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Permian biodiversity of Mahanadi Master Basin, Orissa, India and their environmental countenance

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ABSTRACT. The Permian geology and megafloral, miofloral, acritarchs and ichnofossil assemblages of different basins of the Mahanadi Master Basin, Orissa are enumerated in the present study. This review paper mainly deals with the plant species diversification of *Glossopteris* assemblage in five different lithological formations (Talchir, Karharbari, Barakar, Barren Measures and Lower Kamthi / Raniganj) and the development of flora during Permian in the Mahanadi Master Basin, Orissa. Among the mega-floras, leaves are the dominant part of the preserved flora followed by fertile forms, root forms and seed etc. The *Glossopteris* flora has been meticulously studied to portray the palaeoenvironment (mainly palaeoclimate and palaeovegetation) and palaeofloristics of these basins. Records of typical marine acritarchs and ichno fossils in this master basin in different Permian formations depict there could have been marine influence. These evidences of signature for marine environment demonstrate a paralic (coastal marine to deltaic) mode of origin of the Gondwana coal beds and associated sediments.

KEY WORDS: *Glossopteris* flora, Permian, Talchir, Karharbari, Barakar, Lower Kamthi, India

INTRODUCTION

The Permian Gondwana sediments of Mahanadi Master Basin occupy an area of about 3 500 sq. km and are mainly exposed in five sedimentary basins, viz. Talcher, Ib River, Katringia, Gaisilat and Athmalik basins. The biodiversity of the Mahanadi Master Basin during Permian has been assessed and the palaeoenvironment (mainly palaeoclimate and palaeovegetation) of different basins of this master basin has also been analysed. Moreover, records of typical acritarchs and ichno fossils of marine signature are discussed to get inferences on mode of origin of the Gondwana coal beds and associated sediments.

Apparent diversity of plant (especially of gymnosperm, pteridophyte, and some major Permian genera) and ichno taxa are analysed. The overall biodiversity of this master basin is also interpreted.

GEOLOGY AND STRATIGRAPHY

The Mahanadi Master Basin, Orissa, consists of five sedimentary basins: Talcher, Ib River, Katringia, Gaisilat, and Athmalik. The stratigraphy of the Permian of Mahanadi Master Basin is presented on Table 1.

The Ib River Gondwana basin is named after a tributary of the Mahanadi. The basin is located in the south-eastern part of Mahanadi Master Basin (Fig. 1) and occupies an area of 1460 sq. km. The basin is bounded by latitudes 21°30′ and 22°14′N and longitudes 83°32′ and

Table 1. The stratigraphy of the Permian of Mahanadi Master Basin, Orissa, India

Age	Formation	Lithology	Area
Upper Permian	Lower Kamthi	Fine to medium grained well sorted sandstone, siltstone, clay bed, coal, shale and sandstone	Ib River and Talcher basins
Middle Permian	Barren Measures	Clay and ironstone nodules, shale, sandstone and coal	Ib River and Talcher basins
late Lower Permian	Barakar	Shale, sandstone and coal	Ib River, Talcher, Gaisilat, Katringia and Athmalik basins
middle Lower Permian	Karharbari	Shale, sandstone and coal	ditto
early Lower Permian	Talchir	Boulder bed, needle shale, greenish sandstone, marl and rhythmites	ditto

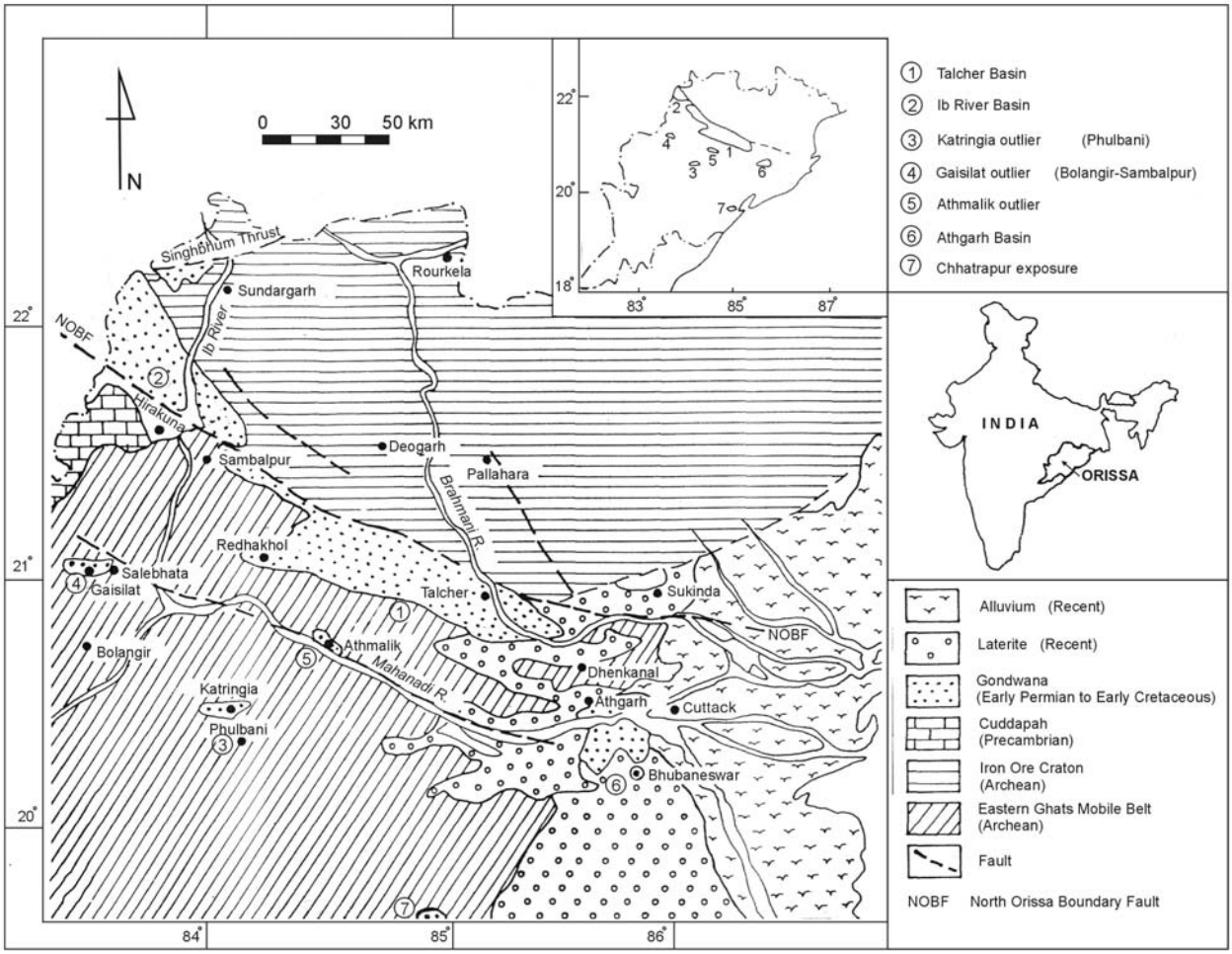

Fig. 1. Gondwana Basins of Mahanadi Master Basin, Orissa, India. After Pandaya (1995), Goswani et al. (in press b) modified

