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GLOSSOPTERIS FLORA FROM THE PALI FORMATION, JOHILLA COALFIELD, SOUTH REWA GONDWANA BASIN, MADHYA PRADESH, INDIA: PALYNOLOGICAL EVIDENCE FOR A LATE PERMIAN AGE

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ABSTRACT

A well preserved plant fossil assemblage comprising the orders Filicales and Glossopteridales has been systematically analyzed for the first time from the Pali Formation, near the Pali village, Johilla Coalfield, Umaria District, South Rewa Gondwana Basin, Madhya Pradesh. The assemblage includes *Neomariopteris hughesii*, fifteen species of *Glossopteris* namely, *G. bosei , G. communis, G. gondwanensis, G. indica, G. intermedia, G. intermittens, G. leptoneura, G. longicaulis, G. searsoliensis, G. spathulata, G. stricta, G. subtilis, G. tenuifolia, G. tenuinervis, G. vulgaris, Vertebraria indica, Utkaliolepis indica* (scale leaf) and dispersed seeds, *Cordaicarpus zeilleri, Rotundocarpus striatus, Samaropsis goraiensis* and *S. feistmantelii.* The palynoassemblage is characterized by dominance of striate bisaccate pollen grains chiefly species of *Striatopodocarpites* and *Faunipollenites* in association with *Striatites, Verticipollenites*, *Densipollenites*, *Lahirites*, *Crescentipollenites*, *Distriatites*, *Arcuatipollenites*, *Scheuringipollenites*, *Decussatisporites* and shows sporadic occurrence of some stratigraphically significant taxa like *Guttulapollenites, Alisporites* and *Weylandites* indicating a late Permian age. The megafloral assemblage of the Pali Formation is comparable with those of non–coaliferous beds of Kamthi and Bijori formations of Mahanadi and Satpura Gondwana basins, respectively, and to some extent with Pachhwara Formation of the Rajmahal Basin. The lithological attributes of the Pali Formation are also shared with these formations. Additionally, the flora is comparable with that of the Raniganj Formation of the Damodar Basin. The palynoflora of the Pali Formation can be correlated with the late Permian palynofloras of other lower Gondwana basins of India, Antarctica, South Africa, South America and Australia.

Keywords: Glossopteris flora, Palynology, Pali Formation, late Permian, Johilla Coalfield, Umaria District.

INTRODUCTION

The South Rewa Gondwana Basin is a rectilinear basin trending in the ENE–WSW direction (Fig.1) and lies in the central part of peninsular India. It comprises Mand–Raigarh, Korba, Hasdo–Arand, Chirimiri, Bisrampur, Umaria, Johilla, Korar, Sohagpur, Tatapani–Ramkola, Sonhat, Jhilimili and Singarauli coalfields. The mapping of the South Rewa Gondwana Basin was done by Hughes (1881, 1884). The term "Supra–Barakar" was initially used by Hughes (1881) for the sedimentary sequences above the Barakar Formation in this basin. The "Supra–Barakar" consists of Pali, Tiki, Parsora and Hartala formations. The age and consequently the stratigraphic order in which the Pali Formation occurs within "Supra–Barakar" has been a matter of debate (Fox, 1931; Rao and Shukla, 1954; Mitra, 1993; Dutta and Ghosh, 1993; Dutta, 2002; Shah, 2004; Ghosh *et al.,* 2007; Mukhopadhyay and Mukhopadhyay, 1999; Tarafdar *et al.,* 1993; Mukerjee *et al*., 2012) (Table 1). Hughes (1881) coined the term "Pali Bed" for the cross–bedded sandstones, claystones and carbonaceous shales exposed along the Johilla River, about 3 km west of the Pali Village (23º 21′ 40″: 80º 3′ 15″) on Pali – Umaria Road, Daigaon and Karkati in Umaria District, Madhya Pradesh. Fox (1931) and Lele (1964) used the terms Tiki Beds and Daigaon Stage for the similar rock sequences around the villages of Tiki and Chota Daigaon, respectively, and considered them as equivalent to Raniganj Formation of Damodar Basin on the basis of lithological similarity.

In the South Rewa Gondwana Basin, plant fossils are mainly known from the Talchir and coal bearing horizons of early Permian age. Surange and Lele (1957) described plant fossils from Talchir Formation of Johilla Coalfield, Chandra and Srivastava (1982) reported megafossils from Birsinghpur Pali, Anuppur and Chirimiri area (Talchir and Karharbari formations). Diverse megafossils were recorded from the Karharbari Formation by Hughes (1881, 1884) from tract lying between the rivers Johilla and Gopad (Gopad River section at Chanduidol, Bajbai and Mahan River section, Murna nala, Son River, Hardi, Umaria, Amadongri) and from Umaria, Dhobghata, Hardi in Sohagpur. Feistmantel (1879, 1882) recorded the plant mega fossils from the coal bearing beds (Parsora near Beli and Daigaon along the Johilla River) and later, Biswas (1955) recorded plant fossils from Kurasia Coalfield. Saksena (1956, 1963) described in detail the glossopterid leaves and seeds from the beds equivalent to the Karharbari Formation exposed near the confluence of Ganjra Nala and Johilla River. These include equisetalean axes, *Gangamopteris cyclopteroides, Glossopteris indica, G. browniana, G. decipiens, Noeggerathiopsis hislopii*, *Samaropsis johillensis* and *S. ganjrensis*. Chandra and Srivastava (1981) reported *Arberia surangei* from the Karharbari? beds of Birsinghpur Pali. The glossopterids from the Barakar Formation have been recorded by Fermor (1914) from Kurasia and Sanhat coalfields by Lele and Maithy (1963) and Maithy (1968) from Ganjra Nala. Recently, mega and micro fossils have been described from the Barakar Formation of Ganjra Nala section (Gautam, *et al*., 2013). Ghosh, *et al.,* (2013) reported disc – like galls from Triassic Corystosperm leaf *Dicrodium hugesii* (Feistmatel) Lele from the Parsora Formation of Dhauri village of Johilla Coalfield, South Rewa Gondwana Basin.

Besides megafossils, Permian megaspores have been reported from the Talchir Formation exposed near Birsinghpur Pali in the Johilla Coalfield, (Lele and Chandra, 1974) and from the sediments of the Barakar Formation exposed near

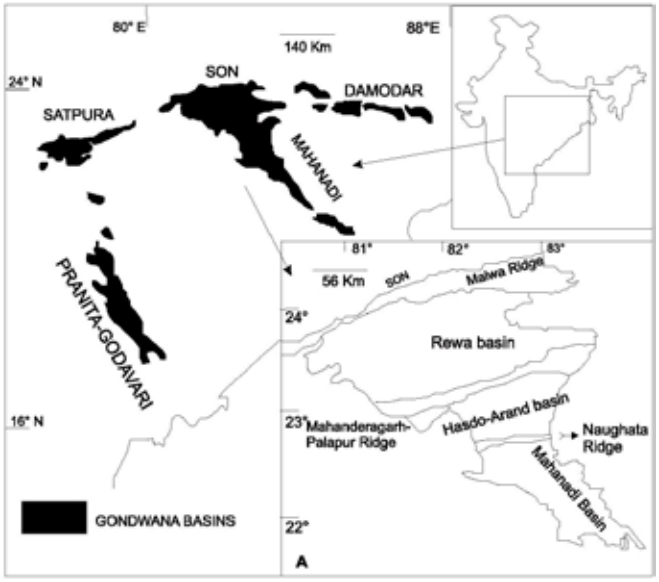

Fig.1. Major Gondwana basins of peninsular India Inset. A. showing the study area South Rewa Gondwana basin (after Mukerjee *et. al.* 2012)

the confluence of Ganjra Nala and Johilla River (Saksena, 1971; Tripathi, 1998, 1999; Tewari and Maheshwari, 1992). Additionally, megaspores have been reported from the Barakar Formation of Umaria Coalfield (Tripathi, 1997b; Tripathi and Mishra, 2001) and Birsinghpur Pali Coalfield (Pant and Mishra, 1986) and Parsora Formation from Beli (Lele, 1963).

Investigations on palynological assemblages have been carried out by Chandra and Lele (1979) from the Talchir Formation (early Permian) from different areas of South Rewa Gondwana Basin. Lele (1965) reported a monosaccate pollen grain *Stellapollenites* from the Talchir Formation and Lele and Chandra (1973) recorded miospore assemblage from the Talchir boulder bed and overlying needle shales in Johilla Coalfield. Lele and Maithy (1969) described the plant micro and macrofossils from the Ganjra Nala beds of Johilla Coalfield. Anand Prakash and Srivastava (1984) recorded palynomorphs from the exposures along the Johilla River and Pali Coal mine. Chandra and Srivastava (1986) recorded palynomorphs from the Karharbari Formation of Umaria, Birsinghpur Pali, Anuppur and Chirimiri areas from the beds equivalent to the Karharbari Formation. From the Pali Formation, palynofloral assemblages have been recorded by Tiwari and Ram–Awatar (1986) and Ram–Awatar (1987, 1996, 1997) These assemblages comprise monosaccate and striates bisaccate pollen grains (*Faunipollenites, Striatopodocarpites, Crescentipollenites* and *Densipollenites*). On the basis of significant pollen taxa, a late Permian age is indicated for the Middle Member of the Pali Formation (Tiwari and Ram Awatar, 1986; Ram–Awatar, 1987).

A triassic palynoflora has been recorded from the Upper Member of the Pali Formation (early to middle Triassic age) exposed in Son–Chundi River Section (Ram–Awatar, 2003). Recently, a group of spore tetrads with variable ornamentations have been recorded from the sub surface samples of the Upper Pali sediments from Shahdol District (Ram–Awatar, 2011).

On the basis of lithological and palynological evidences, the Pali Formation has been assigned varying ages, ranging from middle Permian to middle Triassic by previous workers (Table 1). The Pali Formation was considered to be younger than the Raniganj Formation and was assigned an early Triassic age (Fox, 1931). Later, Pali and Tiki formations were merged together on the basis of lithological similarities and termed as Pali–Tiki Formation ranging from late Permian to early Norian in age (Rao and Shukla, 1954; Dutta *et al.,* 1977; Raja Rao, 1983; Rajaiya and Agasty, 1990; Dutta and Ghosh, 1993; Dutta, 2002; Mukhopadhyay *et al*., 2010 and Mukerjee *et al.,* 2012). A late Permian age has also been suggested for the Pali Formation on the basis of palynology (Tiwari and Ram–Awatar, 1986, 1989; Ram–Awatar, 1987). On the basis of lithology and palynology, the Pali Formation has been divided into lower, middle and upper members (Chakraborti, 1982; Mitra, 1993; Kundu *et al.,* 1993; Tarafdar *et al.,* 1993; Ram–Awatar and Gautam, 2013 and Gautam *et al*., 2016) Accordingly, a middle Permian age for the Lower Pali Member, late Permian age for the Middle Pali Member and early to middle Triassic age for the Upper Pali Member has been suggested. Further, the lower, Middle and Upper Pali members were equated with Barren Measures, Raniganj and Panchet formations of the Damodar Basin, respectively. The present study focuses to resolve the biostratigrahic age of the Pali Formation on the evidences of megafossils and palynofloral assemblage retrieved from the shales of the Pali Formation exposed along Pali–Mangthar road cutting section near Pali Village. This is the first detailed systematic record of the megaflora and miofloral assemblages from the Middle Member of Pali Formation of Johilla Coalfield.

