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Palaeobiodiversity of the Lower Gondwana rocks in the Korba Coalfield, Chhattisgarh, India and observations on the genus *Gangamopteris* McCoy

KAMAL JEET SINGH[1*], ANJU SAXENA[1] AND SHREERUP GOSWAMI[2]

[1]*Birbal Sahni Institute of Palaeobotany, 53 University Road, Lucknow 226 007, India.*
[2]*Department of Geology, Ravenshaw University, Cuttack 753003, Odisha, India.*
[*]*Corresponding author: kamaljeet31@hotmail.com*

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ABSTRACT

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The Korba Coalfield occupies the south-central part of Son-Mahanadi Master basin and is situated in the Korba and Bilaspur districts of Chhattisgarh State. With five open cast mines (Gevra, Dipika, Manikpur, Kusmunda and Laxman) spreading over 530 sq. kms, this coalfield is the biggest coal producing unit in India, however it was never explored for megafloral studies. Extensive investigations were recently conducted in this coalfield to discover the fossiliferous beds in the Lower Gondwana deposits and as a result a large number of plant fossils were recovered from these collieries and their extension sites belonging to the Barakar Formation.

The complete flora includes 38 taxa, representing 13 genera of the orders Equisetales, Cordaitales and Glossopteridales. The order Glossopteridales is highly diversified with 34 taxa and the genus *Glossopteris* with 22 species dominates the flora followed by the genera *Vertebraria*, *Sakoarota* (equisetalean stems), *Cordaites*, *Dictyopteridium*, scale leaves of fertile organs, *Gangamopteris*, *Noeggerathiopsis*, *Euryphyllum* and *Rubidgea*. This is the first ever collection and record of any mega plant fossil from this coalfield. The groups Lycopodiales, Sphenophyllales, Filicales, Ginkgoales, Cycadales and Coniferales are completely absent in this area which shows that the area might not be adequately cool and humid to facilitate the growth of these shade loving under-story plants. The genus *Cordaites*, which is a northern hemisphere taxon has been reported along with Glossopteris floral elements. An equisetalean genus *Sakoarota*, described from Madagascar has been reported for the first time from the Indian Gondwana.

The genus *Gangamopteris* comprising six species, viz. *G. cyclopteroides*, *G. cyclopteroides* var. *subauriculata*, *G. angustifolia*, *G. rajaensis*, *G. clarkeana* and *Gangamopteris* **sp.** has been systematically described and discussed in this paper. The occurrence of *Rubidgea*, *Euryphyllum*, *Noeggerathiopsis*, *Cordaites* and *Gangamopteris* along with *Glossopteris* is indicative of the presence of Karharbari sediments (Early Permian=Lower Artinskian) in the lower part of the Barakar Formation exposed in the Gevra and Dipika collieries. The recovered plant assemblage indicates an Early Permian age, Lower Artinskian (Early Barakar) in the case of the Gevra and Dipika collieries and Upper Artinskian (Late Barakar) for the Manikpur, Kusmunda and Laxman collieries.

Key-words—Son-Mahanadi Basin, Barakar Formation, *Gangamopteris, Glossopteris, Rubidgea, Euryphyllum, Noeggerathiopsis, Cordaites, Sakoarota*.

कोरबा कोयलाक्षेत्र, छत्तीसगढ़, भारत में निम्न गोंडवाना चट्टानों की पुराजैवविविधता तथा *गंगामॉप्टेरिस* मैक्कॉय वंश के प्रेक्षण

कमलजीत सिंह, अंजु सक्सेना एवं श्रीरुप गोस्वामी

सारांश

कोरबा कोयलाक्षेत्र सोन-महानदी मास्टर द्रोणी का दक्षिण-मध्य भाग घेरे हुए है तथा छत्तीसगढ़ राज्य के कोरबा एवं बिलासपुर जिलों में स्थित है। 530 वर्ग किमी से अधिक में विस्तृत पांच विवृत खान (गेव्रा, दीपिका, मानिकपुर, कुसमुंडा एवं लक्ष्मण), यह कोयलाक्षेत्र भारत में सर्वाधिक कोयला उत्पादी इकाई है, लेकिन स्थूलपुष्पी अध्ययनों हेतु ये कभी अन्वेषित नहीं की गई। इस कोयला क्षेत्र में निचले गोंडवाना निक्षेपों में जीवाश्मी संस्तरों की खोज के लिए हाल में गहन अन्वेषण किए गए जिसके परिणाम स्वरुप इन कोयला खदानों में तथा बराकार शैलसमूह के इनके विस्तारण स्थलों में बड़ी संख्या में पादप जीवाश्म मिले।

एक्वीसीटेल्ज़, कॉर्डाइटेल्स एवं ग्लोसोप्टेरीडेल्ज़ वर्गों के 13 वंशों को निरुपित करते हुए समूची वनस्पति-जात में 38 टैक्सा हैं। 34 टैक्सा सहित ग्लोसोप्टेरीडेल्ज़ प्रमुख रुप से विविधरुपायित है *वर्टिब्रेरिया, सकोएरोटा (इक्वीसिटेलियन तना), कॉर्डाइटिज़, डिक्टीओप्टेरिडियम,* उर्वर अंगों के शल्क पत्रों, *गंगामॉप्टेरिस, नैग्गेरैथिऑप्सिस, इयुरीफिल्लम व रुबीडजिया* के अनुगामी 22 जातियों सहित *ग्लोसोप्टेरिस* वंश वनस्पति-जात पर प्रभुत्व रखता है। इस कोयलाक्षेत्रा से किसी भी स्थूल पादप जीवाश्म का अबतक का यह पहला संग्रहण एवं अभिलेख है। इस क्षेत्र में लायकोपोडीएल्ज़, स्फीनोफायलेल्ज़, फिलिकेल्ज, गिंकगोएल्ज़, साइकेडेल्ज़ एवं कोनीफेरल्ज़ समूह पूर्णरुपेण नदारद हैं जो दर्शाता है कि क्षेत्र इन छाया स्नेही छोटे पौधों की बढ़वार में पर्याप्त रुप से शीत एवं आर्द्र सुसाध्य नहीं रहा होगा। *कॉर्डाइटिज़* वंश जो कि उत्तरी अर्धगोला टैक्सान है ग्लोसोप्टेरिस पुष्पी तत्वों के साथ मिली है। मडगास्कर से वर्णित इक्वीसिटेरिलयन वंश *सकोएरोटा* भारतीय गोंडवाना से पहली बार वर्णित किया गया है।

छः जाति अर्थात *जी. सायक्लोप्टेरॉइडिस, जी. सायक्लोप्टेरॉइडिस* प्रकार *सबऑरिक्यूलेटा, जी. अंगस्टिफोलिया, जी. राजोन्सिस, जी. क्लार्केएना* एवं *गंगामॉप्टेरिस* जाति सन्निहित *गंगामॉप्टेरिस* वंश इस शोध-पत्र में क्रमबद्ध रुप से वर्णित व चर्चित है। गेव्रा एवं दीपिका कोयला खदानों में बराकार शैलसमूह के निम्न भाग में अनावरित *रुबीडजीया, इयुरीफिल्लम, नौग्गेराथिऑप्सिस, कॉर्डाइटिज़* एवं *ग्लोसोप्टेरिस* के साथ *गंगामॉप्टेरिस* की प्राप्ति करहरबारी अवसादों (प्रारंभिक पर्मियन = निम्न अर्टीन्सकीयन) की विद्यमानता का द्योतक है। प्राप्त समुच्चय गेव्रा एवं दीपिका कोयलाखदानों के मामले में प्रारंभिक पर्मियन आयु, निम्न अर्टीन्सकीयन (प्रारंभिक बराकार) तथा मानिकपुर, कुसमुंडा व लक्ष्मण कोयलाखदानों हेतु ऊपरी अर्टीन्सकीयन (अंतिम बराकार) दर्शाती है।

संकेत-शब्द—सोन-महानदी द्रोणी, बराकार शैलसमूह, *गंगामॉप्टेरिस, ग्लोसोप्टेरिस, रुबीडजीया, इयुरीफायल्लम, नोएग्गेराथिऑप्सिस, कॉर्डेर्टिस, सकोरेवा*

Palaeobiodiversidade das rochas do Gondwana Inferior no Hulhífero Korba, Chhattisgarh, India e observações no gênero *Gangamopteris* Mccoy

RESUMO

O hulhífero Korba ocupa a parte centro-sul da bacia Son-Mahanadi Master e situa-se nos distritos de Korba e Bilaspur no Estado de Chhattisgarh. Com cinco minas de carvão a céu aberto (Gevra, Dipika, Manikpur, Kusumunda and Laxman), ocupando uma área de 530km^2, este jazigo é a maior unidade produtora de carvão na Índia, no entanto, nunca foi explorado para estudos megaflorísticos. Extensas investigações foram recentemente realizadas neste hulhífero para descobrir os leitos fossilíferos nos depósitos do gondwana inferior e, como resultado, um grande número de fitofósseis foram coletados nestas minas e em extensões de seus níveis pertencentes a Formação Barakar.

A flora completa inclui 38 táxons, representando 13 gêneros das ordens Equisetales, Cordaitales e Glossopteridales. A Ordem Glossopteridales é altamente diversificada, com 34 táxons e o gênero Glossopteris, com 22 espécies , dominam a flora seguida pelo gênero *Vertebraria*, *Sakoarota* (caules de Equisetales), *Cordaites*, *Dictyopteridium*, escamas foliares de órgãos férteis *Gangamopteris*, *Noeggerathiopsis*, *Euryphyllum* e *Rubidgea.* Esta é a primeira coleta e registro de macrofitofósseis feitos neste jazigo. Os grupos Lycopodiales, Sphenophyllales, Filicales, Ginkgoales, Cycadales e Coniferales são completamente ausentes nesta região, o que mostra que esta área talvez não tenha sido adequadamente fria e úmida para facilitar o crescimento de plantas do sub-bosque amantes da sombra (esciófitas). O gênero Cordaite, que é um taxon do hemisfério norte tem sido relatado com elementos da flora de Glossopteris. O gênero equisetaleano *Sakoarota*, descrito para Madagascar foi relatado pela primeira vez no Gondwana Indiano. O gênero *Gangamopteris,* que compreende seis especies, a saber *G. cyclopteroides*, *G. cyclopteroides* var. *subauriculata*, *G. angustifolia*, *G. rajaensis*, *G. clarkeana* e *Gangamopteris* sp., foi sistematicamente descrito discutido neste trabalho. A ocorrência de *Rubidgea*, *Euryphyllum*, *Noeggerathiopsis*, *Cordaites* e *Gangamopteris* junto com *Glossopteris* é o indicativo da presença de sedimentos Karharbari (Eopermiano=Artiskiano Inferior) na parte inferior da Formação Barakar, expostas nas minas de carvão de Gevra e Dopika. A assembléia de planta vegetal coletada indicam uma idade eopermiana, Artinskiano inferior (Eo Barakar) no caso das minas de Gevra e Dipika e Artinskiano Superior (Neo Barakar) para as minas de carvão de Manikpur, Kusumunda e Laxman.

