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EARLY CRETACEOUS FERNS FROM INDIA- DIVERSITY, DISTRIBUTION AND THEIR RELATION TO THE MODERN FERNS

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Ferns are a resilient group with a long fossil record. They were constituents of early terrestrial plant ecosystems and significantly diversified during the Early Cretaceous times. Indian Early Cretaceous sedimentary basins hold important fern relics belongs to the Equisetaceae, Marattiaceae, Osmundaceae, Gleicheniaceae, Dipteridaceae, Matoniaceae, Schizaeaceae, Marsileaceae, Cyatheaceae, Dicksoniaceae, Pteridaceae, Aspleniaceae, Dennstaedtiaceae, Dryopteridaceae and a few more taxa with unknown affinity placed under the miscellaneous ferns. With about 25 species, the Osmundaceae shows greatest taxonomic diversity among all the families. The taxonomic composition and distribution pattern of these fern families largely differ from basin to basin. These discrepancies are attributed to their functional ecology and taphonomy. The maximum numbers of families are reported from the Rajmahal Basin. Coastal sedimentary basins comparatively represented low diversity and usually contain Equisetaceae, Osmundaceae, Gleicheniaceae and Matoniaceae. Comparison of the early Cretaceous ferns with the recent ones connotes little relation between the two. The study suggests that the bulk of recent ferns were evolved during the post Cretaceous period.

Key-Words: Diversity, Ferns, Early Cretaceous, Evolutionary History, India.

The advent of terrestrial plant ecosystems during the Paleozoic era (480-360 Ma) was marked by the first appearance of early land plants (Banks 1968, Gray 1984, Edwards and Fanning 1985, Selden and Edwards 1989, Kenrick and Crane 1997). Plant communities consisted chiefly of early cryptogamic vascular plants-Pteridophytes, which formed bulk of coal forming vegetation (Thomas 2012). Pteridophytes, the primitive vascular plants include the ferns (Filicatae) and related families Isoetaceae, Lycopodiaceae, Psilotaceae and Selaginellaceae. Since the group occupies a unique position between the lower cryptograms and higher vascular plants, their evolutionary status attracted many researchers (e.g. Surange 1966, Smith and Breedlove 1981, Dixit 1984, Fraser-Jenkins 1986, Brownsey & Smith-Dodsworth 1989, Pryer *et al*. 2001, 2004, Schneider *et al*. 2004, Rothwell and Stockey 2008, Christenhusz *et al*. 2008, Taylor and Taylor 2009). Interestingly ferns constitute nearly 90% of pteridophytic diversity. They are an extremely large and diverse group of modern land plants, second only to the angiosperms in the number of extant species (Bierhorst 1971, Rothwell 1996a). Presently there are about 300 extant genera of ferns with 12,000 species widely distributed throughout the world (Tidwell and Ash 1994, Smith *et al*. 2006). The greatest diversity occurs in the tropical regions and at high elevations (Tryon and Tryon 1982). Rich fossil records also demonstrate their diversity during the early Cretaceous (Surange 1966, Sukh-Dev 1972, Vakhrameev 1991, Stewart and Rothwell 1993, Cantrill 1998, Rothwell 1999, Cantrill & Nagalingum 2005, Nagalingum and Cantrill 2006, Taylor *et al*. 2009). Although, ferns first appeared around 360 million years ago (Carboniferous), they attained modern affinity around 145 million years ago during the early Cretaceous (Tidwell and Ash 1994, Collinson 1996, Rothwell 1996, Skog 2001, Soltis *et al*. 2002). The early Cretaceous period witnessed wide distribution of many fern groups forming the understorey in forests (Gould 1975, Skog 2001, Van Konijnenburg-van Cittert 2002, Chinnappa and Rajanikanth 2017).

The Indian record of ferns dates back to the Permian (Feistmantel 1879). However, only a few modern fern families such as Equisetaceae and Gleicheniaceae with extinct taxa are

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known during the Permian. The major radiation of the group in terms of taxonomic and spatial diversity took place during the Mesozoic especially, during the early Cretaceous (Surange 1966). By this time many modern fern families with taxa that can be affiliated to recent ones started to appear. This trend was studiedly increased towards the tertiary period and by end of this period the group attained most of its modern affinity.

Currently, the Indian extant ferns represented by 33 families and 125 genera with about 975 species (Fraser-Jenkins 2008). These are mostly distributed in Himalayan, North east India and Southern India; only a few taxa e.g. *Equisetum, Asplenium, Osmunda* etc. show wide geographic distribution.

The present communication constitutes a critical appraisal to the taxonomic diversity and geographical distribution of the early Cretaceous ferns from the Indian sub-continent. Relation with the extant ferns and evolutionary implications of these fossil ferns are also considered briefly.

1.METHODS AND SOURCE OF DATA

Indian early Cretaceous fossil fern data available in published literature (Sharma 1973, 1975, Lakhanpal *et al.* 1976, Banerji 1990, 1993, 1995, 1995a, 1996, 2000, Pandya & Sukh-Dev 1990, Singh *et al.* 1990, Chandra & Tewari 1991, Patra & Sahoo 1992, Prakash & Sukh-Dev 1995, Banerji & Jana 1998, 2000, Srivastava *et al.* 1999, 2005, Prakash 2000, 2003, Sharma *et al.* 2001, Banerji & Ghosh 2006, Pal *et al.* 2009, Chinnappa and Rajanikanth 2017) has been compiled to provide measures of diversity and distribution pattern. The extant fern diversity and distribution in India, has been recently provided by Chandra (2000) and Fraser-Jenkins (2008). The classification followed here is essentially of Smith *et al.* (2006). Species assignments by original authors are adhered with minor changes. The fossil taxa of unknown affinity have been treated as "Miscellaneous Ferns" (MS). Age assignments for various litho-units are based on the state of art knowledge on early Cretaceous sequences (McDougall and McElhinny 1970, Rajanikanth *et al.* 2000).

2.RESULTS

2.1 Taxonomic diversity and Geographical distribution

2.1.1. Equisetaceae

Equisetaceae constitutes the only surviving lineage of the Sphenopsids (Scagel *et al.* 1984). The family for the first time appeared during the Devonian (Stewart and Rothwell 1993). Existence of this family during the Carboniferous in the form of permineralized remains (Coal ball) is well established (Taylor *et al.* 2009). During the geological past, equisetaleans were common both in Gondwanan and Eurasian locales (Bose *et al.* 1990, Vakhrameev 1991, Bomfleur *et al.* 2013). An earliest reports of the family from India were during the Permian (Feistmantel 1879) and represented by *Schizoneura*, *Neocalamites* and *Equisetites*/*Equisetum*. Among these three genera the former two were known from the sediments older than the Jurassic and the latter is know from younger sediments (early Cretaceous) and extended to date.

