahal Formation, particularly in regards to the pinnule size and venation. *C. sahnii* was based on petrified material and vascular details of the pinnule are well documented; hence it is not feasible to include the present specimens under this taxon as these are impressions. The pinnules of *Cladophlebis* sp. A described in the present study are most similar to *C. srivastavae* Gupta (1954) known from the Rajmahal Formation in characters such as pinnule shape and venation pattern. However, the fragmentary nature and comparatively smaller pinnule size, i.e. 3 mm of the former (approximately 5 mm in latter) is not convincing to place the specimens under *C. srivastavae*. Although comparable in pinnule size (1.5-2.5 x 1.5-2 mm), *Cladophlebis* sp. B, Bose and Banerji (1984), from the Bhuj Formation has simple lateral veins. Species of *Cladophlebis* known from the other Gondwanan countries largely differ in their larger pinnae size.

Cladophlebis sp. B
(Pl. I, fig. 2; Pl. II, fig. 2)

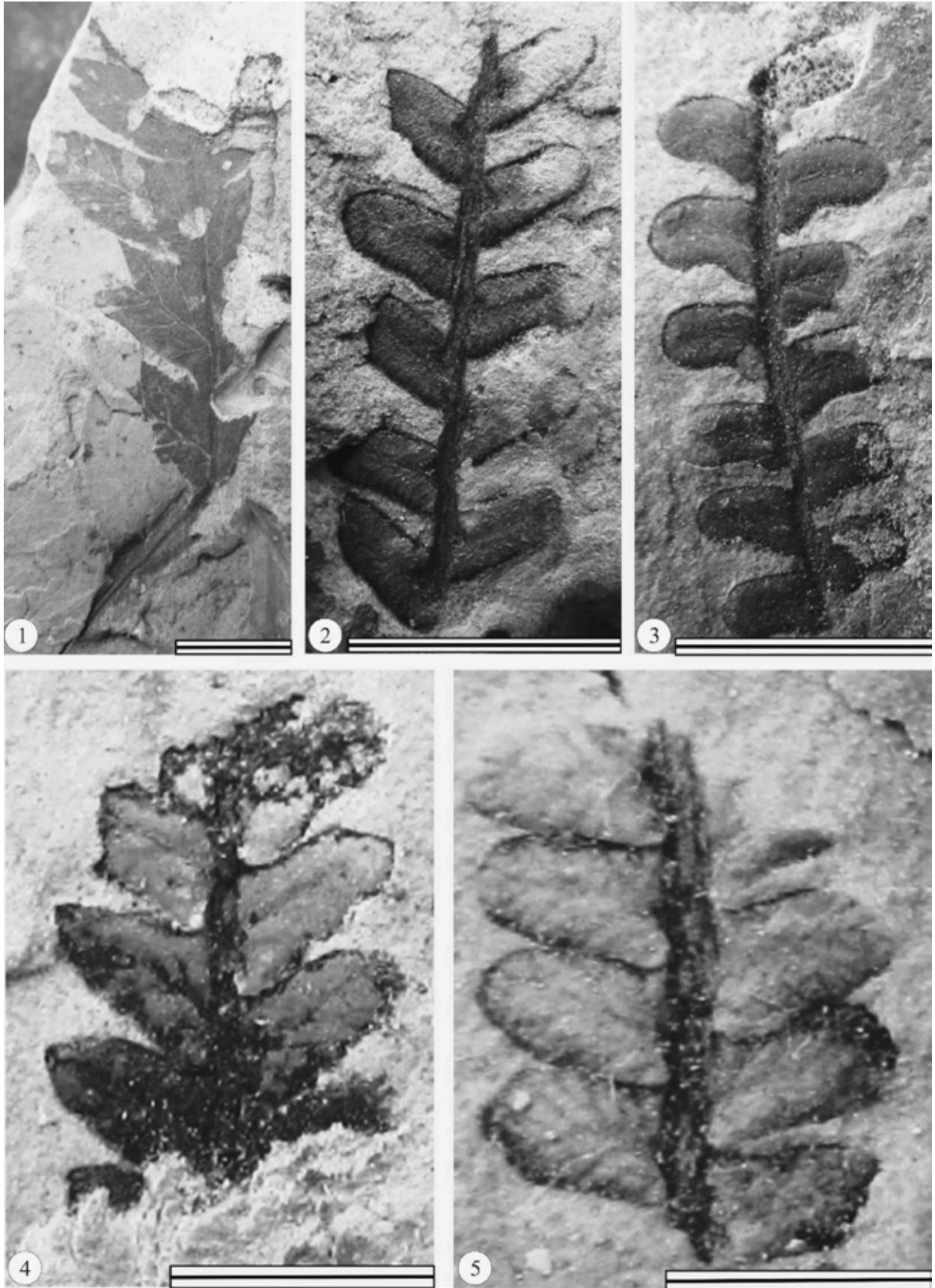
Material: Single well-preserved fragmentary pinnae.

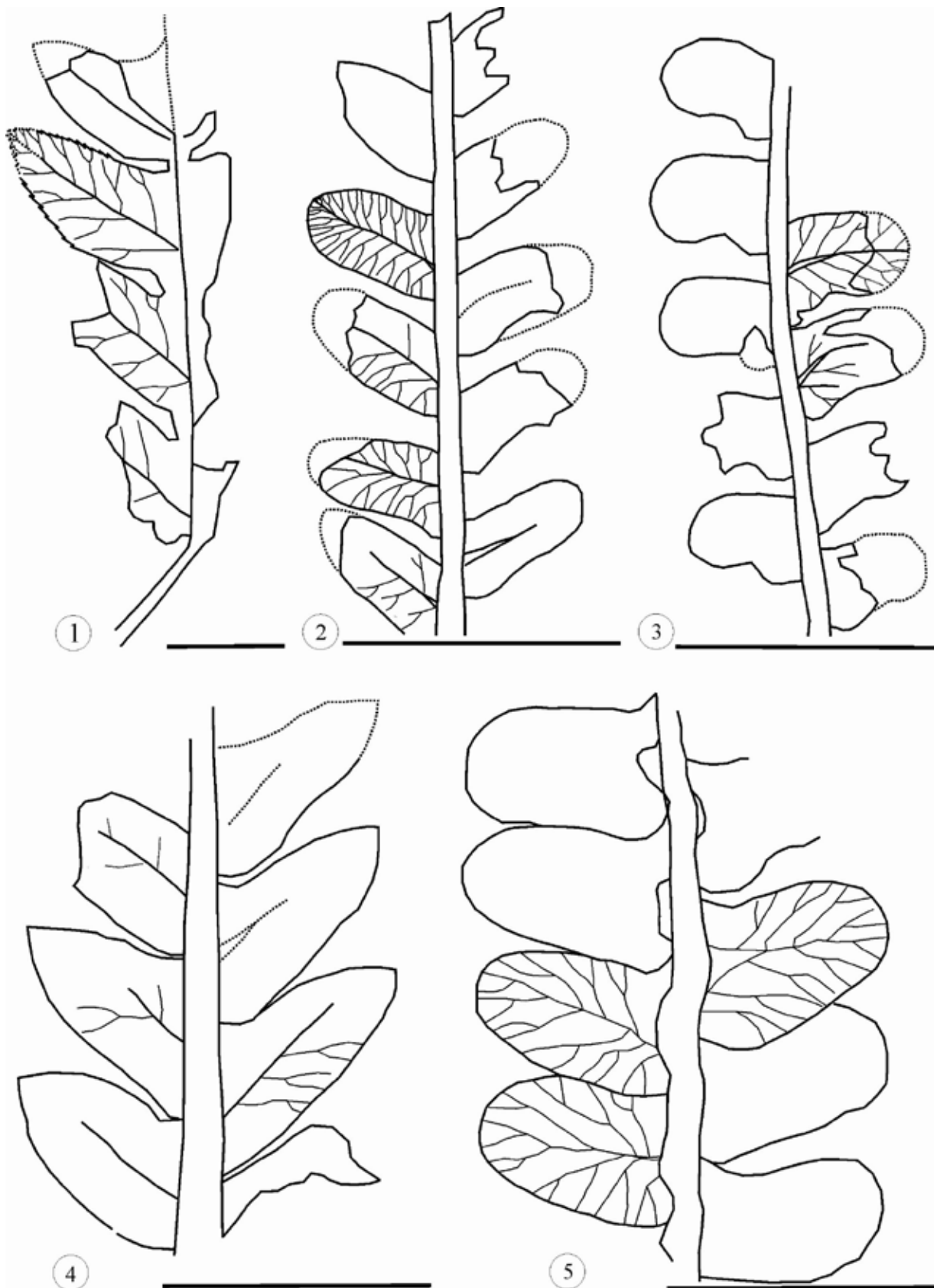
Description: Frond pinnate. Rachilla prominent, less than 1 mm wide and uniform throughout the length. Pinnules attached on the rachilla by entire base. Pinnules alternate, oblong, similar in size; up to 3 mm long and 1 mm wide. Pinnule base symmetrical; both acroscopic base margin and basiscopic base margin slightly truncate, apex obtuse and margins entire. Adjacent pinnule bases

EXPLANATION OF PLATES I & II

(Scale 0.5 cm unless and otherwise mentioned)

Plate I: Natural photographs of the specimens and Plate II: Line drawings of the specimens showing the missing parts and venation. 1. *Cladophlebis kathiawarensis* Roy. 2. *Cladophlebis* sp. B. 3. *Gleichenia rewahensis* Pant & Srivastava. 4. *Cladophlebis* sp. A (scale bar 0.25 cm). 5. *Gleichenia nordenskioldii* Herr.





non-contiguous, pinnules freely arranged. Pinnules arise at an angle 50°-60°, but mostly 50° from rachilla. Midrib prominent, extended up to pinnule apices; secondary veins 8-9 in number, emerging at an angle of about 50°-55°, usually once forked at various level but mostly at centre of pinnule.

Specimen: BSIP Museum No. 40590

Locality: RLQ 2

Horizon and age: Ralpet bed (Gangapur Formation), Early Cretaceous.

Comments: Single well-preserved specimen, only a small fragment of a single pinna is available. However, the specimen has more details of the pinnule with clear venation unlike *Cladophlebis* sp. A, described above.

Comparison: *Cladophlebis* sp. B. differs from the *Cladophlebis* sp. A. described above in many characteristic features of the pinnule. Both can easily be distinguished solely on the basis of pinnule shape. The former has oblong pinnules, whereas the latter has more or less triangular pinnules. *Cladophlebis* sp. (Bose *et al.*, 1982; Sukh-Dev and Rajanikath, 1988a) known from the Gangapur Formation differs from the *Cladophlebis* sp. B, either in larger sized pinnules (Sukh-Dev and Rajanikath, 1988a) or in a lower divergence angle of pinnules from rachilla (Bose *et al.*, 1982). In its widely spaced pinnule, *Cladophlebis* sp. B is closely comparable with *Cladophlebis* sp. cf. *patagonica* Herbst reported from Australia (McLoughlin *et al.*, 2002); however, the pinnule size in the latter is larger (approximately 15mm x 4mm). *Cladophlebis mcloughlinii* Nagalingum and Cantrill (2015) from the Albian of Antarctica includes pinnules with 3 mm length (but ranges from 3 to 15 mm, which is not a case for *Cladophlebis* sp. B); however, it differs in its acute apex.

Family **Gleicheniaceae** Presl, 1825

Genus **Gleichenia** Smith, 1793

Gleichenia rewahensis (Feistmantel) Pant & Srivastava, 1977
(Pl. I, fig. 3; Pl. II, fig. 3)

Material: Two fragmentary pinnae.

Description: Frond pinnate. Rachilla prominent, less than 1 mm wide. Pinnules attached on the rachilla by entire base. Pinnules alternate, oblong ovate, similar in size; up to 2.2 mm long and 1 mm wide. Pinnule base asymmetrical; acroscopic base margin slightly rounded and basiscopic base margin straight to constricted, apex obtuse and margins entire, strongly recurved, lower surface of the lamina concave. Adjacent pinnule bases non-contiguous, pinnules freely arranged. Pinnules arise at an angle 85° from rachilla. Midrib prominent, extended up to apex; secondary veins 4-5 in number, emerging at an angle of about 65°-70°, usually once forked.