Palavras-chave—Bacia Son-Mahanadi, Formação Barakar, *Gangamopteris*, *Glossopteris, Rubidgea, Euryphyllum, Noeggerathiopsis, Cordaites,Sakoarota*.

INTRODUCTION

Permian sediments pertaining to the Talcher Coalfield, Ib-River Coalfield and Mand-Raigarh Coalfield, all parts of the Mahanadi Basin, have been thoroughly investigated by a number of workers over the past fifty years {Subramanian and Rao (1960); Khan (1969); Surange and Maheshwari (1970); Surange and Chandra (1973a, b, c, 1974a, b, c, d); Maithy (1977); Chandra and Surange (1977); Chandra and Rigby (1981, 1983); Chandra (1984); Pant *et al.* (1985); Chandra and Singh (1986,

1988, 1989, 1992, 1995, 1996a, b); Singh and Chandra (1987, 1990, 1995, 1996a, b, 1999, 2000); Srivastava *et al.* (1996); Goswami and Singh (2010); Goswami *et al.* (2006a, b); Singh *et al.*, (2003, 2006a, b, c, 2007)}. However, a very important coalfield within the Mahanadi Basin, i.e. the Korba Coalfield, which is also the biggest coal producing unit in India, was never investigated for plant megafossils. The palaeobotanical studies in this coalfield are limited to a few palynological studies by Bharadwaj and Srivastava (1973); Bharadwaj and Tiwari (1964); Srivastava (1973, 1984) and Vijaya and Sinha (2005) and a recent megafloral report by Singh *et al.* (2011) wherein the authors described 22 species of *Glossopteris*. The Lower Gondwana sediments of the Korba Coalfield were thoroughly examined for megafossils so that a database could be produced for all the four coalfields of the Mahanadi Basin to understand the early developmental history and the evolution of the flora in this master basin.

The Lower Gondwana rocks in this coalfield have been identified with three formations, i e. Talchir, Barakar and Kamthi (Fig. 1). The sediments of the Talchir and the Kamthi formations were found to be unfossiliferous. Plant megafossils have been collected extensively from the Barakar sediments (Early Permian) exposed in five open-cast mines namely Gevra, Dipika, Manikpur, Kusmunda and Laxman. A large collection of plant megafossils (512 specimens, Fig. 2) was made during three excursions to this field. This is the first ever collection and record of any plant megafossils from this coalfield.

The genus *Cordaites*, which is a northern hemisphere taxon, has been reported from the Korba Coalfield along with *Glossopteris* floral elements. Similarly an equisetalean genus *Sakoarota*, originally described from Madagascar, has been reported for the first time from the Indian Gondwana. The groups Lycopodiales, Sphenophyllales, Filicales, Ginkgoales, Cycadales and Coniferales are completely absent from the Korba Coalfield.

In the present study, only the genus *Gangamopteris* having six species, viz. *G. cyclopteroides*, *G. cyclopteroides* var. *subauriculata*, *G. angustifolia*, *G. rajaensis*, *G. clarkeana* and *Gangamopteris* sp. has been systematically described and discussed (Fig. 3) and remaining plant groups have been published elsewhere. The study also incorporates the comparison of the presently described *Gangamopteris* species with those of other coalfields of the Indian Gondwana including the Mahanadi Basin (Fig. 4). The complete flora of the Korba Coalfield has been tabulated in Fig. 5 and its distribution in different collieries has been shown in Fig. 6. Relative percentage of various plant genera/groups found in this coalfield and the stratigraphical distribution of various *Gangamopteris* species in Indian Lower Gondwana formations is provided in Figs 2 and 7, respectively.

The occurrence of the genera *Rubidgea*, *Euryphyllum*, *Noeggerathiopsis*, *Cordaites* and *Gangamopteris* along with the genus *Glossopteris* is indicative of the presence of Karharbari sediments (Early Permian) in the lower part of the

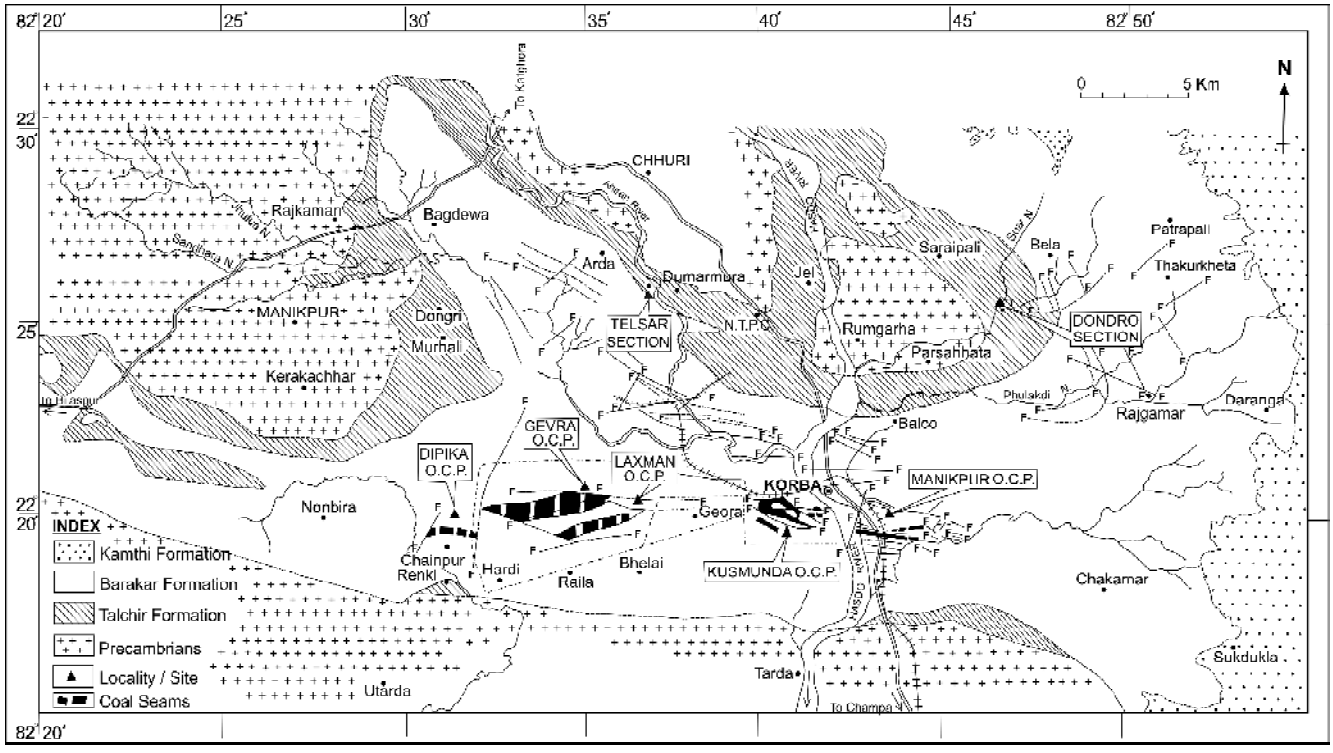

Fig. 1—Geological map of Korba Coalfield, Chhattisgarh showing various localities.

S.N.	Name of genera / group	No. of specimens	Percentage
1.	*Glossopteris*	195	38.08
2.	*Vertebraria*	168	32.81
3.	*Sakoarota* / equisetalean stems	58	11.32
4.	*Cordaites*	43	8.39
5.	*Dictyopteridium* / fertile organs	14	2.73
6.	Scale leaves of fertile organs	13	2.53
7.	*Gangamopteris*	8	1.56
8.	*Noeggerathiopsis*	5	0.97
9.	*Euryphyllum*	2	0.39
10.	*Rubidgea*	2	0.39
11.	Stem casts	2	0.39
12.	Stem branch / twigs	2	0.39
Total	**12**	**512**	**99.95**

Fig. 2—Relative percentage of various genera / groups collected from different collieries, Korba Coalfield.

Barakar Formation exposed in Gevra and Dipika collieries located in the south-central part of this coalfield. The recovered plant assemblage indicates an Early Permian age, Lower Artinskian (Early Barakar) in the case of the Gevra and Dipika collieries and Upper Artinskian (Late Barakar) for the Manikpur, Kusmunda and Laxman collieries.