GEOLOGICAL SETTING

The Johilla Coalfield is located (23º16' : 23º23' N lat.; 80º56' : 81º05' E long.) at about 33 km south–east of Umaria Railway Station on Katni–Bilaspur line of the Central Railway, Umaria District, Madhya Pradesh. The Coalfield was named after the Johilla River. Medlicott (1860) surveyed the central part of the Nerbudda area, South Rewa Gondwana Basin and Hughes (1881, 1884) studied and mapped the area systematically. A brief geological account of Johilla Coalfield was given by Fox (1934) who categorized the Gondwana formations as Talchir, Barakar and Supra Barakar. The Supra–Barakar includes Pali, Tiki and Parsora formations. Geology of the area has been studied by Raja Rao (1983) and Mitra (1993).The lithostratigraphic succession of Johilla Coalfield is given in Table 1 (after Ghosh *et al.,* 2007).

The Pali Formation is well exposed along the right bank of the Ganjra Nala. It is devoid of carbonaceous material and is characterised by fine clastics comprising massive (about 4–5 m thick), red to greyish brown and very dark red coloured mudstone with subordinate moderate brown, pale olive and yellowish grey mudstone showing incipient development of paleosol profile. At places, carbonaceous clay is also seen. A sharp contrast is

EXPLANATION OF PLATE I

1. ***Neomariopteris hughesii*** (Zeiller) Maithy, BSIP museum specimen no. 41173; 2. ***Glossopteris bosei*** Chandra and Surange, BSIP museum specimen no. 41174; 3. ***Glossopteris communis*** Feistmantel, BSIP museum specimen no. 41175a; 4. ***Glossopteris communis*** Feistmantel, BSIP museum specimen no. 41176; 5. ***Glossopteris gondwanensis*** Pant and Gupta, BSIP museum specimen no. 41177; 6. ***Glossopteris indica*** Schimper, BSIP museum specimen no. 41178. (Scale Bar = 1 cm)

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Plate I

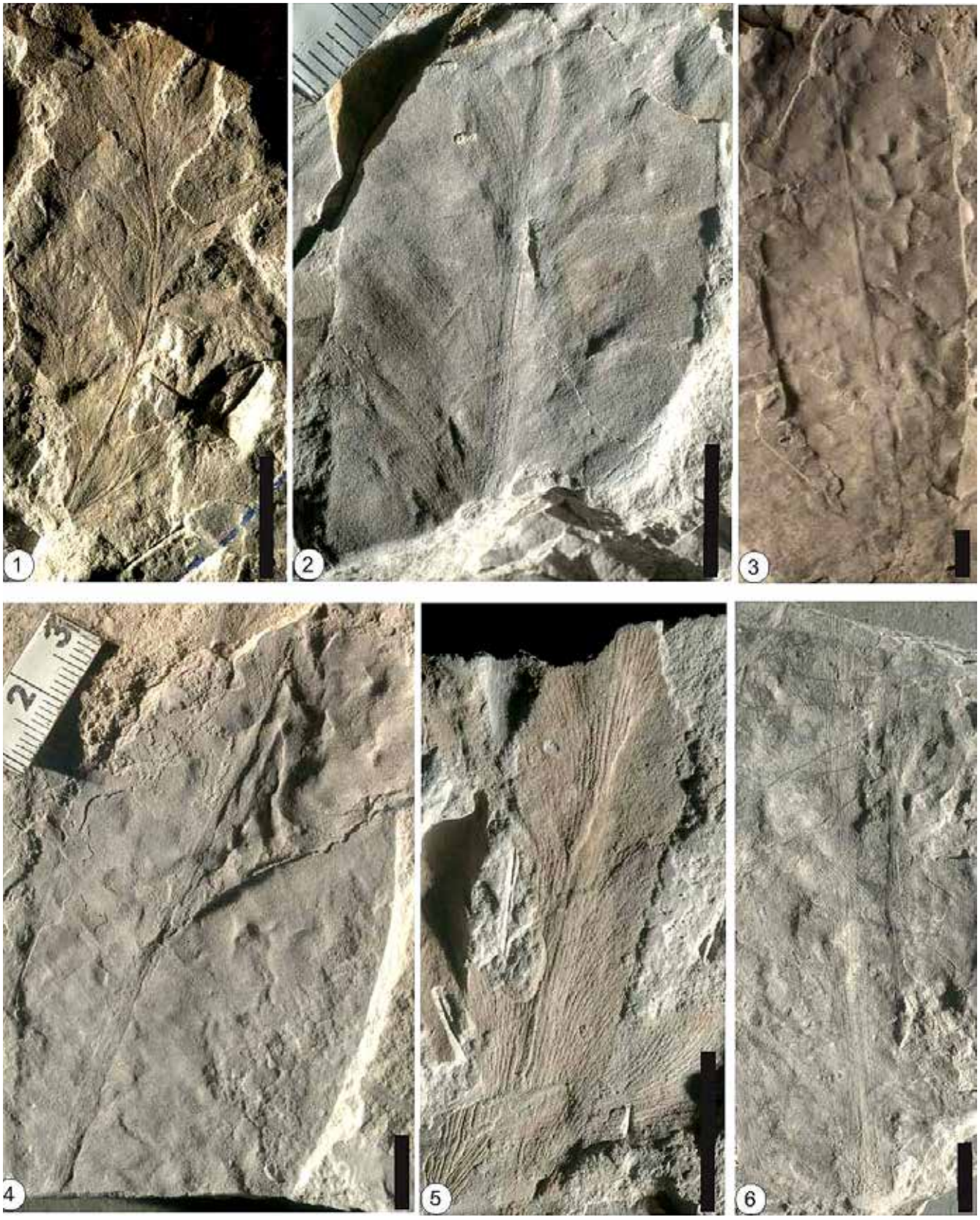

Table 1. Gondwana stratigraphy sequence of the South Rewa Gondwana Basin as proposed by previous workers.

Age	Fox (1931)	Rao and Shukla (1954)	Mitra 1993	Dutta and Ghosh (1993)	Dutta (2002)	Shah (2004)	Ghosh *et al.*, (2007)	Mukhopadhyay (1999)	Tarafdar *et al.*, (1993)	Mukerjee *et al.*, (2012)
Jurassic		Parsora		Parsora	Parsora	Hartala	Hartala			Parsora ?
Triassic	Tiki Parsora Pali	Pali –Tiki Group	Parsora Tiki Pali	Pali –Tiki Group	Pali –Tiki Group	Tiki Parsora	Tiki Parsora	Tiki – Parsora	Parsora Tiki Upper Pali	Tiki Karki Pali
Permian	Raniganj Barakar Talchir	Raniganj Barakar Talchir	Raniganj Barakar Talchir	Raniganj Barakar Talchir	Raniganj Barakar Talchir	Pali Barakar Talchir	Pali Barakar Talchir	Upper Pali Lower Pali Barakar Talchir	Middle Pali Lower Pali Barakar Talchir	Barakar Talchir

observed at the contact of thick, pebbly sandstone of the Pali Formation with the underlying Barakar Formation. In some sections the contact is gradational. The thickness of the Pali Formation in Johilla river section is approximately 184 meters (Shah, 2004).

MATERIAL AND METHODS

The material for the present investigation was collected from the shales of the Pali Formation exposed on the Pali–Mangthar road (Latitude: N 23°20.896'; Longitude: E 81°04.935') near Birsinghpur Railway Station, Umaria District, Madhya Pradesh, India (Fig. 2). The specimens are mostly preserved as impressions on fine grained red to greyish brown shales (Fig. 3). Description of *Neomariopteris* and seeds follows that of Maithy (1964, 1974), Pant and Khare (1974). The morphological features considered for identification of *Glossopteris* leaves are shape, nature of apex, base, midrib, venation pattern and type of meshes. Lawarence (1955) and Chandra and Surange (1979) have been followed for description and identification of *Glossopteris* leaves. The specimens were measured by using hand lens and low power Leica microscope Wilo Heerbrugg and photographed with Nikon 35 mm digital camera.

For recovery of spores and pollen grains, 10 grams each of 4 samples were crushed into small pieces (2–3 mm in size) and treated with hydrofluoric acid (40% concentration) to dissolve the silica. The samples were washed several times to remove the acid and later, kept in commercial nitric acid (HNO_3) for 3–5 days. Fresh HNO_3 was frequently added to digest the organic matter. After washing with water, the samples were treated with 5–10% potassium hydroxide (KOH) for clearing the palynomorphs. For this, the samples were examined under microscope at each stage of maceration. Finally, a few drops of polyvinyl alcohol and palynomorphs were smeared over cover glasses and kept for drying at room temperature. After complete drying, the cover glasses were mounted in canada balsam. The

EXPLANATION OF PLATE II

1. ***Glossopteris intermedia*** Feistmantel, BSIP museum specimen no. 41179; 2. ***Glossopteris intermittens*** Feistmantel, BSIP museum specimen no. 41180; 3. ***Glossopteris leptoneura*** Bunbury, BSIP museum specimen no. 41181; 4. ***Glossopteris longicaulis*** Feistmantel, BSIP museum specimen no. 41182; 5. ***Glossopteris searsoliensis*** Pant and Singh, BSIP museum specimen no. 41183; 6. ***Glossopteris spathulata*** Pant and Singh, BSIP museum specimen no. 41184; 7. ***Glossopteris stricta*** Bunbury, BSIP museum specimen no. 41185; 8. ***Glossopteris subtilis*** Pant and Gupta, BSIP museum specimen no. 41186; 9. ***Glossopteris tenuifolia*** Pant and Gupta, BSIP museum specimen no. 41187 (Scale Bar = 1 cm)

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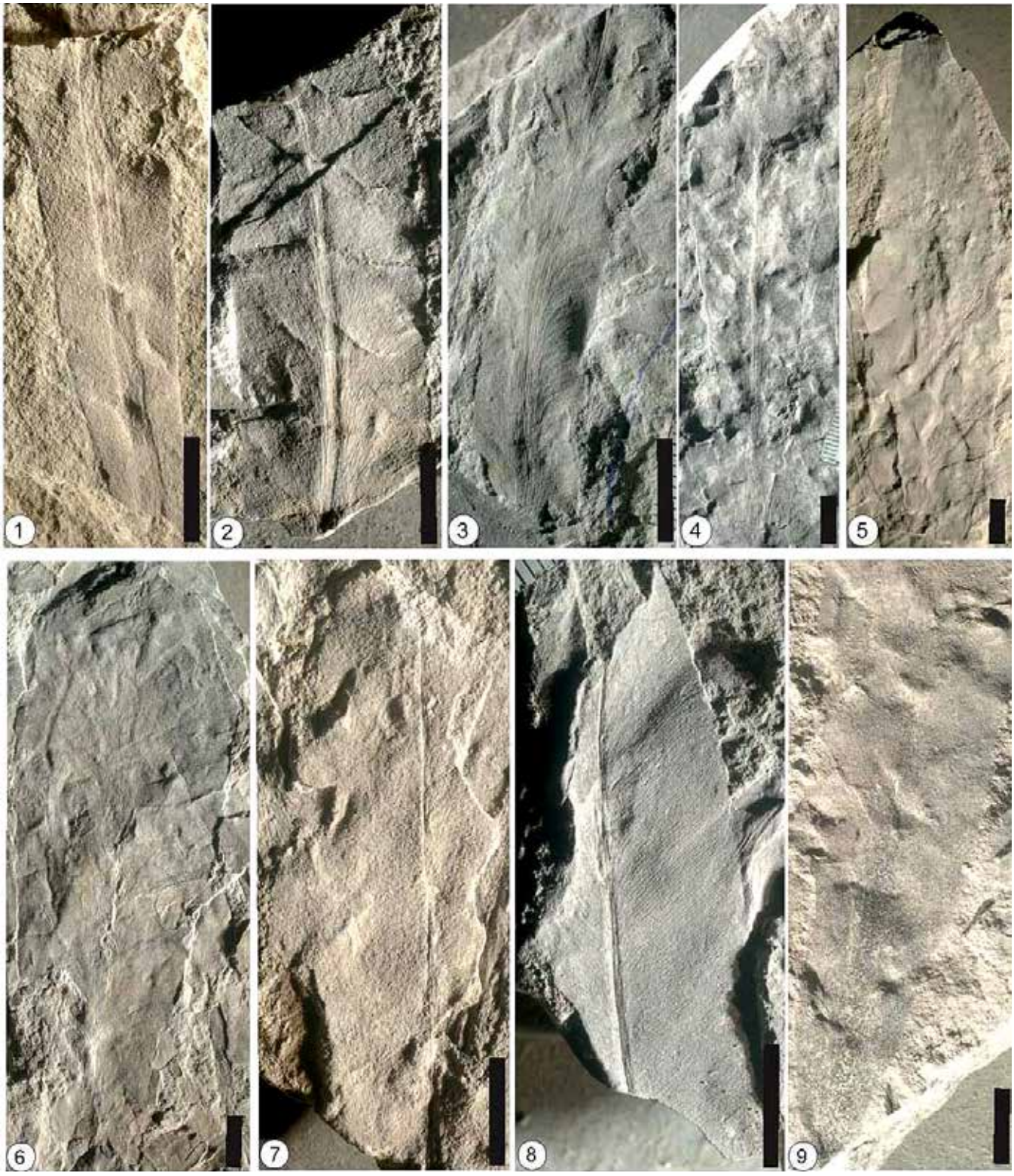
Plate II