Fossil *Equisetum* has been described under the form genus *Equisetites* Sternberg by many authors around the world (e.g. Allen 1941, Kon'no 1962, Bose & Banerji 1984, Sukh-Dev & Rajanikanth 1988). These were well preserved by stem, leaves, rhizomes and nodal diaphragms (Sahni & Rao 1933, Harris 1961). The fossil remains show apparent similarities with living genus in its gross morphology, except for its geological distribution and hence it is preferable to use the extant name *Equisetum* L. (Harris 1961). In India, during the early Cretaceous period, the family was represented by a single genus with three species (Table 2). Geographically the family was widely distributed and it is reported from the Pranhita-Godavari, Cauvery, Mahanadi, Kutch, Rajasthan, Satpura and Rajmahal basins (Oldham and Morris 1863, Feistmantel 1876, Bose and Banerji 1984, Sukh-Dev and Rajanikanth 1988, Singh *et al.* 1990, Patra and

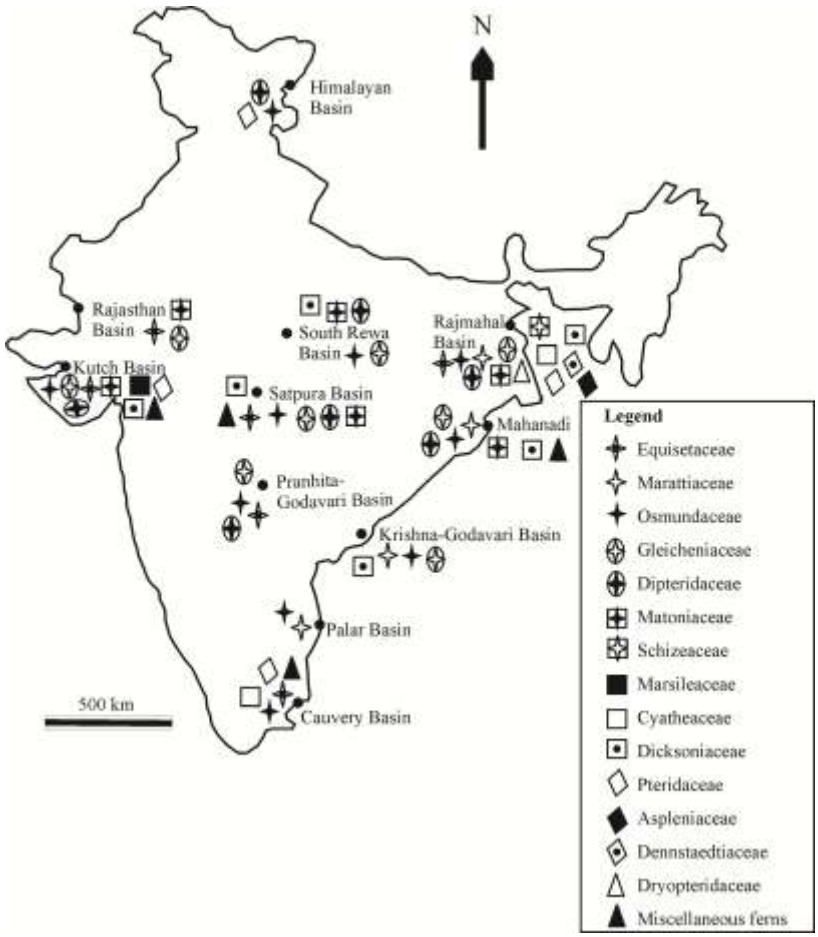

Figure 1: Distribution of Fern families in various early Cretaceous sedimentary basins of India.

Sahoo 1992, See Fig. 1).

The extant members of the family are represented by a single genus i.e. *Equisetum* with 15 species (Smith *et al.* 2006). These are distributed in almost all parts of the globe except Australia and New Zealand (Scagel 1984, Husby 2013). With 4 species, the genus is widely distributed throughout the Indian subcontinent (Fraser-Jenkins 2008). The family mostly grows in wet places such as moist woods, ditches, stream/river banks, wetlands and in where sufficient ground water is available. The same is applies to the Cretaceous representatives as there is apparent morphological similarity.

2.1.2. Marattiaceae

Marattiaceae is a primitive leptosporangiate fern family dating back to the Paleozoic, about 345 million years ago. The family has a more or less continuous fossil record down to the

Table 1: Showing the first appearance of various the fern families in India.

Family	Earliest fossil record
Equisetaceae	Permian
Marattiaceae	Triassic
Osmundaceae	Triassic
Gleicheniaceae	Permian
Dipteridaceae	early Cretaceous
Matoniaceae	early Cretaceous
Schizeaceae	early Cretaceous
Marsileaceae	early Cretaceous
Cyatheaceae	early Cretaceous
Dicksoniaceae	early Cretaceous
Dennstaedtiaceae	early Cretaceous
Pteridaceae	early Cretaceous
Aspleniaceae	early Cretaceous
Dryopteridaceae	early Cretaceous

Table 2: Showing the distribution of fern taxa in various early Cretaceous sedimentary basins of India.

Name of the Basin	**KG**			**PG**	**CV**	**PL**	**MH**	**KC**			**RS**		**ST**	**SR**	**RJ**	**HM**
Name of the Formation	Vem	Rag	Gol	Gan	Siv	Sri	Ath	Bhu	Umi	Gar	Par	Sar	Jab	Ban	Raj	Fuk
Equisetaceae																
Equisetum rajmahalensis Oldham & Morris	-	-	-	-	-	-	+	+	-	+	-	+	-	-	+	-
E. sehoraensis Singh et al.	-	-	-	-	-	-	-	-	-	-	-	-	+	-	+	-
Equisetum sp.	-	-	-	+	+	-	+	+	+	+	-	-	-	-	+	-
Marattiaceae																
Marattiopsis macrocarpa (O & M) Seward & Sahni	-	-	+	-	+	-	+	-	-	-	-	-	-	-	+	-
M. reversa Sharma	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-
Rienitsia sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-
Osmundaceae																
**Ashicaulis amarjolense* (Sharma) Tidwell	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-
**A. estipulare* (Sharma) Tidwell	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-
**A. guptai* (Sharma). Tidwell	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-
**A. rajmahalense* (Mittre) Tidwell	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-
**A. sahnii* (Mittre) Tidwell	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-
**Ashicaulis* sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-
Cladophlebis acutipennis Oishi	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-
C. daradensis Bose & Banerji	-	-	-	-	+	-	-	+	+	-	-	-	-	-	-	-
C. denticulate (Brong.) Fontaine	-	-	-	+	-	-	+	-	+	-	-	-	-	-	+	-
C. indica (O & M) Sahni & Rao	-	-	-	+	+	-	+	-	+	-	-	-	+	-	+	-
C. kakadbhitensis Mehra & Verma	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-
C. kathiawarensis Roy	-	-	-	-	+	+	+	+	+	-	-	-	-	-	-	-
C. longipennis Seward	-	-	+	-	-	-	+	-	-	-	-	-	+	-	-	-
C. medlicottiana (Oldh.) Pascoe	-	+	-	-	-	-	+	-	-	-	-	-	+	-	-	-
C. sahnii Vishnu-Mittre	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-
C. srivastavae Gupta	-	-	-	-	+	-	+	-	-	-	-	-	-	-	+	-
Cladophlebis sp.	+	+	+	+	+	-	+	+	+	+	-	+	-	-	+	-
Cacumen sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-
**Millerocaulis indica* (Sharma) Tidwell	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-
Osmundopsis sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-
Phyllopteroides laevis Cantrill & Webb	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-
Raphaelia diamensis Seward	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+
Todites denticulatus (Brong.) Krasser	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-
T. indicus (O & M) Bose & Sah	-	-	+	-	-	+	+	-	-	-	-	-	+	+	+	-
Gleicheniaceae																
**Actinostelopteris pakurense* Sharma & Bohra	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-
Gleichenia bosahii (O & M) Pant & Srivastava		+	+	+	-	-	+	-	-	-	-	-	+	+	+	-
G. dhokutense Sharma	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-