Gangamopteris occurs as the dominant megafloral component of the *Glossopteris* flora which is well recorded from all the Gondwanan countries, viz. India, Australia, South Africa, Congo, Brazil, Argentina, Rhodesia, Madagascar and Antarctica from the homotaxial sediments deposited during Early Permian (McCoy, 1875; Feistmantel, 1876, 1879, 1881, 1890; Seward, 1905; White, 1908; Zalessky, 1912; Dolianiti, 1954; Srivastava, 1956; Archangelsky, 1958, 1984; Plumstead, 1962; Maithy, 1965d, 1966; Rigby, 1967; Maheshwari & Prakash, 1965; Pant & Singh, 1968; Kulkarni, 1971; Chandra & Srivastava, 1982; Anderson & Anderson, 1985; Bajpai, 1990; Srivastava, 1977, 1992; Srivastava & Tewari, 1996; Singh, 2000; Tewari & Srivastava, 2000; Singh *et al.*, 2005, 2006a, b; Srivastava & Agnihotri, 2010; Tewari *et al.*, 2012; Srivastava *et al.*, in press). The genus is distributed horizontally in almost all the geographical areas pertaining to the erstwhile Gondwana

***Gangamopteris* species**	**Dipika Colliery**	**Gevra Colliery**	**Manikpur Colliery**
G. cyclopteroides	+		+
G. cyclopteroides var. *subauriculata*	+		
G. angustifolia	+		
G. rajaensis		+	
G. clarkeana	+		
Gangamopteris sp.	+		

Fig. 3—Distribution of *Gangamopteris* species in various localities in Korba Coalfield.

but its vertical range is somewhat restricted making it a significant genus stratigraphically. In India it appeared during the early Talchir Period (Early Sakmarian) as evidenced by its occurrence in the sediments close to the tillites (Surange & Lele, 1956) where it was believed to grow in small hospitable pockets free from ice. Towards the end of Talchir Period *Gangamopteris* diversified further (as many as eighteen species of the genus are known from the Talchir Formation, Fig. 7) and its leaves developed considerably as compared to the small, curled or folded leaves found preserved in the tillites of the early Talchir Formation. This genus attained its maximum diversification in the next Karharbari Formation (Lower Artinskian) represented by 24 species. *Gangamopteris* started declining after the Karharbari Formation as indicated by comparatively smaller number of species (23) in the Barakar and (4) in the Raniganj formations Fig. 7). The size of the *Gangamopteris* leaves ranges from 2 to 25 cm in length and they possess different kinds of shape, apex and base (Maithy, 1965d). As compared to the genus *Glossopteris* that has different kinds of fertile organs preserved in attached or detached conditions, the fructifications in the genus *Gangamopteris* are rarely found. Plumstead (1958) reported *Vanus* and *Ottokaria* attached to the *Gangamopteris* leaves. The *Gangamopteris* leaves are rarely known in the upper Permian flora of upper Barakar, Barren Measures and Raniganj formations (Surange, 1966, 1975; Srivastava, 1997).

Srivastava and Agnihotri (2010) described sixteen species of *Gangamopteris* from Barakar Formation of Pench Valley Coalfield in Satpura Gondwana Basin. They have synthesized the data pertaining to the genera *Gangamopteris* and *Glossopteris* in different Lower Gondwana formations of India and found that *Gangamopteris* dominated over *Glossopteris* in Talchir Formation with a percentage ratio of 75% : 25%. However, towards Karharbari, lower Barakar and upper Barakar the dominance of *Gangamopteris* diminished in favour of *Glossopteris* as is evidenced by the following percentage ratio

Gondwana Coalfields/Valleys	**1. Ib-River**	**2. Talcher**	**3. Mand-Raigarh**	**4. Tatapani-Ramkola**	**5. Korba**	**6. Chirimiri**	**7. Singrauli**	**8. Hura**	**9. Pachwara**	**10. Raniganj**	**11. Jharia**	**12. Karanpura**	**13. Bokaro**	**14. Deogarh**	**15. Auranga**	**16. Hutar**	**17. Daltonganj**	**18. Pench Valley**	**19. Pali**	**20. Umaria**	**21. Kashmir**	**22. Giridih**	**23. Mohapani**	**24. Nand Coalfield**	**25. Arunachal Pradesh**
Gangamopteris angustifolia	+	+	+		*+					?	+			+	+			+	+	+	+		+		
G. clarkeana					*+	+									+			+							
G. cyclopteroides	+	+	+		*+	+	+		?	+	+	+		+	+	+	+	+	+	+	+	+	+	+	+
G. cyclopteroides var. *subauriculata*					*+																				
G. rajaensis	+				*+					+															
Gangamopteris sp.	+	+	+		*+	+	+			+	+	+		+	+	+	+	+	+	+	+	+	+		+

Fig. 4—Distribution of *Gangamopteris* species from Korba Coalfield in various Indian Gondwana coalfields.

(58% : 42% in Karharbari, 53% : 47% in lower Barakar and 10% : 90 % in upper Barakars).

Srivastava and Agnihotri (2010) analyzed that the coalescence of median veins in the genus *Gangamopteris* after straightening and consolidation in different species, e.g. *G. clarkeana*, *G. major*, *G. cyclopteroides* and *G. kashmirensis* has led to the midrib-like condition in *Glossopteris*. *Glossopteris decipien*s Feistmantel 1879 where the midrib is present only up to 1/2 or 2/3 of leaf lamina demonstrates the first stage of such process and further consolidation of median veins resulted into the development of species with complete midrib, viz. *Glossopteris churiensis* Srivastava, *G. retifera* Feistmantel and *G. stricta* Bunbury.

GEOLOGICAL SETTING

The Korba Coalfield is a part of the extensively distributed Lower Gondwana formations in the Mahanadi Valley

1. *Sakoarota polyangiata* (Equisetalean stems)	22. *G. taenioides*
2. *Noeggerathiopsis hislopii*	23. *G. syaldiensis*
3. *Cordaites* sp.	24. *G. emarginata*
4. *Euryphyllum indicum*	25. *G. stricta*
5. *Rubidgea obovata*	26. *G. communis*
6. *Gangamopteris cyclopteroides*	27. *G. indica*
7. *G. cyclopteroides* var. *subauriculata*	28. *G. browniana*
8. *G. angustifolia*	29. *G. pantii*
9. *G. clarkeana*	30. *G. karanpuraensis*
10. *G. rajaensis*	31. *G. major*
11. *Gangamopteris* sp.	32. *G. feistmantelii*
12. *Glossopteris intermittens*	33. *G. euryneura*
13. *G. stenoneura*	34. *Glossopteris* sp.
14. *G. arberi*	35. *Dictyopteridium sporiferum*
15. *G. raniganjensis*	36. Scale leaves of *Eretmonia ovoides*
16. *G. spatulata*	37. Scale leaves of *Lidgettonia mucronata*
17. *G. gigas*	38. Scale leaves of *Venustostrobus* sp.
18. *G. sastrii*	39. Scale leaves of *Plumsteadiostrobus* sp.
19. *G. nimishea*	40. *Vertebraria indica*
20. *G. maculata*	41. Stem casts / stem twigs
21. *G. barakarensis*	

Fig. 5—A list of complete megafossil assemblage recovered from Korba Coalfield.

S.N.	Location	Formation	Megafloral assemblage
1.	Manikpur colliery	Barakar Fm.	Abundance of *Vertebraria indica* (45 specimens); 5 species of *Glossopteris* (*G. communis, G. indica, G. browniana, G. arberi* and *G. intermittens*); *Gangamopteris cyclopteroides* (1); Scale leaves of *Lidgettonia mucronata* (3); *Venustostrobus* sp.(2) and a few equisetalean stems (4 specimens).
2.	Kusumunda colliery	Barakar Fm.	Percentage of *Glossopteris* very low (only 3 species, viz. *G. indica*, *G. nimishea*, *G. browniana*); Abundance of *Vertebraria indica* (60 specimens).
3.	Laxman colliery	Barakar Fm.	Plenty of *Sakoarota* stems /equisetalean stems (54 specimens); *Vertebraria* (3 specimens) and *Glossopteris* poorly represented (*G. communis* only).
4.	Gevra colliery	Barakar Fm.	Abundance of *Glossopteris* representing 21 species, viz. *G. communis*, *G. indica*, *G. browniana*, *G. karanpuraensis*, *G. pantii*, *G. nimishea*, *G. maculata*, *G. spatulata*, *G. raniganjensis*, *G. stenoneura*, *G. euryneura*, *G. taenioides*, *G. emarginata*, *G. arberii*, *G. stricta*, *G. sastrii*, *G. major*, *G. barakarensis*, *G. feistmantelii*, *G. gigas* and *G. syaldiensis*. *Gangamopteris rajaensis* (1 specimen); *Noeggerathiopsis hislopii* (3); *Euryphyllum indicum* (2); *Cordaites* sp. (35); *Rubidgea obovata* (2); scale leaves of *Plumsteadiostrobus* sp.(2); *Vertebraria indica* (22 specimens); stem/twig fragments (2)
5.	Dipika colliery	Barakar Fm.	Dominance of *Glossopteris* (11 species)-*G. stenoneura*, *G. intermittens*, *G. sastrii*, *G. nimishea*, *G. communis*, *G. raniganjensis*, *G. gigas*, *G. spatulata*, *G. major*, *G. feistmantelii*, *G. indica*; *Gangamopteris cyclopteroides* (2 specimens), *G. cyclopteroides* var. *subauriculata*, *G. clarkeana*, *G. angustifolia* and *G.* sp. (1 each); *Cordaites* sp. (8 specimens); *Noeggerathiopsis hislopii* (2); *Vertebraria indica* (38 specimens). *Dictyopteridium sporiferum* (14 specimens); Scale leaves of *Eretmonia ovoides* and *Lidgettonia mucronata* (3 each); stem casts (2)

Fig. 6—Distribution of various taxa in different collieries, Korba Coalfield.

Basin that extends over an area of 530 sq km with total coal reserves of around 10115 metric tonnes. It lies in between the drainage areas of the Son and the Mahanadi rivers. The Barakar sediments of the Korba Coalfield are continuous with those of the Mand-Raigarh Basin in the east, whereas, towards the north a vast stretch of Talchir sediments connects this coalfield with the Hasdo-Arand Basin. A narrow strip of Barakar rocks also connects the Korba field with Hasdo-Arand towards the east. Therefore, the Korba, Hasdo-Arand and Mand-Raigarh Basin areas form a master basin in the upper reaches of the Mahanadi Valley. The Korba Coalfield, situated in the Korba and Bilaspur districts of Chhattisgarh State, is elongated in an east-west direction, and is 64 km. long and 4.8 to 16 km. wide (Fig. 1). It is bounded by latitudes 22°15' and 22°30' and longitudes 82°15' and 82°55' (Raja Rao, 1983).

The Korba Coalfield was named by W.T. Blanford in the year 1870 and was first systematically examined by Lala Hiralal during 1886-87 (in Raja Rao, 1983). The Lower Gondwana rocks in this coalfield have been divided into three formations, i.e. Talchir, Barakar and the Kamthi (Fig. 8). The sediments of the Talchir Formation are well exposed in Suar Rivulet near Dondro Village in the eastern part and in the Ahiran Rivulet near Telsar Village in the north-central part of the coalfield but were barren of any plant megafossil. Similarly, the Kamthi sediments exposed in the eastern side of this coalfield near Sukdukla and Daranga villages were found to be unfossiliferous. The stratigraphic sequence met within the Korba Coalfield is given in Fig. 8.