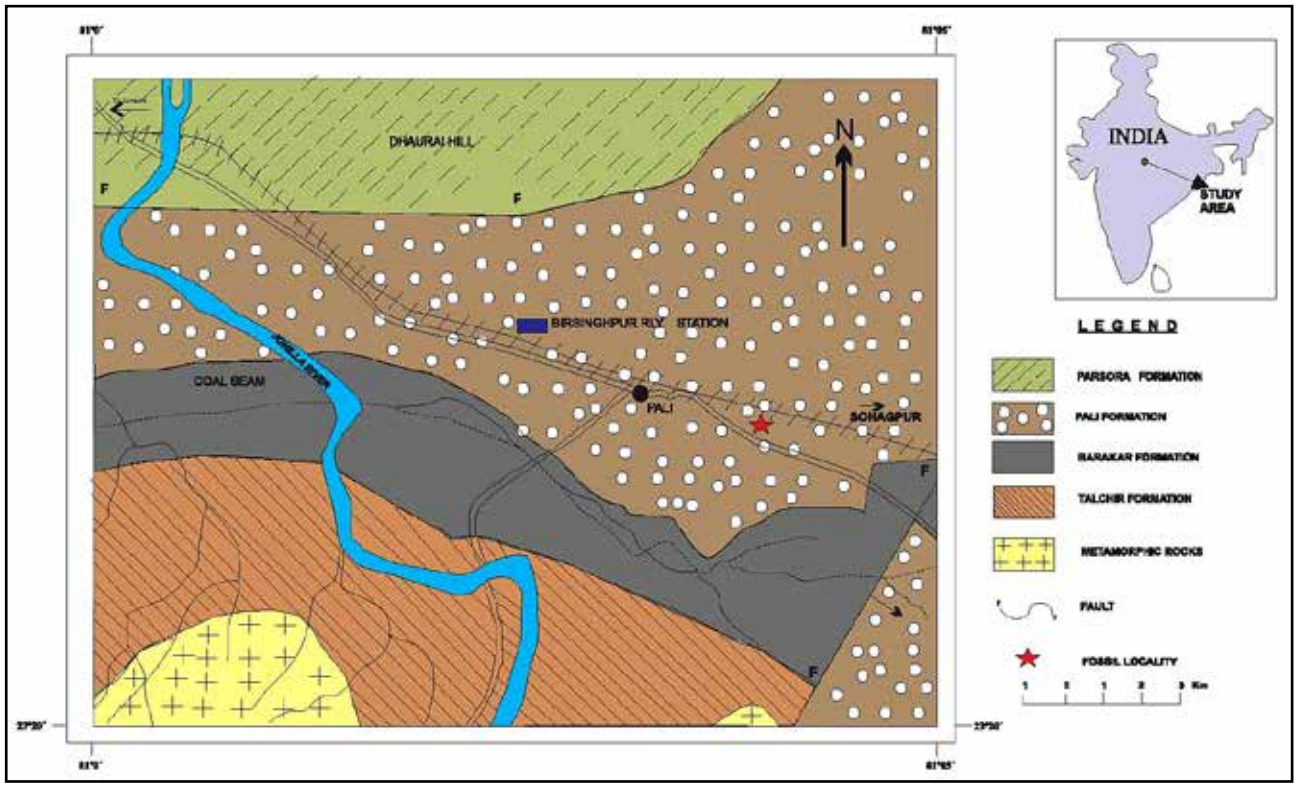


Fig.2. Geological map of Johilla Coalfield, showing fossil locality (modified after Ghosh *et al.,* 2007)

palynomorphs were studied and photographed with the help of high power Olympus Vanox AHBS3 microscope.

REPOSITORY

The megafossils and palynological slides are deposited in the repository of Birbal Sahni Institute of Palaeosciences (BSIP) Lucknow, vide statement No. 1459 (Specimen nos. 41173 to 41194 Slide nos. 41178 a, b, c).

SYSTEMATIC PALAEOBOTANY

PTERIDOPHYTES

Order **Filicales** Engler and Prantl, 1902
Family **Damudopteridaceae** Pant and Khare, 1974
Genus ***Neomariopteris*** (Feistmantel) Maithy, 1974

Neomariopteris hughesii (Zeiller) Maithy, 1974
(Pl. I, fig.1)

Remarks: Only one specimen is present in the collection. Frond measures 4.2 cm in length and 2.2 cm in width, tripinnate, rachis 0.8–1 mm wide, secondary rachis emerges in an alternate manner from the primary rachis at angles of about 45°– 60°, shape of pinnae linear, attachment of pinnae alternate to the

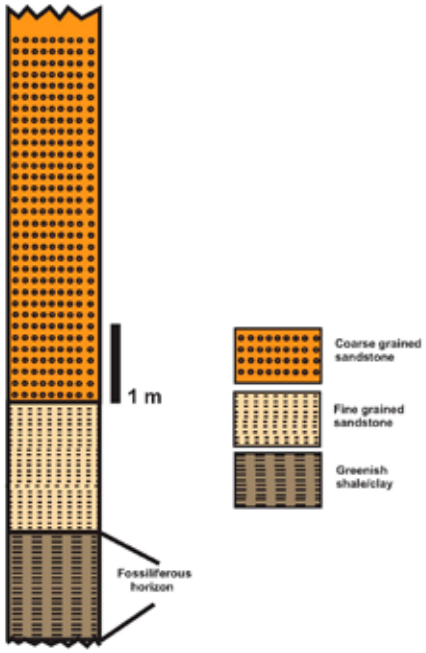


Fig.3. Litholog of the section exposed on the Pali Manthra Road, Johilla Coalfield

EXPLANATION OF PLATE III

1. ***Glossopteris tenuifolia*** Pant and Gupta, BSIP museum specimen no. 41175b; 2. ***Glossopteris tenuifolia*** Pant and Gupta, BSIP museum specimen no. 41188; 3. ***Glossopteris tenuifolia*** Pant and Gupta, BSIP museum specimen no. 41182b; 4. ***Glossopteris tenuifolia*** Pant and Gupta, BSIP museum specimen no. 41189; 5. ***Glossopteris tenuifolia*** Pant and Gupta, BSIP museum specimen no. 41190; 6. ***Glossopteris tenuifolia*** Pant and Gupta, BSIP museum specimen no. 41191; 7. ***Glossopteris tenuinervis*** Pant and Gupta, BSIP museum specimen no. 41192; 8. ***Glossopteris vulgaris*** Pant and Gupta, BSIP museum specimen no. 41182c; 9. ***Vertebraria indica*** (Unger) Feistmantel, BSIP museum specimen no. 41193; 10. ***Utkaliolepis indica*** (Scale leaf), BSIP museum specimen no. 41194a. (Scale Bar = 1 cm)

Plate III

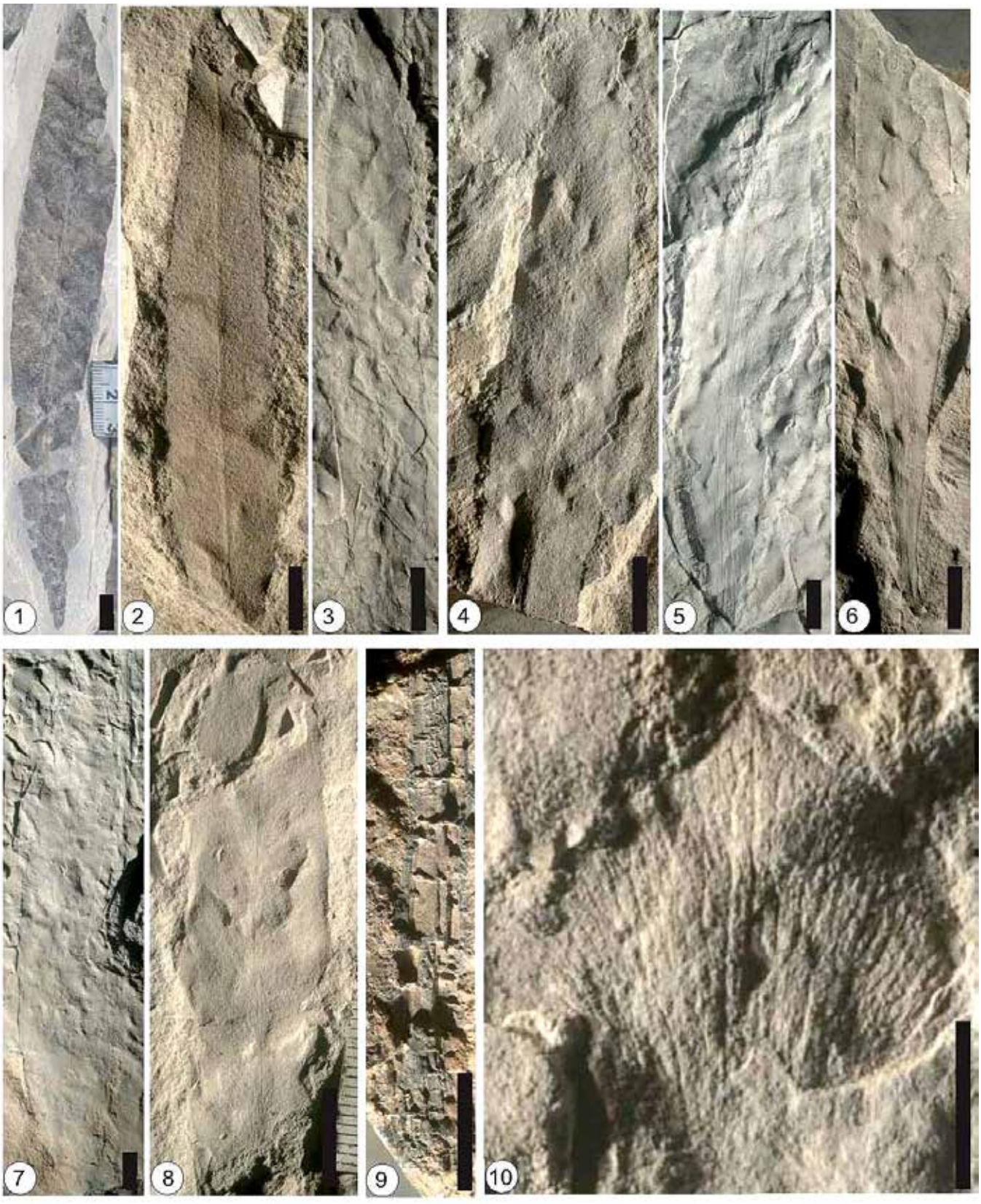


Table 2. Lithostratigraphic succession of Johilla Coalfield, Madhya Pradesh (after Ghosh *et al.,* 2007)

Group	Formation	Geological age
Post Gondwana	Alluvium	Recent
	Deccan Trap	Late Cretaceous–Palaeocene
	Lameta	Late Cretaceous
	Bansa beds	Early Cretaceous
Upper Gondwana	Hartala	Jurassic
	Tiki	Triassic
	Parsora	
Lower Gondwana	Pali	Late Permian
	Barakar	Early Permian
	Talchir	
	Unconformity	
	Granite, gneiss and schists	Precambrian

secondary rachis at an angle of 45°. Pinnules are lanceolate in shape and show maximum width in the middle part, 1.5–2.2 cm long and 5.5–9 mm broad, fused at base laterally, apex acute, margin crenulate. Median veins arise from the point where basal margin of pinnule joins the pinnae rachis. Lateral nervules shows rare dichotomy before reaching the margin. 6–7 nervules are present in one pinnule.