84°10′E. It covers parts of Sundargarh, Jharsuguda and Sambalpur districts. It embraces the Hingir Sub-basin in the north and the Rampur Sub-basin in the south. The Ib River Basin shows a westerly plunging synclinal flexure, which is like a half elliptical basin closed towards the northwest and having an axial trend in a NW-SE direction. This basin represents a synformal basin with an arched long northern limb (GSI 1997). Based on the work carried out by earlier workers of the Geological Survey of India (GSI), Central Mine Planning and Design Institute Ltd. (CMPDI) and other workers (Mehta & Anandalwar 1960, Pandey & Chakraborty 1964a, b, Raja Rao 1982, CMPDI 1987, Chadhury 1988, Mukhopadhyay 1987, 1989, Chaudhury et al. 1991, 1994, Pal et al. 1992, GSI 1997, Goswami 1997, 2002, 2006, in press, Goswami et al, in press a, b, c, Singh et al, 2006a, b, in press, Meena & Goswami 2004), the proposed geological succession for Ib River Basin has been presented

in Table. 2. Here the Kamthi Formation is classified into two members i.e. Lower Kamthi and Upper Kamthi of Late Permian and Triassic age, respectively, on the basis of lithology, megafloral and palynofloral assemblages. The Barakar Formation is also divided into two members: Lower Barakar and Upper Barakar depicts a north-westerly plunging synclinal structure with closure to the east and younger horizons outcropping towards the west. The bed dips to the north and the number of coal seams increases in that direction, indicating a possible homoclinal structure. The geological succession for Talcher Basin is presented

Table 2. Stratigraphic nomenclature for Ib River Basin, Orissa, India (after CMPDI 1987, Chaudhury 1988, Mukhopadhyay 1987, 1989, Pal et al. 1992, GSI 1997, Goswami 2002, 2006, in press, Goswami et al. in press a, b, c)

Age	Group	Formation	Lithology and fossil contents (thickness)	Thickness in m
Recent		Alluvium/ Laterite	Recent gravel and conglomerate	
Lower to Middle Triassic	Upper Gondwana	Upper Kamthi =Kamthi	Conglomerate, red shale with *Dicroidium* flora (Pal et al., 1992), coarse ferruginous-sandstone with clasts	>150
			Unconformity	
Upperr Permian	Lower Gondwana	Lower Kamthi =Raniganj	Fine to medium grained well sorted sandstone, siltstone, clay bed, coal, shale with broad mesh *Glossopteris* species, some arthrophytes and ferns (Goswami 2002). Palynoassemblage dominated by *Striatopodocarpites*, *Crescentipollenites*, *Faunipollenites*, along with *Verticipolelnites*, *Arcuatipollenites*, *Gondisporites*, and *Densipollenites* (Maiti 1994, Meena 1998)	>180
Middle Permian		Barren Measures	Grey shale, carbonaceous shale, fine to coarse grained sandstone,clay and ironstone nodules/shale.	>250
Lower Permian		Upper Barakar	Interbanded sequence of fine to medium grained sandstone, grey shale, claystone, siltstone, carbonaceous shales with plenty of *Glossopteris*, some ferns and arthrophytes (Goswami 2002) fireclay and thick coal seams with major ironstone bands. Palyno-assemblage is dominated by *Faunipollenites*, *Scheuringipollenites* and followed by *Striatopodocarpites*, *Barakarites*, *Microbaculispora*, *Striatites, Weylanditites*, and *Horriditriletes* etc. (Tiwari 1968, Meena 1999, 2000)	
		Lower Barakar	Arkosic, coarse to granular to pebbly sandstone with minor grey shale, carbonaceous shale with *Gangamopteris-Noeggerathiopsis-Euryphyllum* fossil assemblage (Goswami 2002) and thick coal seams. Palynoassemblage is dominated by *Scheuringipollenites*, *Faunipollenites* and followed by *Primuspollenites*, *Brijrajisporites*, *Callumispora*, *Lahirites*, *Rhizomaspora*, *Cuneatisporites, Platysaccus* and *Apiculatisporis* (Tiwari 1968)	350–500
		Karharbari	Conglomerate, carbonaceous sandstone with fresh feldspar grains containing thin coal bands only along the NW margin of the basin	30–65
		Talchir	Diamictite, greenish sandstone, olive green coloured needle shales and rhythmites.	>130
			Unconformity	
Precambrian			Granites, gneisses, amphibolites, and migmatites etc.	

purely on the basis of palaeobiology (evidenced from megaflora and palynoflora).

The Talcher Basin constitutes the south-eastern most member of the Lower Gondwana Mahanadi Master Basin (Fig. 1) and occupies an area of over 1813 sq km. The basin is bounded by latitudes 20°50′ and 21°15′N and longitudes 84°09′ and 85°33′E. This basin mainly occupies the Brahmani River Valley. It covers parts of Dhenkanal and Angul districts along with a small portion of the adjoining Sambalpur District. This basin in Table 3 (Basu 1964, Raja Rao 1982, CMPDI 1986, Mohanty & Chaudhury 1989, Manjrekar et al. 1995, Pal et al. 1991, Pal & Ghosh 1997, Goswami et al. in press b, Singh et al. 2006b). Similar to the Ib River Basin, here Kamthi Formation is also divided into two members Lower Kamthi of Upper Permian age and Upper Kamthi classified into lower and upper beds of Lower Triassic and Upper Triassic age on the basis of megafloral and palynofloral assemblages.