MATERIAL AND METHODS

The material described in this paper is a part (8 specimens of *Gangamopteris*) of a large collection of plant mega fossils (512 specimens, Fig. 2) from the Barakar sediments, exposed in five open-cast mines/projects (O.C.P'S) namely Gevra, Dipika, Manikpur, Kusmunda and Laxman of the Korba Coalfield. The specimens of *Gangamopteris* have been collected from first three collieries (Figs 9, 10, 11). The collections were made during three excursions to this coalfield. The specimens are preserved as impressions as well as compressions on fine-grained carbonaceous shale and grey shale belonging to the Barakar Formation (Early Permian). They are measured and photographed to record the morphological characters using low power Leica Microscope and Nikon 35 mm Camera. Different kinds of external morphological features such as shape of the leaf, nature of apex and base, midrib, type of

***Gangamopteris* species**	**Talchir**	**Karharbari**	**Barakar**	**Barren Measures**	**Raniganj**	**Kamthi**
1. *Gangamopteris angustifolia* McCoy 1875	+	+	*+			
2. *G. anthrophyoides* Feistmantel 1880					+	
3. *G. buriadica* Feistmantel 1879	+	+	+			
4. *G. chatterjei* Bhattacharyya 1963			+			
5. *G. clarkeana* Feistmantel 1879	+	+	*+			
6. *G. cyclopteroides* Feistmantel 1876	+	+	*+		?	
7. *G. cyclopteroides* var. *acuminata* Feistmantel 1881	+					
8. *G. cyclopteroides* var. *areolata* Feistmantel 1879	+	+				
9. *G. cyclopteroides* var. *attenuata* Feistmantel 1879	+	+				
10. *G. cyclopteroides* var. *auriculata* Feistmantel 1879		+				
11. *G. cyclopteroides* var. *cordifolia* Feistmantel 1881	+					
12. *G. cyclopteroides* var. *crassinervis* Feistmantel 1881	+					
13. *G. cyclopteroides* var. *subauriculata* Feistmantel 1879	+	+	*+			
14. *G. fibrosa* Maithy 1965	+	+	+			
15. *G. flexuosa* Srivastava 1956					+	
16. *G. gondwanensis* Maithy 1965		+	+			
17. *G. hispida* Pant & Singh 1968		+	+			
18. *G. hughesii* Feistmantel 1876			+			
19. *G. intermedia* Maithy 1965	+	+	+			
20. *G. karharbariensis* Maithy 1965	+	+	+			
21. *G. kashmirensis* Seward 1905		+	+			
22. *G. maheshwarii* Bajpai 1990			+			
23. *G. major* Feistmantel 1879	+	+	+			
24. *G. media* Pant & Singh 1968		+				
25. *G. mucronata* Maithy 1965	+	+	+			
26. *G. oblanceolata* Maithy 1970		+				
27. *G. obliqua* McCoy 1875	+	+	+			
28. *G. obtusifolia* Pant & Singh 1968		+	+			
29. *G. papillosa* Pant & Singh 1968		+				
30. *G. rajaensis* Srivastava 1992			*+			
31. *G. spathulata* McCoy 1875	+	+	?			
32. *G. srivastavae* Maithy 1968		+				
33. *G. whittiana* Feistmantel 1876			+		+	
34. *G. sethiaensis* Srivastava & Agnihotri 2010			+			
35. *G. satpuraensis* Srivastava & Agnihotri 2010			+			
36. *G. indica* Srivastava 1956					+	
37. *Gangamopteris* sp.	+	+	*+			
Total number of taxa	**18**	**24**	**23**	**0**	**4**	**0**

*Denotes new contribution

Fig. 7—Stratigraphical distribution of *Gangamopteris* species in Indian Lower Gondwana formations.

Age	Formation		Lithology (Thickness)
Recent	Alluvium		
Late Permian to Early Triassic	Kamthi		Conglomerates, sandstones minor shales
Early Permian	Barakar	Upper Member	Sandstones, shales and thick coal seams inter-bedded with carbonaceous shale (350 m)
		Middle Member	Sandstones and conglomerate (300 m)
		Lower Member	Sandstones, shales and Ghordewa groups of seams (160 to 250 m)
	Talchir		Diamictites, greenish sandstones, olive green coloured needle shales, rhythmites, varves and black shale (200 m)
----------Unconformity----------			
Precambrian			Gneisses, migmatites, granites, etc.

Fig. 8—Geological succession of the Korba Coalfield area, Chhattisgarh (after Raja Rao, 1983).

meshes and the venation pattern have been taken into account during identification. The methodology given by Chandra and Surange (1979) has been adopted for the description for the various species of the genus *Gangamopteris*.

REPOSITORY

All the megafossil specimens described in this paper are deposited in the Repository of Birbal Sahni Institute of Palaeobotany, Lucknow vide statement no. 1307 and Museum Specimen Nos 39438-39445.

SYSTEMATICS

Division—GYMNOSPERMOPHYTA

Order—GLOSSOPTERIDALES

Genus—*Gangamopteris* McCoy, 1875

Type species—*Gangamopteris angustifolia* McCoy, 1875

Gangamopteris angustifolia McCoy 1875

(Pl. 2.1)

Remarks—This species is represented by a single specimen preserved as impression on carbonaceous shale. The leaf is incomplete and measures 6.3 cm in length and 1.5 cm in width. Leaf appears to be small, linear, narrow and lanceolate in shape. Apex and base not preserved and the margin of the leaf is broken at many places. 6-8 sub-parallel running veins present in the median portion of the leaf forming secondary veins that emerge at about 30-40º, arching a little outwards and then pass on to the margin in gentle curves. The meshes are linear, elongate and narrow throughout the lamina. Our specimen resembles *Gangamopteris angustifolia* described by McCoy 1875 (Pl. XII, fig. 1; Pl. XIII, fig. 2), Feistmantel (1879, Pl. IX, fig. 5; 1881, Pl. XXX, fig. 10), Maithy 1965d (Pl. 2, figs 9, 10), Chandra and Srivastava 1982 (Pl. 2, fig. 14) and Singh *et al.* 2006 (Pl. 2., fig. 4) in shape of the leaf and venation pattern.

Occurrence—Dipika Colliery.

Distribution in India—Talchir, Karharbari and Barakar formations.

Gangamopteris cyclopteroides Feistmantel 1876

(Pl. 1.1-4; Pl. 2.2, 3)

Remarks—This is the most common species of *Gangamopteris* and represented by three incomplete specimens in the collection. One of them is a compression and other two are impressions. Leaves small to medium in size, obovate, comparatively broader in the upper portion and tapering towards the basal portion. The preserved leaves measure 4.7 to 6.5 cm in length and 2.1 to 3.1 cm in width. The apex preserved in two leaves and is acute whereas the base is cuneate in one leaf and missing in others. Margin of the specimens is not continuous and broken at many places. The veins arise from the base, median region of the leaf is occupied by 5-7 thick parallel running strands. Lateral veins emerge

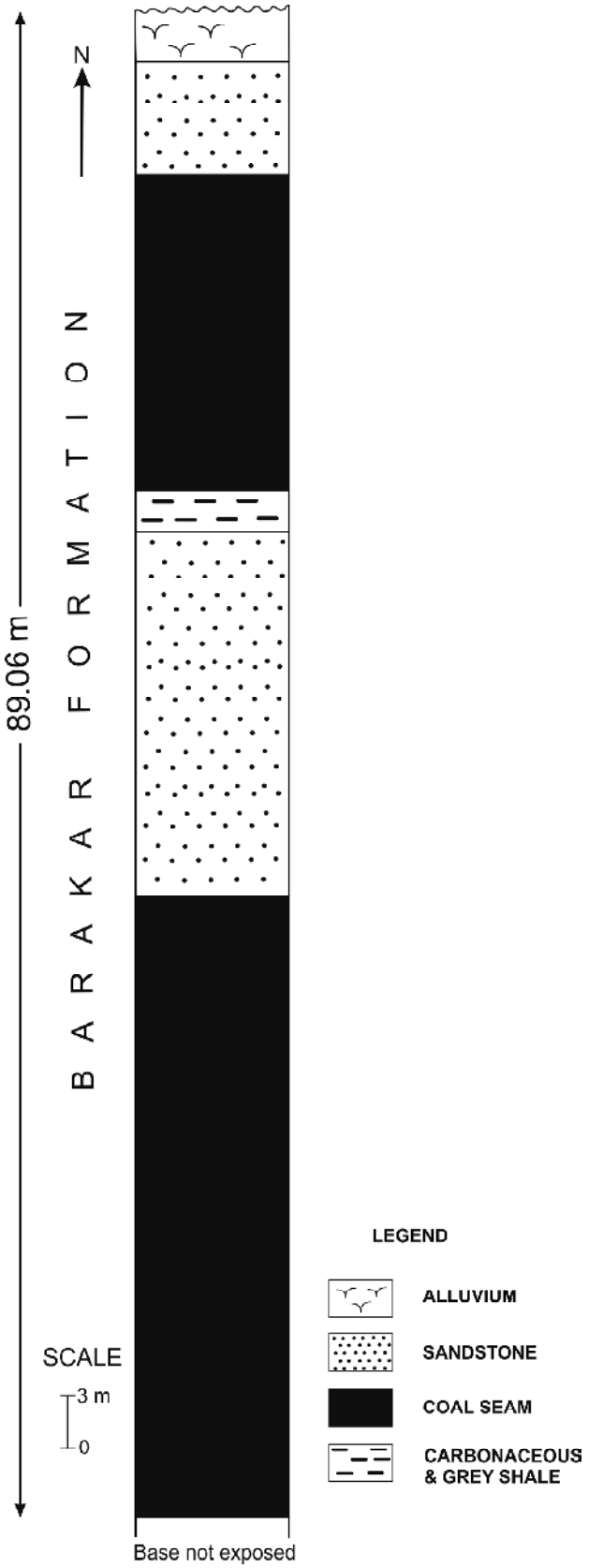

Fig. 9—Lithological succession at Gevra Colliery, Korba Coalfield.

