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EARLY PERMIAN MACRO AND MIOFLORAL DIVERSITY FROM SINGRAULI COALFIELD, SON-MAHANADI BASIN, INDIA

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ABSTRACT

Mega and miofloral diversity of the coal bearing sequences of the Barakar Formation of the Block-B and Nigahi collieries, Singrauli Coalfield has been studied in detail to infer the palaeofloristics, age assessment and palaeoenvironment. A diverse glossopterid assemblage has been recorded from a sequence of Block B colliery, whereas from the Nigahi colliery no megafossil is reported. The assemblage comprises of *Gangamopteris*, *Glossopteris* and equisetalean axes. The genus *Glossopteris* dominates the assemblage and is represented by ten species, namely, *G. arberi, G. communis, G. gigas, G. indica, G. longicaulis, G. mohudaensis, G. nautiyalii, G. raniganjensis, G. spatulata,* and *Glossopteris* species. The genus *Gangamopteris* is represented by five species namely, *G. angustifolia, G. cyclopteroides, G. karharbariensis, G. major* and *Gangamopteris* sp. Interestingly, the procured fossil leaves of *Glossopteris* and *Gangamopteris* are fairly large and broad as evidenced by the abundance of *Glossopteris gigas* and *Gangamopteris cyclopteroides* species in the assemblage suggesting the existence of low light or the shady conditions in and around the vegetated area.

The palynological study has revealed two palynoassemblages, Palynoassemblage I and Palynoassemblage II from the Barakar sediments of Block B and Nigahi collieries respectively. Both the assemblages reveals the dominance of non-striate bisaccate pollen grains *Scheuringipollenites* and sub dominance of striate bisaccate pollens *Faunipollenites* followed by *Parasaccites*, *Plicatipollenites*, *Potonieisporites*, *Densipollenites*, *Divarisaccites*, striate bisaccate pollen grains viz. *Striatopodocarpites*, *Crescentipollenites* and spore *Rhizomaspora*.

The dominance of palynomorph *Scheuringipollenites barakarensis* suggests a late early Permian (Artinskian) age to the studied coal bearing sequences of Block-B and Nigahi collieries which is also substantiated by the diverse occurrence of *Gangamopteris* in the mega plant assemblage.

Keywords: Megaflora, *Glossopteris*, Palynology, Barakar Formation, Singrauli Coalfield, Son–Mahanadi Basin.

INTRODUCTION

The Son-Mahanadi Basin is one of the most significant Gondwana basins of India which has very thick and extensive sedimentary deposits of coal bearing sequences of the Permian period. This basin occupies the central and eastern part of the country and is the largest coal producing basin. Around eighteen coalfields and their adjoining areas form the major sedimentary deposits of Son-Mahanadi Basin. The coal bearing sequences of this basin have been studied in detail for the palaeofloristic diversity and associated depositional environments. Significant contributions pertaining to megafloral and palynological studies in some of the coalfields and their adjoining areas namely, Korba, Tatapani-Ramkola, Ib-River, Talcher, Chirimiri, Mand-Raigarh, South Rewa, Sohagpur and Johilla have been made by many workers (Agnihotri *et al*., 2016; Goswami and Singh, 2010, 2013; Goswami *et al*., 2006, 2018; Singh *et al*., 2006a, b, 2011, 2012; Tewari *et al*., 2017; Pillai *et al*., 2018; Saxena *et al*., 2014, 2019a). However, in comparison to comprehensive palaebotanical studies carried out in the above mentioned coalfields, the Singrauli coalfield has received little attention. Earlier reports of the glossopterid megaplants from the area are from the Talchir and Barakar sediments carried out about five decades ago (Lele, 1966; Lele *et al.,* 1968), this coalfield is being investigated recently for its mega and miofloral diversity. A diverse megafloral assemblage of glossopterid remains has been studied in detail from the Raniganj Formation of Jhingurdah Colliery (Singh and Saxena, 2015; Singh *et al*., 2017; Singh *et al*., 2016) and Barakar Formation of Bina Colliery (Saxena *et al*., 2016a) in the Singrauli Coalfield. Though, a number of palynological and petrological studies are available from this coalfield (Trivedi, 1950; Bhardwaj and Sinha, 1969 a, b; Pareek, 1969, 1970; Tiwari, 1969, 1971; Sinha, 1972; Tiwari and Srivastava, 1984; Mishra and Singh, 1990; Singh and Mishra, 1991; Vijaya *et al.,* 2012; Saxena *et al*., 2016b; Singh *et al*., 2017).