Katringia, Gaisilat, Athmalik basins (Fig. 1)

Table 3. Stratigraphic nomenclature for Talcher Basin, Orissa, India (after Manjrekar et al. 1995, Pal et al. 1991, Pal & Ghosh 1997, Goswami et al. press b)

Age	Formation/ Member	Lithology and fossil content	Thickness in m
Recent		Alluvium and laterite	
Triassic	Upper Kamthi	Upper bed (Upper Triassic): ferruginous, hard and quartzitic sandstones, bands of compact brown, grey and yellow shales and clasts of creamy white shales. Megafloral assemblage is dominated by *Dicroidium*, *Lepidopteris*, *Elatocladus*, *Yabiella*, and *Desmiophyllum*. Palynoassemblage includes *Brachysaccus*, *Rimaesporites*, *Samaropollenites*, and *Callialasporites*	>250
		Lower bed (Lower Triassic): medium-grained, crossbedded ferrugineous yellowish white sandstones, alternating with thick bands of red and grey shales. Megafloral assemblage is dominated by *Glossopteris* with few *Neomariopteris*, *Lepidopteris*, and *Dicroidium* (?). Palynoassemblage includes *Striatopodocarpites*, *Satsangisaccites*, *Falcisporites*, *Weylandites*, *Muraticavea*, *Lundbladispora*, *Arcuatipollenites*, *Playfordiaspora*, and *Alisporites*	
Upper Permian	LowerKamthi	Medium to coarse grained, pebbly cross-bedded ferruginous sandstones, clasts of greenish-white and grayish-white shales, pink clays. Megafloral assemblage is dominated by medium and broad mesh forms *Glossopteris* species with plenty of ferns and arthrophytes. Palynoassemblage is dominated by *Striatopodocarpites*, *Faunipollenites*, and *Crescentipollenites*	
Middle Permian	Barren Measures	Coarse to medium grained greenish grey feldspathic sandstones with shreds and lenses of chocolate coloured clay, micaceous siltstone, dark grey shale, carbonaceous shale, purple brown shale and clay ironstone. Palynofloral assemblage is dominated by *Densipollenites* and *Striatopodocarpites*	>317
Lower Permian	Barakar	Fine to coarse grained feldspathic whitish sandstones, siltstone, grey shale, sandy shale, fireclay and coal seams with polymictic conglomerate at the base. Megafloral assemblage is dominated by narrow and medium mesh forms *Glossopteris* species with few ferns and arthrophytes. Palynoassemblage is dominated by *Scheuringipollenites*, *Faunipollenites*, and *Striatopodocarpites*	600
	Karharbari	Medium to coarse grained whitish arkosic sandstones, carbonaceous shale, grey shale and coal seams. Megafloral assemblage is dominated by *Gangamopteris*, *Euryphyllum*, and *Noeggerathiopsis*. Palynoassemblage is dominated by *Parasaccites, Microbaculispora* and *Brevitriletes*	270
	Talchir	Diamictites, rhythmites, turbidites, conglomerate, fine to medium-grained greenish sandstones, olive coloured needle shales, turbidite, tiliets and tilloids etc. Megafloral assemblage comprises *Gangamopteris*, *Arberia*, *Ottokaria*, etc. Palynoassemblage is dominated by *Plicatipollenites*, *Potonieisporites*, and *Caheniasaccites*	>170
Unconformity			
Precambrian		Granites, gneisses, amphibolites, migmatites, quartzite, and pegmatites etc.	

are different small Lower Gondwana outliers and are located: Katringia at about 15 km from Phulbani town between latitude 20°28′ to 20°32′N and longitude 84°0′ to 84°12′E; Gaisilat 30 km. north of Bolangir town and 45 km. south of Baragarh town between latitude 21°2′ to 21°5′N and longitude 83°28′ to 83°37′E; and Athmalik about 40 km. northeast from Phulbani town between latitude 20°50′ to 20°54′N and longitude 84°27′ to 84°33′E respectively. They occupy an area about 75 sq. km within Phulbani and Baudh districts (Katringia), about 150 sq. km within Bolangir and Sambalpur districts (Gaisilat) and 75 sq. km within Angul, Phulbani and Baudh districts (Athmalik). The Gondwana sediments of these basins are lying discordantly over Precambrian basement. These basins comprise of Talchir, Karharbari and Barakar formations (Mohanty 1966a, Goswami et al. in press b).

PERMIAN BIODIVERSITY OF IB RIVER BASIN

Feistmantel (1880) reported *Schizoneura gondwanensis*, *Vertebraria indica*, *Sphenopteris* cf. *polymorpha*, and four species of *Glossopteris*, viz. *G. communis*, *G. indica*, *G. damudica*, and *G. browniana* from the Lower Kamthi sediments exposed at Garjan hill, Girundla, Kodaloi and Belpahar areas. This is the first published palaeobotanical record from the Ib River Basin. In subsequent years, a good collection of plant fossils ranging in age from Lower Permian to Upper Per-

mian were collected in this basin from various exposures of Barakar Patrapali, Lajkura and Jurabaga, open cast coal projects (locality near Belpahar Railway Station, locality near Brajaraj Nagar Railway Station, Ratanpur Fireclay quarry etc.), and Lower Kamthi/Raniganj (Garjan Hill, Girundla, Kodaloi, Sitaram, Dungri, Gopalpur and Laxamanpur Pahars etc.) formations (Mehta & Anandalwar 1960, Pande & Chakraborty 1964a, b, Sastry et.al. 1977, Singh & Chandra 1990, 1995, 1996b, 1999, Goswami 1997, 2002, 2006, in press, Goswami et al. in press a, b, c, Singh et al. 2006a, in press). In addition, from Barakar, Barren Measures, and Lower Kamthi formations of this basin 8, 17, 13 ichno taxa are also reported respectively (Mukhopadhyay 1996). A chart of megafossils and ichnofossils found in various formations is given in Table 4. The megafloral assemblage of Barakar Formation of this basin is one of the richest palaeofloral assemblages of Indian Gondwana comprising the lycopodiales, equisetales, sphenophyllales, filicales, cordaitales, coniferales, ginkgoales, cycadales and glossopteridales groups (consisting of fructifications, leaf and root forms). A large number of *Glossopteris* species (52) also have been reported from the Barakar Formation of this basin (Goswami 2002, Goswami et al. in press b). This is again the largest report of specific diversity in the genus *Glossopteris* occurring in the Barakar Formation in different Lower Gondwana basins of India. As a whole 87 (11 pteridophytes and