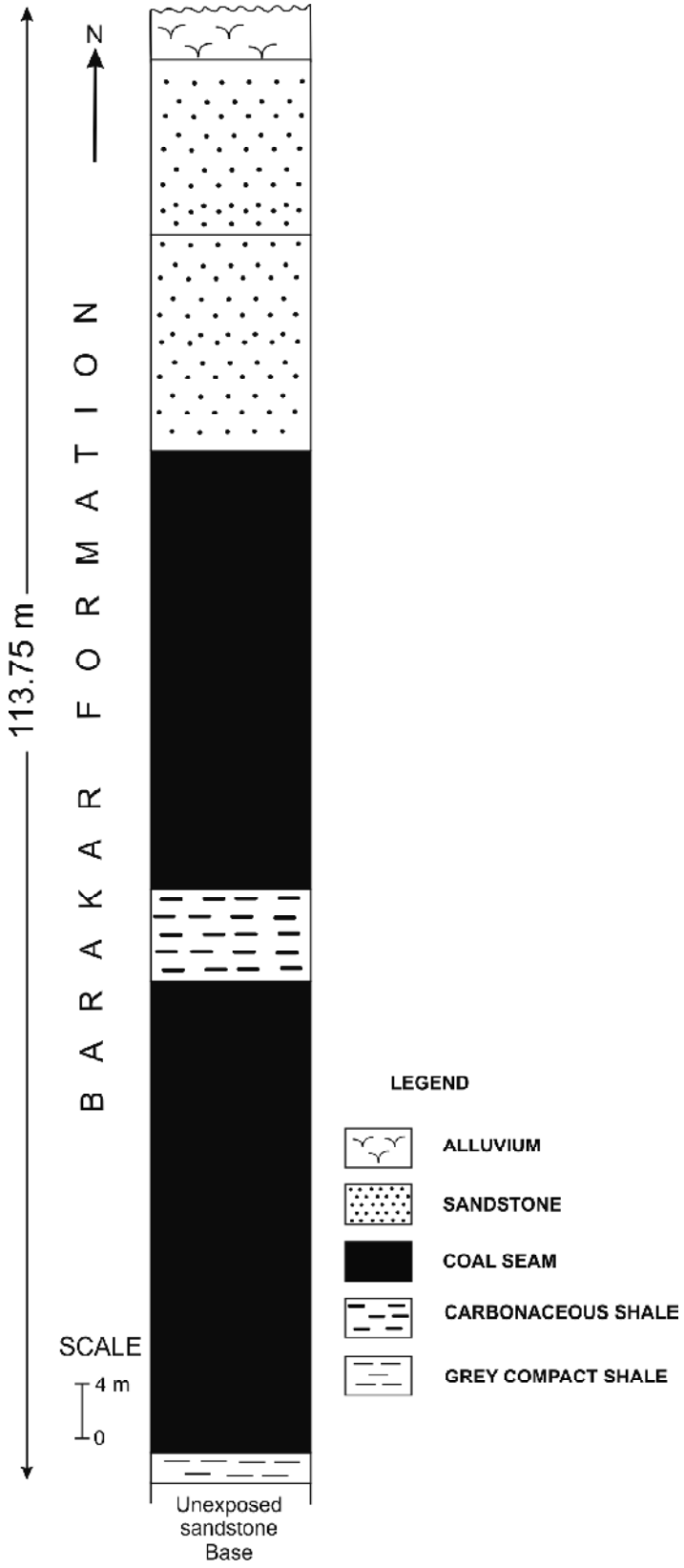

Fig. 10—Lithological succession at Dipika Colliery, Korba Coalfield.

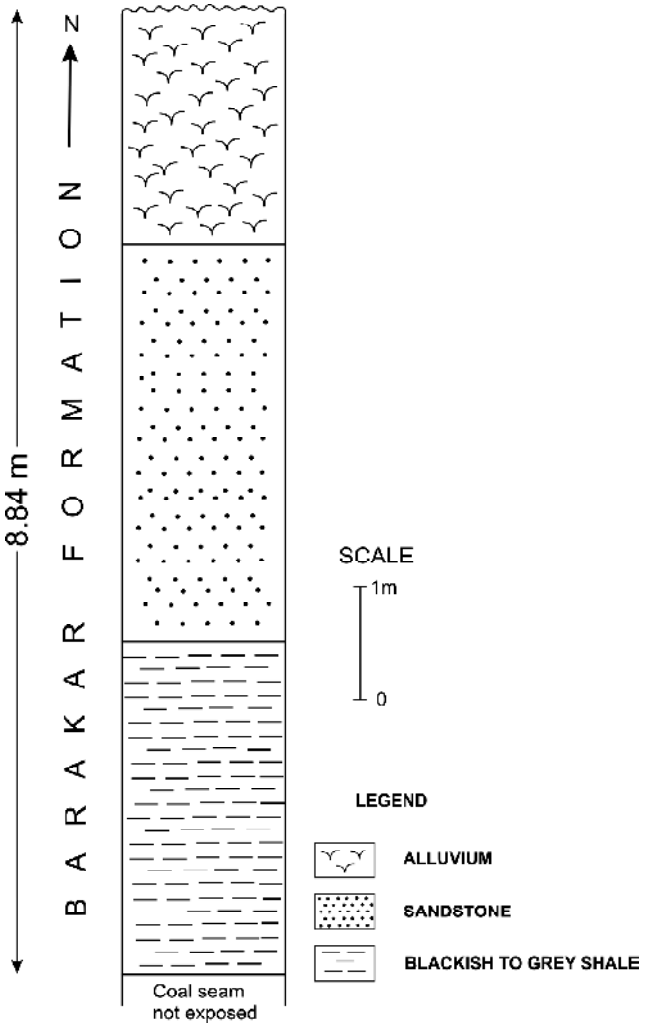

Fig. 11—Lithological succession at Manikpur Colliery, Korba Coalfield.

from the median strands at angles of 10°-15° and pass out to the margin with slight curves and meet at 30°-40°. Lateral veins form broad, long and polygonal meshes in the middle part and linear, narrow meshes near the margins. The present specimens are comparatively smaller in size but they resemble in their general shape and venation pattern with the specimens of *Gangamopteris cyclopteroides* described by Feistmantel 1879 (Pl. IX, figs 2, 4; Pl. X, fig. 3; Pl. XXVI, fig. 1), Maithy 1965d (Pl. 1, figs 1-3), Pant and Singh 1968 (Pl. 27, fig. 1), Srivastava 1977 (Pl. 1, fig. 1), Chandra and Srivastava 1982 (Pl. 1, fig. 1), Singh *et al.*, 2005 (Pl. 2, fig. 2), 2006a (Pl. 2, fig. 2), 2006b (Pl. 2, fig. 1).

Occurrence—Dipika and Manikpur collieries.

Distribution in India—Talchir, Karharbari and Barakar formations.

***Gangamopteris rajaensis* Srivastava** 1992

(Pl. 3.1, 2)

Remarks—The species is represented by a single complete leaf preserved as an impression. Leaf is simple, small, obovate in shape, broader in the apical part and tapering towards base. It measures 3.7 cm in length and 1.8 cm in width with an entire margin. Apex is obtuse and a small protuberance makes it mucronate, base acute-cuneate. The median region of the leaf occupies 5-6 parallel running dichotomizing veins which also show fibre like structures in between. Lateral veins arise at around 10-15°, arch slightly outwards and meet the margin at 40-45°. Meshes are elongate, narrow and polygonal. The specimens resembles very well with the Holotype and the other illustrated specimen of *Gangamopteris rajaensis* described by Srivastava 1992 (Pl. 5, figs 1, 2; BSIP Nos 36620, 36621) in shape, size and the venation pattern. It also compares with *G. rajaensis* described by Singh *et al.* 2006b (Pl. 2, figs 3, 5).

Occurrence—Gevra Colliery.

Distribution in India—Barakar Formation.

Gangamopteris clarkeana Feistmantel, 1879

(Pl. 3.3; Pl. 4.4)

Remarks—A single specimen of this species is present in the collection. The leaf is almost complete, small, coriaceous, entire, symmetrical and spathulate-rounded in shape and measures 4.2 cm in length and 3 cm in width. Apex is slightly broken at two places but appears broadly rounded and the base is acute. As the base is slightly deformed the median veins (4-6) can only be seen a little above the base in the median region. These sub-parallel interconnecting veins are comparatively thick and give rise to lateral veins which after anastomosis and dichotomization form narrow, oblong and polygonal meshes. The specimen is comparable with the specimens of *G. clarkeana* described by Feistmantel 1890 (Pl. XX, fig. 3), Maithy 1965d (Pl. 4, fig. 25), Srivastava 1977 (Pl. 2, fig. 9) and Chandra and Srivastava 1982 (Pl. 1, fig. 2) in general shape of the leaf and venation pattern.

PLATE 1

1. *Gangamopteris cyclopteroides* Feistmantel 1879, showing an incomplete leaf. Manikpur Colliery, BSIP Specimen No. 39438, Scale 5 mm.
2. Upper portion of the leaf in Fig. 1 showing interconnecting median strands and the emerging lateral veins. Scale Bar 5 mm.
3. *Gangamopteris cyclopteroides* Feistmantel 1879. Leaf preserved with apex and the middle portion. Dipika Colliery. BSIP Specimen No. 39439, Scale Bar 5 mm.
4. A portion of the leaf in fig. 3 showing acute apex and diverging lateral veins. Scale Bar 5 mm.