The Singrauli Coalfield is a part of the extensively distributed Lower Gondwana formations in the northernmost boundary of the Son-Mahanadi Basin. In the present study, the coal bearing sequences of the Barakar Formation of Block-B and Nigahi collieries have been studied for the mega and microfloral diversity. A diversified Glossopterid assemblage comprising *Gangamopteris*, *Glossopteris*, seeds and equisetalean axes has been recorded from the Block-B colliery, whereas from the Nigahi colliery, only a stem is recorded. However, from both the collieries two significant palynoassemblages namely, Palynoassemblage I and Palynoassemblage II, both showing the dominance of non-striate bisaccate pollen *Scheuringipollenites* and sub dominance of striate bisaccate pollen *Faunipollenites* have been recorded. In the present communication, an attempt has been made to assess the megafloral composition and palynostratigraphic status of the Barakar sediments. For a better understanding of the vegetational scenario, mega and miofloral assemblages have also been compared and correlated with the contemporaneous strata of other Gondwana coalfileds/basins of India.

GEOLOGICAL SETTING

The Singrauli Coalfield lies between the latitudes 23º47′ and 24º12′ and longitudes 81º48′ and 82º52′ and is located in the drainage area of Son and Rihand rivers. The total geographical area of this coalfield is around 2200 sq km, approximately 80 sq km comes in Sonbhadra District of Uttar Pradesh State and the rest falls in Singrauli District of Madhya Pradesh State. The north eastern part of the coalfield sits on plateau with an altitude of 500 m above msl. The Singrauli Coalfield is divided into two parts: the Moher sub-basin which lies in the Sidhi District of Madhya Pradesh (a small part lies in the Sonbhadra District of Uttar Pradesh) and the Singrauli main basin which lies in the western and southern parts of the coalfield and is largely unexplored and has little coal reserve.

The coalfield is structurally divided into two tectono–sedimentary sub–basins: (i) Singrauli main sub–basin to the west and (ii), the Moher sub–basin on the north–eastern side. However, these two sub–basins are not precisely delineated as all the Lower Gondwana formations are successively exposed in both the basins. The sediments of Permian age belonging to Talchir, Barakar, Barren Measures and Raniganj formations are extensively exposed in the Moher sub–basin. Sediments of Panchet (Pali) and Mahadeva (Parsora) formations belonging to Triassic age are mainly confined to the Singrauli main sub–basin (Raja Rao, 1983). The only difference between both the sub–basins lies in the amount of coal reserves found in them. The coal reserves in the Moher sub-basin covering an area of around 220 sq km, is about 9000 million tonnes, out of which 2,724 million tonnes are proved reserves. All the ten working opencast mines of Singrauli Coalfield, viz. Dudhichua, Jayant, Kakri, Bina, Krishnashilla, Amlohri, Khadia, Block B, Nigahi and Jhingurdah belong to Moher sub- basin. Of these, Jhingurdah Colliery belongs to Raniganj Formation and rest belong to the Barakar Formation. The Barakar Formation has three coal seams, lowermost Turra seam, middle Purewa Bottom and the uppermost Purewa Top (Fig. 1). Below Turra, a thin seam, namely Kota also exists that is in the Karharbari Formation. The stratigraphic sequence met within the Singrauli Coalfield is given in Table 1.

MATERIAL AND METHODS

The megafossil assemblages described in the present paper has been procured from the coal bearing sequence of the Turra coal seam of the Barakar Formation of the Block-B colliery (Fig. 2). In addition, 5 palynological samples were also collected from this section (Fig. 3A). From the Nigahi colliery, no megafossil could be procured except a big stem cast which was not collected. However, 6 samples for the palyological analysis were collected from a coal bearing sequence of the Purewa Top seam of Nigahi colliery (Fig. 3B). In all, 43 megafossil specimens comprising of equisetalean axes, leaves of *Gangamopteris, Glossopteris,* seeds and leaf of the genus *Euryphyllum* were studied. The detailed study pertaining to the genus *Gangamopteris* is being published elsewhere. Rest of the assemblage is studied and discussed herein. The specimens are preserved as impressions on grey shale and siltstone units of the coal-bearing sequence. They are measured and photographed to record the morphological characters using low power Leica microscope and Sony HX 400 digital camera. For the identification and species determination, various morphological features such as shape of the leaf, nature of apex and base, midrib, type of meshes and the venation pattern have been taken into consideration for which methodology as given by Chandra and Surange (1979) has been adopted.