Table 4. Comparative analyses of Permian plant, animal and ichno taxa in different basins of Mahanadi Master Basin, Orissa, India

Plant/Animal/Ichno taxa (number of taxa)	IB RIVER BASIN					TALCHER BASIN					
	A. Talchir Formation (Lower Permian)	B. Karharbari Formation (Lower Permian)	C. Barakar Formation (Lower Permian)	D. Barren Measures Formation (Middle Permian)	E. Lower Kamthi Formation (Upper Permian)	F. Talchir Formation (Lower Permian)	G. Karharbari Formation (Lower Permian)	H. Barakar Formation (Lower Permian)	I. Barren Measures Formation (Middle Permian)	J. Lower Kamthi Formation (Upper Permian)	K. KATRINGIA OUTLIER, PHULBANI
Total number of plant taxa (155)	0	0	87	0	30	9	14	30	0	95	7
Bryophytes (1)											
Bryophytic remains						+					
Pteridophytes (31)	0	0	11	0	4	3	1	10	0	18	2
Lycopodiales (1)											
Cyclodendron leslii			+							+	
Equisetales (10)											
Bengalia raniganjensis			+								
Eqisetaceous spikes						+		+			
Equisetaceous stems			+		+	+		+			+
Lelstotheca robusta										+	
Phyllotheca indica										+	
P. westensis							+				
Raniganjia bengalensis			+							+	
R. etheridgei										+	
R. indica								+			
Schizoneura gondwanensis			+		+			+		+	
Sphenophyllales (6)											
Benlightfootia indica			+								
Sphenophyllum churulianum										+	
S. crenulatum										+	
S. speciosum								+			

Table 4. Continued

Plant/Animal/Ichno taxa (no. taxa)	A	B	C	D	E	F	G	H	I	J	K
Sphenophyllum utkalensis										+	
Trizygia speciosa			+					+		+	
Filicales (14)											
Asansolia sp. cf. *Asansolia phegopteroides*										+	
Cladophlebis sp. A											+
Cyathea sp. cf. *Cyathea tchihatcheffi*								+			
Damudopteris bengalensis										+	
Dichotomopteris sp.			+								
Dizeugotheca phegopteroides										+	
Merianopteris major								+			
Neomariopteris hughesii			+		+			+		+	
N. khanii										+	
N. lobifolia								+		+	
N. polymorpha										+	
N. talchirensis			+			+					
Pantopteris gracilis										+	
Sphenopteris polymorpha			+		+						
Gymnosperms (124)	0	0	76	0	26	5	13	20	0	77	5
Cordaitales (7)											
Cordaites sp.			+								
Euryphyllum maithyi			+				+				
Euryphyllum whittianum			+				+				
Kawizophyllum dunpathriensis			+								
Noeggerathiopsis hislopii			+			+	+				
Noeggerathiopsis minor			+								
Noeggerathiopsis sp.			+								
Cycadales (7)											
Macrotaeniopteris wianamattae					+						
Macrotaeniopteris feddeni					+		+				
Pseudoctenis balli								+		+	
Ginkgoites eximia			+								
Handapaphyllum indicum										+	
Rhipidopsis gondwanensis								+			
Senia reticulata										+	
Coniferales (1)											
Buriadia heterophylla			+				+				
Glossopteridales Leaf forms (80)											
***Gangamopteris* (9)**											
Gangamopteris angustifolia			+								
G. buriadica			+								
G. clarkiana						+	+				
G. cyclopteroides			+			+	+				+
G. hispida			+								
G. major			+			+	+				
G. obtusifolia			+								
G. rajaensis			+								
Gangamopteris sp.			+			+					
Surangephyllum elongatum			+				+			+	
Palaeovittaria kurzii			+								
***Glossopteris* (69) Total taxa**	0	0	52	0	22	0	3	15	0	46	3
Glossopteris acuminata										+	
G. ampla			+								
G. angusta			+							+	

Table 4. Continued

Plant/Animal/Ichno taxa (no. taxa)	A	B	C	D	E	F	G	H	I	J	K
Glossopteris angustifolia			+		+			+		+	
G. arberi			+							+	
G. barakarensis			+							+	
G. bosei			+							+	
G. browniana			+		+		+	+		+	+
G. churiensis			+		+						
G. communis			+		+		+	+		+	+
G. conspicua					+			+		+	
G. damudica			+		+			+		+	
G. decipiens			+		+						
G. dhenkanalensis										+	
G. divergens										+	
G. euryneura			+								
G. feistmantelii										+	
G. gigas			+		+			+		+	
G. giridihiensis			+								
G. gondwanensis										+	
G. gopadensis										+	
G. gregoryi			+								
G. hinjridaensis			+							+	
G. inaequalis										+	
G. indica			+		+		+	+		+	+
G. intermedia			+		+			+		+	
G. intermittens			+		+			+			
G. kamthiensis										+	
G. karanpuraensis			+								
G. karharbariensis			+		+						
G. kusumiae			+								
G. lanceolatus			+							+	
G. leptoneura			+					+		+	
G. longicaulis								+			
G. maculata			+								
G. maheshwarii										+	
G. major			+		+						
G. mohudaensis			+							+	
G. nautiyalii			+							+	
G. nimishea			+							+	
G. obscura										+	
G. oldhamii			+							+	
G. pandurata										+	
G. pantii			+								
G. radiata			+							+	
G. raniganjensis			+		+						
G. recurva			+								
G. retifera			+		+					+	
G. rewaensis			+		+						
G. sastrii			+							+	
G. searsolensis			+								
G. spathulato-cordata			+								
G. spatulata			+		+					+	
G. stenoneura			+		+			+		+	
G. stricta										+	
G. subtilis			+		+			+		+	