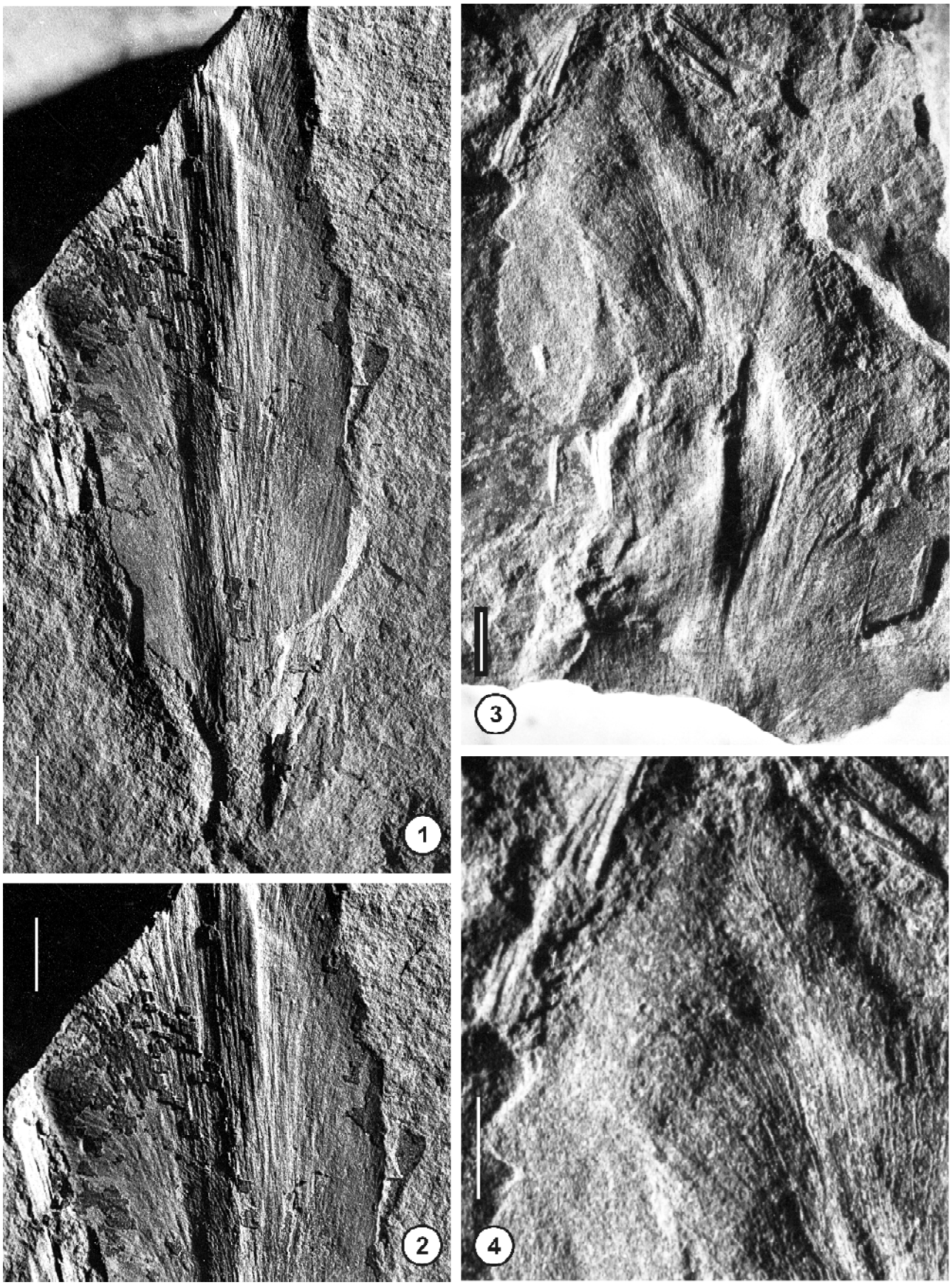

PLATE 1

Occurrence—Dipika Colliery.

Distribution in India—Talchir, Karharbari and Barakar formations.

Gangamopteris cyclopteroides var. **subauriculata** Feistmantel 1879

(Pl. 4.1-3)

Remarks—This species is represented by a single specimen preserved as compression. The leaf is incomplete, of medium size and oblanceolate in shape. The preserved portion of the leaf measures 11.4 cm in length and 2.3 cm in width in the upper part. The leaf becomes a little narrower towards the base and then gets broader again and finally terminates as roundly subauriculate. Apex not preserved, base auriculate and is 2.4 cm wide. 9-10 thick median veins arise from the auriculate base and proceed upwards up to the upper portion of the leaf. They are distantly placed in the basal-most part, however, in the upper region the veins are comparatively closely placed. Lateral veins start emerging from the median veins mostly in the upper portion of the leaf at an angle of 10-15º and they meet the margin at 35-40º. The meshes formed after anastomosis and dichotomization are narrow, oblong and polygonal. The present specimen is comparable with the specimens of *G. cyclopteroides* var. *subauriculata* described by Feistmantel 1879 (Pl. XIII, fig. 2; Pl. XV, figs 1, 3; Pl. XVI, fig. 3) in general shape of the leaf and venation pattern.

Occurrence—Dipika Colliery.

Distribution in India—Talchir, Karharbari and Barakar formations.

Gangamopteris sp.

(Pl. 3.4)

Remarks—A single incomplete leaf measuring 5.6 cm in length and 1.5 cm in width is present in the collection. Apex is not preserved, base cuneate and margin broken at many places. 5-7 thick median veins are present in the median region, however, the lateral veins which emerge from these median veins are faintly preserved. Very few ill-preserved meshes can be seen on the left side of the lamina. As the present leaf is not well preserved and its morphological features too are not distinct, we are unable to identify it up to the specific level and describe it here as *Gangamopteris* sp.

Occurrence—Dipika Colliery.

Distribution in India—Talchir, Karharbari and Barakar formations.

DISCUSSION, COMPARISON AND CONCLUSION

The biggest coal producing unit of India, i.e. the Korba Coalfield, located in Chhattisgarh State, central India, herein, has been explored for the first time for megafossil occurrences. Only few palynological records (Bharadwaj & Srivastava, 1973; Bharadwaj & Tiwari, 1964; Srivastava, 1973, 1984; Vijaya & Sinha, 2005) and a single megafloral record (Singh *et al.*, 2011), are known from this coalfield. Though, enormous megafossil data have been generated during past fifty years from the adjacent three coalfields, i.e. the Talcher, Ib-River and the Mand-Raigarh of the Mahanadi Basin, nothing was known of the Korba Coalfield. Work in the Korba Coalfield was taken up so that a database could be generated for all the four coalfields of the Mahanadi Basin to ascertain the early developmental history and the evolution of the flora in this master basin. Extensive investigations have been carried out in this field and as a result a huge collection of plant megafossils (512 specimens, Fig. 2) was made from the Barakar sediments exposed in five open cast mines, namely the Gevra, Dipika, Manikpur, Kusmunda and Laxman during three excursions. Although, sediments of the Talchir and Kamthi formations are also exposed at many places (Fig. 1), we could not find any plant megafossil in these strata.

The complete megaflora of the Korba Coalfield includes 13 genera with 38 species, representing three orders (Fig. 5). They are Equisetales (*Sakoarota polyangiata* / equisetalean stem), Cordaitales (*Noeggerathiopsis*, *Cordaites* and *Euryphyllum*) and Glossopteridales (*Gangamopteris*, *Rubidgea*, *Glossopteris*, *Dictyopteridium*, *Vertebraria* and scale leaves of *Eretmonia*, *Lidgettonia*, *Venustostrobus* and *Plumsteadiostrobus*). The order Glossopteridales is highly diversified with 34 taxa and the genus *Glossopteris* with 22 species (38.08%) dominates the flora followed by the genera *Vertebraria* (32.81%), *Sakoarota* (11.32%), *Cordaites* (8.39%), *Dictyopteridium* (2.73%), scale leaves of fertile organs (2.53%), *Gangamopteris* (1.56%), *Noeggerathiopsis* (0.97%), *Euryphyllum* (0.39%) and *Rubidgea* (0.39%) —Fig. 2. The distribution of various taxa from collieries in the Korba Coalfield has been shown in Fig. 6.

Eight specimens of *Gangamopteris* representing six species, viz. *G. cyclopteroides*, *G. cyclopteroides* var. *subauriculata*, *G. angustifolia*, *G. rajaensis*, *G. clarkeana* and *Gangamopteris* sp. have been systematically described and

PLATE 2 ⟶

1. *Gangamopteris angustifolia* McCoy 1875. An incomplete lanceolate leaf showing thick median veins, lateral veins and indistinct meshes. Dipika Colliery. BSIP Specimen No. 39440, Scale Bar 5 mm.
2. *Gangamopteris cyclopteroides* Feistmantel 1879. An ill-preserved leaf with apical and middle portions preserved. Dipika Colliery. BSIP Specimen No. 39441, Scale Bar 5 mm.
3. Upper portion of the leaf in fig. 2 enlarged to show the acute apex, lateral veins and meshes. Scale Bar 5 mm.