G. gleichenoides (O & M) Seward & Sahni	-	-	-	-	-	-	+	-	-	-	-	-	-	-	+	-
G. nordenskioldii Borkar & Chiplonkar	-	-	-	+	-	-	+	-	+	-	-	-	-	+	-	-
G. rewahensis Feist.	-	-	-	-	-	-	-	-	-	+	-	-	+	+	+	-
G. sonajoriense Bohra & Sharma	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-
Gleichenia sp.	-	-	-	+	-	-	+	+	+	-	+	-	-	-	+	-
**Gleicheniarachis jurassica* Sharma	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-
**Gleichenioamyelon diarcha* Sharma & Bohra	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-
Dipteridaceae																
Dictyophyllum indicum Bose & Jana	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-
Dictyophyllum sp.	-	-	-	-	-	-	-	+	+	+	-	-	-	-	-	-
Hausmannia buchii Andreae	-	-	-	+	-	-	-	-	-	-	-	-	+	-	-	-
H. cookshankii Shah & Singh	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-
H. crenata (Nath.) Moller	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-
H. dichotoma Dunker	-	-	-	-	-	-	-	+	+	-	-	-	+	-	-	-
H. pachyderma Sukh-Dev	-	-	-	-	-	-	-	-	+	-	-	-	+	-	-	-
Hasmannia sp.	-	-	-	+	-	-	+	+	-	-	-	-	-	-	+	-
Mattoniaceae																
Matonidium indicum Sahni	-	-	-	-	-	-	-	-	+	-	-	-	+	-	-	-
Matonidium sp.	-	-	-	-	-	-	+	+	+	-	-	-	-	-	-	-
Phlebopteris arcuta Sukh-Dev	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-
P. athgarhensis Jain	-	-	-	-	-	-	+	-	-	-	-	+	-	-	-	-
P. indicus Prakash	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-
P. minutifolius Banerji	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-
P. polypodiodes Sukh-Dev	-	-	-	-	-	-	+	-	-	-	-	-	+	-	-	-
Phlebopteris sp.	-	-	-	-	-	-	+	-	+	+	+	-	-	-	+	-
Piazopteris branneri (White) Lorch	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+
Weichselia reticulate (Stokes & Webb) Ward	-	-	-	-	-	-	-	-	+	-	-	-	-	+	-	-
Schizaeceae																
Klukia rajmahalensis Sharma	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-
Klukia sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-
Mohriopsis sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-
Schizaeangium jurassica Bohra & Sharma	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-
**Solenostelopteris jurassica* Bohra & Sharma	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-
**S. nipanica* Vishnu-Mittre	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-
**S. sahnii* Vishnu-Mittre	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-
Marsileaceae																
Marsilea sp.	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-
Cyatheaceae																
**Guptioxylon amarjolense* Sharma	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-
Haydenia thyrsopteroides Seward	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-

Protocyathea cyatheoides (Unger) Feist.	-	-	-	-	+	-	-	-	-	-	-	-	-	-	+	-
P. cretacea (Stenzel) Ogura	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-
P. rajmahalense Jacob	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-
P. tokunagae (Ogura) Jacob	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-
P. trichinopoliensis Feist.	-	-	-	-	+	-	-	-	-	-	-	-	-	-	+	-
Dicksoniaceae																
Coniopteris hymenophylloides (Brong) Seward	-	-	-	-	-	-	-	+	+	-	-	-	-	+	+	-
C. minturensis Brick	-	-	-	-	-	-	-	+	+	-	-	-	-	-	-	-
C. quinqueloba Phill.	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-
C. tatungensis (Sze). Shuying	-	-	-	-	-	-	-	-	-	-	-	-	+	-	+	-
Coniopteris sp.	-	-	-	-	-	-	+	-	-	-	-	-	+	-	+	-
Culcites madagascariensis Appert	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-
Dicksonia rajmahalensis Sharma	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-
D. speciosa Sharma	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-
Dicksonia sp.	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-
Eboracia lobifolia (Phill.) Thomas	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-
Onychiopsis psilotoides (Stocks & Webb) Ward	-	-	+	-	-	-	+	-	+	-	-	-	+	-	-	-
O. paradoxus Bose & Sukh-Dev	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-
Onychiopsis sp.	-	-	-	-	-	-	+	-	-	-	-	-	-	+	+	-
#Tinpaharia sinuosa Jacob	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-
Pteridaceae																
Actinopteris peitata Schenk	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-
Actinopteris sp.	-	-	-	+	+	-	-	-	+	-	+	-	-	-	-	-
Acrostichopteris sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+
Adiantopteris sp.	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-
Aspleniaceae																
Murlipaharopteris indica Banerji	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-
Dennstaediaceae																
Asplenites sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-
Dennstaedia rajmahalensis Sharma	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-
Dryopteridaceae																
Dryopteris cladophleboides Sharma	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-
D. indicus Sharma	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-
Miscellaneous Ferns																
**Dictyostelopteris fasciosteleoides* Vishnu-Mittre	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-
**D. jacobii* Vishnu-Mittre	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-
**D. rajmahalensis* Vishnu-Mittre	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-
**Filicoamyelon actinostachyoides* Bohra & Sharma	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-
**F. cryptogrammoides* Bohra & Sharma	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-

Rhizomopteris ballii Feist.	-	-	-	-	-	-	+	-	-	-	-	-	-	-	+	-
R. chukschu Ganju	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-
R. rajmahalense Gupta	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-
R. sahnii Gupta	-	-	-	-	-	-	-	+	-	-	-	-	-	-	+	-
Rhizomopteris sp.	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-
Sphenopteris anderssonii Halle	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-
S. arguta Lindley & Hutton	-	-	-	-	-	-	-	-	+	-	-	-	+	-	+	-
S. bindrabunensis Feist.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-
S. elaminata Sharma	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-
S. hislopii Feist.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-
S. imbricata Sharma	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-
S. khairbaniensis Ganju	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-
S. membranosa Feist.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-
S. metzgerioides Harris	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-
S. naukhoffiana (Heer) Halle	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-
S. otagoensis Arber	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-
S. patagonica Halle	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-
S. rajmahalensis Sahni & Rao	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-
S. sakrigaliensis Sah	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-
S. tiruchirapalliense Sukh-Dev & Rajanikanth	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-
Sphenopteris. sp.	+	+	-	+	+	-	+	-	+	+	-	+	+	+	+	-