Table 4. Continued

Plant/Animal/Ichno taxa (no. taxa)	A	B	C	D	E	F	G	H	I	J	K
Glossopteris syaldiensis			+							+	
G. taeniensis			+							+	
G. taeniopteroides			+								
G. tenuifolia			+		+			+		+	
G. tenuinervis			+		+			+		+	
Glossopteris sp. cf. *Glossopteris taenioides*			+								
G. tortuosa										+	
G. utkalensis										+	
G. varia			+							+	
G. vulgaris			+							+	
G. waginanus			+								
G. zeilleri			+		+					+	
Glossopteris sp.			+								
Root form (1)	0	0	1	0	1	0	1	1	0	1	1
Vertebraria indica			+		+		+	+		+	+
Fertile form (26)	0	0	2	0	0	0	0	2	0	24	0
Cistella ovata										+	
Cistella sp.										+	
Denkania indica										+	
Dictyopteridium sporiferum								+		+	
Eretmonia utkalensis										+	
E. hinjridaensis										+	
E. karanpuraensis										+	
E. ovata										+	
Eretmonia sp.								+			
Glossotheca immanis										+	
G. orissiana										+	
G. utkalensis										+	
Indocarpus elongatus										+	
Khania dhenkanalensis										+	
Lidgettonia indica										+	
L. mucronata										+	
Lidgettonia sp.										+	
Nesowalesia indica										+	
Ottokaria bengalensis			+								
Partha indica										+	
P. spathulata										+	
Scutum elongatum										+	
S. indicum										+	
S. sahnii			+							+	
Scutum sp.										+	
Utkalia dichotoma										+	
Seeds (1)	0	0	0	0	0	0	0	0	0	1	0
Samaropsis sp.										+	
Miscellaneous (1)	0	0	1	0	0	0	0	0	0	1	0
Scale leaf			+		+					+	
Animals (2)	0	0	0	0	0	2	0	0	0	0	0
Annelids						+					
Insect Wing						+					
Total number of Trace/Ichno taxa (36)	0	0	8	17	13	14	0	12	4	2	0
Arenicolites			+	+	+						
Bivalve trails						+					
Bivalvian resting traces						+					

Table 4. Continued

Plant/Animal/Ichno taxa (no. taxa)	A	B	C	D	E	F	G	H	I	J	K
Chondrites								+		+	
Corophioides				+	+						
Cyclindrichnus					+			+			
Diplocraterion			+	+	+						
Feather stitch trails						+					
Furculosus						+					
Gastropod trails						+					
Granularia						+					
Lingulichnus				+	+						
Macaronichnus				+	+						
Monocraterion				+	+				+		
Muensteria				+	+						
Nereites						+					
Ophiomorpha								+			
Palaeophycus			+								
Palykladichnus				+							
Pasyphycus				+							
Pelecypodichnus						+					
Phycodes				+							
Planolites			+	+	+	+		+	+	+	
Psilonichnus				+				+	+		
Rhizocorallium			+	+		+					
Rosselia				+				+			
Sabellarifex						+					
Scalarituba						+					
Scolicia and other Trails			+	+	+						
Skolithos			+	+	+	+		+	+		
Spiral gastropod burrow								+			
Talchirichnus gondwanensis						+					
Teichichnus					+			+			
Terebellina								+			
Thalassinoides			+	+	+			+			
Zoophycos								+			
Total number of taxa (193)	0	0	95	17	43	25	14	42	4	97	7

76 gymnosperms) and 30 (4 pteridophytes and 26 gymnosperms) plant taxa are recovered from Barakar and Lower Kamthi formations of Ib River Basin. Altogether 95 taxa (plant/animal) from Barakar, 17 from Barren Measures and 43 from Lower Kamthi formations, are recorded.

A few palynoassemblages of Barakar and Lower Kamthi/Raniganj formations are recorded from different boreholes (IBH-6, 16, IBSH-6, IBT-2, 3, 4, 5, 6, 7) and from Chaturdhara and Basundhara Nala sections in this basin (Tiwari 1968, Maiti 1994, Meena 1998, 1999, 2000, Meena & Goswami 2004, Goswami 2002, in press). Palynoassemblages of these two formations are given in Table 2. Moreover, a few acritarchs namely *Foveofusa*, *Leiosphaeridia*, *Singraulipollenites*, etc. are recorded from Barakar and Barren Measures formations of Ib River Basin (Tiwari et al. 1995).

PERMIAN BIODIVERSITY OF TALCHER BASIN

The first published palaeobotanical records from Talcher Basin were by Blanford et al. (1859) and Feistmantel (1880). Subsequently, plant fossils ranging in age from Lower Permian to Upper Permian were recorded from different localities of Talchir (Saranga Village), Karharbari (South Balanda Colliery), Barakar (Gopal Prasad Village), Lower Kamthi (Handapa and Madhupur villages) formations in

the Talcher Basin (Roy & Bhattacharya 1967, Khan 1969, Surange & Maheshwari 1970, Surange & Chandra 1973a, b, c, 1974a, b, c, d, 1978, Chandra & Rigby 1981, 1983, Chandra 1984, Pant et al. 1985, Chandra & Singh 1986, 1988, 1989, 1992, 1995, 1996a, b, Patra & Panigrahy 1988, Patra & Swain 1991, Singh 1985, 2000, Singh & Chandra 1987, 1996a, 2000, Pal et al. 1991, Pal & Ghosh 1997, Bhattacharya et al. 2001, Singh et al. 2003, 2006b, Goswami et al. in press b). In addition, 14, 12, 4, 2 ichno taxa (see Tab. 4) are also reported from Talchir, Barakar, Barren Measures and Lower Kamthi formations of this basin respectively (Srivastava et al. 1996, De 1998, 1999a, b, 2001, Goswami 2002). A chart of megafossils and ichnofossils found in various formations of this basin is presented in Table 4. The megafloral assemblage of Lower Kamthi Formation of this basin is one of the richest palaeofloral assemblages of Indian Gondwana comprising the bryophytes, Lycopodiales, Equisetales, Sphenophyllales, Filicales, Coniferales, Cycadales, and Glossopteridales groups (consisting of fructifications, leaf, seed and root forms). A large number of *Glossopteris* species (46) also have been reported from the Lower Kamthi Formation of this basin (Goswami 2002, Goswami et al. in press b). This is again the largest report of specific diversity in the genus *Glossopteris* occurring in the Lower Kamthi Formation in different Lower Gondwana basins of India. Moreover, a large number of fructifications (24 species) are recovered from this Lower Kamthi Formation. As a whole 9 (1 bryophyte, 3 pteridophyte, 5 gymnosperm), 14 (1 pteridophyte and 13 gymnosperms), 30 (10 pteridophytes and 20 gymnosperms) and 95 (18 pteridophyte, 77 gymnosperm) plant taxa are recovered from Talchir, Karharbari, Barakar and Lower Kamthi formations of this basin respectively. Chandra and Singh (1996b) reported animal fossils from the type locality of Talchir Formation exposed near Sarang Village, Angul District. The fossils include impressions of nematodes, annelids and an insect wing. This is the first record of plant/animal co-existence in the earliest Permian Talchir rocks in India. Altogether 25, 14, 42, 4 and 97 taxa (plant/animal) are recorded from Talchir, Karharbari, Barakar, Barren Measures, and Lower Kamthi formations.