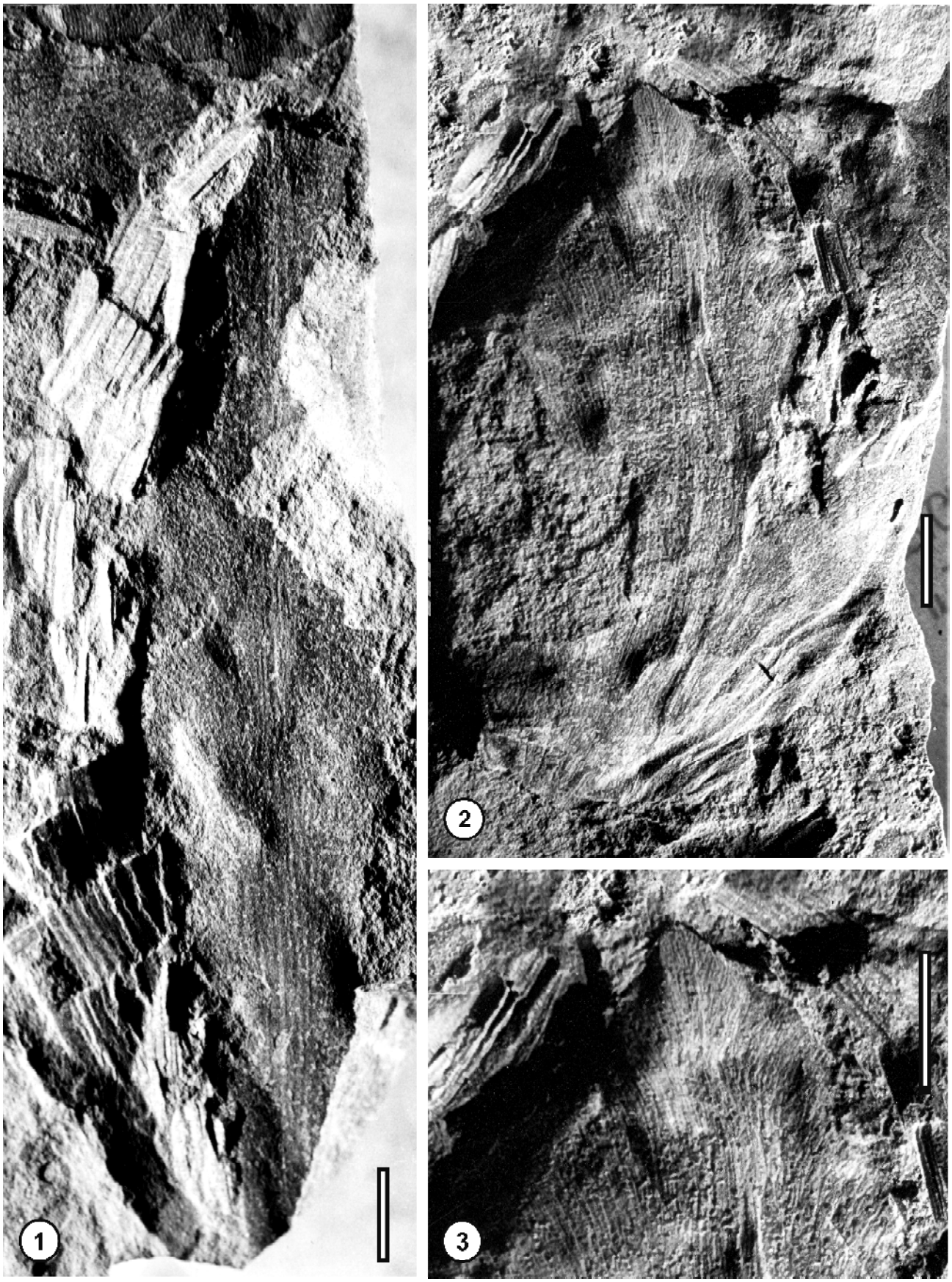

PLATE 2

discussed in this paper. These are recorded from the carbonaceous and grey shales in the Gevra, Dipika and Manikpur collieries (Figs 9, 10, 11). The remaining plant groups are being published elsewhere. So far, *Gangamopteris* has been reported from as many as 25 coalfields/localities belonging to Lower Gondwana covering almost all the five sedimentary basins of India (Fig. 4). It also depicts the distribution of presently studied *Gangamopteris* species in various Indian Gondwana coalfields. *G. cyclopteroides* is widely spread throughout the Indian Gondwana. *G. angustifolia* is also well represented in different coalfields, however *G. clarkeana*, *G. cyclopteroides* var. *subauriculata* and *G. rajaensis* have localized occurrences (Fig. 4). Out of a total of 37 species of *Gangamopteris* described till date, maximum (24) belong to Karharbari Formation, whereas, Talchir and Barakar formations have 18 and 23 species respectively (Fig. 7), confirming its maximum diversification during Karharbari Formation.

The occurrence of *Gangamopteris* is poor (eight specimens) in Korba Coalfield as compared to *Glossopteris* leaves (195 specimens, Fig. 2). *Gangamopteris cyclopteroides* represents the highest number of specimens (3) and the rest five species have one specimen each. *Gangamopteris clarkeana* and *G. cyclopteroides* var. *subauriculata* have been reported for the first time from Mahanadi Basin. Similarly, *G. cyclopteroides* var. *subauriculata* is being reported for the first time from Barakar Formation of Indian Gondwana.

It is interesting to note that the coal measures in all the five coal mines of Korba Coalfield belong to the Barakar Formation lithologically, however the composite megaflora (Fig. 6) recovered from two of the collieries, i.e. Gevra and Dipika, shows the presence of some of the typical Karharbari elements, viz. *Rubidgea*, *Euryphyllum*, *Noeggerathiopsis*, *Cordaites* and *Gangamopteris* in association with *Glossopteris* and *Vertebraria*. This clearly indicates that these elements appeared in the Karharbari Formation and continued in the Barakar Formation. The other three collieries, viz. Manikpur, Kusmunda and Laxman are completely devoid of these Karharbari elements (barring *Gangamopteris cyclopteroides* in Manikpur), they only have *Glossopteris*, *Gangamopteris*, *Vertebraria*, *Sakoarota* (equisetalean stem) and some scale leaves.

The genus *Cordaites*, which is a northern hemisphere taxon has been reported from the Korba Coalfield along with *Glossopteris* floral elements. An equisetalean genus *Sakoarota*, described from Madagascar has been reported for the first time from the Indian Gondwana. The groups Lycopodiales, Sphenophyllales, Filicales, Ginkgoales, Cycadales and Coniferales are completely absent in this area which shows that the area might not be adequately cool and humid to facilitate the growth of these shade loving understory plants.

The occurrence of *Botrychiopsis*, *Buriadia*, *Ottokaria*, *Euryphyllum* and *Rubidgea* along with *Gangamopteris*, *Noeggerathiopsis*, *Cordaites* and *Glossopteris* distinguishes the megaflora of the Karharbari Formation from the other Lower Gondwana megaplant assemblages found in Talchir, Barakar, Kulti and Raniganj formations (Banerjee, 1987). The presence of typical mega elements of the Karharbari Formation and the total absence of characteristic megafossils, viz. *Barakaria*, *Giridia*, *Gondwanophyton*, *Lelstotheca*, *Maheshwariphyllum*, *Palaeovittaria*, *Sphenophyllum*, *Trizygia*, *Pseudoctenis*, *Belemnopteris*, *Bengalia*, *Neomariopteris*, *Dichotomopteris*, *Raniganjia* and *Pteronilssonia* of the younger horizons (Barakar and Raniganj formations) in the present assemblage, further support that the assemblage of Korba Coalfield is comparable to that of Karharbari Formation of Giridih Coalfield of Damodar Basin (Maithy, 1965a, b, c, d; 1966; 1970) as most of the marker fossils (*Rubidgea*, *Euryphyllum*, *Noeggerathiopsis* and *Gangamopteris*) are common to both, whereas, *Botrychiopsis*, *Buriadia* and *Ottokaria* from the Karharbari Formation are missing in the present assemblage. Similarly, the assemblage containing *Neomariopteris*, *Gangamopteris*, *Noeggerathiopsis*, *Euryphyllum*, *Glossopteris*, *Vertebraria* and *Samaropsis*, described from the Karharbari Formation in the Auranga Coalfield (Srivastava, 1977) is closely comparable to the present assemblage.

The present assemblage can also be compared with the megaflora recorded recently from the Nand Coalfield, Maharashtra (Singh *et al.*, 2005). The genera *Noeggerathiopsis*, *Gangamopteris* and *Glossopteris* are common to both the coalfields, even all the *Glossopteris* species (barring *G. angusta*) namely *G. gigas*, *G. indica*, *G. major*, *G. spatulata*, and *G. browniana* found in the Nand Coalfield Assemblage are common with those of Korba Coalfield. *Buriadia* and a seed genus *Alatocarpus* present in the Nand Coalfield are missing in the present assemblage whereas *Sakoarota*, *Cordaites*, *Euryphyllum*, *Rubidgea* and *Vertebraria* found here are absent from the Nand Coalfield.

PLATE 3

1. *Gangamopteris rajaensis* Srivastava 1992. An obovate complete leaf showing well preserved median strands and venation pattern. Gevra Colliery. BSIP Specimen No. 39442, Scale Bar 5 mm.
2. Apical portion of the leaf in Fig. 1 enlarged to show a mucronate protuberance on the obtuse apex. Scale Bar 5 mm.
3. *Gangamopteris clarkeana* Feismantel 1879. Spathulate-rounded leaf showing broadly rounded apex, acute base and prominent median veins. Dipika Colliery. BSIP Specimen No. 39443, Scale Bar 5 mm.
4. *Gangamopteris* sp. An incomplete arched leaf showing prominent median veins, lateral veins and faint meshes. Dipika Colliery. BSIP Specimen No. 39444, Scale Bar 5 mm.