*Fossils other than leaf forms,#Fossil with organic connection, "-" : absent; "+": present.
Legend-KG: Krishna-Godavari Basin. PG: Pranhita-Godavari Basin. CV: Cauvery Basin. PL: Palar Basin. MH: Mahanadi Basin. KC: Kutch Basin. RS: Rajasthan Basin. ST: Satpura Basin. SR: South Rewa Basin. RJ: Rajmahal Basin. HM: Himalaya Basin Vem: Vemavaram. Rag: Raghavapuram. Gol: Golapalli. Gan: Gangapur. Siv: Sivaganga. Sri: Sriperumbudur. Ath: Athgarah. Bhu: Bhuj. Umi: Umia. Gar: Gardeshwar. Par: Pariwar. Sar: Sarnu Hills. Jab: Jabalpur. Ban: Bansa. Raj: Rajmahal. Fuk: Fukche

present, and has undergone little major structural changes (Maps and Schabilion 1979). The group consists mostly of tree ferns and was dominant element in the Upper Carboniferous and Permian forests of the northern hemisphere (Tidwell and Ash 1994). Paleozoic reports of the family from southern hemisphere were not (yet) known. In southern hemisphere, including India, the family started to appear during the Triassic period (Sharma 1981) and became very common by the early Cretaceous. Fossils belong to Marattiaceae were known from the early Cretaceous sediments of Krishna-Godavari, Cauvery, Mahanadi and Rajmahal basins (Feistmantel 1877a, Seward and Sahni 1920, Sharma 1969, Jeyasingh and Sudhersan 1985, See Fig. 1). Two genera- *Marattiopsis* Schimper and *Rientisia* Walkom were recognized so far from these sediments. The former includes two species and the latter represented by *Rienitsia* sp. (Table 2). The fossil *Marattiopsis* differs from the extant *Marattia* Swartz only in the geological age.

Currently, the family is represented by four genera- *Angiopteris*, *Christensenia*, *Danaea* and *Marattia* with 150 species (Smith et al. 2006). The genera *Angiopteris* and *Christensenia* are widespread throughout South Asia, Australia and Polynesia, whereas *Danaea* is neotropical and *Marattia* is pantropical. Three genera- *Angiopteris*, *Christensenia*, and *Marattia* altogether with 4 species are present in India and each one has its own distribution pattern (Fraser-Jenkins 2008). *Christensenia* is confined to North East India; *Angiopteris* is widespread in South India and from Nepal eastwards; *Marattia* is in South India. The members mainly grow where the

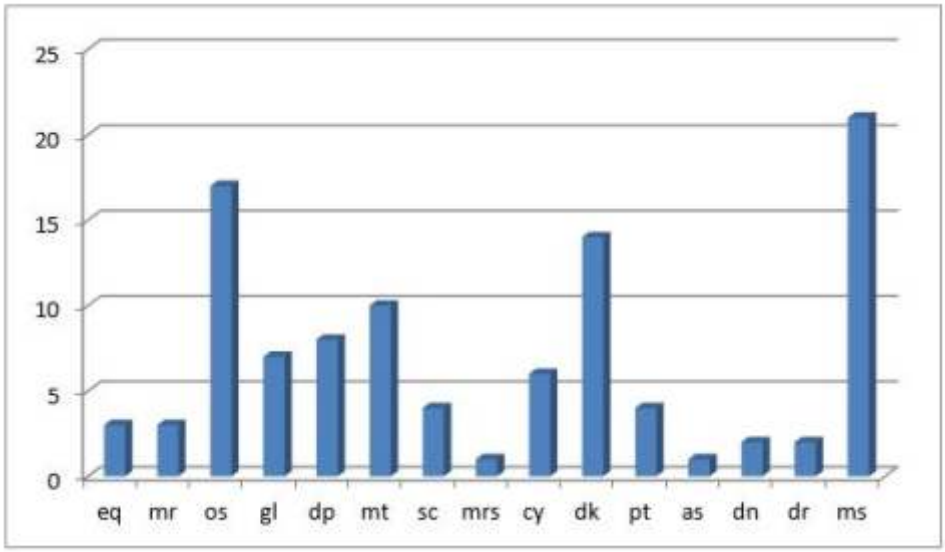

Figure 2: Species diversity of the early Cretaceous Fern families of India. [For legend see Fig 3].

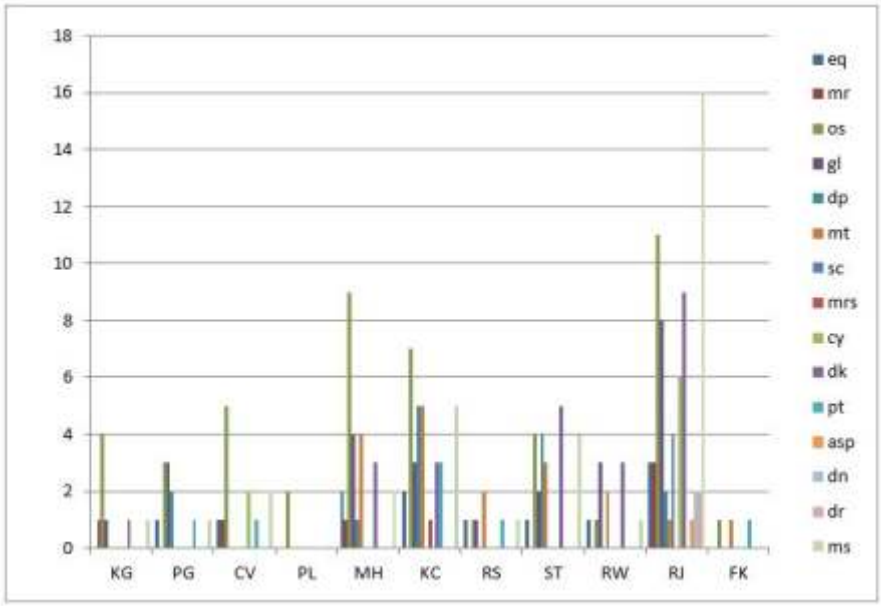

Figure 3: Distribution pattern of fern families in various early Cretaceous sedimentary basins of India.