Specimen: BSIP Museum No. 40591, 40592

Locality: RLQ 2

Horizon and age: Ralpet bed (Gangapur Formation), Early Cretaceous.

Comments: Two fragmentary pinnae, one showing the abaxial side of the pinnae and other with adaxial side. The two specimens look as if they are part and counterpart, although they do not. Venation can be seen only in one specimen (BSIP 40591). Midrib is visible as a narrow ridge, best seen only at proximal half of the pinnule; towards the distal half it is not clearly marked. The preserved length of midrib appears slightly zigzag. Lateral veins are faintly marked, they are once forked in between pinnae margin and midrib. Although the other specimen (BSIP 40592)

has not preserved the venation, it is also included under the same taxon based on the rest of morphological similarities such as pinnule size, shape and nature of margins.

Comparison: Pinnules with strongly recurved margins and strongly concave lower margin are the characteristic features of *G. rewahensis*. These characters separate the present species from other known species such as *G. gleichenoides* and *G. nordenskioldii* (Pant and Srivastava, 1977; page 155, table 1). The pinnule size in *G. rewahensis*, although, matches with *Gleicheniaceaphyllum acutum* Nagalingum and Cantrill (2006), the pinnule shape in the latter is rhombic and fertile pinnules are known. *Lophosoria cupulatus* Cantrill (1998) described from the Early Cretaceous sequences of Antarctica, is very similar to the present specimens in pinnule size, curved margins and strongly concave pinnules; however, it is known by fertile pinnules.

Gleichenia gleichenoides (Oldham & Morris)

Bose & Sah, 1968

(Pl. III, fig. 1; Pl. IV, fig. 1)

Material: Two fragmentary pinnae with distinct venation.

Description: Frond pinnate. Rachilla prominent, up to 0.2 mm wide. Pinnules attached on the rachilla by entire base. Pinnules sub-opposite to alternate, oblong, similar in size; up to 2 mm long and 1 mm wide, substance of lamina thick. Pinnule base asymmetrical; acroscopic base margin slightly decurrent and basiscopic base margin straight to constricted, apex obtuse and margins entire. Adjacent pinnule bases non-contiguous, pinnules freely arranged. Pinnules arise at an angle of 80°-85° from rachilla. Midrib prominent, extended up to ¾ of the pinna and thereby irregularly forking and each ending with dichotomy; secondary veins 2-3 in number, emerging at an angle of about 65°-70°, usually once forked near pinna margin.

Specimen: BSIP Museum No. 40593, 40594

Locality: BNS

Horizon and age: Butarmal Nala bed (Gangapur Formation), Early Cretaceous.

Comments: The specimens are also preserved as the previously described ones. However, unlike the previous specimens, venation is well preserved in both the specimens.

Comparison: Pant and Srivastava (1977) described similar specimens under *G. bosahii* Pant and Srivastava from the Jabalpur Formation, India. Both *G. bosahii* and *G. gleichenoides* share identical morphological and fertile characters. However, the specimens described by Pant and Srivastava possess cuticular details, which are not known in *G. gleichenoides*. The authors considered *G. bosahii* as synonym for *G. gleichenoides* and suggested to reserve the name for specimens with cuticular details (Pant and Srivastava, 1977). Since no cuticular details are available for the present specimens, we are placing the specimens in *G. gleichenoides* based on gross morphological similarity. *Microphylopteris gleichenoides* McLoughlin (1996) from the Western Australian Early Cretaceous sequences, though similar to the present species, has smaller pinnules (1 x 1 mm).

Gleichenia nordenskioldii Herr, 1874

(Pl. I, fig. 5; Pl. II, fig. 5)

Material: Single fragmentary pinnae.

Description: Frond pinnate. Rachilla prominent, less than 1 mm wide. Pinnules attached on the rachilla by median sinus at pinna base. Pinnules sub-opposite to alternate, ovate to oblong ovate, similar in size; up to 3.5 mm long and 2 mm wide. Pinnule base asymmetrical; basiscopic base margin round and

extended on to the rachilla and acroscopic base margin straight and short, apex obtuse and margin entire. Adjacent pinnule bases contiguous, pinnules closely arranged and imbricate. Pinnules arise at an angle 85° from rachilla. Midrib prominent, extended up to $\frac{3}{4}$ of the pinnule and thereby irregularly forking and each ends with dichotomous; secondary veins-3 in number, emerging at an angle of about 45° - 50° , usually once forked near pinnule margin.

Specimen: BSIP Museum No. 40595

Locality: RLQ 2

Horizon and age: Ralpet bed (Gangapur Formation), Early Cretaceous.

Comments: Although fragmentary and with only small portion of the pinnae with 3 pairs of pinnules, they are well preserved with clear venation pattern to determine their taxonomic affinity.

Comparison: The pinnules in the present specimens closely match with pinnules *G. nordenskioldii* in their size, shape, nature of base and venation. Morphologically, the pinnules also show some resemblance to *G. gleichenoides* (Oldham and Morris) Bose and Sah (1968). Basicopic base margin in *G. gleichenoides* is less expanded and is more or less equal to the acroscopic base margin. But, in the present specimen, the basicopic base margin is strongly expanded and it covers the pinnule rachis/ rachilla, which is an important character for identification for *G. nordenskioldii*.

Gleichenia sp A

(Pl. III, fig. 4; Pl. IV, fig. 4)

Material: Two fairly preserved and incomplete pinnae.

Description: Frond bipinnate. Rachis prominent, less than 0.4 mm wide. Rachilla 0.1 mm wide, uniform and alternately arising at an angle of 75° - 90° from rachis. Pinnules attached on the rachilla by entire base. Pinnules sub-opposite to alternate, ovate to globular, less than 1 mm long and 0.5 mm wide. Pinnule base asymmetrical; acroscopic base margin slightly decurrent and basicopic base margin normal, apex obtuse and margins entire. Adjacent pinnule bases contiguous, pinnules closely arranged and imbricate. Pinnules arise at an angle of 100° - 110° from rachilla. The lowermost pair of the pinnule on the pinnae extends on to the rachis. Venation obscure.

Specimen: BSIP Museum No. 40596, 40597

Locality: RLQ 2

Horizon and age: Ralpet bed (Gangapur Formation), Early Cretaceous.

Comments: The specimens are characterized by the presence of very minute pinnules, among the specimens studied under the genus *Gleichenia* Smith in the present study. Moreover, these are the only specimens preserved with two orders of rachis. The main rachis is cylindrical and on opposite sides to the rachis arise pinnae, almost at right angles. The pinnae rachis emerges from basicopic and acroscopic sides of the rachis and runs separately little over and then unit to form a single unit. This results in the formation of triangulate structure at the base of each pinnae, i.e. where pinnae joins the main rachis. Although the pinnules are more or less similar in size, the lowermost pair

of pinnules seems to be larger than the rest.

Comparison: *Microphylopteris unisora* Nagalingum and Cantrill (Cantrill and Nagalingum, 2005) described from Antarctica is most readily comparable with the present specimens. Both these specimens agree in divergence angle of pinnae and pinnules, and pinnule size. However, the absence of venation and fertile parts in the present specimens hinders better comparison.

Family **Dicksoniaceae** Schomb, 1848

Genus **Coniopteris** Brongniart, 1849

Coniopteris sp. A

(Pl. III, fig. 3; Pl. IV, fig. 3)

Material: Single poorly preserved fragmentary pinnae.

Description: Fronds pinnate, as a whole linear-lanceolate. Rachilla about 0.5 mm wide with longitudinal striations. Pinnules attached on the rachilla by entire base. Pinnules alternate, rhomboidal or wedge shaped, up to 5 mm long and 1.5 mm wide. Pinnule base asymmetrical; acroscopic base margin slightly truncate and basicopic base margin truncate-decurrent. Pinnules lobed and margins of each lobe further notched at unequal distance. Apices of lateral lobes rounded or broadly obtuse, never acute; apex of the apical lobe not preserved. Adjacent pinnule bases non-contiguous, pinnules freely arranged. Pinnules arise at an angle of 60° - 70° from rachis. Midrib prominent, extended up to pinna apex; secondary veins 2 in each lateral lobe, emerging at an angle of about 50° - 60° , once forked away from the midrib.

Specimen: BSIP Museum No. 40598

Locality: RLQ 2

Horizon and age: Ralpet bed (Gangapur Formation), Early Cretaceous.

Comments: Small fragmentary pinnae, only the basalmost part of the pinnule is available. A single pinnule provides little information regarding nature and venation. This pinnule indicates that the pinnules appear to be trilobed, with lobes distributed unequally, though single lobe on the basicopic side can be seen clearly. Apex of the pinnule is not available even in the best preserved one; however, the characteristic shape of the pinnule signals that they may end with bluntly acute-obtuse apex. Venation shows a single prominent midrib extending from base to apex, from which arise lateral veins running into lobes. Each lobe usually receives two lateral veins which fork once away from the midrib.

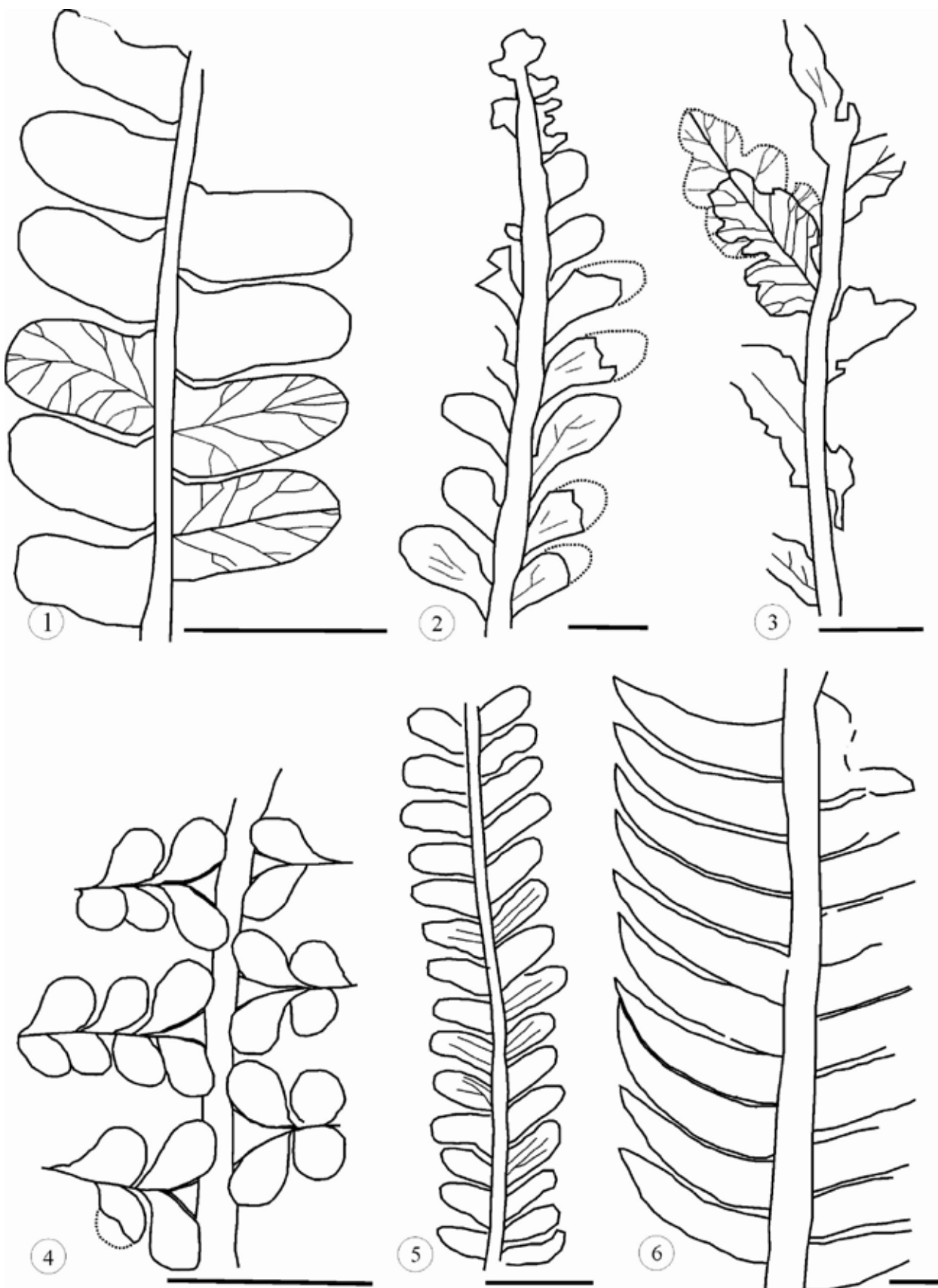
Comparison: The poor preservation of specimens makes comparison difficult with better preserved specimens of similar type. However, the available information regarding the pinnules indicates affinity with *Coniopteris* Brongniart. The specimen shows some gross morphological similarities with *C. lobata* (Oldham and Morris) Halle (1913) described from Hope Bay and Botany Bay, Antarctica in pinnule divergence angle and shape. However, in the latter, the pinnule base is symmetrical, the number of lobes is 7-13 per pinnule and lateral veins are always simple with each lobe receiving a single vein. *C. bella* Harris (1961) has a trilobed pinnule with each lobe receiving two lateral veins, which are once forked as in the present specimen;

EXPLANATION OF PLATES III & IV

(Scale 0.5 cm unless and otherwise mentioned)

Plate III: Natural photographs of the specimens and Plate IV: Line drawings of the specimens showing the missing parts and venation. 1. *Gleichenia gleichenoides* Bose & Sah (scale bar 0.25 cm). 2. *Pachypteris* cf. *specifica* (Feistmantel) Bose & Banerji (scale bar 0.25 cm). 3. *Coniopteris* sp. A., (scale bar 0.25 cm). 4. *Gleichenia* sp. A (scale bar 0.25 cm) 5. *Ptilophyllum rarineris* (Feistmantel) Bose & Bano. 6. *P. acutifolium* (Morris) Bose & Bano.





the latter is, however, known by fertile pinnule.