Similarly a number of palynoassemblages from Talchir, Karharbari, Barakar, Barren Measures, and Lower Kamthi formations are recorded from different boreholes drilled in this basin and from some surface exposures (Das 1958, Navale 1966, Navale & Tiwari 1966, Bharadwaj & Srivastava 1969a, b, Navale & Srivastava 1971, Srivastava 1970, 1984, Tiwari et al. 1991, Tripathi 1993, 1996, 2001, Tripathi & Bhattacharya 2001, Meena 2003). Palynoassemblages of different formations are presented in Table 3. Moreover, a few acritarchs namely *Foveofusa*, *Pilasporites*, *Plurigenus*, *Talcheridium*, and *Leiosphaeridia* of marine signature are recorded from Barakar and Karharbari formations of Talcher Basin (Tiwari et al. 1995).

PERMIAN BIODIVERSITY OF KATRINGIA BASIN

Mohanty (1966b) recorded megafloral assemblages from five different Talchir and Barakar exposures of this basin. These assemblages comprise of different species of *Glossopteris*, *Gangamopteris*, *Cladophlebis*, and *Vertebraria* along with one petrified fossil wood and several indistinct stem impressions of unknown affinity. Altogether 7 taxa (2 pteridophytes and 5 gymnosperms) are recorded from Talchir and Barakar formations of this basin. Among those *Glossopteris communis* and *Gangamopteris cyclopteroides* are dominant. So far no ichno/animal fossils are recorded from this basin (Goswami et al. in press b)

No plant or animal taxa are recovered so far from Gaisilat and Athmalik basins. Therefore it warrants the need for systematic study of the sediments around this basin to gather palaeontological information and to interpret Permian biodiversity of these basins.

DISCUSSION

In the Mahanadi Master Basin, *Glossopteris* flora is recorded from Talchir, Karharbari, Barakar (Lower Permian), Lower Kamthi (Upper Permian) formations of Talcher, Ib River and Katringia basins. A comparative analysis of Permian plant, animal and ichno taxa in different formations of these basins has been given in Table 4.

It is reviewed that in the Mahanadi Mas-

Table 5. A chart depicting apparent diversity trend of plant/ animal during Permian in Mahanadi Master Basin, Orissa, India

Fossils	Number of taxa found in Permian formations				
	Talchir	Karhar-bari	Barakar	Barren Measures	Lower Kamthi
Pteridophytes	3	1	17	0	20
Gymnosperms	5	13	84	0	86
Glossopteris	0	3	54	0	53
Plant taxa	9	14	101	0	106
Ichno taxa	14	0	17	17	14
Plant and animal taxa	25	14	118	17	120

ter Basin the number of plant taxa belonging to *Glossopteris* flora is variable in different formations. These are recorded from Talchir (early Lower Permian) 9 taxa, Karharbari (middle Lower Permian) 14, Barakar (late Lower Permian) 101, and Lower Kamthi (Upper Permian) 106 taxa (Tab. 5). Apparent diversity of Pteridophyta and gymnosperms of Mahanadi Mastetr Basin during the Permian is illustrated on Figures 2, 3.

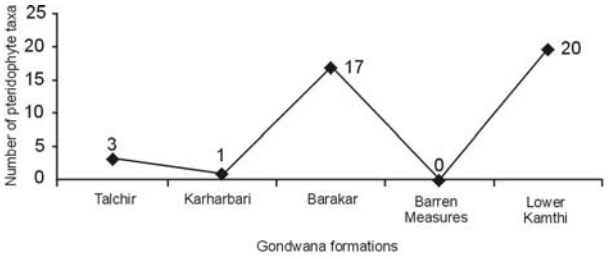

Fig. 2. Apparent diversity of pteridophytes taxa during Permian in Mahanadi Basin, Orissa, India

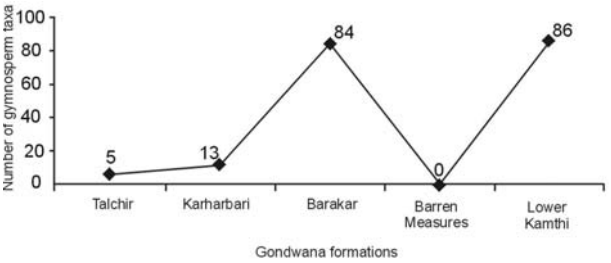

Fig. 3. Apparent diversity of gymnosperms taxa during Permian in Mahanadi Basin, Orissa India

The data depicts that the over all apparent diversification of taxa reached at its peak stage during Upper Permian (during the deposition of Lower Kamthi) and late Lower Permian (during the deposition of Barakar) time. The apparent diversity trend of the Permian plant is plotted in the Figure 4.

Various number of pteridophyte taxa are recorded from different formations of the

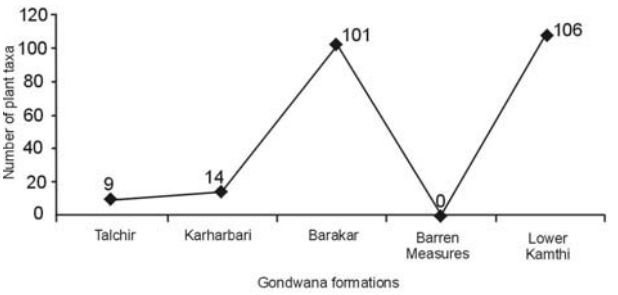

Fig. 4. Apparent plant diversity during Permian of Mahanadi Master Basin, Orissa, India

Mahanadi Master Basin: from Talchir 3 taxa, Karharbari 1, Barakar 17, Barren Measures 0, and Lower Kamthi 20, whereas the number of gymnospermous taxa recorded from Talchir is 5, from Karharbari 13, Barakar 84, Barren Measures 0, and Lower Kamthi 86 (Tab. 5). Apparent diversity trends of pteridophytes and gymnosperms reached in its peak in Lower Kamthi and Barakar formations and are presented separately in Figures 2, 3.