Legend: KG: Krishna-Godavari Basin; PG; Pranhita-Godavari Basin; CV: Cauvery Basin; PL: Palar Basin: MH: Mahanadi Basin; KC: Kutch Basin; RS: Rajasthan Basin; ST: Satpura Basin; RW: South Rewa Basin; RJ: Rajmahal Basin; FK: Fukche Formation. eq: Equisetaceae; mr: Marattiaceae; os: Osmundaceae; gl: Gleicheniaceae; dp: Dipteridaceae mt: Matoniaceae; sc: Schizaeceae; Mrs: Marsileaceae cy: Cyatheaceae; dk: Dicksoniaceae; pt: Pteridaceae; as: Aspleniaceae; dn: Dennstaediaceae; dr: Dryopteridaceae; ms: Miscellaneous ferns.

temperature and humidity remain high during most part of the year. They can be generally found in low land rain forests, closed canopy and montane forests and other shady, humid places along stream banks near waterfalls (Kramer *et al.* 1990).

2.1.3. Osmundaceae

The family has been known around the Permian (Kidston and Gwynne Vaughan 1907-14) with an extensive fossil record of nearly a hundred species. The Paleozoic records of the family were not known from India. In India, the oldest records of the Osmundaceae were from the Triassic (Lele 1962). However, the diversification of family took place only

during the early Cretaceous period with as many as 24 species (Table 2). The family was known by vegetative, fertile fronds and petrifications. The vegetative fronds were placed under 5 genera namely, *Cacumen* Cantrill and Webb., *Cladophlebis* Brong., *Osmundopsis* Harris, *Phyllopteroides* Medwell and *Raphaelia* Debey & Etting., and they are reported from the various basins (Sahni and Rao 1934, Gupta 1954, Bose 1959, Vishnu-Mittre 1959, Roy 1968, Sharma 1971a, Sukh-Dev 1972, Mehra and Verma 1982, Bose et al. 1983, Banerji 1992, Prakash and Sukh-Dev 1995, Banerji & Jana 1998) Among these, *Cladophlebis* is a major element of the family and it includes 11 species (Table 2). The genera *Phyllopteroides, Raphaelia, Cacumen* and *Osmundopsis* each composed of a single species respectively (Table 2). The fertile fronds were commonly placed under *Todites* Seward, which is represented by two species- *T. indicus* and *T. denticulatus* (Bose and Sah 1968, Banerji 1992). However, some fertile fronds were also reported in the species of *Cladophlebis indicus* (Sahni and Rao 1933). The petrifications were described under *Ashicaulis* Tidwell and *Millerocaulis* (Miller) Tidwell and are mostly known from Rajmahal hills. The former genus constitutes five species and *Millerocaulis* include one species (Table 2). Geographical distribution of this family during the early Cretaceous was very rich when compared to the other families. It was known from all the early Cretaceous sediments of India (Fig. 1).

Globally, extant members are represented by 3 genera- *Leptopteris, Osmunda* and *Todea* altogether with 20 species (Smith *et al.* 2006). Among the three genera, *Osmunda* has nearly global distribution, while the *Leptopteris* and *Todea* are mainly confined to southern hemisphere (Tryon and Lugardon 1991). A single genus i.e. *Osmunda* with 4 species are distributed throughout the Indian subcontinent (Fraser-Jenkins 2008). The family favors shady areas, moist woods, wetlands, damp habitats, mountain slopes and open stream banks.

2.1.4. Gleicheniaceae

Gleicheniaceae is an ancient leptosporangiate fern family, having fossil records from Paleozoic. The earliest genus attributed to the family was from the Upper Carboniferous *Chansitheca* from China and the Permian of South Korea and *Sizea* from Permian of China (Rege 1921, Halle 1927, Andrews & Boureau 1970, Yao and Taylor 1988). The family had wide geographical distribution during the early Cretaceous, but the Tertiary fossil records are scarce and indicate the fall down of the family (Tidwell and Ash 1994). In India, the traces of the family were from the Permian (Thiergart & Frantz 1962). The early Cretaceous fossil relics of the family were represented by the vegetative, fertile fronds and petrifications. The vegetative and fertile fronds have been placed under *Gleichenia* or *Gleichenites*. These fossil fronds mostly resemble with the living ones thus the name *Gleichenia* Smith has been preferred over the old name *Gleichenites* Goeppert (Bose and Sah 1968, Sharma 1971a, 1975). It includes 7 species (Table 2), reported from the Krishna-Pranhita-Godavari, Mahanadi, Kutch, Rajasthan, Satpura, South Rewa and Rajmahal basins (Feistmantel 1877, 1882, Seward & Sahni 1920, Sukh-Dev 1961, Bose & Sah 1968, Sukh-Dev 1970, Sharma 1975, Maheshwari and Singh 1976, Pant & Srivastava 1977, Bohra and Sharma 1979, Bose et al. 1982a, b, Bose and Banerji 1984, Chinnappa and Rajanikanth 2017). The petrifications were described under *Gleicheniarachis jurassica*, *Gleichenia sonajoriense* and *Actinostelopteris pakurense* (Sharma 1973a, Sharma and Bohra 1976, Bohra and Sharma 1979) known only from the Rajmahal. During the early Cretaceous, the family was widely distributed and has abundant fossil records in Indian sedimentary basins (Fig. 1).

Extant members of the family are represented by 6 genera: *Dicranopteris, Diplopteryginum, Gleichenella, Gleichenia, Sticherus* and *Stromatopteris*, altogether with about 125 species distributed mainly in tropical regions with some extra-tropical extension (Kramer *et*

al. 1990, Smith *et al.* 2006). Two genera namely *Dicranopteris* and *Gleichenia* together with 7 species are represented in India (Fraser-Jenkins 2008). These are distributed in Nicobar Islands, North Western/Eastern Himalayas, Tamil Nadu, Karnataka, Kerala and Madhya Pradesh (Dixit 1984, Chandra 2000, Fraser-Jenkins 2008).

2.1.5. Dipteridaceae

Dipteridaceae was a large family in the past, with 6 genera and about 60 species. The earliest known representative so far is *Dictyophyllum* Lindley & Hutton described from the Triassic (Webb 1982). The family reached its maximum in Rhaetic and Liassic (Lower Jurassic) and began to decline numerically towards the end of the Mesozoic (Corsin &Waterlot 1979, Tidwell & Ash 1994). The chief characteristic feature of the family is a typical frond branching pattern similar to that of the Matoniaceae. The family constituted a significant part of Mesozoic plant ecosystem (especially in Late Triassic and Jurassic) with many genera distributed all over the world (Tidwell & Ash 1994, (Collinson 1996). In India, the early evidences of the family were from the early Cretaceous fossiliferous rocks of Athgarh Sandstone (Crookshank 1935). During this time, the family was represented by two now extinct genera- *Hausmannia* Dunker and *Dictyophyllum* Lindley & Hutton. The former includes 6 species distributed to the Pranhita-Godavari, Mahanadi, Kutch, Satpura, South Rewa, and Rajmahal basins (Crookshank 1935, Shah & Singh 1964, Bose & Sah 1968, Sukh-Dev 1961, 1972, Zeba-Bano, 1980, Bose et al. 1982b, Banerji et al. 1983, Bose & Banerji 1984, Banerji & Jana 2000) and the latter includes 2 species (Table 2) restricted to Kutch Basin (Bose & Jana 1979).