The present specimen resemble with *Neomariopteris hughesii* Maithy (1974, Pl. 2, figs. 7–11; Text figs. 3B, C) with respect to shape of frond, pinnae, margin and venation pattern of pinnules.

Number of specimen: One (41173).

Distribution: Karharbari, Barakar, Raniganj, Kamthi and Bijori, formations.

Gymnosperms

Order Glossopteridales *Sensu* Pant, 1982
Genus ***Glossopteris*** Brongniart, 1828
Type species *Glossopteris browniana* Brongniart, 1828

Glossopteris bosei Chandra and Surange, 1979
(Pl. I, fig. 2)

Remarks: There are two incomplete specimens in the collection. The apex and base are not preserved. Preserved portions of leaves measure 4.1-10 x 3–4 cm in size, shape oblanceolate, margin entire, midrib thick, striate, prominent and tapers gradually towards the apex, 2.2–2.5 mm wide at base, secondary veins arise at acute angles from the midrib, curve backwards at 70°–80° to meet the margin after dichotomizing and anastomosing. Meshes are 4–5 mm long and 0.2–0.6 mm broad throughout the lamina. The vein density is 22–26 per cm throughout the lamina.

The present specimens resemble *Glossopteris bosei* Chandra and Surange (1979, Pl. 47 fig. 5) in shape, midrib and venation pattern. The specimens are also identical to those described by Srivastava and Agnihotri (2010, Pl. 2, figs. 1, 2) from Bijori Formation of Satpura Gondwana Basin. The leaf described by Banerji *et al.* (1976, Pl. 1, fig. 9) from Triassic of Nidhpur as *G. stenoneura* was transferred to *Glossopteris bosei* by Chandra and Surange (1979).

Number of specimens: Two (41174, 41184b).

Distribution: Raniganj, Kamthi and Bijori formations.

Glossopteris communis Feistmantel, 1876
(Pl. 1, figs. 3, 4)

Remarks: The species is represented by 2 incomplete specimens. Apex and base not preserved; preserved portions of leaves measures 9.5–11.4 x 4.4–5.5 cm in size, shape apparently elliptic, margin entire. Midrib 1.2 mm broad at base, distinct, persistent, striate, thinning towards apex. Lateral veins arise from midrib at an angle of 45°and arch out to form linear, fine meshes throughout the lamina, venation is dense. Meshes are arcuate near midrib and narrow, elongate and 4.0–6.0 mm long and 0.3 – 0.4 mm broad throughout the lamina. The vein density is 25–28 per cm near the midrib and margin.

The present specimens closely resemble in shape, midrib and venation pattern with the leaves of *Glossopteris communis* described by Feistmantel (1879, Pl. 17, figs.1, 2, 1882, Pl. 21, figs. 13, 14), and Chandra and Surange (1979, Pl. 1 figs. 2, 3).

Number of specimens: 41175a, 41176).

Distribution: Talchir, Karharbari, Barakar, Barren Measures, Raniganj, Kamthi, Bijori and Pachhwara formations.

Glossopteris gondwanensis Pant and Gupta, 1971
(Pl. I, fig. 5)

Remarks: Only one fragmentary specimen is present in the collection. Leaf incomplete, narrow linear, middle part measuring 5 x 1.1 cm in size is preserved, margin entire. Midrib flat, striate, 1mm wide at base narrowing towards apex. Secondary veins arise at angles of about 20–25º from midrib and follow straight course to meet margin after dichotomizing and anastomising; meshes short, broad and arcuate measure 3–5 mm x 0.4–6 mm in size near midrib, trapezoid elsewhere, narrower and smaller, 4.0–6.0 mm long and 0.3–0.5 mm broad near the margin. The vein density near the midrib is 14–16 per cm and 16–18 per cm near margin.

Leaf is identical in shape, midrib and venation pattern to *Glossopteris gondwanensis* Pant and Gupta (1971, Pl. 16 fig. 2) and specimens described by Chandra and Surange (1979, Pl. 13 figs. 3, 6; Pl. 44 figs. 1, 3).

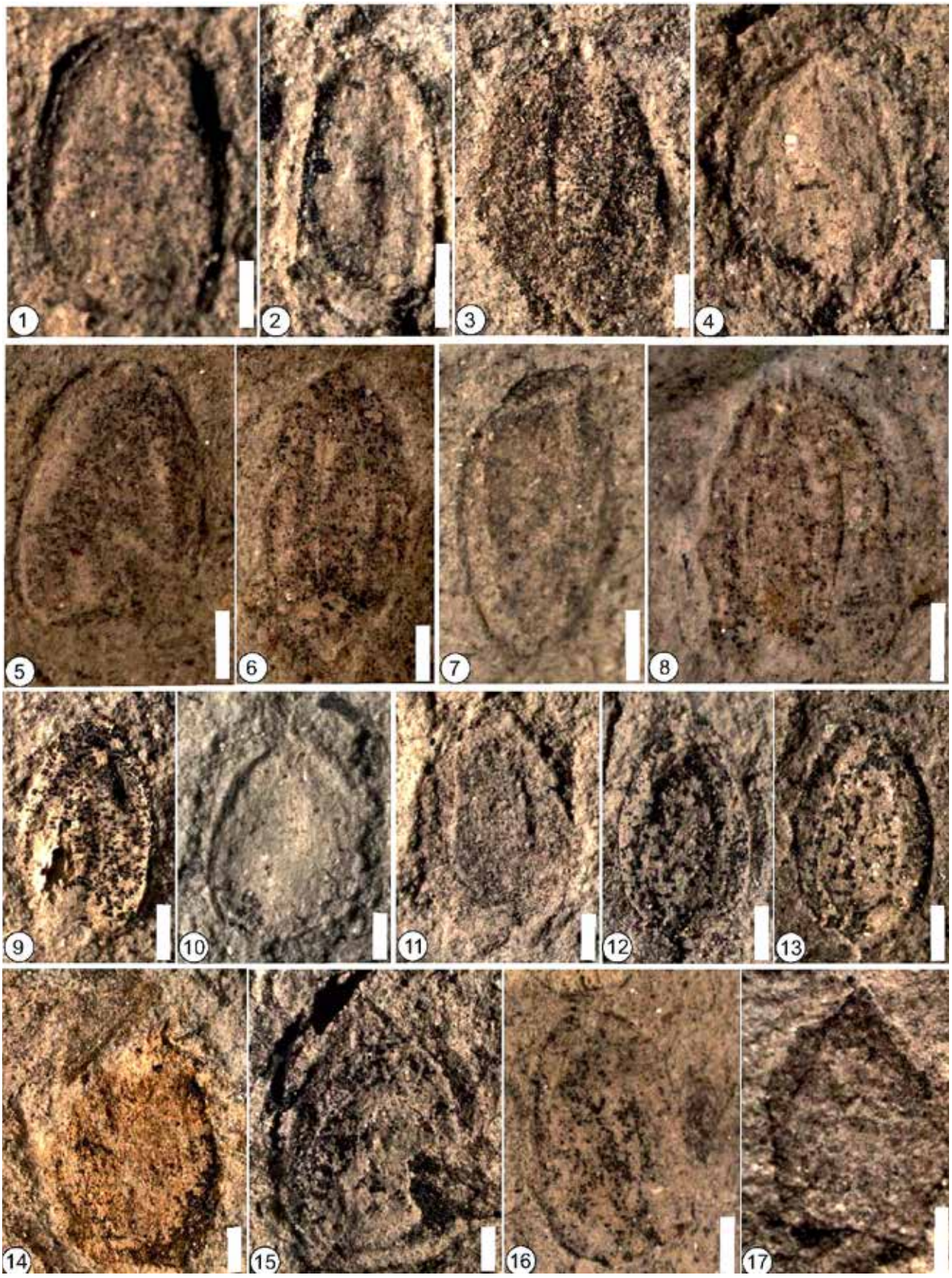
Number of specimen: One (41177).

Distribution: Raniganj, Kamthi and Pachhwara formations.

EXPLANATION OF PLATE IV

1. ***Cordaicarpus zeilleri*** Maithy, BSIP museum specimen no. 41194(1); 2. ***Cordaicarpus zeilleri*** Maithy, BSIP museum specimen no. 41194(2); 3. ***Cordaicarpus zeilleri*** Maithy, BSIP museum specimen no. 41194(3); 4. ***Cordaicarpus zeilleri*** Maithy, BSIP museum specimen no. 41194(4); 5. ***Samaropsis goraiensis*** Surange and Lele, BSIP museum specimen no. 41194(5); 6. ***Samaropsis goraiensis*** Surange and Lele, BSIP museum specimen no. 41194(6); 7. ***Rotundocarpus striatus*** Maithy, BSIP museum specimen no. 41194(7); 8. ***Samaropsis goraiensis*** Surange and Lele, BSIP museum specimen no. 41194(8); 9. ***Cordaicarpus zeilleri*** Maithy, BSIP museum specimen no. 41194(9); 10. ***Samaropsis feistmantelii*** Maithy, BSIP museum specimen no. 41194(10); 11. ***Rotundocarpus striatus*** Maithy, BSIP museum specimen no. 41194(11); 12. ***Cordaicarpus zeilleri*** Maithy, BSIP museum specimen no. 41194(12); 13. ***Rotundocarpus striatus*** Maithy, BSIP museum specimen no. 41194(13); 14. ***Samaropsis goraiensis*** Surange and Lele, BSIP museum specimen no. 41194(14); 15. ***Samaropsis feistmantelii*** Maithy, BSIP museum specimen no. 41194(15); 16. ***Samaropsis goraiensis*** Surange and Lele, BSIP museum specimen no. 41194(16) (Scale Bar=1 mm)

Plate IV



Glossopteris indica Schimper, 1869
(Pl. I, fig. 6)

Remarks: Only one incomplete leaf is present in the collection. Middle and basal parts of the leaf are preserved. Preserved portion of the leaf measures 10.4 x 3.5 cm in size. Shape lanceolate, base narrow, attenuate, margin entire. Midrib distinct, persistent, 3 mm wide at base, thinning towards apex, Secondary veins arise at acute angles from midrib, slightly arch backwards to meet margin after dichotomizing and anastomising; meshes short, broad, arcurate 3.0–4.0 mm long and 0.3–0.5 mm broad near midrib, narrower and smaller near the margin measuring 4–5 mm long and 0.2–0.3 mm broad. The vein density near the midrib is 16–18 per cm and 20–22 per cm near the margin.