Class **Pteridospermsida** Pant, 1957
Order **Corystospermales** Petriella, 1981
Family **Incertae Sedis**
Genus **Pachypteris** Brongniart, 1828

Pachypteris cf. *specifica* (Feistmantel) Bose & Banerji, 1984
 (Pl. III, fig. 2; Pl. IV, fig. 2)

Material: Two moderately preserved pinnae.

Description: Fragmentary pinnate frond. Rachilla prominent, slender, less than 1 mm wide and gently tapering distally. Pinnules attached on the rachilla by entire base. Pinnules sub-opposite to opposite, club shaped, pinnule size gradually reducing towards the apex of frond; up to 2.5 mm long and 1 mm wide at basal region and small towards the apical region of frond, substance of lamina thin. Pinnae base contracted and asymmetrical; acroscopic base margin normal and basiscopic base margin largely decurrent and joins with the acroscopic base margin of the pinna below, apex rounded and margins entire. Pinnules freely arranged. Pinnules arise at an angle of 60°-70° from rachilla. Venation indistinct.

Specimen: BSIP Museum No. 40599, 40600

Locality: RLQ 2

Horizon and age: Ralpet bed (Gangapur Formation), Early Cretaceous.

Comments: Part of the pinnae, probably the terminal part of the ultimate pinnae preserved with small number of pinnules. Of the two specimens recovered, one (BSIP 40600) showing the pinnules of similar size and other (BSIP 40599) with reduced pinnule size towards the apical region, this specimen is probably the terminalmost part of the ultimate pinnae. The major difference lies in the base of the pinnules; the pinnule base at most part of the pinnae is converged and gives a small stalk-like appearance but pinnules at apical parts of the pinnae are negatively converged. The venation can be seen imperfectly in basal larger pinnule.

Comparison: *Pachypteris* Brongniart is well known from the Jurassic and Early Cretaceous sediments of Southern Hemisphere. However, the species described from the Early Cretaceous sequences of Australia are quite different in their morphology and it is doubtful whether they belong to *Pachypteris* (Cantrill, 2000). *Pachypteris* is known by a single species, i.e. *P. indica* (Oldham & Morris) Bose and Roy in Antarctica (Cantrill, 2000; Rees and Cleal, 2004) and this can easily be distinguished from the present one based on its distinct pinnule shape. *Pachypteris* in India consists of about six to seven species. Morphologically, the pinnules of the present specimens are best comparable with *P. specifica* (Feistmantel) Bose and Banerji (1984). However, lack of cuticle only permits to place the specimen as a comparative form. The fragmentary pinnae also show some morphological similarities with *Sphenopteris* sp. A from Australia (McLoughlin, 1996) and *Sphenopteris* sp. B from India (Zeba-Bano, 1980), but can be separated based on distinct pinnule morphology.

Class **Cycadopsida** Brongniart, 1843
Order **Pentoxylales** Sahni, 1948
Family **Incertae Sedis**
Genus **Taeniopteris** Brongniart, 1828

Taeniopteris spatulata (McClelland) Bose and Banerji 1981
 (Pl. V, figs. 5 & 6)

Material: Five incompletely preserved leaves.

Description: Leaves simple, maximum available size is up to 60 mm long and 8 mm wide at widest region and attenuating towards the base and apex, linear shape. Margin entire to slightly undulate, base tapering acute, petiolate and apex not known. Midrib prominent, up to 2 mm wide with a median groove. Lateral veins closely spaced, depart midrib at an angle of 50°-60°, up to 35 per cm leaf area. Lateral veins usually fork soon after the emergence from midrib and rarely away from midrib.

Specimen: BSIP Museum No. 40601-40605

Locality: RLQ 1, RLQ 2

Horizon and age: Ralpet bed (Gangapur Formation), Early Cretaceous.

Comments: The specimens are partially preserved; none have preserved full length of the leaf. One specimen (BSIP 40605) has preserved with almost complete basal part, including petiole. Rest of them are fragmentary, probably representing the basal parts of leaf. Although there is a significant variation in the size of fragments recovered, they share common venation pattern, hence placed under a single species.

Comparison: The venation pattern of the specimens described here is best comparable with *T. spatulata* known from India (Bose and Banerji, 1981). Though the specimens show similar secondary vein concentration as in the *T. daintreei* known from Australia (Douglas, 1969), they differ in secondary vein divergence angle.

Taeniopteris cf. *daintreei* McCoy, 1874
 (Pl. V, figs. 4 & 7)

Material: Two leafy impressions; one preserved almost full length and the other is fragmentary.

Description: Leaves simple, maximum available size is up to 90 mm long and 4 mm wide at widest region and attenuating towards the base and apex, linear-lanceolate shape. Margin gently undulate-lobed, base tapering, petiolate and apex not known. Midrib prominent, about 1 mm wide with a median ridge.

Specimen: BSIP Museum No. 40606, 40607

Locality: RLQ 2

Horizon and age: Ralpet bed (Gangapur Formation), Early Cretaceous.

Comments: Two leaves are described under this species based on their gross morphological similarity. One is preserved with most part of leaf along with petiole but apex is missing; and the other one is fragmentary. None has preserved venation pattern. Both the specimens are characterized by lobed margins and characteristic shape that justify their placement under *Taeniopteris* cf. *daintreei*.

Comparison: *T. daintreei* is for the first time described by McCoy (1874) from the Early Cretaceous sediments of Victoria, Australia. Subsequently, similar leaves have been described from various Jurassic to Early Cretaceous strata of southern Gondwana (Arber, 1917; Walkon, 1919b, 1944; White, 1961a, b; Gould, 1980; Drinnan and Chambers, 1985; McLoughlin, 1996; Hawe and Cantrill, 2001). There is a considerable variation in shape of the leaves collected from the different localities, e.g. the leaves described from Antarctica include narrow and linear leaves (Hawe and Cantrill, 2001; page 782, fig. 2), whereas those from Australia are wide and spatulate (McLoughlin, 1996; page 38, fig 7A). The specimens described here are best comparable with *T. daintreei* from Antarctica (Hawe and Cantrill, 2001). However, lack of venation precludes better comparison and hence, they are placed under the comparative form. The specimens also show

some gross morphological similarity with *T. spatulata* known from the Vemavaram Formation, Krishna-Godavari Basin, east coast of India in their size and shape (Feistmantel, 1879; Plate I, figs. 8, 9). However, the figured specimens of Feistmantel show entire margin, which is lobed in the present specimen.

Taeniopteris sp.
(Pl. VI, figs. 1, 2 & 3)

Material: Single partly preserved leaf.

Description: Leaves simple, maximum available size is up to 65 mm long and 6 mm wide at widest region and attenuating towards the base and apex, linear shape. Margin entire to slightly undulate, base tapering acute, petiolate and apex not known. Midrib prominent, about 1 mm wide with a median groove and striations. Lateral veins closely spaced, density of lateral veins increasing towards the apex of the leaf, depart from the midrib at angle of 50°, up to 40 per cm leaf area. Lateral veins fork mostly soon after emergence from midrib and the lower one forks again near leaf margin.

Specimen: BSIP Museum No. 40608

Locality: RLQ 2

Horizon and age: Ralpet bed (Gangapur Formation), Early Cretaceous.

Comments: Single leaf with considerable length; however, neither base nor apex of the leaf is known; further, the venation towards end of the leaf is not clear. The lateral veins usually fork twice; once near midrib and then at margins. However, there is considerable variation in the position of first-order forking of lateral veins. The second-order forking of lateral veins is also not constant; in most cases only the lower one is forking; however, forking of upper vein is not uncommon.

Comparison: The present specimen largely differs from the existing species of *Taeniopteris* in its characteristic venation pattern. *T. kutchensis* Bose and Banerji (1984) shows some similarity with the present specimens, in venation pattern, i.e. twice forking of veins. However, in the former, the character is infrequent and majority of the lateral veins are simple and leaves are very wide (up to 4 cm). The leaf size and shape of *Taeniopteris* sp. described here also resemble *T. spatulata* described from the Vemavaram Formation, Krishna-Godavari Basin, east coast of India (Feistmantel, 1879), but differ in having twice-forked lateral veins. *T. daintreei* Drinnan and Chambers (1985) from Australia shows twice-forked lateral veins, though it is a rare character. Although comparable in its lateral vein density (30-34/cm) and twice forking lateral veins, *Taeniopteris* sp. from Antarctica (Césari *et al.*, 1998) has a thick midvein (2 mm) and the too fragmentary leaves to be compared. Their figured specimens indicate presence of twice-forked lateral veins. *T. thomsoniana* Arber from New Zealand (Blaschke and Grant-Mackie, 1976) has different shape and mostly once-forked lateral veins.

Class **Cycadopsida** Brongniart, 1843

Order **Bennettitales** Engler, 1892

Family **Williamsoniaceae** Carruthers, 1870

Genus ***Ptilophyllum*** Morris, 1840

Ptilophyllum rarinervis (Feistmantel) Bose & Kasat, 1972
(Pl. III, fig. 5; Pl. IV, fig. 5)

Material: Single leafy axis.

Description: Leaf pinnate, broadly linear shape, maximum available length of the leaf is about 30 mm. Rachis slender and about 1 mm wide. Pinnules sub-opposite to alternate, linear, straight or slightly falcate at places, inserted on adaxial surface of rachis at angle of 50°-70°, up to 1 mm wide and 2-4 mm long. Pinnule base not clear, apices obtuse and margins entire. Pinnules closely arranged and never imbricate. Venation parallel, 2-3 or rarely 4 veins run from base to apex of the pinnule.

Specimen: BSIP Museum No. 40609

Locality: RLQ 2

Horizon and age: Ralpet bed (Gangapur Formation), Early Cretaceous.

Comments: The species is characterized by the presence of a few veins (2-3; mostly 3) and are once forked. The specimens of this type are very rarely encountered and are mostly from the east coast of India. Only a single specimen has been recovered in the present study, which is assigned to *P. rarinervis* based on a few number of veins with forking.

Comparison: *Ptilophyllum* leaves with a few numbers of veins can also be found in the *P. tenerrima* (Feistmantel) Bose and Kasat and *P. nipanica* (Vishnu-Mittre) Bose and Kasat (1972). *P. tenerrima* shows simple veins and has long and narrow pinnae. *P. nipanica* is known by its cuticular details.

Ptilophyllum acutifolium (Morris) Bose & Kasat 1972
(Pl. III, fig. 6; Pl. IV, fig. 6)

Material: Four incompletely preserved leafy axes.