Today, Dipteridaceae includes two genera, *Cheiropleuria* and *Dipteris* together with 11 species and are distributed in India, Southeast Asia, eastern and southern China, central and southern Japan and Malaysia to Melanesia and western Polynesia (Smith et al. 2006). A single genus i.e. *Dipteris* with one species is known from India and it is distributed in Sikkim, Meghalaya, Arunachal Pradesh, west Bengal, Assam and east Nepal (Fraser-Jenkins 2008). The members preferably grow in moist and humid environments.

2.1.6. Matoniaceae

The fossil records of Matoniaceae were known from the Triassic period onwards and it was widespread during the Mesozoic era, especially in the Jurassic and Cretaceous (Skog 2001; Tidwell & Ash 1994). But, currently the family has very narrow distribution and is restricted to Malaysia (Kramer et al. 1990). Typical pedal branching pattern for the fronds is an important character of the family. In India, the family has been known from the early Cretaceous onwards and was represented by *Matonidium* Schenk., *Phlebopteris* Brog., *Piazopteris* Lorch, and *Weichselia* Stiechler (Sahni 1936, Sukh-Dev 1961, 1970, Jain 1968, Banerji 1982, Bose et al. 1983, Prakash 2008). *Matonidium* represented by a single species, *Phlebopteris* with 6 species and *Piazopteris* and *Weichselia* were represented by one species each (Table 2). The family was also recovered as petrified rhizome from the Rajmahal (Sharma & Bohra 1978). Members of the family were identified from Mahanadi, Kutch, Rajasthan, Satpura, South Rewa and Rajmahal basins (Bose & Sukh-Dev 1959, Sukh-Dev 1961, 1970, Baksi & Naskar 1981, Banerji et al. 1983, Bose & Banerji 1984, Kumaran et al. 1984, Banerji & Pal 1986, Srivastava et al. 1999; See Fig. 1).

Two genera, *Matonia* and *Phanerosorus* each with 2 species are recognized in the new world Matoniaceae and these occur very locally on isolated tropical hills and mountains of Malaysia (Kramer et al 1990, Smith 2006). At present, the family is not known from India. The extant members of the Matoniaceae show wide ecological tolerance and prefer moist habitat. However, during the Cretaceous the family was adopted to coastal habitats (Skoog 2001).

2.1.7. Schizeaceae

The first unequivocal occurrence of

Schizeaceae was during the Liassic e.g. *Stachypteris* from China or middle Jurassic *Klukia* from all over the world (Van Konijnenburg-Van Cittert 2002). In India, however, the fossils of this family were recovered from the early Cretaceous (Vishnu-Mittre 1959). The fossil remains were known by all plant parts such as rhizomes, roots, petioles, fronds (vegetative and fertile), and sporangia and spores (Sharma 1969, Bohra & Sharma 1978, 1979, Banerji 1993). Vegetative and fertile fronds were assigned under *Klukia* Raciborski, *Schizeangium* Bohra & Sharma and *Morhriopsis* Appert. Each of these genera are represented by a single species (Table 2). The petrifications were known by S*olenostelopteris jurassica*, *S. nipanica*, and *S. sahnii* (Vishnu-Mittre 1959, Bohra and Sharma 1979). The family has very restricted distribution and was known only from Rajmahal Formation to date (Fig. 1).

The extant family constitutes 2 genera namely *Actinostachys* and *Schizaea* altogether with 30 species and are predominantly tropical or southern warm-temperate ferns (Smith et al. 2006). A single genus- *Schizaea* and two species are known from India, confined to Assam, Meghalaya, Kerala and Karnataka (Dixit 1984, Fraser-Jenkins 2008). The family grows well in fairly moist areas.

2.1.8. Marsileaceae

The early origin of Marsileaceae is indeed ambiguous due to the lack of concrete evidence of mega-fossil reports. The spores attributed to this aquatic fern were known from the early Cretaceous, but assignment to the family is found to be difficult (Collinson 1991, 1996, Balme 1995). Recovery of *Marsilea* like plant material from the early Cretaceous fossiliferous rocks of Kutch Basin was worth mentioning (Banerji 1987). Their identity in *Marsilea* was accepted by Tidwell and Ash 1994). Substantial evidences for the early Cretaceous origin of the family are provided by the recent phylogenetic studies of ferns (Pryer 1999). Presence of megaspores of the aquatic fern family Azollaceae from Argentina (Archagelsky *et al*. 1999), records of microspores belongs to *Crybelosporites* and *Regnellites* (Marsileaceae) from the early Cretaceous of Australia, India, Mongolia and Japan also supports the above idea (Dettmann 1963, Li & Batten 1986, Prasad and Pundir 1999, Yamada and Kato 2002). Diversification of the family was initiated in later part of the Cretaceous and by Tertiary reached its peak with global distribution (Collinson 1992, Skog 2001).

These days the family is found in tropical to warm temperate regions of the world and 3 genera with 75 species are recognized (Smith et al. 2006). The members predominantly occur in moist to flooded plains and some Australian species occur in drought conditions (Kramer et al.1990). A single genus, *Marsilea* with 3-4 species are known in India, although many more have been reported as species in error (Fraser-Jenkins 2008). The species are distributed throughout the country, mostly along the shores of ponds or streams.

2.1.9. Cyatheaceae

Cyatheaceae, the scaly tree fern family includes world's tallest tree fern and the family is characterized by a tropical and subtropical distribution. Fossils of Cyatheaceae were very scarce (Van Konijnenburg-Van Cittert 2002). The first trustworthy plant fossils were from the Jurassic (Tidwell and Ash 1994, Collinson 1996). The fossils belong to the family were known from the early Cretaceous of India and it is represented by *Protocyathea* Fiestmantel and *Haydenia* Seward (Feistmantel 1877b, Jacob 1937, Sharma 1969). The former includes five species and the latter has a single species (Table 2). *Guptiorachis amarjolense*, a petrified petiole of Cyatheaceae described from the Rajmahal (Sharma 1971). The family had a narrow distribution compared to other families and was known only from Cauvery and Rajmahal basins (Fig. 1).

The living members of the family are placed in up to 5 genera *viz*., *Alsophila, Cyathea, Gymnosphaera, Hymenophyllopsis* and *Sphaeropteris*, though 4 of these are often combined into *Cyathea*, altogether with more

than 600 species (Kramer *et al.* 1990). The family is found in both new and old world tropical wet montane forests and cloud forests with some species extending into south-temperate regions (Korall *et al.* 2007). In India, distribution of the family ranges from the Andaman and Nicobar Islands to the Himalaya through Peninsular and Central India. It is represented by single genus *Cyathea* with 11-12 species (Fraser-Jenkins 2008). The family has been retained most of its external and internal characters throughout the evolutionary history and has undergone minor morphologic and anatomic changes from its origin (de Seoane 1999).