Leaf is identical in shape, base and venation pattern to *Glossopteris indica* Schimper (1869) described by Chandra and Surange (1979, Pl. 5, fig. 1; Pl. 10, fig. 4; Pl. 15, fig. 11; Pl. 28, fig. 1; Pl. 29, fig. 1) and Tewari (2007, Pl. 1, fig. 4; Pl. 3, fig. 1; Pl.4, fig 2; Pl.6, figs. 5, 7).

Number of specimen: One (41178).

Distribution: Talchir, Karharbari, Barakar, Barren Measures, Raniganj, Kamthi, Bijori and Pachhwara formations.

Glossopteris intermedia Feistmantel, 1880
(Pl. II, fig. 1)

Remarks: One incomplete leaf is present in the collection. Lower half of leaf preserved, extreme basal end of leaf broken, leaf narrow, measures 5.0 x 1.5 cm in size, margin entire, midrib thick and distinct, flat, striated, 3 mm wide in basal region and narrows to 2.5 mm further upwards, secondary veins arise at acute angles from the midrib, arch slightly, take a straight course to meet the margin after dichotomizing and anastomosing, meshes arcuate near midrib, broad and uniform in size, 2–3 mm long and 0.4–0.6 mm broad throughout the leaf lamina. The vein density is 18–20 per cm throughout the lamina.

Leaf is identical in shape and venation pattern to *Glossopteris intermedia* Feistmantel (Chandra and Surange 1979, Pl. 6, fig. 10; Pl. 11, fig. 6; Pl. 18, fig. 10; Pl. 21, fig. 3; Pl. 27, fig. 2; Pl. 43, fig. 1). Leaf also resembles with *Glossopteris intermedia* described by Tewari *et al*., (2012, fig. 7F) from the Barakar Formation of Wardha Basin and Goswami (2006, Pl. 5 fig. h) from lower part of the Kamthi Formation of Mahanadi Basin.

Number of specimen: One (41179).

Distribution: Barakar, Barren Measures, Raniganj and Kamthi formations.

Glossopteris intermittens Feistmantel, 1881
(Pl. II, fig. 2)

Remarks: An incomplete leaf with middle part preserved is present in the collection. It measures 4 x 2.5 cm in size; midrib distinct, persistent, 1.5 mm wide in the basal portion, narrowing towards apex, margin entire. Secondary veins arise at acute angles from midrib, gracefully curve towards margin after dichotomizing and anastomosing. Meshes are 2.5–3.0 mm long and 0.7–1.0 mm broad near midrib and 3.0–3.5 mm long and 0.5–0.6 mm broad near the margin. Vein density is 12–14 per cm near midrib and 14–16 per cm near margin.

Leaf is similar to *Glossopteris intermittens* described by Feistmantel, (1881, Pl. 33A, figs. 2–4) and Tewari, 2007 (Pl. 7, fig. 5; Pl. 8, fig. 1) in venation pattern.

Number of specimen: One (41180).

Distribution: Barakar, Raniganj, Kamthi, Bijori and Pachhwara formations.

Glossopteris leptoneura Bunbury, 1861
(Pl. II, fig. 3)

Remarks: An incomplete specimen with middle and basal parts preserved is present in the collection. Leaf linear, base narrow, attenuate, margin entire, measures 5 x 1.7 cm in size; midrib strong, distinct, persistent, 3 mm wide at base and 1.5 mm wide further upwards, secondary veins arise from midrib at less than 45°, slightly arch backwards, form gentle curves to meet margin after dichotomizing and anastomosing; meshes short, broad, 2.8–3.1 mm long and 0.6–1.0 mm and arcuate near midrib, long, narrow and 3.0–3.5 mm long and 0.4–0.6 mm broad in rest of the lamina. Vein density is 14–16 per cm near midrib and 16–18 per cm near the margin.

Leaf is similar to *Glossopteris leptoneura* Bunbury (1861, Pl. 9, figs. 1–4) and those described by Chandra and Surange (1979, Pl. 44, fig. 2; Text figs. 22F f, 46H) in shape, nature of midrib and venation pattern.

Number of specimen: One (41181).

Distribution: Barakar, Raniganj and Kamthi formations.

Glossopteris longicaulis Feistmantel, 1879
(Pl. II, fig. 4)

Remarks: There are four incomplete specimens in the collection with basal parts preserved. Leaves measure 4.5–10.5 x 2.0–4.3 cm in size, margin entire. Base attenuate, distinctly petiolate, 1–1.5 cm long. Midrib distinct, striate, 5–9 mm broad at base and gradually tapers upwards. Secondary veins arise at acute angles from midrib and run straight to the margin after dichotomizing and anastomising. Meshes are long, polygonal, 4–7 mm long and 0.4–0.6 mm broad near midrib and 5.0–7.0 mm long and 0.4–0.5 mm broad near margin. Vein density is 16–18 per cm near midrib and 20–22 per cm near margin.

Leaves resemble *Glossopteris longicaulis* described by Feistmantel (1879, Pl. 31, figs. 1, 3) and Chandra and Surange (1979, Pl. 1, fig. 4; Pl. 15, fig. 13) in presence of a distinct petiolate base and venation pattern. They are also similar to leaf described by Tewari and Srivastava (2000, Pl. 1, fig. 3) from the Bhareli Formation, Arunachal Pradesh.

Number of specimens: Four (41182, 41188a, 41188b, 41188c).

Distribution: Karharbari, Barakar and Raniganj formations.

Glossopteris searsolensis Pant and Singh, 1974
(Pl. II, fig. 5)

Remarks: An incomplete leaf with upper part of leaf preserved is present in the collection. Preserved portion measures 9.5 x 3 cm in size, narrow, elliptic, acute apex, entire margin. Midrib thin, distinct, persistent, striate, 2 mm broad at base, thinning towards apex. Secondary veins arise from midrib at an angle of 45°and arch out to form dense linear, fine, 2.0–5.0 mm long and 0.2–0.4 mm broad meshes. Vein density is 20–22 per cm.

Leaf resemble *Glossopteris searolensis* described by Chandra and Surange (1979: Pl, 47, Fig. 1) in shape and venation pattern with *G. searsolensis* was instituted on the basis of cuticular studies by Pant and Singh (1974, Pl. 23, figs. 1, 2). Later Chandra and Surange (1979) described its external features and maintained the species.

Number of specimen: One (41183).

Distribution: Raniganj Formation.

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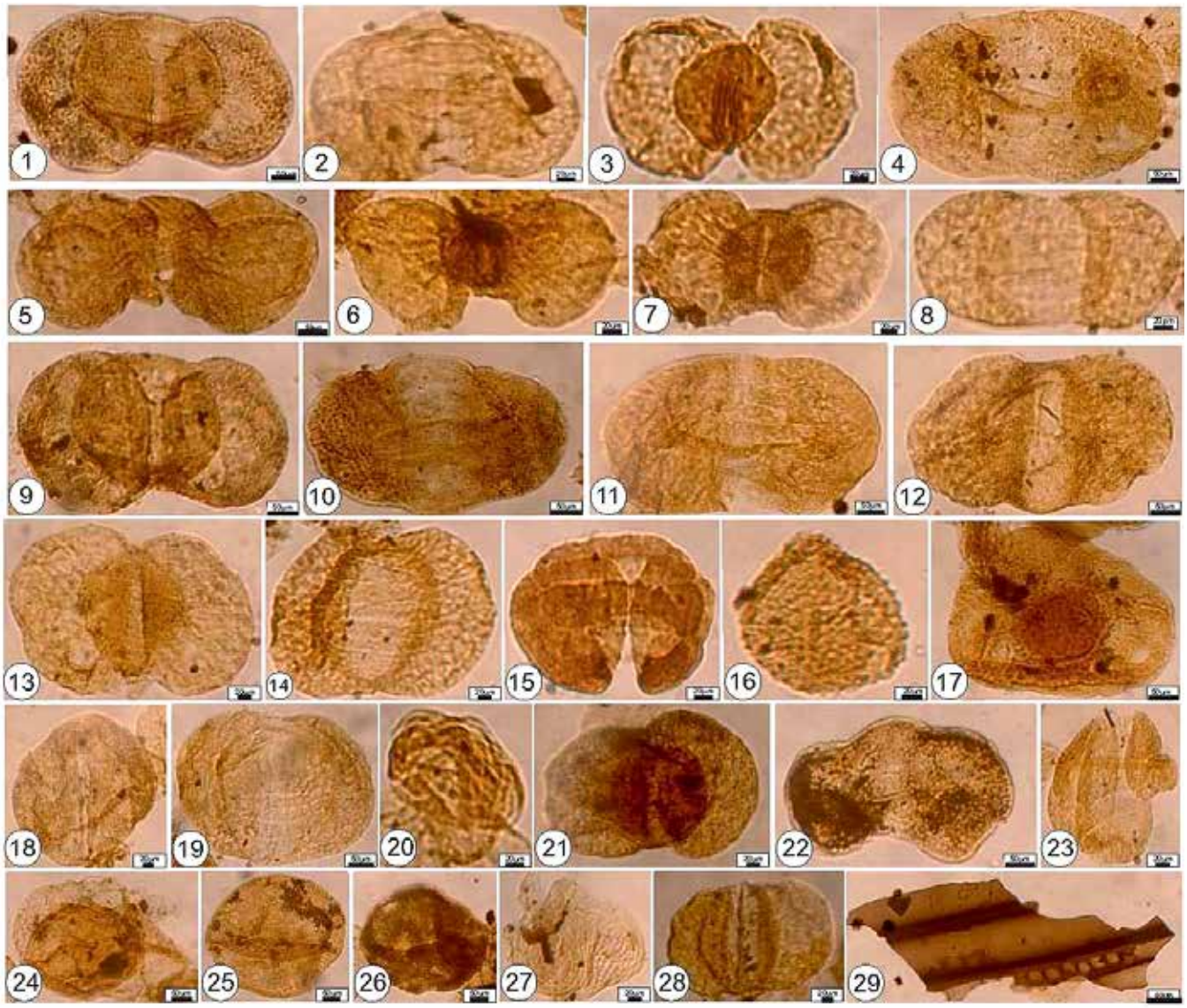
Plate V