Description: Leaf pinnate, broadly linear shape maximum available length of the leaf is up to 95 mm. Rachis stout and up to 3 mm wide. Pinnules opposite to sub-opposite, lanceolate, slightly falcate, inserted on adaxial surface of rachis at angle of 40°-70°; mostly 60°-70°, up to 2 mm wide and 8-15 mm long. Pinnule base not clear, apices acute and margins entire. Pinnules closely arranged or imbricate.

Specimen: BSIP Museum No. 40610-40613

Locality: RLQ 2, BNS

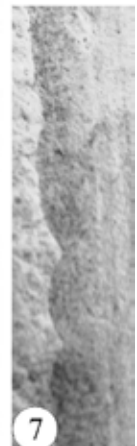
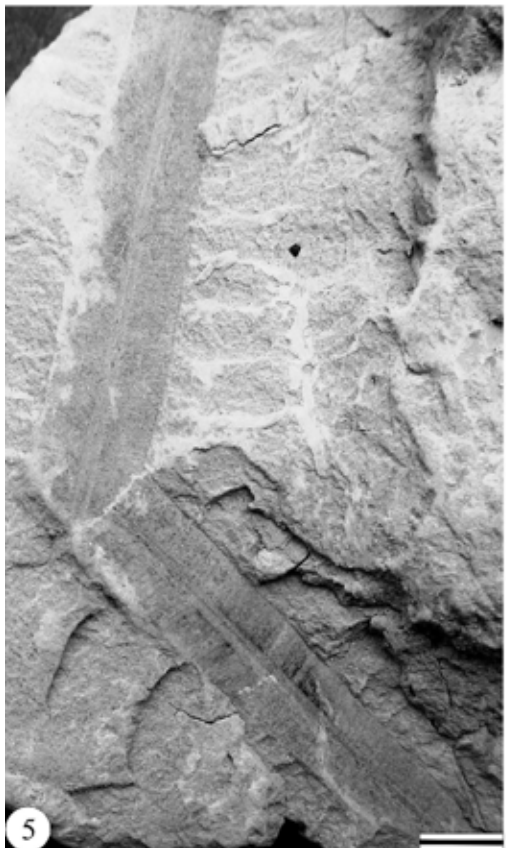
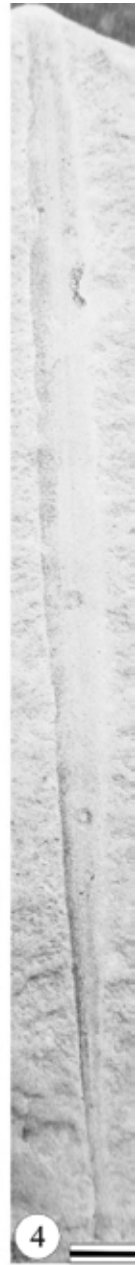
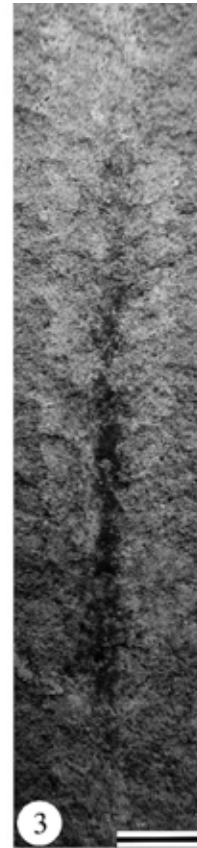
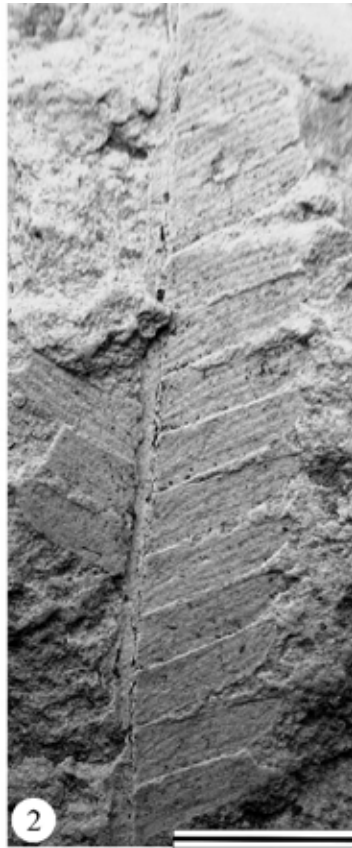
Horizon and age: Ralpet bed (Gangapur Formation), Early Cretaceous.

Comments: *Ptilophyllum acutifolium* Morris was recently emended by Bose and Kasat (1972). Out of the three specimens originally figured by Morris (in Grant, 1840), the best preserved one (no. v21330 (9942) was selected as a lectotype. The lectotype is having leaf width about 40 mm and pinnule with acute apices. However, Bose and Kasat (1972) suggested that all the specimens, in the range of 40-100 mm width, having pinnule with acute apices and lacking cuticle, be placed in this taxon. The specimens resembling the original lectotype and emended size range are usually found at Kutch and Rajmahal. The specimens known from the east coast are mostly smaller than 40 mm, but characterized by pinnules with acute apices (Chinnappa *et al.*, 2014). The separate taxonomic status for these specimens is also not ignorable in view of their smaller pinnule size. However,

EXPLANATION OF PLATE V

(Scale 0.5 cm unless and otherwise mentioned)

1. *Ptilophyllum kutchense* (Morris) Bose & Bano. 2. *P. kutchense* (Morris) Bose & Bano- Showing the venation pattern. 3. *Ptilophyllum* sp. A. 4. *Taeniopteris* cf. *daintreei* McCoy. 5. *Taeniopteris spatulata* (McClelland) Bose & Banerji. 6. *T. spatulata* (McClelland) Bose & Banerji.-part of the leaf enlarged to show venation pattern 7. *Taeniopteris* cf. *daintreei* McCoy- part of the leaf enlarged to show lobed margin.



this needs a critical re-examination of all previous specimens, along with better preserved new material from the east coast, as opined by Bose and Kasat (1972) and Chinnappa *et al.* (2014). The material described here is provisionally placed under *P. acutifolium* based on their acute pinnule apices and lack of cuticle.

Comparison: *Ptilophyllum acutifolium* is a well-known Jurassic to Cretaceous form spread in both the southern and northern hemispheres. The specimens of *P. acutifolium* known from Australia, Argentina, and South America differ from the Indian specimens in having much longer pinnules (Arrondo and Petriella, 1980; Longobucco *et al.*, 1985; McLoughlin, 1996; Passalia, 2007). The specimens described from Antarctica (Halle, 1913) were recently transferred to *Zamites* Brongniart, as the leaf bases are symmetrical (Gee, 1989; Rees, 1990). *P. acutifolium* from New Zealand described by Arber (1917) has auriculated acroscopic base and contracted basiscopic base margin; hence it is best placed in *Otozamites* Braun, as opined by Cantrill (2000). *P. menendezii* described from Antarctica (Cantrill, 2000), although similar in having acute pinnule apices, has very large pinnules and preserved cuticle. Specimens from Japan, described under the comparative form of *P. acutifolium*, are larger than the Indian specimens. *P. acutifolium* from Spain (Dieguéz *et al.*, 2009) is closely comparable to the Indian specimens.

P. cutchense (Morris) Bose & Kasat, 1972
(Pl. V, figs. 1 & 2)

Material: Five incomplete leaf impressions.

Description: Leaf pinnate, broadly linear shape, maximum available length up to 75 mm. Rachis slender and about 1.5 mm wide. Pinnules sub-opposite to alternate, linear-lanceolate, straight or slightly arched distally, inserted on adaxial surface of rachis at angle of 60°-80°, up to 1 mm wide and up to 5 mm long. Pinnule bases slightly rounded, apices obtuse or truncate and margins entire. Pinnule closely arranged. Venation parallel, 4-5 veins run from base to apex of the pinnule and once forked.

Specimen: BSIP Museum No. 40614-40618

Locality: BNS

Horizon and age: Butarmal Nala bed (Gangapur Formation), Early Cretaceous.

Comparison: The specimens are best comparable with *P. cutchense* described from the east coast of India (Chinnappa *et al.*, 2014a, b). The specimens known from Japan under the comparative form possess large-sized pinnules (Kimura *et al.*, 1991).

Ptilophyllum sp. A
(Pl. VII, fig. 3)

Material: Four fragmentary leaves with indistinct venation pattern.

Description: Leaf pinnate, narrow elliptical shape, maximum available length of the leaf is up to 30 mm. Rachis slender, about 1 mm wide and concealed by pinnae base. Pinnules alternate, broadly elliptical, straight or slightly falcate distally, inserted on adaxial surface of rachis at angle of 60°-80°, up to 1.5 mm wide

and 3 mm long. Pinnule bases symmetrical, apices obtuse and margins entire. Pinnule sparsely arranged.

Specimen: BSIP Museum No. 40619-40622

Locality: RLQ 1, BNS

Horizon and age: Gangapur Formation, Early Cretaceous.

Comments: Four fragmentary specimens, without any information about their venation pattern. The characteristic nature of pinnules with decurrent basicopic margin indicates their affinity with the *Ptilophyllum* Morris (Harris, 1969; Watson and Sincock, 1992). However, lack venation pattern and/or the cuticle precludes assigning them to any known species.

Comparison: The size of the pinnule comes close to *P. rarinervis*, *P. tenerrima*, *P. nipanica* and *P. indicum*. The former set of the species are based on their characteristic venation and latter are based on cuticle. However, neither venation nor cuticle is preserved in the present specimens and makes difficult to determine their relation with the above-mentioned taxa. *P. irregularae* Douglas and *Ptilophyllum* sp. B described from Australia (Douglas, 1969), although with same size pinnule, have recently been transferred to *Otozamites* by McLoughlin *et al.* (2002) due to the presence of auriculated pinnae base.

Class **Coniferopsida** Endlicher, 1847

Order **Coniferales** Hankel & Hochstrter, 1865

Family **Araucariaceae** Coulter & Chamberlain, 1917

Genus **Pagiophyllum** Heer, 1881

Pagiophyllum sp. cf. *burmense* Sahni, 1928
(Pl. VI, fig. 7)

Material: Single moderately preserved branched leafy axis.

Description: A single branched shoot up to 70 mm long and 5 mm wide (including diverged leaves). Lateral shoots arise from main shoot at an angle of 60°-70°, up to 40 mm long and 4-5 mm wide (including divergent angle); width decreasing only slightly towards the shoot apex. Leaves arise spirally on the shoot and at more or less right angle to the shoot. Leaf base entire, margins converging from leaf base to acute apex. Leaf apices mostly directed towards the shoot apex. Leaves 3-4 mm long and 1-2 mm wide, traversed by single vein.