2.1.10. Dicksoniaceae

Lovis (1977) included Dicksoniaceae under Cyatheaceae. However, Tidwell and Ash (1994) separated them on the basis of their marginal sori contracting with the superficial sori of the Cyatheaceae. The family made its first appearance during the early Triassic (Ouyang and Li 1980). However, in India the fossils relate to this family were known from the early Cretaceous (Sahni and Rao 1933). The fossils were known, both as impressions (fronds) and petrifications. Impressions were placed under *Dicksonia* L'Heritier, *Eboracia* Thomas, *Culcites*, Appert *Coniopteris* Brongniart and *Onychiopsis* Yokoyama (Table 2). The genus *Dicksonia* was represented by three species (Sharma 1971a, 1975), *Coniopteris* with five species- (Sahni and Rao 1933, Bose and Banerji 1984, Banerji 1995, Srivastava et al. 2005). *Onychiopsis* correlates well with the living fern *Onychium* Kaulf in its morphology and spore nature and it includes 3 species. (Bose 1959, Bose and Sukh-Dev 1961). The genus *Culcites* and *Eboracia* were represented single species each (Banerji 1988, 1993). Petrifications represent one species *Tinpaharia sinuosa* (Jacob 1943). The early Cretaceous distributed of the family extended to the Krishna-Godavari, Mahanadi, Kutch, Satpura, South Rewa and Rajmahal basins (Suk-Dev 1961, Sharma 1969, 1971a, 1975, Bose and Banerji 1984, Banerji 1988, 1993, Prasad and Pundir 1999).

With 3 genera and 30 species the family is now globally scattered in tropical, sub tropical, and warm temperate regions (Kramer *et al.* 1990, Smith *et al.* 2006). Most species occur as under growth of dense forests often in thickets or more open vegetation and on montane slides. A single genus, *Cibotium* Kaulf. with one species is confined to North Eastern India and the lower Himalaya (Fraser-Jenkins 2008).

2.1.11. Dennstaedtiaceae

Dennstaedtiaceae is having a pantropical distribution. Global distribution of the genus *Pteridium* L., near cosmopolitan nature of *Dennstaedtia*, *Hypolepis*, *Microlepia*, made this family cosmopolitan (Thomson 2000). The group is characterized by long creeping stems bearing large, decompound leaves with marginal or sub-marginal indusiate sori. Many species have epipetiolar buds which develop into branches (Kramer *et al.* 1990). The family has been considered to appear for the first time during the middle-late Cretaceous (Tidwell and Ash 1994, Skog 2001). However, the Indian fossil records suggest the early Cretaceous origin for this family (Sharma 1975). Recent phylogenetic studies of Schneider *et al.* (2004) have also established the early Cretaceous origin of the family. In India, the plant fossils of the family were represented by *Dennstaedia rajmahalensis* and *Asplenites* sp. (Sharma 1975, Banerji 1993). It was known only from early Cretaceous sediments of Rajmahal (Fig. 1).

Today the family is globally represented by 11 genera with 170 species (Smith et al. 2006). Six genera: *Dennstaedtia*, *Histiopteris*, *Hypolepis*, *Microlepia*, *Monachosorum* and *Pteridium* together 23 species are present in India (Fraser-Jenkins 2008). Members of the family are common in warm temperate-cool temperate areas. The majority of these ferns exhibits global distribution except a few genera confined to one or two continents (Kramer *et al.* 1990).

2.1.12 Pteridaceae

Pteridaceae is a large and diverse family of

nearly worldwide distribution with about 35 genera altogether over 950 species (Smith *et al.* 2006). It comprises approximately 10% of extant fern diversity and is notable for its extreme morphological and ecological diversity (Rothfels *et al.* 2008). The family is characterized by sporangia borne abaxially on unmodified veins or borne marginally and then often covered by a marginal indusium by trilete spores. This family made its first appearance during the Jurassic (e.g. *Adiantites* Goepp.). But, in India it was known only from the early Cretaceous times (Feistmantel 1876). The distribution pattern of the family during the early Cretaceous was rather confusing due to poor understanding of the fossils. In India, it was represented by *Actinopteris* Schenk, *Acrostichopteris* sp., and *Adiantopteris* sp. (Feistmantel 1876, Bose *et al.* 1983, Banerji 1987, Table 2). These were known from Cauvery, Kutch, Rajasthan and Himalayan basins (Das Gupta *et al.* 1975, Ayyasami and Gururaja 1977, Bose *et al.* 1983a, Banerji 1987, See Fig. 1).

The extant members of the family grow in terrestrial to epipetric or epiphytic habitats and exhibit global distribution; notably numerous in the tropical regions (Smith *et al.* 2006). One hundred and forty species in 20 genera are distributed throughout the country in moist and humid regions (Fraser-Jenkins 2008).

2.1.13 Aspleniaceae

Aspleniaceae, with about 700 species, represents a largest homogenous family of wide geographical distribution (Kramer et al. 1990). It is characterized by presence of a single "X" shaped xylem element in the vascular bundle near the base of the petiole or two "C" shaped elements in separate bundles, each facing towards a side of the xylem (Tryon & Tryon 1982). The members of the family have inter-marginal, linear sori with a flap like indusium arising along one edge (Tryon 1990). Earlier classifications treated this family in the order Polypodiales; however, recent classifications separated the family from Polypodiales and placed it under a separate order Aspliniales (Smith *et al.* 2006). The origin of the family was traced to the early Cretaceous (Kirichkova 1985, Banerji 1995, Sun *et al.* 2010). *Murlipaharopteris indica* is the only taxa known from the early Cretaceous sediments of Rajmahal, India (Banerji 1995, See Fig. 1).

Representative living genera of this family are delimited due to contradictions in recent molecular data (Smith *et al.* 2006). These occupy various rain and montane forests ecosystem and show different habitats ranging from terrestrial to epipetric or epiphytic with worldwide distribution, but abundant in tropical regions (Tryon and Tryon 1982). In India, it is represented by a single genus *Asplenium* with about 71-73 species distributed in moist parts of the country (Fraser-Jenkins 2008).

2.1.14. Dryopteridaceae

Origin of the family Dryopteridaceae is somewhat controversial. The family bears historical records from the early Cretaceous of China, India and eastern United States (Sharma 1971, 1975, Deng 1994, Skog & Litwin 1995, Sun et al. 1995). Indian records were represented by single genus, *Dryopteris* Adanson, with two species (Table 2) restricted to the early Cretaceous sediments of Rajmahal (Sharma 1971, 1975- originally placed under the Aspidiaceae). Many of the affiliations of taxa are determined in this family are based on monolete spores and sterile/fertile fronds. However, placement of the early Cretaceous fossils in Dryopteridaceae is ambiguous; many of the fossils in this family were misidentified (Sessa *et al.* 2012).