The assemblage of *Glossopteris* flora in these basins is dominated by gymnosperms throughout the Lower Gondwana as compared to pteridophytes and the maximum number of species is reported for the genus *Glossopteris*: from Karhari Formation 3 species, from Baraka 54 species, and from Lower Kamthi Formation 53 species (Tab. 5). Apparent diversity of *Glos-*

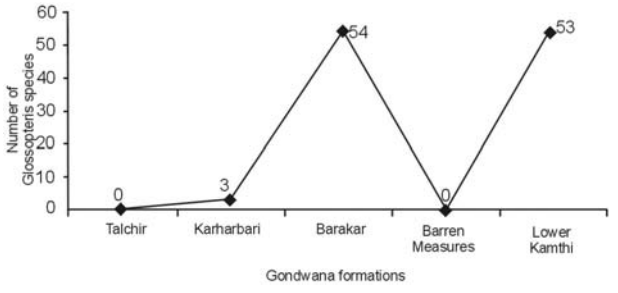

Fig. 5. Apparent diversity trend of the genus *Glossopteris* during Permian in Mahanadi Basin, Orissa, India

sopteris is peak in Barakar and Lower Kamthi formations and is sketched in Figure 5.

In this master basin, apparent diversification of the genus *Gangamopteris* started at the Lower Permian i.e. in Talchir (4 taxa) and Karharbari (3 taxa) and reached at its peak in Lower Barakar (8 taxa) and disappeared from the scene in Upper Permian (during the deposition of Lower Kamthi) time. Climate during the deposition of Upper Barakar and later time might comparatively be warmer and more humid. This climatic change did not favour the continuation of *Gangamopteris* plants further.

It is clearly observed that the mega-fossil remains in the Barren Measures Formation are yet not recorded in any basins of the Mahanadi Master Basin. It is because mostly due to the change in facies rather than the paucity of floral elements during that period. As is evidenced by presence of ironstone shales and purple brown shales in this formation, the depositional environment was mostly oxidising, thus preventing good preservation of vegetative remains. The ecological conditions may also have been arid with dry hot and wet humid spells as postulated by various workers, but not to that extent that plant life couldn't leave its signature on the sediments. Besides, wherever carbonaceous / grey shale sediments were deposited, miofloral remains (spores/ pollen) are found in good amount as discussed earlier (Tripathi & Bhattacharya 2001). The tectonic set up was also not stable enough to form coal and the depositional regime was also not conducive for the preservation of megafloral remains during Barren Measures time in this master basin seams (Cassyap & Tewari 1988, Goswami 2002, Goswami et al. in press b).

Palaeoclimate and palaeovegetation of different Gondwana formations of different basins of Mahanadi Master Basin, Orissa have been inferred on the basis of megafloral and palynofloral assemblages and is presented in Table 6 (Fox 1940, Lele 1976, Chandra & Chandra 1988).

The trace fossils occur in all the Permian formations except Karharbari of this master basin with striking density and diversity suggesting the high ichnological potential of the sediments. The following numbers of ichnotaxa have been reported from the formations: Talchir14, Karharbari 0, Barakar17, Barren Measures 17, and Lower Kamthi 14 (Tab. 5)

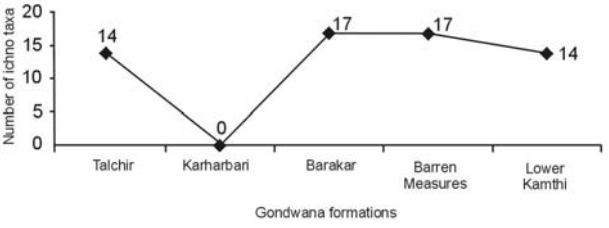

Fig. 6. Apparent diversity of ichno taxa during Permian of Mahanadi Basin, Orissa, India

and their apparent diversity trend is sketched in Figure 6. The presence of marine *Skolithos* ichno-facies in Talcher and Ib River basins and the observed uniformity in stratigraphic distribution of these forms suggests parallel palaeoenvironmental development characterized by frequent shallow marine events. According to De (2001) all these forms are comparable to the marine-influenced lower deltaic plain ichno-faunas of the Pennsylvanian of United States (Archer & Maples 1984) and marine Permian Gondwana ichno-taxa of South Africa (Hobday & Tavener-Smith 1975, Masson & Christie 1986). These ichno facies with very high ichno-diversity as noticed in Talchir (14 taxa) and Barakar (12 taxa) formations of this basin are typically marine in origin (Rhoads 1975, Chamberlain 1975, Kamola 1984). This fact suggests that short-lived marine incursions, splitting of coal seams at places into transgressive-regressive couplets and strong infaunal activities might have occurred in the Talcher and Ib River basins during respective time. The incursions that occurred during the Talchir, Barakar, Barren Measures and Lower Kamthi times were possibly the most conspicuous (De 2001). The above ichnological evidences reflect a paralic (coastal marine to deltaic) mode of origin of the Gondwana coal beds and associated sediments in this basin (De 2001, Goswami 2002).

The following numbers of plant/ichno/ animal taxa are recorded from the formations: Talchir 25 taxa, Karharbari 14, Barakar 118, Barren Measures 17, and Lower Kamthi 120 (Tab. 5). Accordingly, the apparent biodiversity trend of Mahanadi Master Basin during Permian has been plotted in Figure 7. It is inferred that the Permian biodiversity of this master basin is peak in Barakar and Lower Kamthi formations.

Records of acritarchs in different basins of the Mahanadi Master Basin, Orissa, also reflects marine to fresh water environment.