Specimen: BSIP Museum No. 40623

Locality: BNS

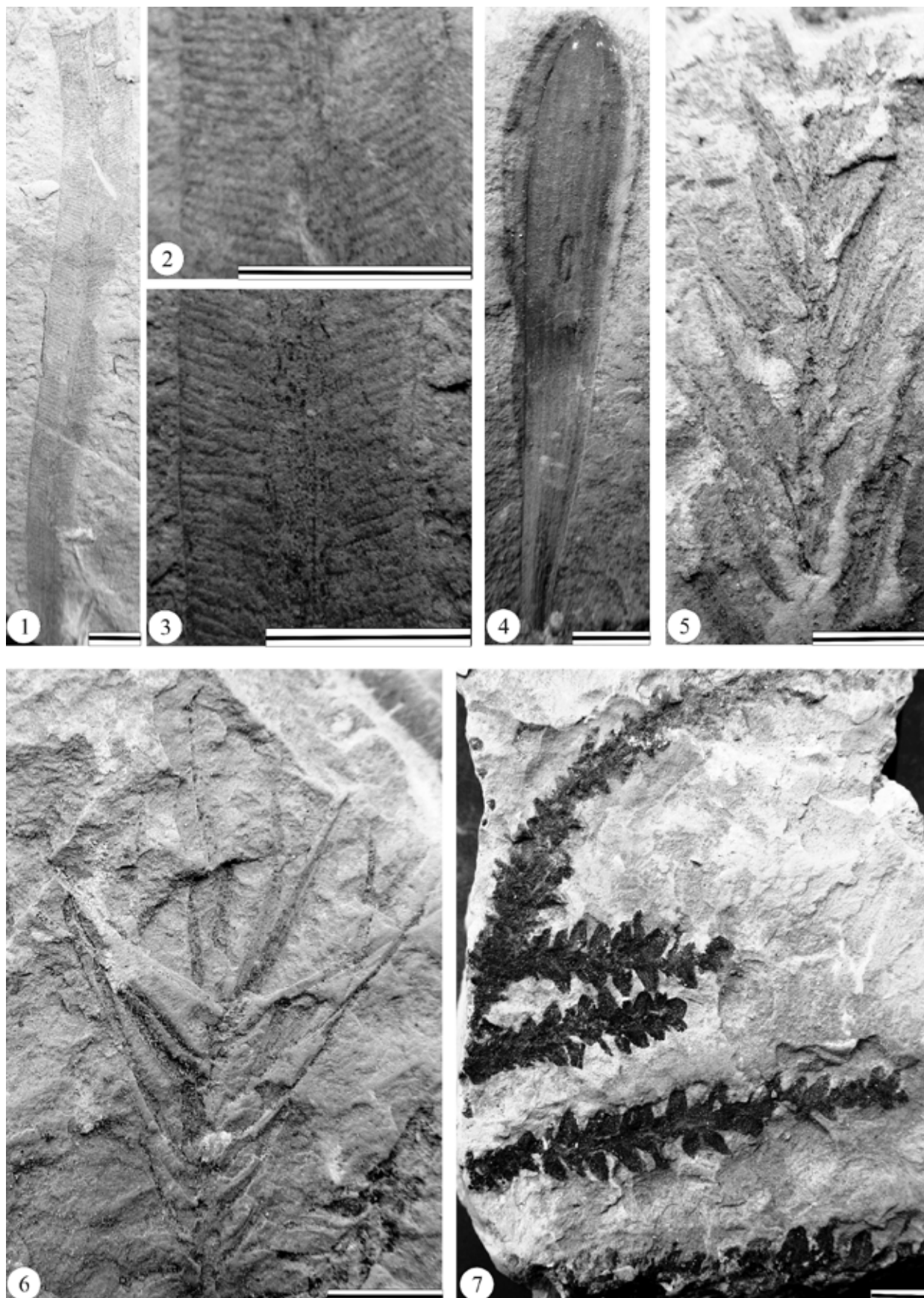
Horizon and age: Butarmal Nala bed (Gangapur Formation), Early Cretaceous.

Comments: A single specimen with well-preserved branching pattern. However, branching can be seen only on one side of the main shoot and this precludes the determination of arrangement of the branching pattern. Leaves on the main shoot are not clear, they are highly compressed; only at places they are preserved. These preserved leaves on the main shoot are similar to the leaves on the lateral shoots; both are characterized by acute apex. Individual branchlets are characterized by small scaly leaves basally that grade into large-sized spreading leaves and then back to smaller leaves. These suggest strong seasonal control on plant growth (Cantrill and Falcon-Lang, 2001).

EXPLANATION OF PLATE VI

(Scale 0.5 cm unless and otherwise mentioned)

1. *Taeniopteris* sp. 2. *Taeniopteris* sp.- Upper part of the leaf enlarged to show venation pattern. 3. *Taeniopteris* sp. - Lower part of the leaf enlarged to show venation pattern. 4. *Harrisiohyllum lanceolatus* n. sp. 5. *Taxites lanceolatus* Ganju. 6. *Torreyites sitholeyi* Ganju. 7. *Pagiophyllum* cf. *burmense* Sahni



Comparison: Present specimen mostly resembles *P. burmense* Sahni (1928) in leaf shape, arrangement and orientation of the leaf apex. However, the leaves of this specimen are sparsely located than those seen on *P. burmense*. Additionally, the leaves on the lateral shoot show size variations with respect to their position; small scaly leaves basally grade into large-sized spreading leaves and then back to smaller leaves, whereas this is not the case in the specimens originally described by Sahni (1928). Because of these differences, the present specimen has been compared with *P. burmense*. The present specimen is also comparable with *P. sherensis* Maheshwari and Kumaran (1976) and *Pagiophyllum* sp. A Bose *et al.* (1972) in leaf size; however, it differs in its leaf orientation. *P. sherensis* is also known by cuticular details.

Family **Podocarpaceae** Endlicher, 1847

Genus ***Elatocladus*** Halle, 1913

Elatocladus confertus Halle, 1913
(Pl. VII, figs. 1 & 2)

Material: Thirteen fragmentary small leaf axes.

Description: Slender terminal leafy axes, measuring about 20-80 mm long and 5-15 mm wide. Leaves numerous, linear shape and univeined. Leaves spirally inserted, although basally twisted to lie in a common plane. Leaves inserted on axes at an angle of 50°-60° at base and middle part of the axes, and about 80° at terminal parts of the axes. Leaves up to 8 mm long and 1 mm wide, swept back, margins entire and apices bluntly acute to obtuse. Leaf bases contracted but not significantly petiolate, slightly decurrent.

Specimen: BSIP Museum No. 40624-40636

Locality: RLQ 1, RLQ 2

Horizon and age: Ralpet bed (Gangapur Formation), Early Cretaceous.

Comments: The specimens belonging to *E. confertus* are most commonly encountered; however, all of them are fragmentary with small leaf axis. Among these specimens, there is a slight variation in leaf size and leaf divergence angle, but they all share important diagnostic character, i. e. swept back nature of the leaves. Among all specimens, however, one specimen with branching pattern is of special interest (BSIP 40636). This specimen consists of two types of shoots; a radial shoot with appressed leaves and dorsiventral shoots with leaves well spreading out. Halle (1913) described specimens of this type under *E. heterophylla*. Recently, Rees and Cleal (2004), however, transferred all these specimens to *E. confertus*. Heterophyllous conifer shoots are not unusual in extant conifers, two types of leaves can be found in the same species. The heterophyllous shoots recovered in the present study are showing poorly preserved radial axis.

Comparison: The specimens are best comparable with *E. confertus* known from India (e.g. Sahni, 1928; Bose *et al.*, 1982; Maheshwari and Singh, 1976; Chinnappa *et al.*, 2014) and Antarctica (Rees and Cleal, 2004; Cantrill and Hunter, 2005). The species has also been reported from the Early Cretaceous succession of Argentina; the leaf size of these specimens, however, is comparatively smaller (Arrondo and Petriella,

1980). The specimens described here are also comparable with *E. pseudotenerimus* Maheshwari and Kumaran (1976) in their foliar morphology. However, lack of cuticular details precludes further comparison.

Elatocladus spinosum Sukh-Dev & Rajanikanth, 1989
(Pl. VII, figs. 6)

Material: Single leafy axis.

Description: Slender leafy axes, measuring about 16 mm long and 10 mm wide. Leaves numerous, linear-lanceolate shape and univeined. Leaves spirally inserted, although basally twisted to lie in a common plane. Leaves inserted on axes at an angle of 80°-90°. Leaves up to 6 mm long and 1.5 mm wide, straight, margins entire, converge towards the apex and apices pointed. Leaf bases normal.

Specimen: BSIP Museum No. 40637

Locality: RLQ 1

Horizon and age: Ralpet bed (Gangapur Formation), Early Cretaceous.

Comments: Single leafy axis with leaves aligned almost at right angles to the axis. The species was instituted by Sukh-Dev and Rajanikanth (1989a) from the same lithounit, i.e. Gangapur, India. The species can easily be recognized from other species of *Elatocladus* based on its characteristic leaf shape. The leaf in this species is broad at the base and gradually narrowing towards the apex to give spine-like appearance.

Comparison: *E. plana* (Feistmantel) Sahni (1928) shows similar leaf alignment and morphology; at right angles to the axis and gradual narrowing from base to apex. The leaves of *E. plana*, however, are linear and leaf base is strongly decurrent, which are spine like and base is normal or poorly decurrent in *E. spinosum*. Similar leafy axis can also be found in *Pagiophyllum feistmantelii* Halle (Rees and Cleal, 2004). However, the leaves of *P. feistmantelii* significantly differ in their arrangement and keeled leaf base.

Elatocladus jabalpurensis (Feistmantel)
Seward & Sahni, 1920
(Pl. VII, figs. 3)

Material: Three well preserved incomplete leafy axes.

Description: Slender leafy axes, measuring about 35 mm long and 10-16 mm wide. Leaves numerous, linear-lanceolate shape, univeined and spread sideways. Leaves spirally inserted although basally twisted to lie in a common plane. Leaves inserted on axes at an angle of 60°-70°. Leaves 5-9 mm long and 1 mm wide, straight, margins entire and apices acute. Leaf bases contracted but not significantly petiolate, slightly decurrent.

Specimen: BSIP Museum No. 40638-40640

Locality: RLQ 1

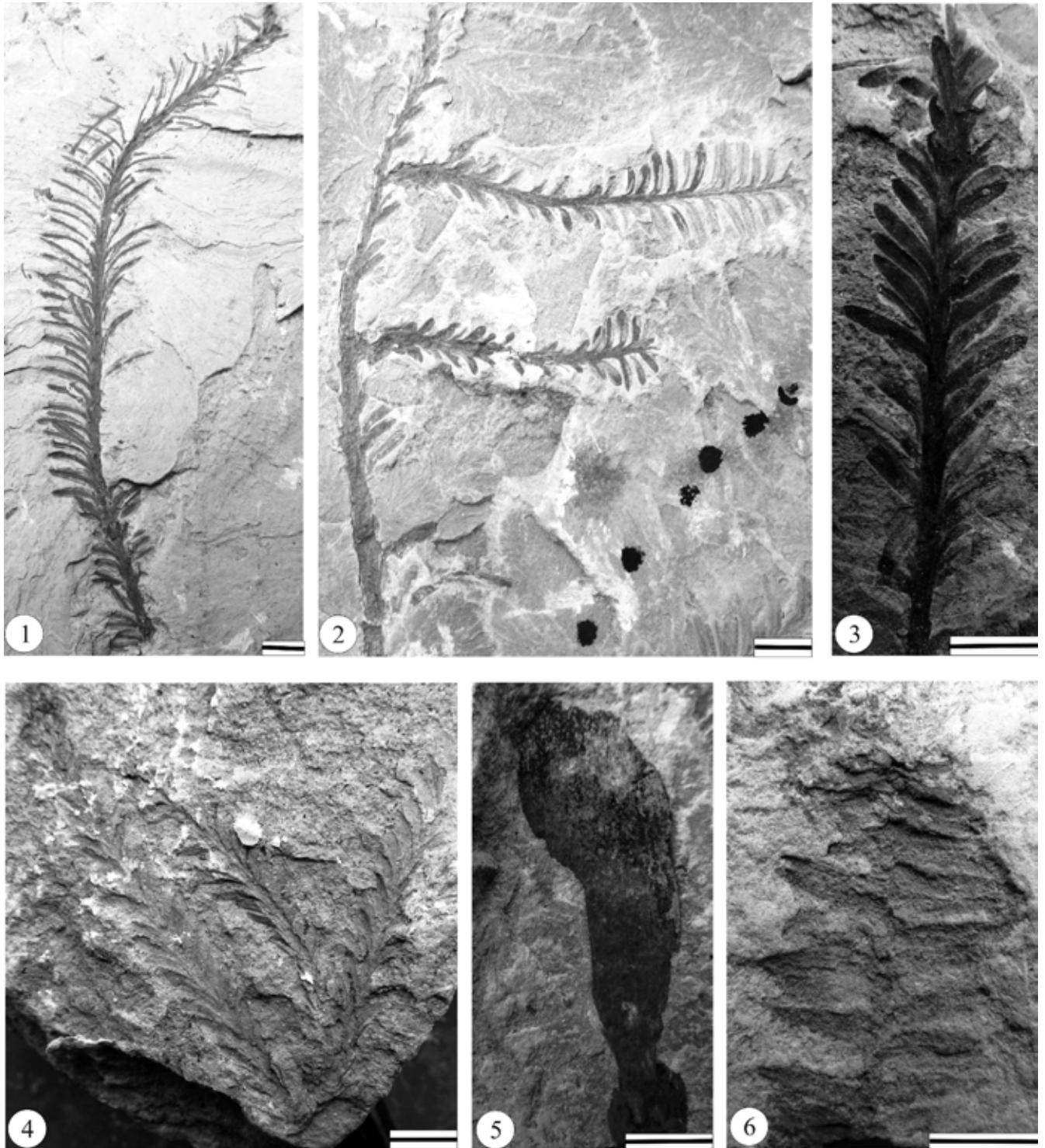
Horizon and age: Ralpet bed (Gangapur Formation), Early Cretaceous.