Extant members of the family arose in temperate humid region and spread to the northern areas of higher rain fall, these are distributed worldwide. However, the greatest diversity, with intermediate subgenera towards other genera is in South East Asia. The family constitute about 40-54 genera with 1700 species, about 70% of the species belong to four genera- *Ctenitis*, *Dryopteris*, *Elaphoglossum* and *Polystichum* (Smith et al. 2006). Eastern Asia is considered to be the

centre for diversity of the family with many genera widespread here (Tryon and Tryon 1982). In India, with about 161-163 species (included *Tectaria*) Dryopteridaceae is next to the Polypodiaceae in its species richness (Fraser-Jenkins 2008).

2.1.15. Miscellaneous Ferns

Sphenopteris Brongniart was a complex genus including frond of ferns as well as Lyginopterideae. The fronds are bipinnate or multipinnate, divided irregularly and with or without distinct lamina. The genus first appeared during the Carboniferous (Hoeg et al. 1956). In India, during the early Cretaceous it was represented by about 16 species (Table 2). Most of the species were known from the Rajmahal, except a few from other basins such as Satpura, Cauvery and Kutch (Oldham and Morris 1863, Fiestmantel 1876, Sahni and Rao 1934, Ganju 1947, Sah 1966, Bose and Sah 1968, Sharma 1969, 1975, Zeba-Bano 1980, Bose & Banerji 1984, Sukh-Dev & Rajanikanth 1988; Banerji 1993).

Rhizomopteris Schimper was the impression of the rhizomes with wrinkled surface provided by spirally arranged roots and marks of vascular traces. It was represented 5 species (Table 2) reported from the Rajmahal, Athgarh and Kutch basins (Fiestmantel 1877a, Ganju 1947, Gupta 1954, Borkar and Phadke 1974).

Dictyostelopteris was established by Vishnu-Mittre (1959) for the rhizomes of dictyostelic vascular nature. It is represented by the 3 species (Table 2) reported from the Nipania Chert of Rajmahal. *Filicoamyalon* was recovered from Sonajori-Pakuri, Rajmahal and includes two species (Bohra and Sharma 1979).

3.DISCUSSION AND CONCLUSION

The ferns constitute an ancient division of vascular plants, some of them as old as the Carboniferous Period and perhaps older. They are sister to seed plants (Pryer *et al.* 2001) and are the second largest group of vascular land plants, with ca. 12000 species (Smith et al. 2006). They inhabit a great variety of substrates, climates, and light regimes, both in habitats dominated by flowering plants and those where few angiosperms can survive (Sessa *et al.* 2012). However, their diversity and distribution is largely controlled by temperature and rainfall (Skoog 2001). The finest display of fern diversity is seen in the tropical rainforests where rainfall is high and temperature is moderate to low (Kramer *et al.* 1990, Tryon 1990). Some ferns (e.g. *Pteridium*) play a role in ecological succession, growing from the crevices of bare rock exposures and in open bogs and marshes prior to the advent of forest vegetation (Ouden 2000, Marrs *et al.* 2000).

An inquiry into historical background of the Indian ferns shows that the group was made its appearance as early as in the Permian period (e.g. Equisetaceae and Gleicheniaceae-Table 2). However, most families were started to appear during the Mesozoic, particularly in the early Cretaceous, only a few families namely Marattiaceae and Osmundaceae have the fossil records from the Triassic onwards (Table 2). It is also possible that, at least some of the families those with fossil records from the early Cretaceous might be originated in the Jurassic period itself. However, lack of precise continental Jurassic sediments (Rajanikanth and Chinnappa 2015) with well preserved macro plant fossils precludes validation of this idea. In India, 14 families and 41 genera (excluding miscellaneous ferns-four genera) are recognized during the early Cretaceous period. Within them, the total numbers of about 94 species are recognized (excluding miscellaneous ferns-26 species). The greatest taxonomic diversity among these families can be observed in Osmundaceae (Fig. 2; Table 1).

A perusal of distribution of the various fern families in India (Fig. 1), during the early Cretaceous shows a rich diversity of ferns in the Rajmahal Basin (Fig. 3). Ferns from the coastal regions (KG, CV, PL and Kutch) are comparatively less represented (Fig. 3; although MH is one of the coastal basin there are no reports of early Cretaceous marine fauna, this delimits the influence of marine on

flora). Formation of fossil assemblages is limited by taphonomic constraints and provides only a partial picture of what actually existed (Spicer 1991). However, variable distribution of ferns in different sedimentary basins of the India reflects existence of various ecological conditions rather than depositional milieu (taphonomic constraints). The taxonomic composition and distribution pattern of ferns more importantly suggestive of clue for ecological conditions prevailed during the time of deposition. Ferns are being sensitive to ecological conditions it is expected to show variations in the taxonomic composition and diversity pattern among the coastal and continental sites. Although coastal regions are having high humidity in the air, they usually maintain high temperature and further, the land is frequently inundated by salt water. This type of sites favors growth of certain fern components only (e.g. Equisetaceae, Matoniaceae, Gleicheniaceae and species of *Cladophlebis* and *Hausmannia*). Mesozoic Matoniaceae and the genus *Hausmannia* were inferred to grow in coastal settings, similarly Gleicheniaceae can withstand for drier environments (Harris 1961, Watson & Alvin 1996, Skoog 2001). In contrast, continental regions (intra-cratonic sites-ST, SR, RJ & PG) with high water table provide best sites for the rich growth of ferns. The distribution pattern of the Indian early Cretaceous ferns was testifying the similar view. In general, the intracratonic and fresh water sediments show the highest diversity and abundant ferns than the paralic/coastal sediments (Fig. 3).

Today, the Indian ferns constitute 33 families and 125 genera with about 975 species, these are mostly distributed in Himalayan, North east India and Southern India; only a few taxa (e.g. *Equisetum*, *Osmunda*, *Marsilea* and *Asplenium*) show wide geographic distribution (Fraser-Jenkins 2008). Among the 33 families, 13 have been known from the early Cretaceous onwards. The comparison of ferns from the early Cretaceous times and recent times indicates that, while the diversity of Osmundaceae has been declined, the Matoniaceae was totally disappeared in the present times. The new world taxa show very little relation with Cretaceous ones; only a few genera (e.g. *Equisetum*, *Marattia*, *Gleichenia*, *Marsilea* and *Onychium*) can be best related. There is zero relation at species level. Bulk of the recent ferns exhibits South East or North East Asian/Malesian relation and relatively small group of ferns have European-Mediterranean connection (personal communication with Fraser-Jenkins). This connote much of the extant Indian fern flora has evolved during the post Cretaceous times. However, lack of well preserved fern fossils from post Cretaceous sediments i.e. from Tertiary period (Surange 1966) hinders better understanding of evolutionary history of the many new world families and genera. Since ferns and flowering plants dominated the post-Cretaceous Earth, diversity studies on southern continents go a long way to understand the group evolution. Dissolution of the regional floral dominance and enhancement of the fern flora with global orientation is suggestive of the resilience and endurance of ferns as a group.

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