Table 6. Palaeoclimate and palaeovegetation during Permian of the major basins of Mahanadi Master Basin, Orissa, India

Major basins	Ib River Basin		Talcher Basin	
Gondwana Formation	Palaeoclimate	Palaeovegetation	Palaeoclimate	Palaeovegetation
Lower Kamthi (Upper Permian)	Warm, humid (very high), temperate with intermittent rainfalls. Dry as compared to Talcher Basin	Dense forest (but not so dense as compared to Talcher Coalfield), small trees growing underneath big tree, upland vegetation, with small lakes, ponds. Dominated by small, large arborescent trees and sub-dominated by bushy shrubs	Warm, humid (very high), temperate with intermittent rainfalls	Thick swampy dense forest with diversified plants, small trees growing underneath big tree, with small lakes, ponds. Small, medium and large arborescent trees, herbs and shrubs were also well represented
Barren Measures (Middle Permian)	Warm climate with medium humidity, temperate with dry hot and wet humid spells	Sparse scattered forest, small arborescent trees with herbaceous plants, semi aquatic, uplands	Warm with medium to low humidity, temperate with dry hot and wet humid spells	Sparse, forest like, semi aquatic, uplands, herbaceous plant is dominated
Barakar (Lower Permian)	Moderately warm, humid (high), temperate, abundant rainfall, hot and cold season	Thick, dense and swampy forest with diversified plants, low-lying river valley, majority of the plants are strongly built, arborescent, some are herbaceous and shrubby. Few plants are also semi aquatic	Warmer, humid (high), temperate, abundant rainfall, hot and cold season. Dry as compared to Ib River Basin	Forest dense (but not so dense as compared to Ib River Coalfield), low-lying river valley, some plants are semi aquatic. Forest was of arborescent trees with some herbs and shrubs
Karharbari (Lower Permian)	Cold, dry with medium to high humidity, strong winds, completely free from ice, ample sunlight and rainfall, small ponds and lakes appear	Forest like vegetation but sparse and not dense. Mediumly built plants, generally shrubs and herbs	Cold, dry with medium to high humidity, strong winds, completely free from ice, ample sunlight and rainfall, small ponds and lakes appear	Forest like vegetation appeared, but not dense. Mediumly built plants, generally shrubs and herbs
Talchir (Lower Permian)	Freezing cold with low to medium humidity, frigid glaciated strong winds	Sparse, patchy vegetation, very weakly built plants	Freezing cold, low to medium humidity, strong winds	Sparse, patchy vegetation, very weakly built plants

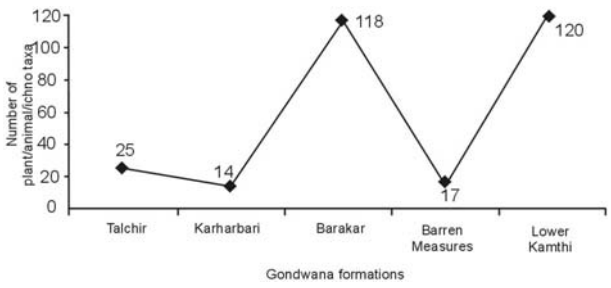

Fig. 7. Apparent biodiversity trend during Permian in Mahanadi Basin, Orissa, India

As opined by Traverse (1988), a group of a large range of presumed algal bodies, which are the indicators of brackish water, deltoid region and closed water bodies with increased salinity are included in acritarchs. These are recorded from Ib River, Talcher, Athgarh basins in Permian successions only (Tiwari et al. 1987, Srivastava 1984, Tripathi 1993, Tiwari et al. 1995, Goswami 2002). *Foveofusa*, *Leiosphaeridia Singraulipollenites*, etc. are recorded from Barakar and Barren Measures formations of Ib River Basin, while *Foveofusa*, *Pilasporites*, *Plurigenus*, *Talcheridium*, and *Leiosphaeridia* are recorded from Barakar and Karharbari formations of Talcher Basin and only *Leiosphaeridia* is found in Talchir sediments of Athgarh Basin, which clearly demonstrates that deposition of Permian sediments of these basins might have taken place in brackish water regime. Their occurrence also indicates a near-shore, shallow water condition and an open epicontinental marine environment (Tappam 1980, Traverse 1988) in Mahanadi Master Basin. The Gondwana Sequence of this Mahanadi Master Basin represented by different depositional settings is conventionally thought to be of non-marine origin (Sastry et al. 1977) due to the non-availability of faunal evidences. But later evidences of signatures for marine environment such as records of typical acritarchs and ichno fossils at various levels depict that there could have been marine influence in the Lower Gondwana basins of Orissa State.

It has been speculated on the basis of megafloral assemblages that there were two

inter-connected ecosystems in the Mahanadi Master Basin, Orissa during Permian time: (a) trrestrial system and (b) marshy system. Most of the gymnosperms form terrestrial system, which provide organic detritus for formation of coal. Similarly majority of the pteridophytes (ferns, lycopods and arthrophytes) growing in and around form marshy system as almost all arthrophytes and lycopods were probably aquatic or semi-aquatic plants growing in shallow waters or marshy places around lakes, ponds or rivers.

CONCLUSION

Talchir assemblage of Mahanadi Master Basin includes *Gangamopteris, Ottokaria* and *Arberia* and some monosaccate pollen (*Parasaccites*, *Plicatipollenites*, and *Potonieisporites*). It depicts some plants could thrive even when the land was largely ice covered, but the vegetation was scanty and thriving on ice-free areas. Subsequently in Upper Talchir time floral diversification started with increased sunlight and temperature. Assemblage of Karharbari Formation consists of *Gangamopteris*, *Euryphyllum*, *Noeggerathiopsis*, *Buriadia*, *Glossopteris communis*, *G. indica*, etc. and some palynotaxa viz., *Parasaccites*, *Microbaculispora*, *Brevitriletes* etc. All of the leaf forms of the Talchir, Karharbari, Lower Barakar assemblages are without a midrib except narrow mesh species of *Glossopteris communis* and *G. indica*, that demonstrates a cooler climate throughout the Talchir-Karharbari (early Lower Permian) time. During Upper Barakar time the climate tended to become warm and temperate. As a result *Gangamopteris*, *Euryphyllum*, *Noeggerathiopsis*, and *Buriadia* shows an abrupt decline after Lower Barakar and disappeared from the scene in Upper Barakar time. On the contrary the climate of Upper Barakar and Lower Kamthi time (Upper Permian) was favoured for the rapid growth and diversification of *Glossopteris* (Chandra & Singh 1992).

Palynoassemblage from Barakar Formation of Talcher Basin (Tripathi & Bhattacharya 2001, Tiwari 2001) reflects the change where the monosaccate-rich palynofloras were replaced by disaccate rich assemblage. In Barren Measures striate disaccate miofloras are recorded, where as in Lower Kamthi sediments (Upper Permian) striate disaccate with trilete miofloral are frequent.

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