PILLAI, AGNIHOTRI, GAUTAM AND TEWARI

EXPLANATION OF PLATE V

1. ***Striatopodocarpites decorus*** Bharadwaj and Salujha, 1964, BSIP museum specimen no. 41178a; 2. ***Diastriates*** sp. cf. *D.bilateris* Bharadwaj, 1962, BSIP museum specimen no. 41178c; 3. ***Stritaites subtilis*** Bharadwaj and Salujha, 1964, BSIP museum specimen no. 41178a; 4. ***Faunipollenites varius*** Bharadwaj, 1962 emend. Tiwari *et al*., 1989, BSIP museum specimen no. 41178b; 5. ***Lahirites raniganjensis*** Bharadwaj, 1962, BSIP museum specimen no. 41178a; 6. ***Verticipollenites gibbosus*** Bharadwaj, 1962, BSIP museum specimen no. 41178c; 7. ***Stritaites notus*** Bharadwaj and Salujha, 1964, BSIP museum specimen no. 41178a; 8. ***Faunipollenites singrauliensis*** Sinha 1972 emend. Tiwari *et al*., 1989, BSIP museum specimen no. 41178a; 9. ***Striatopodocarpites decorus*** Bharadwaj and Salujha, 1964, BSIP museum specimen no. 41178a; 10.11. ***Faunipollenites varius*** Bharadwaj, 1962 emend. Tiwari *et al*., 1989, BSIP museum specimen no. 41178b; 12. ***Crescentipollenites fuscus*** (Bharadwaj) Bharadwaj *et al*., 1974, BSIP museum specimen no. 41178b; 13. ***Crescentipollenites notabilis*** Tiwari, 1965, BSIP museum specimen no. 41178a; 14. ***Faunipollenites perexiguus*** Bharadwa and Salujha, 1965 emend. Tiwari *et al*., 1989, BSIP museum specimen no. 41178b; 15. ***Arcuatipollenites paliensis*** (Tiwari and Ram–Awatar) Tiwari and Vijaya, 1995, BSIP museum Specimen no. 41178a; 16. ***Cyclobaculisporites indicus*** Bharadwaj and Salujha, 1964, BSIP museum specimen no. 41178a; 17. ***Densipollenites indicus*** Bharadwaj, 1962, BSIP museum specimen no. 41178c; 18. ***Scheuringipollenites tentulus*** (Tiwari) Tiwari, 1973, BSIP museum specimen no. 41178b; 19. ***Faunipollenites magnus*** (Bose and Kar) Tiwari *et al*., 1989, BSIP museum specimen no. 41178a; 20. ***Weylandites minutus*** Bharadwaj and Srivastava, 1969, BSIP museum specimen no. 41178b; 21. ***Stritaites communis*** Bharadwaj and Salujha, 1964, BSIP museum specimen no. 41178a; 22. ***Arcuatipollenites damudicus (***Tiwari and Rana) Tiwari and Vijaya, 1995, BSIP museum specimen no. 41178a; 23. ***Guttulapollenites*** sp. cf *G. hannonicus* (Goubin) Venkatachala, Goubin and Kar, 1968, BSIP museum specimen no. 41178b; 24. ***Densipollenites densus*** Bharadwaj and Srivastava, 1969, BSIP museum specimen no. 41178a; 25. ***Densipollenites invisus*** Bharadwaj and Salujha, 1964, BSIP museum specimen no. 41178a; 26. ***Densipollenites magnicorpus*** Tiwari and Rana, 1981, BSIP museum specimen no. 41178b; 27. ***Decussatisporites dubius*** Venkatachala and Kar, 1968, BSIP museum specimen no. 41178a; 28. ***Alisporites indicus*** Bharadwaj and Srivastava, 1969, BSIP museum specimen no. 41178a; 29. Wood debris, BSIP museum specimen no. 41178a

Glossopteris spathulata Pant and Singh, 1971
(Pl. II, fig. 6)

Remarks: One specimen with part and counterpart preserved is present in the collection. Leaf measures 12.2 x 4.2 cm in size, shape oblanceolate, apex obtuse, apical portion broader than rest of the leaf, base narrow, and margin entire. Midrib distinct, striate, 3 mm broad at base gradually tapering upwards. Secondary veins arise at acute angles from midrib, gradually arch backwards to meet margin after dichotomizing and anastomising. Meshes are dense, 4–5 mm long and 0.5–0.8 mm broad near midrib and narrow, elongate, trapezoid, 5.0–7.0 mm long and 0.4–0.6 mm broad elsewhere. The vein density is 16 – 18 per cm near midrib and 18–22 per cm near margin.

Leaf is identical in shape and venation pattern with *Glossopteris spathulata* Pant and Singh, 1971, Pl. 10, fig. 60) and with the specimens described by Chandra and Surange (1979, Pl. 8, fig. 1; Pl. 12, fig.5; Pl. 17, fig. 7; Pl. 18, fig. 1; Pl. 27, fig. 1).

Number of specimen: One (41184).

Glossopteris stricta Bunbury, 1861
(Pl. II, fig. 7)

Remarks: An incomplete leaf with middle part of the leaf preserved is present in the collection. The size of leaf is 6.1 x 2 cm, midrib is 1.3 mm wide. Secondary veins arise at acute angles of about 80°–85° from midrib, slightly arch near midrib and run straight to reach the margin. Meshes are comparatively broader near midrib, 4.0–6.0 mm long and 0.5–0.7 mm broad and 5.0–7.0 mm long and 0.3–0.4 mm broad near margin. Vein density is 16–18 per cm near the midrib and 22–24 per cm near the margin.

The present specimen closely resembles in venation pattern with the leaves of *Glossopteris stricta* Bunbury, 1861 described by Chandra and Surange (1979, Pl. 5, fig. 4; Pl. 32, fig. 1) and Chandra and Prasad (1981, Pl. 1, figs. 2, 3; Text figs. 2 I, J) from Kamthi beds of Kanhargaon, Handappa, Odisha.

Number of specimen: One (41185).

Distribution: Barakar, Raniganj and Kamthi formations.

Glossopteris subtilis Pant and Gupta, 1971
(Pl. II, fig. 8)

Remarks: An incomplete leaf with middle part preserved is present in the collection. The size of the leaf is 5 x 1.7 cm, margin entire. Midrib distinct, flat, striate and 1 mm broad. Secondary veins arise at an acute angle from midrib, arch backwards, continue to meet margin after dichotomizing and anastomosing. Meshes are deltoid, 3–4 mm long and 0.3–0.5 mm broad near midrib and elongated, oblong, polygonal, 4–5 mm long and 0.3–0.6 mm elsewhere. The vein density is 16–18 veins per cm throughout the lamina.

Leaf resemble *Glossopteris subtilis* Pant and Gupta 1971 described by Chandra and Surange (1979, Pl. 3, fig.7; Pl. 14, fig. 3; Pl. 21, fig. 2; Pl. 22, figs. 3, 12) and Tewari (2007, Pl. 8, fig. 5; 2008, Pl. 3, fig. 2; Pl. 4, fig. 2) in venation pattern and in presence of elongate, oblong, polygonal meshes.

Number of specimen: One (41186).

Distribution: Barakar, Barren Measures, Raniganj and Kamthi formations.

Glossopteris tenuifolia Pant and Gupta, 1968
(Pl. II, fig. 9; Pl. III, fig. 1–6)

Remarks: There are seven specimens present in the collection. One leaf is complete. Leaves measure 7–18 x 1.2–1.8 cm in size, linear-lorate in shape, narrow, elongate, with apex, attenuate base and entire margin. Midrib prominent, thick, striate, 1.5– 2 mm broad at base and tapers gradually towards apex. Secondary veins arise at acute angles from the midrib, slightly arch backwards to meet the margin after dichotomizing and anastomosing. Meshes are 3–4 mm long and 0.3–0.4 mm broad throughout the lamina. The vein density is 16–20 per cm throughout.

Leaves resemble *Glossopteris tenuifolia* Pant and Gupta (1968, Pl. 21, fig. 15) and those described by Tewari (2007, Pl. 2, fig. 4–5) from the Kamptee Coalfield, Wardha Basin in shape and venation pattern.

Number of specimens: Seven (41187, 41175b, 41188, 41182b, 41189, 41190, 41191).

Distribution: Talchir, Barakar, Raniganj, Kamthi, Bijori and Pachhwara formations.

Glossopteris tenuinervis Pant and Gupta, 1971
(Pl. III, fig. 7)

Remarks: An almost complete specimen is present in the collection. Leaf measures 13 x 2.8 cm, shape oblong–lorate, margin entire, apex acute, base narrow, midrib 2 mm wide at basal region, flat, striate, persistent, gradually thinning upwards. Secondary veins arise at angles of about 80˚–90˚ from the midrib, arch backwards to meet the margin after dichotomizing and anastomosing. Meshes are arcuate, shorter and broad, 2–2.5 mm long and 0.4–0.6 mm near midrib and 2.5–3.5 mm long and 0.2–0.3 mm broad, narrow and elongate elsewhere. The vein density near the midrib is 24–26 per cm and 28–30 per cm near margin.

Leaf is similar in shape and venation pattern to *Glossopteris tenuinervis* Pant and Gupta (1971, Pl. 18, fig. 14) and Chandra and Surange (1979, Pl. 6, fig. 3; Pl. 7, fig. 3; Pl. 14, fig. 6; Pl. 18, fig. 2; Pl. 22, figs. 4, 13; Pl. 23, figs. 1, 15;Pl. 46, fig. 3).

Number of specimen: One (41192).

Distribution: Barakar, Raniganj and Kamthi formations

Glossopteris vulgaris Pant and Gupta, 1968
(Pl. III, fig. 8)

Remarks: An incomplete leaf with middle part preserved is present in the collection. The size of the leaf is 4.5 x 1.6 cm, margin entire. Leaf narrow, midrib 1mm broad at base and gradually tapers upwards. Secondary veins arise at an angle from 25° near midrib and slightly curve to meet the margin. Meshes are few, polygonal and broad, 3.0–5.0 mm long and 0.7–0.9 mm broad near midrib and 4.0–6.0 mm long and 0.6–0.8 mm broad near margin. Vein density near the midrib is 14–16 per cm and 16–18 per cm. near margin.

Leaves are identical to *Glossopteris vulgaris* Pant and Gupta 1968, described by Chandra and Surange (1979, Pl. 6, fig. 9; Pl. 15, fig. 9; Pl. 42, fig. 5) in venation pattern.

Number of specimen: One (41182c).

Distribution: Barakar, Raniganj and Kamthi formations.

Genus ***Vertebraria*** Royle ex McCoy, 1847
Type species *Vertebraria australis*, McCoy, 1847

Vertebraria indica (Unger) Feistmantel, 1877
(Pl. III, fig. 9)

Remarks: The specimen is incomplete, horizontally preserved, unbranched, measuring 5 cm in length and 0.4–0.5 cm in width, consisting of 14 unequal rectangular areas, arranged in

two linear rows and separated by 2–3 mm wide median grooves, a longitudinal median ridge is present in between the rows.

The specimen is identical to *Vertebraria indica* described from Raniganj and Giridih coalfields (Pant and Singh, 1968, Pl. 124, figs. 2–5), Barakar Formation of Auranga Coalfield (Srivastava, 1995, Pl. 1, figs. 3,4,9), Bijori Formation of Satpura Gondwana Basin (Srivastava and Agnihotri, 2010, Pl. 4, fig. 3), Bhareli Formation of Arunachal Pradesh (Tewari and Srivastava, 2000, Pl. 2, fig. 9), lower part of the Kamthi Formation of Ib River Coalfield (Goswami, 2006, Fig. 3c).

Number of specimen: One (41193).

Distribution: Karharbari, Barakar, Raniganj, Bijori and Kamthi formations.

Genus ***Utkaliolepis*** Tiwari *et al.*, 2009

Type Species *Utkaliolepis indica* Tiwari *et al.*, 2009

Utkaliolepis indica Tiwari *et al.,* 2009

(Pl. III, fig. 10)

Remarks: An incomplete specimen is present in the collection. Leaf is deltoid in shape 2.8 x 1.8 cm size with acuminate apex, elevated ridge and broad base. Median region is occupied by 3 parallel median veins arising from the base. Parallel veins are 1–1.2 mm apart in the centre, run straight upto the apex, dichotomize towards the apical region, but do no anastomose. Lateral veins arise from the base, divert at angle of 30°–40°, gradually arching backwards to meet the margin after dichotomization and anastomoses. Meshes are long, narrow and hexagonal.