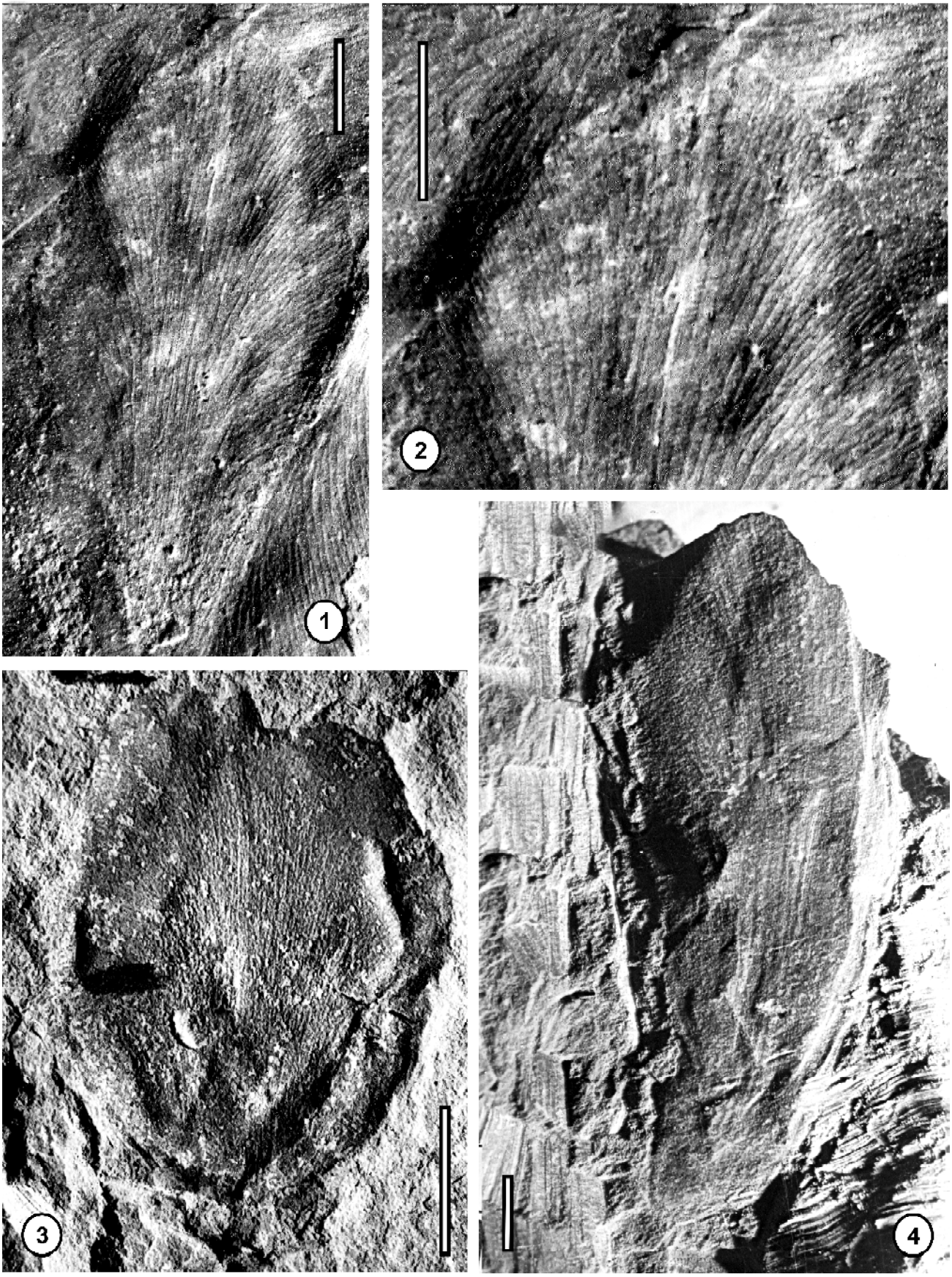

PLATE 3

With the taxa *Phyllotheca westensis*, *Noeggerathiopsis hislopii*, *Buriadia heterophylla*, *Gangamopteris cyclopteroides*, *Surangephyllum elongatum*, *Macrotaeniopteris feddenii*, *Glossopteris communis* and *G. browniana*, the assemblage of the South Balanda Colliery, Talcher Coalfield (Singh *et al.*, 2006a) is comparable with the Korba Coalfield Assemblage.

The assemblage containing *Buriadia*, *Botrychiopsis*, *Noeggerathiopsis*, *Barakaria*, *Gondwanophyton*; seven species of *Gangamopteris*, equisetalean stems, *Dictyopteridium*, *Vertebraria*, scale leaves and 29 species of *Glossopteris*, recently recorded from the Mand-Raigarh Coalfield in Chhattisgarh State (Singh & Chandra, in press) is also common with the Korba Coalfield Assemblage.

The above mentioned assemblages having typical marker fossils show similarity with the assemblage of Karharbari Formation. However, these generally lack ferns, sphenophils and various equisetales in their composition. There are reports (see below) of certain Barakar floras in the Indian Gondwana which have *Euryphyllum*, *Rubidgea*, *Noeggerathiopsis*, *Cordaites*, *Gangamopteris* and *Glossopteris* (typical elements of Karharbari Formation) along with some other elements of Barakar Formation including *Phyllotheca*, *Lelstotheca*, *Schizoneura*, *Sphenophyllum*, *Trizygia*, *Barakaria*, *Dizeugotheca*, *Alethopteris*, *Neomariopteris*, *Palasthalia*, *Rhabdotaenia*, *Palaeovittaria*, *Giridia*, *Gondwanophyton*, *Gondwanophyllites*, *Maheshwariphyllum*, *Pseudoctenis*, *Saportaea*, *Rhipidopsis*, *Ginkgoites*, *Scutum*, *Partha*, *Lidgettonia*, *Samaropsis*, *Cordaicarpus* and *Rotundocarpus* (Maheshwari & Prakash, 1965, Bansloi Valley, Rajmahal Hills; Maithy, 1971, Auranga Coalfield; Srivastava, 1988, 1992, Raniganj Coalfield; Srivastava, 1996, Auranga Coalfield; Srivastava & Tewari, 1996, Auranga Coalfield). The Korba plant assemblage correlates partially with these Barakar floras.

Generally, it has been observed that the genus *Vertebraria* is either absent or, if present, it is less common than in the beds where prolific number of *Glossopteris* species is found. It is interesting to note that both *Glossopteris* and *Vertebraria* are abundant in the same beds of the Korba Coalfield. *Vertebraria indica* axes have also been reported by Singh and Chandra (1995) from the Barakar Formation of the Ganga Nagar Rivulet Section near Braj Rajnagar Town, Ib-River Coalfield. These were preserved vertically (*in-situ*) in the sediments. Incidentally, similarly preserved *in-situ* roots are also found at the Manikpur and Kusmunda collieries of the present study. These two records of *in-situ* preservation of *Vertebraria* axes demonstrate the possibilities of autochthonous preservation of the vegetation and suggest the possibility that palaeosols may occur at least in some areas in this coalfield.

The plant fossil assemblage from the Korba Coalfield area indicates a dense forest type vegetation dominated by arborescent trees bearing *Glossopteris* foliage along with other plants belonging to the Equisetales and Cordaitales. The *Glossopteris* plants were deciduous (Plumstead, 1958) which is evident from the fact that abundant leaves of this genus are found preserved in different layers of sediments in a manner indicative of annual leaf fall. All the leaves of *Glossopteris* and other taxa are found detached and dispersed. There are 512 grey and carbonaceous shale specimens of various taxa (Fig. 2) in the present collection, and 70% of them are well preserved with minor distortion. This indicates that the deposition site for the vegetal matter was close to the original growing site. It also suggests that the deposition took place in a lacustrine environment from trees growing around the lake. The fine grained carbonaceous shale of the Barakar Formation having well preserved plant remains, was probably deposited in a low energy environment of an ox-bow lake as is shown by the unaltered nature of the biomass.

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PLATE 4

1. *Gangamopteris cyclopteroides* var. *subauriculata* Feistmantel 1879. Oblanceolate leaf, gradually narrowing towards the base and then gets broader again and finally terminates as roundly subauriculate. Dipika Colliery, BSIP Specimen No. 39445, Scale Bar 5 mm.
2. Apical portion of the leaf in Fig. 1 enlarged to show the median strands and the venation. Scale Bar 5 mm.
3. Basal portion of the leaf in Fig. 1 enlarged to show wide auriculate base having numerous prominent veins. Scale Bar 5 mm.
4. *Gangamopteris clarkeana* Feismantel 1879. Upper portion of the leaf in Plate 3, fig. 3, enlarged to show the rounded apex and diverging lateral veins. Dipika Colliery. BSIP Specimen No. 39443, Scale Bar 5 mm.

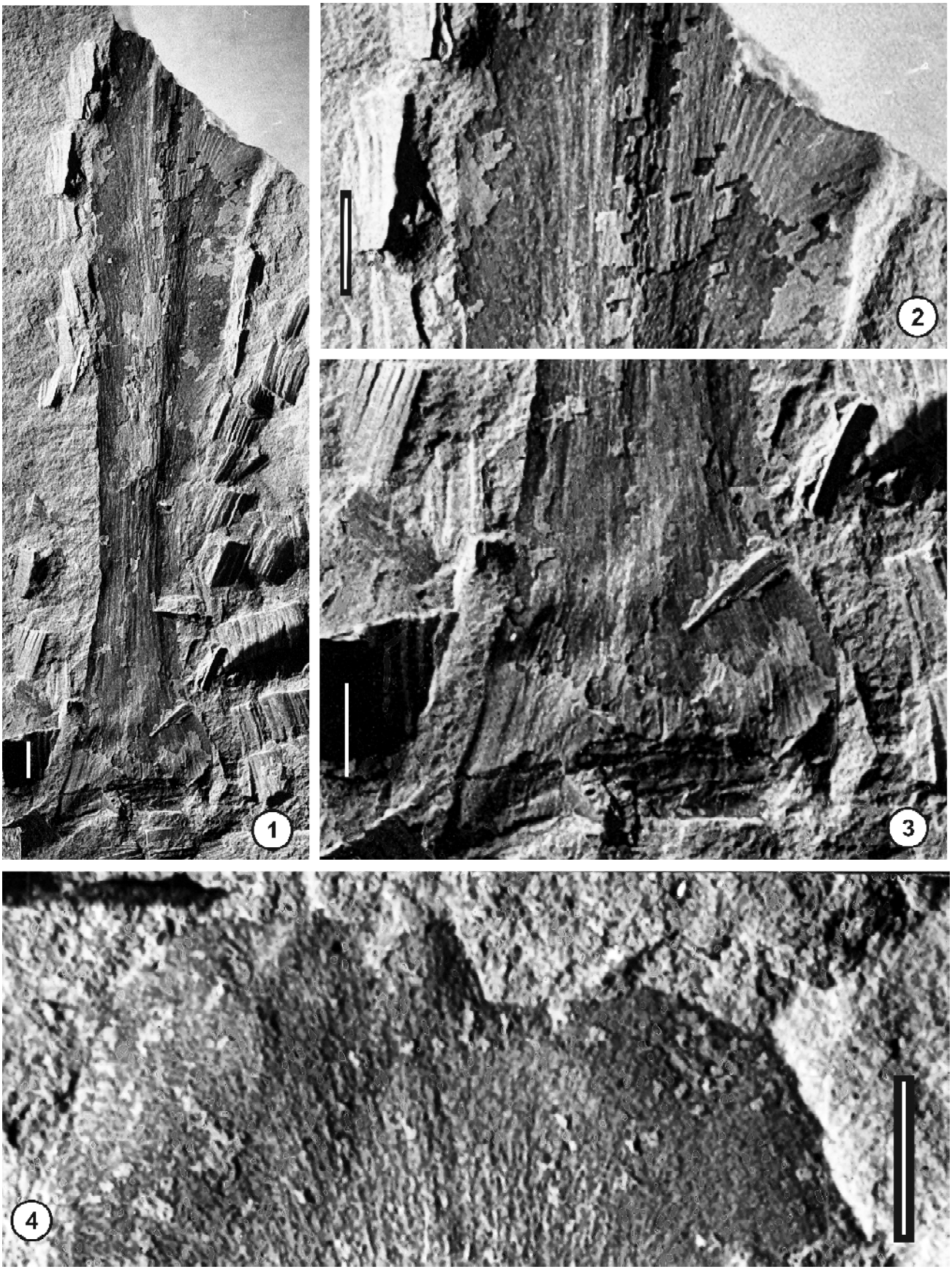

PLATE 4

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