Comments and Comparison: *E. jabalpurensis* known from Antarctica (Halle, 1913; Gee 1989) was recently transferred to *E. confertus* by Rees and Cleal (2004). However, the leaf morphology of the former is very distinct and largely differs from the latter. The leaves in *E. jabalpurensis* are straight and

EXPLANATION OF PLATE VII

(Scale 0.5 cm unless and otherwise mentioned)

1. *Elatocladus confertus* Halle. 2. *E. confertus* Halle- Showing dorsiventral and radial shoots. 3. *E. jabalpurensis* (Feistmantel) Halle., Seward & Sahni.
4. *E. sehoraensis* Maheshwari & Kumaran. 5. *Pityospermum* sp. 6. *E. spinosum* Sukh-Dev & Rajanikanth



stiff, never swept back and they almost align parallel to the axis, whereas the leaves in *E. confertus* are swept back. The leafy axis described here shows gross morphological similarity with the specimens described under *E. jabalpurensis* from Antarctica (Halle, 1913; Gee, 1989) and India (Sahni, 1928; Bose and Banerji, 1984). The specimens are also comparable with *E. kingianus* Bose *et al.* (1982) from the Early Cretaceous sediments of the Gangapur Formation, India in their foliar morphology. However, *E. kingianus* is known by its cuticular details.

Elatocladus sehoraensis Maheshwari & Kumaran, 1976
(Pl. VII, fig. 4)

Material: Six well preserved incomplete leafy axis.

Description: Branched slender leafy axes, measuring about 40 mm long. Leaves numerous, linear-lanceolate shape, univeined and spread forward. Leaves spirally inserted although basally twisted to lie in a common plane. Leaves inserted on axes at an angle of 40°-50°. Leaves up to 5 mm long and 1 mm wide, straight, margins entire and apices bluntly acute. Leaf bases slightly contracted but not significantly petiolate, decurrent.

Specimen: BSIP Museum No. 40641-40646

Locality: RLQ 1, RLQ 2

Horizon and age: Ralpet bed (Gangapur Formation), Early Cretaceous.

Comments: The specimens are preserved as impressions on fine-grained, cream-whitish mudstone/shale. *E. sehoraensis* was originally erected on the basis of the cuticular details (Maheshwari and Kumaran, 1976), but in the present specimens the cuticle is not known. The specimens are here assigned to the species solely based on their gross morphological similarities.

Comparison: The specimens show apparent similarities with the leafy twigs of *E. sehoraensis* described from the Gangapur Formation, east coast, India (Chinnappa *et al.*, 2014). The specimens differ from *E. confertus* in the absence of swept back nature of leaves and from *E. jabalpurensis* by leaf divergence angle from the axis. *E. kingianus* Bose *et al.* (1982), although comparable in leaf divergence angle, has longer leaves - 8 to 12 mm.

Family Taxaceae Gray, 1821

Genus Torreyites Seward, 1919

Torreyites sitholeyi Ganju, 1947
(Pl. VI, figs. 6)

Material: Two fairly preserved specimens, represents terminal most part of leafy axis.

Description: Slender terminal leafy axes, measuring 25-30 mm long and 15-20 mm wide at terminal part. Leaves numerous, linear-lanceolate shape and spread forward. Leaves spirally inserted on axes at an angle of 20°-30°. Leaves up to 20 mm long and less than 1 mm wide, straight or arched at base, margin entire, apices acute. Leaf bases normal and decurrent. Midrib indistinct.

Specimen: BSIP Museum No. 40647, 40648

Locality: RLQ 1

Horizon and age: Ralpet bed (Gangapur Formation), Early Cretaceous.

Comments: The genus *Torreyites* was instituted by Seward (1919) for the coniferous leaves. It resembles the modern *Torreya* Arnott (1838), but cannot safely be placed in the modern taxon. The modern leaves of *Torreya* are characterized by two

well-marked stomatal grooves on the lower surface and absence of distinct midrib. Although Seward (1919) considered the same characters to distinguish the fossil forms under the newly erected genus *Torreyites*, he did not ascertain any relation with the modern forms due to the lack of additional information. The presence of two well-marked stomatal grooves in fossil leaves is mostly influenced by the state of preservation, hence this feature cannot be expected in many cases and this is true for the present specimens and previously known specimens of *T. sitholeyi* (Muralidhara Rao and Ramakrishna, 1988). The only reliable character is the absence of distinct midrib and characteristic leaf shape.

Comparison: To date, *Torreyites* in India is known by two taxa namely, *T. sitholeyi* Ganju (1947) and *T. constricta* Seward and Sahni (1920). The latter largely differs from the present leafy twig in their leaf morphology. *T. sitholeyi* has been reported from the Rajmahal (Ganju, 1947) and Gangapur formations (Muralidhara Rao and Ramakrishna 1988). The specimens from the Rajmahal Formation are clearly marked by the presence of two well-marked stomatal grooves in leaf, but this character is not clear in the specimens from Gangapur. However, the leaves in the figured specimens from the Gangapur Formation (Muralidhara Rao and Ramakrishna, 1988; page 203, figs. 1, 2) show morphological resemblance with that of the holotype. The two leafy twigs described here are closely comparable with the specimens of Muralidhara Rao and Ramakrishna (1988) in their leaf morphology. Their figured specimens indicate that the leaf twig represents the middle parts of the twig and hence shows little variations in divergence angle and shape of the leaves when compared to the present ones.

Genus Taxites Brongniart, 1828

Taxites lanceolata Ganju, 1947
(Pl. VI, figs. 5)

Material: Single leafy twig.

Description: Slender terminal leafy axes, measuring 25 mm long and 10 mm wide. Leaves numerous, linear-lanceolate shape and spread forward. Leaves spirally inserted on axes at an angle of 20°-30°. Leaves up to 8 mm long and 1 mm wide, straight, margins entire and apices acute. Leaf bases contracted and decurrent. Midrib distinct.

Specimen: BSIP Museum No. 40649

Locality: RLQ 1

Horizon and age: Ralpet bed (Gangapur Formation), Early Cretaceous.

Comments and Comparison: The specimens previously described under the genus *Taxites* Brongniart by Feistmantel (1879, 1882) were later transferred to *Elatocladus* Halle on the ground that the lamina is not contracted at the base (Seward and Sahni, 1920). However, Ganju (1947) described some specimens from Rajmahal in which the lamina base is contracted and gives small petiole. Based on the presence of contracted base with small petiole, he distinguished them from the *Elatocladus* and placed them in *Taxites* and erected a new species namely *T. lanceolatus*, after the characteristic shape of the leaves. He also compared the specimens, with *Taxites* sp. Seward (1911). The present specimen is also characterized by contracted lamina base with a small petiole and leaves are lanceolate in shape. The features suggest its relation with *T. lanceolatus* rather than the any known taxon of *Elatocladus*.

Genus *Harrisiophyllum* Pant *et al.*, 1983

Harrisiophyllum lanceolatus n. sp.
(Pl. VI, fig. 4)

Material: Single well preserved leaf.

Derivation of name: after characteristic leaf shape.

Holotype: BSIP Museum No. 40650.

Diagnosis: Frond 40 mm long and up to 7 mm wide at sub-apical region, gradually narrowing towards the base, 1.5 mm at basal region, spatulate shape, margin entire and revolt, apex bluntly acute, six veins runs parallally towards the distal margin, no bifurcation and anastomoses, veins thick, central two veins placed very close.

Description: Single available spatulate frond 40 mm long and up to 7 mm wide at sub-apical region, gradually narrowing towards the base, 1.5 mm at basal region. Frond margin entire and revolt, apex bluntly acute. Six veins emerge from base, runs parallel towards the distal margin, no bifurcation and anastomoses. Veins thick, central two veins placed very closely and there by appearing as a single vein, rest of the veins placed sparsely.

Specimen: BSIP Museum No. 40650.

Locality: RLQ 1.

Horizon and age: Ralpet bed (Gangapur Formation), Early Cretaceous.

Comments: Single strap shaped leaf with parallel venation has preserved most of its details. Although at basal region only single leaf impression can be seen, away from the leaf base it indicates presence of two leaves almost overlapping each other. It also indicates that both the leaves probably share common point of attachment at leaf base and are shed simultaneously from the parent plant. The veins are running from the base to apex, which are very thin at the base and more in number, but after crossing the basal region they became strong and reduced in number. The reduction in number and more thickness of the veins indicate that two-three veins unite to form a single prominent vein. The swollen part of the leaf margins is indicative of leaf margin revolt to abaxial side of the leaf. The central region of the leaf towards the apex is characterized by presence of capsule-like notch. The nature of this notch is indeterminable as the specimen is an impression.

Comparison: The genus *Harrisiophyllum* was instituted by Pant *et al.* (1983) to accommodate "gymnosperm leaves with strap shape, variable in form but lamina gradually narrowing towards base, leaf base truncate, apex round to acute, margin entire and veins more or less parallel..." (Pant *et al.*, 1983; page no: 40). The generic diagnosis of *Harrisiophyllum* mainly included the cuticular information. However, in the same paper (page 42) the authors provided the provision to place the specimens of similar type preserved as impressions in the genus by using the specific epithet *lanceolatus*. Among the known species of *Harrisiophyllum*, *H. lanceolatus* described here is more closely comparable with *H. spatulatus* Pant *et al.* (1983) in gross morphology. However, the latter is based on the cuticular details, but cuticle is not known in the former. *H. lanceolatus* also resembles *Roebuckia spatulata* McLoughlin (1996) from Western Australia in its external appearance. However, the latter can be distinguished based on its single robust vein in leaf base/petiole, repeatedly dichotomizing and gently diverging across the lamina. Further, all the veins in *R. spatulata* end with bifurcation or dichotomy, but in *H. lanceolatus* veins always end simply.

Genus *Pityospermum* Nathorst, 1897

Pityospermum sp.
(Pl. VII, fig. 5)

Material: Single well preserved winged seed impression.

Description: Isolated winged seed, up to 26 mm in length. Seed more or less globular in shape, 5 mm in diameter. Wing 21 mm long, narrow at base, 2.5 mm wide, expanding towards the apex, about 8 mm wide. Margins entire, wing margins at one side convex and at on opposite side concave, there by the wing gives falcate appearance. Surface of the wing and seed marked by longitudinal striations.

Specimen: BSIP Museum No. 40651.

Locality: RLQ 1.

Horizon and age: Gangapur Formation, Early Cretaceous.

Remarks: The specimens recovered in the present study are preserved as impressions on buff coloured mudstone, with clear distinction between the basal globular seed-like structure and the upper club-shaped and falcate wing. The basalmost part of the seed is not preserved, however, the available evidences indicate that the seed is circular to globular in shape.

Comparison: Recovery of winged seeds from the Early Cretaceous sediments of India is not common. *Pityospermum* sp. Jeyasingh and Kumarasamy (1994) from Sriperumbudur Formation and *P. godavarianum* Chinnappa *et al.* (2015) from the Raghavapuram Formation are the only reports known to date. The present specimen is comparable with above two species in size of the wing and seed, but differs in having club-shaped, falcate wing and circular to globular seed. Nathorst (1878) described several winged seeds from the Rhaetic beds of Scania under the genus *Pinus*. Later, he transferred them to a new form genus *Pityospermum*, along with some new forms (Seward, 1919, p. 396-398). Seward (1919) has provided the detailed account of Nathorst's species namely, *P. lundgreni*, *P. nilssoni* and *P. nanseni*. The new species, here described, differs from the above species in length and shape of the wing. The length of the wing in *Pityospermum* sp. is 2.1 mm and is club shaped but, it is 9-11 mm and spatulate-elliptical in *P. lundgreni*, *P. nilssoni* and *P. nanseni*. Additionally, the seed in the *Pityospermum* sp. is more or less circular to globular in shape but it is elliptical to ovule shape in *P. lundgreni*, *P. nilssoni* and *P. nanseni*. *P. amplexum* Krassilov (1982) from Mongolia is close to *Pityospermum* sp. in the wing shape and size, but differs in seed shape, size and its arrangement within the wing.

Although it is difficult to determine the precise generic affinity of seeds of this type, the important striking resemblance between such seeds and seeds of recent *Pinus* and other Abietineaceae is noteworthy (Seward, 1919).