The present specimen closely resembles in shape and venation pattern with *Utkaliolepis indica* described by Srivastava and Agnihotri, 2012 (Pl. 1, fig. 5) from Barakar Formation of Satpura Gondwana Basin.

Number of specimen: One (41194a).

Distribution: Barakar and Kamthi formations.

Genus ***Cordaicarpus*** Geinitz, 1862

Type Species *Cordaicarpus cordai* Geinitz, 1862

Cordaicarpus zeilleri Maithy, 1965

(Pl. IV, figs. 1–4, 9, 12)

Remarks— There are seven seed specimens present in the collection. Seeds are platyspermic, oval to cordate, measure 3.5–6 mm in length and 2–4 mm in width, apex pointed, base rounded, sarcotesta 0.4–1 mm wide, surrounds cordate sclerotesta.

The present seeds resemble *Cordaicarpus zeilleri* Maithy (1965, Pl. 1, figs. 1, 2, Text–figs. 1, 2) in external morphological characters like shape, nature of apex, sarcotesta and base.

Number of specimens: Seven {41194(1), 41194(2), 41194(3), 41194(4), 41194(c), 41194(9), 41194(12)}.

Distribution: Karharbari and Barakar formations.

Genus ***Rotundocarpus*** Maithy, 1965

Type species *Rotundocarpus striatus* Maithy, 1965

Rotundocarpus striatus Maithy, 1965

(Pl. IV, figs. 7, 11, 13)

Remarks—Three specimens are present in the collection. Seeds radiospermic, oval, convex, wingless, spindle shape with pointed apex and base measure 2.5–4.5 mm in length and 1.5–3.0 mm in width. Vertical striations running from apex to base are seen on the surface.

The seeds resemble *Rotundocarpus striatus* (Maithy, 1965, Pl. 2, fig. 14; Text-fig. 9) in shape, nature of apex and base and presence of vertical striations on the surface. The genus *Rotundocarpus* is known by two another species, viz. *Rotundocarpus ovatus* (Maithy, 1965, Pl. 2, fig. 15; Text-fig. 10) and *R. mucronatus* (Tewari *et al.,* 2012, Pl. 1, fig.10).

Number of specimen: Three {41194(7), 41194(11), 41194(13)}.

Distribution: Karharbari and Barakar formations.

Genus ***Samaropsis*** Göeppert, 1864

Type species *Samaropsis ulmiformis* Göeppert, 1864

Samaropsis goraiensis Surange and Lele, 1956

(Pl. IV, figs. 5, 6, 8, 14, 16)

Remarks–There are five specimens present in the collection. Seeds are platyspermic, pear shaped, 3–4.5 x 2.5 mm in size, with pointed ends. The sarcotesta is 0.2 mm. wide, encircles the sclerotesta and has a median sinus at the apex and a broad V–shape notch at the base, which appears cordate. The sarcotesta is symmetrical and wider at the base.

The seeds resemble *Samaropsis goraiensis,* Surange and Lele 1956 (Pl. 1, figs. 3, 4, 14), described from the Talchir Formation, Goraia, South Rewa Gondwana Basin and from Karharbari Formation of Giridih Coalfield, of Damodar Basin (Maithy, 1965, PI. 1, figs. 9, 10; Text–fig. 6) in shape, presence of median sinus at the apex and a broad V–shape notch at the base.

Number of specimens: Five {41194(5), 41194(6), 41194(8), 41194(14), 41194(16).

Distribution: Talchir and Karharbari formations.

Samaropsis feistmantelii Maithy, 1965

(Pl. IV, figs.10, 15)

Remarks—There are two specimens present in the collection. Seeds are platyspermic, almost circular in shape, measuring 2.5 x 2 mm in size. Sarcotesta 0.2 mm wide surrounds circular sclerotesta.

The seeds resemble *Samaropsis feistmantelii* Maithy (1965, Pl. 1, fig. 11) in shape and size.

Number of specimens: Two {41194(10), 41194(15)}.

Distribution: Karharbari and Barakar formations.

PALYNOLOGICAL ANALYSIS

The palynoassemblages of the Pali Formation of present study comprise 17 genera and 34 species of spores and pollen grains. The gymnospermous pollen grains dominate the assemblage whereas, the taeniate pollen grains, pteridophytic spores and costate grains are rare. The palynomorphs are well preserved. Some stratigraphically significant taxa are illustrated in Plate 5. On the basis of quantitative analysis of three productive samples, one palynoassemblage (Assemblage 1) has been identified. The palynoassemblage is characterized by dominance of striate bisaccate pollen grains mainly the species of *Striatopodocarpites* (25–35%) and *Faunipollenites* (20–25%) in association with *Striatites* (7–10%), *Verticipollenites* (5–7%), *Densipollenites* (2–4 %), *Lahirites* (2–3%), *Crescentipollenites* (1–2%), *Distriatites* (1–2%), *Arcuatipollenites* (1–2%), *Scheuringipollenites* (0–1%) and *Decussatisporites* (0–1%). Additionally, the assemblage shows sporadic occurrence of some stratigraphically significant taxa like *Guttulapollenites, Alisporites* and *Weylandites* indicating a late Permian affinity and hence belongs to the Middle Member of the Pali Formation. The assemblage corresponds with the *Densipollenites magnicorpus* Assemblage–Zone IX of Tiwari and Tripathi (1992).

PALYNOLOGICAL CORRELATION WITH INDIAN BASINS

Tiwari and Tripathi (1992) synthesized a palynozonation scheme for the late Permian sediments in the Damodar and Rajmahal basins on the basis of FAD (First Appearance Data) and LAD (Last Appearance Data) of selected key taxa to correlate these sediments with the Permian sediments of other basins of Indian Gondwana. They identified three palynoassemblage zones namely, the *Densipollenites densus* assemblage zone (zone VII), the *Gondisporites raniganjensis* assemblage zone (zone VIII) and the youngest– the *Densipollenites magnicorpus* assemblage zone *(*zone IX). The Assemblage zone VII of Tiwari and Tripathi (1992) is equated with the Kulti Formation (Barren Measures), while Assemblage zones VIII and IX are equivalent to the Raniganj Formation (late Permian).

Palynoassemblage recovered from the Middle Member of the Pali Formation, Johilla Coalfield, South Rewa Gondwana Basin is closely comparable with the late Permian palynoassemblages of different coalfields of India. The palynomorphs retrieved compare with the palynoassemblages of Raniganj Coalfield (Bharadwaj, 1962; Bharadwaj and Salujha, 1964, 1965; Tiwari *et al.,* 1991; Tiwari and Tripathi, 1992; Murthy *et al.,* 2010; Vijaya, 2011), East Bokaro Coalfield (Vijaya, *et al*., 2012a), North and South Karanpura coalfields (Kar, 1969; Murthy *et al*., 2014b) and Jharia Coalfield (Murthy *et al*., 2015) of Damodar Basin. The most significant and common palynotaxa available for correlation include *Striatopodocarpites, Faunipollenites*, *Distriatites, Crescentipollenites, Striatites, Verticipollenites, Densipollenites, Guttulapollenites*, *Arcuatipollenites* (=*Lunatisporites)*, *Scheuringipollenites, Alisporites* and *Weylandites*. *Chordasporites*, *Falcisporites*, *Indospora*, *Klausipollenites* and *Playfordiaspora* are not recorded from the Pali Formation. Therefore, the studied section shows an older affiliation. The present palynoassemblage can be correlated with the similar assemblages described from different coalfields of Son–Mahanadi Basin, Johilla (Tiwari and Ram Awatar, 1986, 1987a, 1989), Korar (Tiwari and Ram-Awatar, 1987b), Sohagpur (Ram-Awatar, 1997; Ram–Awatar *et al*., 2004; Ram-Awatar and Gautam, 2013; Gautam *et al*., 2016); Singrauli (Tiwari and Srivastava, 1984; Vijaya *et al*., 2012b), Mand–Raigarh (Jana *et al*., 2002; Chakraborti and Ram–Awatar, 2006; Murthy *et al*., 2014a) and Talcher (Tiwari *et al*., 1991; Tripathi, 1997a; Tripathi and Bhattacharya, 2001) coalfields on the basis of the presence of common taxa like *Striatopodocarpites*, *Faunipollenites*, *Crescentipollenites*, *Arcuatipollenites*, *Alisporites* and *Densipollenites*. However, some forms like *Klausipollenites, Falcisporites, Playfordiaspora, Brachysaccus* and *Goubinispora* described from the Johilla (Tiwari and Ram–Awatar, 1986, 1987a) and Korar (Tiwari and Ram–Awatar, 1987b) coalfields have not been recorded in the present study.

Tripathi (1989, 1996) and Vijaya (2006, 2009) described late Permian palynofloras from various bore-cores of Rajmahal Basin dominated by striate bisaccate pollen grains such as *Striatopodocarpites* and *Faunipollenites* in association with *Densipollenites*, *Arcuatipollenites*, *Crescentipollenites*, *Alisporites* and *Weylandites*. There is a remarkable similarity between the palynoflora of the Pali Formation and those of the Rajmahal Basin. However, absence of the *Densipollenites* in borehole RJNE–8 (Tripathi, 1989) suggests that the assemblage recorded from the middle Member of the Pali Formation is younger.

The late Permian palynoflora of the present study can be closely correlated with the palynoassemblage A of the Tamia Ghat Section (Kumar, 1996) and Palynoassemblage IV (Murthy *et al*., 2013) described from the Bijori Formation (Bharadwaj *et al*., 1978) of Pench Valley Coalfield, Satpura Gondwana Basin, Madhya Pradesh. The common taxa available for correlation in both these assemblages are striate bisaccate pollen grains (*Striatopodocarpites* and *Faunipollenites*) which occur in dominance along with *Densipollenites*, *Guttulapollenites*, *Crescentipollenites, Distriatites, Striatites, Scheuringipollenites, Lahirites*, *Verticipollenites, Arcuatipollenites* (=*Lunatipollenites*) and *Alisporites*.

The palynoassemblages of the present study show similarity with those of the Chintalapudi sub – basin (Srivastava and Jha, 1994; Jha *et al*., 2014), Ramagundam, Ramakrishnapuram (Srivastava and Jha, 1988), Bhudharam (Srivastava and Jha, 1995), Bhopalpalli (Srivastava and Jha, 1998), Satrajpalli (Jha and Aggarwal, 2010), Mamakannu (Jha and Aggarwal, 2010), Gundala (Jha and Aggarwal, 2011) and Kachinapalli coalfields (Jha *et al.,* 2011) areas of Godavari Graben. The assemblages described from various areas of the Godavari Graben are dominated by striate bisaccate pollen grains *Striatopodocarpites* sp. and *Faunipollenites* sp. Due to the presence of *Densipollenites* sp. and nonstriate bisaccate forms like *Scheuringipollenites maximus, S. ovatus, Alisporites* sp., *Guttulapollenites hannonicus, Weylandites lucifer,* which are diagnostic late Permian taxa, the palynoassemblages of the late Permian of the Godavari Graben can broadly be correlated with the palynofloral assemblage of the middle Member of the Pali Formation.