DISCUSSION

Taphonomy and palaeoecology

The present study identified a great number of fern and gymnosperm taxa, many of them have not yet been described from the target basin. The taxa identified in the study include members of Osmundaceae, Gleicheniaceae, Dicksoniaceae, Corystospermales, Pentoxylales, Taxaceae and Williamsoniaceae. The total flora can be categorised into three assemblages based on their relative association of various taxa. The first assemblage is mostly dominated by *Elatocladus*, which represents more than 90% of abundance, followed by *Torreites*

and *Taxites*. Ferns and other groups such as *Corystospermales*, *Pentoxylales* and *Williamsoniaceae* are scarce and taxa belonging to *Araucariaceae* are altogether absent. In the second assemblage, ferns *Gleichenia*, *Coniopteris*, *Cladophlebis* were found along with *Corystospermales* and *Pentoxylales*. This association also contains few representatives of *Ptilophyllum*, *Elatocladus* and a winged seed. These remains are irregularly fragmented, poorly sorted and suggest that they were possibly transported from other subenvironments and mixed up with this assemblage. The third fossil assemblage constitutes *Ptilophyllum* and *Pagiophyllum* with few fern representatives; here, the foliage of *Ptilophyllum* is dominant. Interestingly, all three assemblages occur in similar lithofacies, i.e. mudstone indicates an operation of similar depositional settings on the flora.

The fossil plants recovered are mostly fragmentary; the maximum available specimen length is not more than the 10 cm, none are complete. The fern foliages are mostly represented by isolated small pinnae. The fragmentary nature of the material suggests it was subjected to the transportation from source area to the depositional site, before the burial (Spicer 1991). Experimental observations of Ferguson (1985), Spicer and Wolf (1987), Gastaldo *et al.* (1985) indicated that the maximum distance travelled by any given leaf material is less than 1.5 km. Fragmentation of leaves depends not only on the transportation, but also on the other factors such as water quality, nature and rate of sedimentation, the presence and number of biological agents as well as certain characteristics of the leaves themselves (Ferguson, 1985). Ferns, especially, those having herbaceous nature with thin, filmy leaves are not easily preserved and tend to be reduced to fragments within a short distance (Hartman *et al.*, 2002); the same must have been the case for the non-coniferous taxa, as they also produce frail leaves. Therefore, the preserved leaves of the ferns and non-coniferous taxa were possibly subjected to the minimal transport and represent local components in the vegetation. In contrast, coniferous taxa mostly produce robust leaves and comparatively they can be transported to much longer distance with minimal damage before their fossilization (Spicer, 1991); hence they represent the regional elements in the vegetation. Although taphonomic processes incorporate large biases into the fossil record through differential preservation, the plant fossils from Lower Cretaceous strata of the PG Basin indicate presence of both regional and local components of the vegetation. The fossil material preserved parallel to the bedding plane and irregularly oriented did not well accumulate; this indicates that the deposition was rapid and did not allow the plant material to settle distantly. This may indicate a flood plain deposition.

Floral Diversity, Dominance and Comparison

The Early Cretaceous PG flora has been known from the last three decades (Chinnappa *et al.*, 2014 and references therein). All of the previous studies identified the dominance of conifers in the flora. The present study also recognised similar floristic compositions, i.e. conifer dominance. Plant taxa identified in the study includes pteridophytes (8 species), and Gymnosperms (19 species). The total flora comprises 30 genera containing approximately 70 species (Table 2). In general, conifers are the most abundant plant fossils, mostly represented by foliage remains and, less commonly, axes. Among the conifers, *Elatocladus* foliage is numerically dominant. *Elatocladus* is the one major component of Early Cretaceous macrofloras across Gondwana (Douglas, 1969, Drinnan and Chambers, 1986; Cantrill, 2000; Chinnappa *et al.*, 2015).

The flora also includes a high diversity of ferns contributing about 22% of the species diversity. Taxa preserved have been allied to extant families including *Equisetaceae*, *Osmundaceae*, *Gleicheniaceae*, *Dipteridaceae*, and *Dicksoniaceae*. Pteridosperms are less represented in the flora and constituted only 5% of total flora. Gymnosperms are the dominant component and make up to 73% of the flora. Within the gymnosperms, conifers contribute major share of 41%. Taxa preserved have been allied to *Pentoxylales*, *Cycadaceae**, *Williamsoniaceae*, *Podocarpaceae*, *Araucariaceae* and *Taxaceae*. The genus *Harrisiophyllum* cannot be attributed to any family.

When compared to other flora of East India, the Early Cretaceous PG flora is quite distinct from coeval floras such as the Krishna-Godavari, Cauvery, Palar and Mahanadi (KG, CV, PL and MH) assemblages in the east coast of India. The unique nature of the Early Cretaceous PG flora is the high diversity and abundance of ferns, which is much higher than any other Early Cretaceous floras from the east coast, India, but similar to other intra-cratonic early Cretaceous floras of India (Prakash, 2008). The Early Cretaceous PG flora is predominant by the conifers in regard to the abundance and diversity. The other Early Cretaceous floras such as KG, CV, PL and MH from east coast are predominated by bennettitaleans (Fig. 5). The Early Cretaceous MH flora shows similar floristic pattern in regard to the diversity of ferns as seen in the PG flora; however, families such as *Dipteridaceae* and *Matoniaceae* are well represented in the former and are unknown in the latter.

Other important Indian Early Cretaceous floras of India include the Kutch, Rajasthan (western India), Rajmahal, Satpura, South Rewa (central India) floras. The coeval flora from western India is also predominated by bennettitaleans (Bose and Banerji, 1984). Further, *Caytoniaceae*, a pteridosperm family, is well known in the western Indian flora through leaves and reproductive parts, but the family is totally absent from the east coast. While *Weichselia*, *Kachchhia*, *Trambaua* and *Lorumformophyllum* are common in the western Indian flora, there are no reports of these taxa from PG and other east coast Early Cretaceous floras to date. The variation in the taxonomic composition of western and eastern floras signifies the prevalence of distinct floras and environments at two oppositely faced coastal margins of India.

Among the Early Cretaceous floras of India, the Rajmahal flora has received great attention (e.g. Sahni, 1928, 1948; Vishnu-Mittre 1957, 1958, 1959a, b; Sharma *et al.*, 1971; Sen Gupta, 1988; Banerji, 2000). The flora has a high diversity and ferns are the major components with regard to the both dominance and diversity. Many fern families such as *Dennstaedtiaceae*, *Aspleniaceae* and *Dryopteridaceae* are common in the Rajmahal flora, the groups which are unknown from eastern, western and central Indian floras. Bennettitaleans occupy second position in the flora, and the foliar size of this group is comparatively larger than the east coast foliages. Conifers are less represented relative to ferns and bennettitaleans. South Rewa flora is mainly composed of araucarian and podocarpacean elements. *Elatocladus* is less common, which is a dominant element of the PG flora. The Rajasthan flora is less known and hence better comparison is not plausible. The Satpura flora shows close similarity with Gangapur flora among the all Indian Early Cretaceous floras. Both these floras are characterised by dominance of conifers over the bennettitaleans and 22% ferns in total flora (Prakash, 2008).

Early Cretaceous floras are widespread in other areas of Gondwana, being known from, South America (e.g.

Table 2: Taxonomic composition of Early Cretaceous macroflora, PG Basin

Pteridophytes	Gymnosperms	
Equisetaceae	Corystospermales	Podocarpaceae
<i>Equisetites</i> sp.	<i>Pachypteris gangapurensis</i>	<i>Elatocladus andhrii</i>
Osmundaceae	<i>Pachypteris indica</i>	<i>E. bosei</i>
<i>Cladophlebis denticulata</i>	<i>P. specifica</i>	<i>E. confertus</i>
<i>C. indica</i>	* <i>Pachypteris</i> cf. <i>specifica</i>	<i>E. heterophylla</i>
* <i>C. kathiawarensis</i>	<i>Pachypteris</i> sp.	<i>E. jabalpurensis</i>
<i>Cladophlebis</i> sp.	<i>Thinnfeldia</i> sp.	<i>E. kingianus</i>
* <i>Cladophlebis</i> sp. A	Cycadaceae*	<i>E. plana</i>
* <i>Cladophlebis</i> sp. B	<i>Cycadites</i> sp.	<i>E. sehoraensis</i>
Gleicheniaceae	Pentoxyleales	<i>Elatocladus</i> sp.
<i>Gleichenia bosahii</i>	<i>Taeniopteris kutchense</i>	Araucariaceae
* <i>G. gelichenoides</i>	<i>T. spatulata</i>	* <i>Pagiophyllum burmense</i>
<i>G. nordenskioldii</i>	<i>Taeniopteris</i> sp.	<i>P. marwarensis</i>
<i>G. rewahensis</i>	Williamsoniaceae	<i>P. peregrinum</i>
<i>Gleichenia</i> sp.	<i>Dictyozamites gondwanensis</i>	<i>P. rewahensis</i>
* <i>Gleichenia</i> sp. A	<i>Otozamites</i> sp.	<i>P. spinosum</i>
Dipteridaceae	<i>Pterophyllum medlicottianum</i>	<i>Pagiophyllum</i> sp.
<i>Hausmannia buchii</i>	<i>Ptilophyllum acutifolium</i>	<i>Allocladus bansaensis</i>
<i>Hausmannia</i> sp.	<i>P. kutchense</i>	<i>Araucarites kutchensis</i>
Dicksoniaceae	<i>P. distans</i>	<i>A. minutus</i>
<i>Coniopteris</i> sp.	<i>P. horridum</i> Roy	<i>Araucarites</i> sp.
* <i>Coniopteris</i> sp. A	<i>P. rarineris</i>	<i>Brachyphyllum sehoraensis</i>
<i>Onychiopsis psilotoides</i>	<i>Ptilophyllum</i> sp.	<i>Brachyphyllum</i> sp.
Incertae Sedis	* <i>Ptilophyllum</i> sp. A	Taxaceae
<i>Actinopteris</i> sp.	<i>Nilssonia</i> sp.	<i>Arthrotaxites feistmantelii</i>
<i>Sphenopteris</i> sp.	? <i>Anomozamites</i> sp.	<i>Taxites lanceolata</i>
		<i>Torreites sitholeyi</i>
		Incertae Sedis
		<i>Coniferocaulon rajmahalense</i>
		<i>Conites sripermaturensis</i>
		* <i>Harrisiohyllum lanceolatus</i> n. sp.
		* <i>Pityospermum</i> sp.

(Sources: Bose *et al.*, 1982; Ramakrishna and Muralidhar Rao, 1986, 1991; Muralidhar Rao and Ramakrishna, 1986; Sukh-Dev and Rajanikanth, 1989; Chinnappa *et al.*, 2014 and includes the present study*).

Archengelsky, 1963, 2001), South Africa (e.g. Anderson and Anderson, 1985), Australia (e.g. Douglas, 1969; Drinnan and Chambers, 1986; McLoughlin, 1996; McLoughlin *et al.*, 2000, 2002), New Zealand (Parrish *et al.*, 1998) and Antarctica (e.g. Jefferson, 1981; Hernández and Azcárate 1971; Cantrill, 1995, 1996, 1997a, b, 2000; Nagalingum and Cantrill, 2015). The detailed comparisons, however, are made only with Antarctic Early Cretaceous flora due to its geographical vicinity.

The Early Cretaceous floras from Antarctica are known from Alexander Island (Jefferson, 1981; Cantrill, 1995, 1996, 1997, 2000; Cantrill and Nichols, 1996; Cantrill and Nagalingum,

2005, 2006; Cantrill and Falcon-Lang, 2001; Nagalingum and Cantrill, 2015), Livingstone Island (Byers Peninsula) (Hernández and Azcárate, 1971; Vera, 2013) and Snow Island (President Head) (Cantrill, 1998, 2000). Among these floras, the flora from President Head is best comparable as the flora is

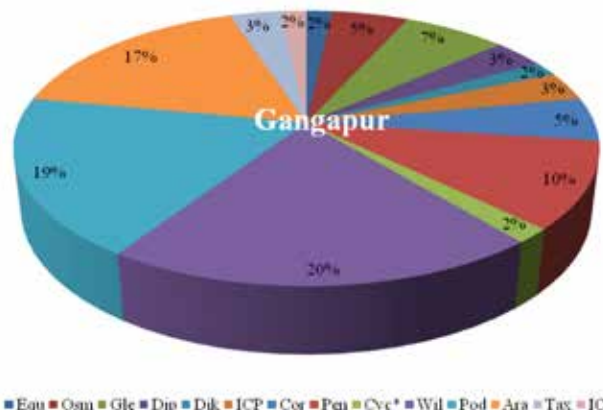


Fig. 4. Showing the taxonomic diversity of various pteridophytic and gymnospermous families. **Legend:** Equ- Equisetaceae; Mar- Marratiaceae; Osm- Osmundaceae; Gle- Gleicheniaceae; Dip- Dipteridaceae; Mat- Matoniaceae, Cya- Cyatheaceae; Dik- Dicksoniaceae; ICP- pteridophyte incertae sedis; Cor- Corystospermales; Pen- Pentoxyleales; Cyc*- ?Cycadaceae; Wil- Williamsoniaceae; Gin- Ginkgoaceae; Pod- Podocarpaceae; Ara- Araucariaceae; Tax- Taxaceae; ICC- conifer incertae sedis. * uncertain affinity.

dominated by *Elatocladus* and absence of ginkgos as in the PG flora (Cantrill, 1998, 2000). The floral elements common between these two floras are *Gleichenia* (=Lophosoria), *Sphenopteris*, *Ptilophyllum* and *Araucarites*. Although macrofossil elements belonging to bryophytes are unknown in the PG flora, their existence is well established through the microfloral studies (e.g. Prabhakar, 1987; Ramakrishna and Ramanujam, 1987). The late Albian Alexander Island flora is well diversified with liverworts, ferns, conifers and angiosperms (Jefferson, 1981; Cantrill, 1995, 1996, 1997, 2000; Cantrill and Nichols, 1996; Cantrill and Nagalingum, 2005, 2006; Nagalingum and Cantrill, 2015). Although the conifers are abundant in the Alexander flora, they make up a small percentage of floral species diversity (~25%), ferns are the most diverse components, contributing more than 40% species diversity (Cantrill and Poole 2012). On the contrary, PG flora exhibits dominance of conifers (more than 40%), and ferns share only 22% (fig. 4). Further, the Alexander flora is characterised by the presence of ginkgos and angiosperms (Cantrill and Nichols, 1996), which have not been reported from the PG flora.

The Early Cretaceous PG flora greatly differs from approximately coeval South African floras. The South African Early Cretaceous floras are totally free from *Elatocladus* and *Ptilophyllum* (Anderson and Anderson, 1985), but they are common and important taxa in PG flora. Although the Early Cretaceous South American flora shows little generic similarity, it largely differs in species composition (Archengelsky, 2001).

Regionalism in Gondwana floras is well known in micro- and macro-floras (Dettmann and Thomson, 1987; Venkatachala, 1990; Dettmann, 1992; Rajanikanth, 1996; Cantrill, 1997b; Cantrill and Poole, 2002). This can also be observed in

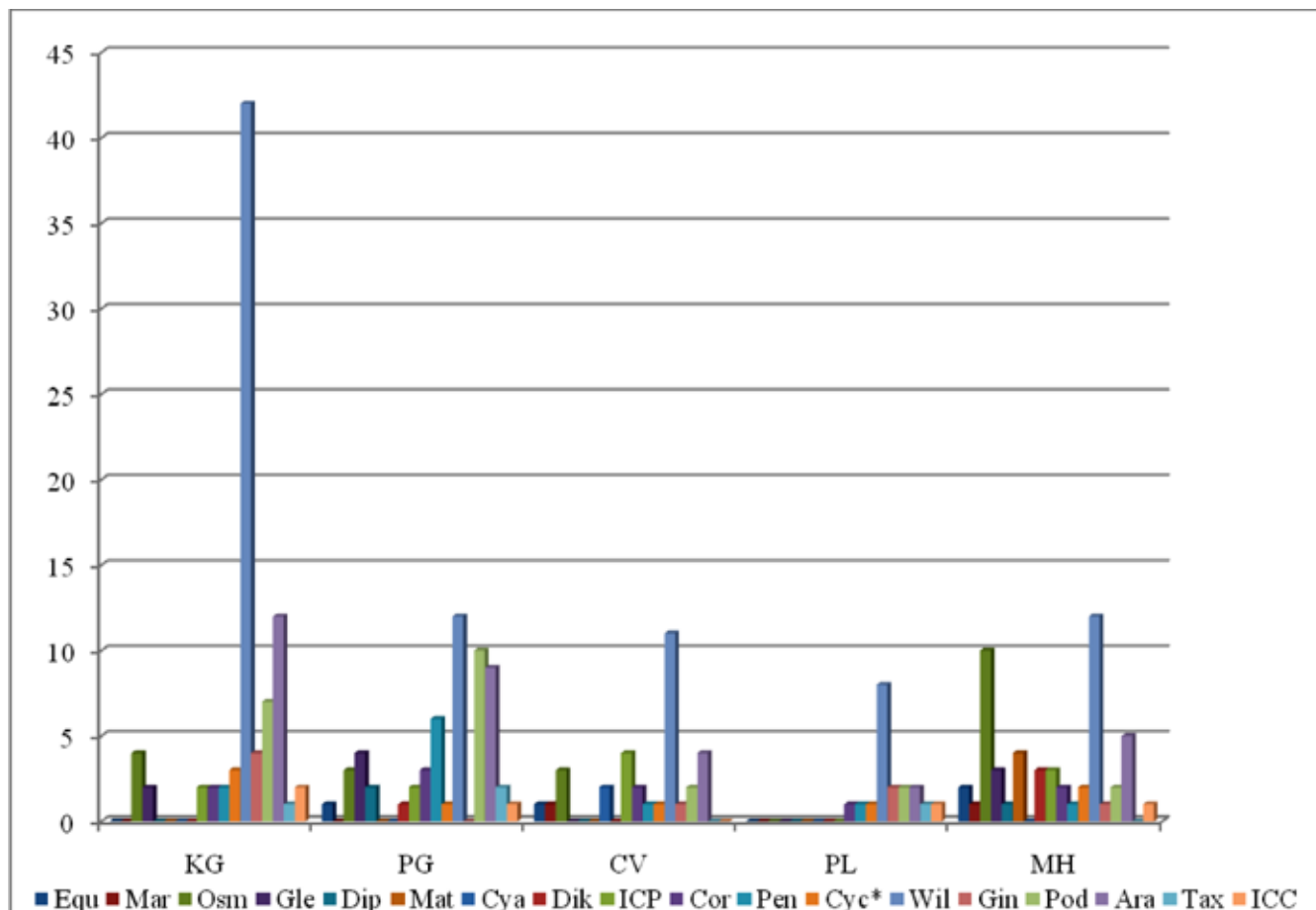


Fig. 5. Bar graph showing the comparative distributions of various floral components in Early Cretaceous sediments of east coast, India. (X axis: families represented in various basins; Y axis: number of species) **Legend:** KG- Krishna-Godavari; PG- Pranhita-Godavari, CV- Cauvery; PL- Palar; MH- Mahanadi, Equ- Equisetaceae; Mar- Marratiaceae; Osm- Osmundaceae; Gle- Gleicheniaceae; Dip- Dipteridaceae; Mat- Matoniaceae; Cya- Cyatheaceae; Dik- Dicksoniaceae; ICP-pteridophyte *incertae sedis*; Cor- Corystospermaceae; Pen- Pentoxyleae; Cyc*- ?Cycadaceae; Wil- Williamsoniaceae; Gin- Ginkgoaceae; Pod- Podocarpaceae; Ara- Araucariaceae; Tax- Taxaceae; ICC- conifer *incertae sedis*. * uncertain affinity.

Early Cretaceous macroflora of the PG Basin and other early Cretaceous floral assemblages. The similarity of PG flora with Australian and Antarctic Flora is an obvious outcome of geographical intimacy and wide distribution of some taxa across the supercontinent, during the Early Cretaceous (McLoughlin, 2001).

Palaeovegetation and Environments

The intracratonic macrofloral studies of the PG Basin indicate the existence of luxuriant vegetation during the Early Cretaceous. Microfloral studies have revealed the presence of a Berriasian-Aptian palynoflora comprising bryophytes, lycophytes, and several fern families along with other seed plants belonging to cycadophytes, pentoxylales and coniferales (Rajeshwar Rao and Ramanujam, 1979; Ramanujam and Rajeshwar Rao, 1979, 1980; Bose *et al.*, 1982; Rajeshwar Rao *et al.*, 1983; Ramakrishna *et al.*, 1985; Prabhakar, 1987; Ramakrishna and Ramanujam, 1987). Similar floral composition can also be observed from the macrofloras, although bryophytes and lycophytes have not been recovered.

The qualitative distribution of various plant remains from the Early Cretaceous PG Basin indicates that the vegetation was not uniform in space. Distinct plant assemblages suggest the existence of spatially-complex plant communities. The

vegetation preserved within the Lower Cretaceous succession of the PG Basin represents diverse communities that grew across the flood plain area that can be divided into well-structured communities that occupied different subenvironments. Members of the araucarians and bennettitaleans were generally considered to grow in lowlands (Venkatachala, 1966; Krassilov, 1978; Vakhrameev, 1991). A few ferns, especially gleicheniacean taxa, which can withstand intensive sunlight (Konijnenburg-van Cittert, 2002) must have been dwelling as a ground cover under araucarians and bennettitaleans. The riverbanks support the vegetation comprising *Taeniopteris* (Howe and Cantrill 2001) and *Pachypteris* along with large group of ferns (Konijnenburg-van Cittert, 2002). Away from the river channel/uplands, the vegetation is composed of podocarpacean trees and taxaleans along with few understory ferns. Taxaleans, in the PG flora, are found to be associated with podocarpaceans, thus considered under the similar subenvironment. The tree habit for the podocarpaceans (*Elatocladus*) can be inferred based on their plagiotropic shoot system (Cantrill and Falcon-Lang, 2001) and large trunk impressions frequently associated with leafy axes of these fossil groups. This interpretation is also supported by the presence of fossil wood of podocarpaceans (Manik and Srivastava, 1991). Similar vegetational dynamics can also be

observed in flood-plain deposits of Early Cretaceous Alexander Island, Antarctica (Falcon-Lang *et al.*, 2001; Cantrill and Poole, 2012).

The presence of *Pagiophyllum* and *Elatocladus* foliages often as individual shoot units with basal scale leaves indicates a deciduous nature. Individual branchlets are characterised by scaly leaves basally that grade into larger and more spreading bifacial flattened foliage and then back to smaller leaves apically (Pl. IV, fig. 7; Pl. V, figs. 1, 2 & 3). This all suggests a strong seasonal control on growing conditions and is consistent with evidences from the Antarctica and Australian early Cretaceous foliages (Douglas, 1969; Cantrill, 2000; Cantrill and Falcon-Lang, 2001). The presence of matted *Taeniopteris* leaves suggests deciduous or semi-deciduous habit for these pentoxylaleans and these plants were adapted to a seasonal climatic regime (McLoughlin, 1996). The deciduous or semi-deciduous habit for *T. daintreei* is well established (Douglas and Williams, 1982; Drinnan and Chambers, 1986). The presence of *Taeniopteris* leaves comparable to *T. daintreei* with long petioles further supports this idea. A deciduous habit for other members cannot be determined with confidence, although there is equally a strong possibility for deciduous to semi-deciduous habit for the other members especially for bennettitalean (e.g. *Ptilophyllum*) foliages (Delevoryas, 1968; Krassilov, 1975; Wills and McElwain, 2013).

Ferns mostly grow near water bodies and shady places, prefer warm and humid climatic conditions (Konijnenburg-van Cittert, 2002). Similarly, modern cycadophytes typically grow in mesothermal to megathermal conditions, and most forms probably occupied similar climates in the past (Douglas and Williams, 1982; McLoughlin, 1996). The presence of bennettitalean foliage in the Early Cretaceous PG flora probably favoured warm (though seasonal) climate. This was also true for Australian Early Cretaceous flora (McLoughlin, 1996). The total flora with well diverse foliages and spores belonging to bryophytes, pteridophytes and gymnosperms from the early Cretaceous PG Basin suggests prevalence of warm and humid climatic conditions during the time of deposition.

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