CORRELATION WITH OTHER GONDWANIC CONTINENTS

The present palynoassemblage is comparable with that of the late Permian Weller Formation of Allan Hills, Central Transantarctic Mountains South Victoria Land, Antarctica (Ram–Awatar *et al*., 2014) on the basis of common occurrence of taeniate, bisaccate genera such as *Protohaploxipinus* (=*Faunipollenites*), *Striatopodocarpidites*, *Guttulapollenites, Lunatisporites* (=*Arcuatipollenites*), non–taeniate bisaccate pollen *Scheuringipollenites*, *Alisporites, Weylandites* and *Densipollenites*. However, the taxa *Calamospora microrugosa, Camptotriletes warchianus* and *Didecitriletes ericianus,* present in the palynoassemblage of the Allan Hills, are absent in the middle member of the Pali Formation.

Late Permian palynofloras are defined on the basis of first or consistent appearance of spores and pollen taxa in western (Helby *et al*., 1987; Mory and Backhouse, 1997) and eastern Australian basins (Evans, 1969; Kemp *et al.,* 1977; Foster, 1982; Price, 1983, 1997). The basal part of the *Protohaploxypinus microcorpus* Zone (Helby *et al*., 1987) and the APP601 subzone in Australia contain high diversity and abundance of taeniate, bisaccate pollen grains like *Protohaploxypinus* (=*Faunipollenites*), S*triatopodocarpites* and non-taeniate, bisaccate pollen grains (*Scheuringipollenites ovatus=Alisporites ovatus*). According to Metcalfe *et al*. (2008) the *Protohaploxypinus microcorpus* Zone in western Australia has been dated independently as late (but not latest) Changsingian age. Foster (1982) also described assemblages assignable to the 'Upper Stage 5' from the Bowen Basin in Queensland, eastern Australia. The 'Upper Stage 5'

i.e. Playfordiaspora crenulata Zone of Foster (1982) is characterized by the presence of striate bisaccate pollen grains *Protohaploxypinus* (=*Faunipollenites*) and non–striate bisaccate pollen grain *Scheuringipollenites*. On the basis of presence of *Protohaploxypinus* (=*Faunipollenites*), S*triatopodocarpites, Scheuringipollenites*, *Weylandites lucifer, Alisporites* spp. in assemblage of middle Member the Pali Formation, the present assemblage can be correlated with the assemblages of 'Upper Stage 5' of the Bowen Basin (Foster, 1982), which is late Permian in age. The present assemblage is also similar with those described from the Sabina Sandstone in southern Perth and Wagina Sandstone in the northern Perth basins of Australia (Backhouse, 1993) due to the presence of some common taxa like *Protohaploxypinus* spp (=*Faunipollenites*), S*triatopodocarpites* sp., *Guttulapollenites hannonicus, Densipollenites indicus, Weylandites lucifer*. However, forms like *Densoisporites playfordii, Limatulasporites fossulatus, Densoispoirtes* sp. and *Ephedripites* sp. are not recorded in the present study which suggests that the middle Member of the Pali Formation is older than the Sabina and Wagina sandstones of the Perth Basin of Australia.

Table 3. Comparative distribution of plant fossil taxa of the middle member of the Pali Formation, Johilla Coalfield and those of the late Permian sequences of other lower Gondwana basins of India.

	Basins	Satpura	Mahanadi	Wardha	Godavari	Rajmahal	Damodar
Sl.No.	Name of Taxa	Bijori Formation	Kamthi Formation			Pachhwara Formation	Raniganj Formation
1.	*Glossopteris bosei*	*	*	*			
2.	*Glossopteris communis*	*	*	*	*	*	*
3.	*Glossopteris gondwanensis*		*			*	*
4.	*Glossopteris indica*	*	*	*	*	*	*
5.	*Glossopteris intermedia*		*	*			*
6.	*Glossopteris intermittens*	*	*	*		*	*
7.	*Glossopteris leptoneura*		*	*			*
8.	*Glossopteris longicaulis*			*			*
9.	*Glossopteris searsoliensis*						*
10.	*Glossopteris spathulata*		*	*			*
11.	*Glossopteris stricta*		*	*			*
12.	*Glossopteris subtilis*		*	*			*
13.	*Glossopteris tenuifolia*	*	*	*		*	*
14.	*Glossopteris tenuinervis*						*
15.	*Glossopteris vulgaris*						*
16.	*Neomariopteris hughesii*	*	*	*		*	*
17.	*Utkaliolepis indica*		*	*			
18.	*Vertebraria indica*	*				*	
19.	*Samaropsis ganjrensis*			*			
20.	*Cordaicarpus zeilleri*	*		*			

Based on the palynological data obtained from surface and subsurface samples, Souza and Marques–Toigo (2005) identified two interval palynozones *Vittatina costabilis* and *Lueckisporites virkiiae* in the Permian successions of the Parana Basin, Brazil. The base of the youngest Biozone (*Lueckisporites virkiiae*) is marked by the first appearance of *Lueckisporites* (*L. virkiiae, L. densicorpus*) in association with *Weylandites lucifer, Protohaploxypinus* spp. (=*Faunipollenites*) spp. and *Lunatisporites* spp. According to Souza and Marques–Toigo (2005) the *L. virkkiae* Zone is assigned a late Cisularian to early Guadalupian age. Therefore, occurrence of *Weylandites lucifer* along with *Lunatisporites* sp. and *Protohaploxypinus* sp. (=*Faunipollenites*) in the present study allows a tentative correlation of the middle Member of the Pali Formation with the *Lueckisporites virkiiae* Zone of Parana Basin of Brazil. Recently, Balarino (2014) identified two biozones in the Permian sediments of the Claromecó Basin (Argentina). The lower *Converrucosisporites confluens–Vittatina vittifera* (CV) Zone recorded from the Piedra Azul and Bonete formations was assigned a Cisuralian–Guadalupian age, while the upper *Tornopollenites toreutos–Reduviasporonites chalastus* (TC) Zone is equated with the Guadalupian–Lopingian age. The TC Zone can be correlated with the Middle Pali palynoassemalge owing to the presence of *Protohaploxypinus* (=*Faunipollenites*), *Striatopodocarpites fusus, Lunatisporites* spp, *Weylandites lucifer* and *Hamiapollenites* spp. *Staurosaccites cordubensis* and *Circulisporites parvus*. The characteristic taxa of the Triassic strata are absent in the present study suggesting that the age of the middle member of the Pali Formation is equivalent to the Lopingian.

Late Permian palynological studies have been carried out by several researchers from the main Karoo Basin as well as subsidiary basins of South Africa (Falcon, 1975, 1978; Utting, 1976; Anderson, 1977; Wright and Askin, 1987; Hankel, 1992; Semkiwa *et al*., 2003 and Prevec *et al.,* 2010). The Microfloral Zone 5 of Anderson (1977), Assemblage Zone IV of Falcon (1975) and the palynoflora described from the New and Old Wapadsberg Pass, eastern Cape Province, (Prevec *et al.,* 2010) South Africa are characterized by the presence of the late Permian palynotaxa like *Protohaploxypinus*(=*Faunipollenites*), *Striatopodocarpites fusus* along with *Microbaculispora tentula, M. micronodosa, Horriditriletes tereteangulatus, Brevitriletes levis, Baculatisporites bharadwaji, L. directus, Latosporites colliensis, Guttulapollenites hannonicus*, *Lunatisporites pellucidus, Marsupipollenites* spp., *Alisporites* spp., *Hamiapollenites* spp. and *Weylandites lucifer*. There

is a remarkable similarity between the palynoflora of the Middle Member of the Pali Formation and the South African assemblage in presence of common taxa *Protohaploxypinus* (=*Faunipollenites*), *Striatopodocarpites fusus, Hamiapollenites, Alisporites*, *Guttulapollenites hannonicus*, *Lunatisporites pellucidus* and *Weylandites lucifer*. Further, the present assemblage can be correlated with the palynofloras of the Upper part of the Madumabisa Formation, Zambia (Utting, 1976); Lower Sakamena Group, Madagascar (Wright and Askin, 1987); Karoo sequence of the Mombasa Basin, Kenya (Hankel, 1992) and palynological assemblages of the Lower Karoo Sequence of the Sonwe–Kiwira Coalfield, Tanzania (Semkiwa *et al*., 2003). The assemblages described from the subsidiary basins of Africa (Utting, 1976; Wright and Askin, 1987; Hankel, 1992; Semkiwa *et al*., 2003) show remarkable similarity with the palynoassemblage of the present study. However, *Marsupipollenites triradiates,* present in the South African assemblages has not been recorded in the Pali Formation (Middle Member).

CONCLUDING REMARKS

The Pali Formation is divided into three parts i.e. lower, middle and upper on the basis of lithology and palynology (Tarafdar *et al.,* 1993; Ram–Awatar, 2003; Gautam *et al.,* 2016) (Table 1). The three members are equated with the Barren Measures, Raniganj and Panchet formations, respectively, of the Damodar Basin. The plant fossils from the Pali Formation are represented by *Neomariopteris hughesii,* fifteen species of the genus *Glossopteris* namely, *G. bosei, G. communis, G. gondwanensis, G. indica, G. intermedia, G. intermittens, G. leptoneura, G. longicaulis, G. searsoliensis, G. spathulata, G. stricta, G. subtilis, G. tenuifolia, G. tenuinervis, G. vulgaris, Vertebraria indica,* scale leaf *Utkaliolepis indica*, dispersed seeds *Cordaicarpus zeilleri, Rotundocarpus striatus, Samaropsis goraiensis* and *Samaropsis feistmantelii.* The palynoassemblage of this Formation includes striate bisaccate pollen grains mainly *Striatopodocarpites, Faunipollenites, Striatites*, *Verticipollenites*, *Densipollenites*, *Lahirites*, *Crescentipollenites*, *Distriatites*, *Arcuatipollenites*, *Scheuringipollenites*, *Decussatisporites* and some stratigraphically significant taxa like *Guttulapollenites, Alisporites* and *Weylandites* indicating a late Permian affinity. The megafloral assemblage is comparable with those described from the Kamthi Formation (late Permian) of Wardha (Bunbury, 1861; Tewari, 2007, 2008), Godavari (King, 1881; Lakshinarayana and Murthy, 1990) and Mahanadi (Feistmantel, 1880,1881; Chandra and Prasad, 1981; Goswami, 2006; Singh and Saksena, 2015) basins, Pachhwara Formation of Rajmahal Basin (Prasad *et al.,* 1987; Maheshwari, 1992), Bijori Formation of Satpura Basin (Srivastava and Agnihotri, 2010), Raniganj and Maitur formations of Damodar Basin (Srivastava, 1979; Srivastava, 1956; Pant and Gupta, 1968; 1971; Pal *et. al*., 2010) (Table 3). The similarity of palynomorphs of this Formation with those of the Raniganj, Bijori and Kamthi formations of Damodar, Satpura and Wardha/Godavari/Mahanadi basins of India and late Permian palynomorph assemblages of South America, South Africa, Antarctica and Australia indicates a late Permian age. Megaflora of the middle member of the Pali Formation shows similarity with the late Permian flora of Antarctica (Tewari *et al.,* 2015), early Permian flora of South Africa (Anderson and Anderson, 1985), Brazil (Iannuzzi, 2010) and Argentina (Archangelsky, 1958, 1996). However, taxa like *Glossopteris bosei*, *G. gondwanensis*, *G. searsoliensis*, *G. tenuinervis*, *G. vulgaris, Neomariopteris hugesii, Cordaicarpus zeilleri* and *Rotundocarpus striatus* are endemic to India. The mega and micro- floral assemblages described herein apparently belong to the Middle Member of the Pali Formation which is late Permian in age. Additionally, the present study corroborates the floral similarity between the middle member of the Pali Formation and the lower part of the Kamthi Formation which is also late Permian in age (Joshi *et. al.,* 2014).

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