For the palynological analysis, approximately 50 gms of crushed samples were processed following the standard palynological techniques. For the removal of silicates from the shale sequence, the samples were kept in hydrofluoric acid (40% HF) for two to three days. Subsequently, the resultant acid–free

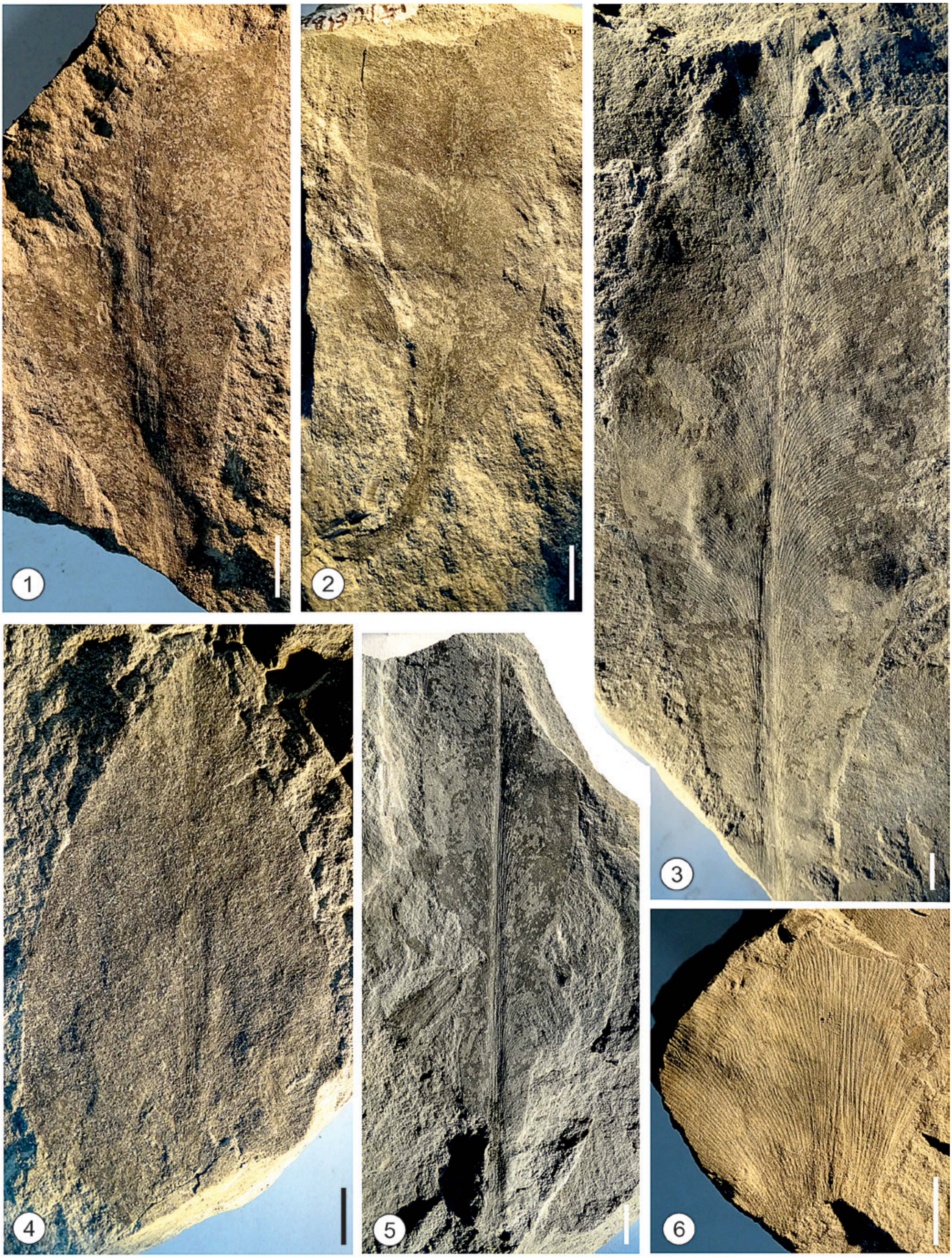
Table 1. General stratigraphic succession of Singrauli Coalfield (after GSI unpublished report, in Vijaya *et al.* 2012).

Age	Formation/Group	Thickness	General Lithology
Recent			Alluvium
Cretaceous	Basic intrusive		Dolerite dykes and sills
Late Triassic	Parsora (Mahadeva)	500 m +	Medium to coarse-grained ferruginous quartzose sandstone
Early Triassic	Pali (Panchet)	700 m +	Greenish yellow to reddish yellow, medium- to coarse-grained sandstone with variegated siltstone and clay
Late Permian	Raniganj	215-400 m	Fine to medium-grained dirty to buff coloured subarkosic to feldspathic wacke with alternation of thin lamination of grey and carbonaceous shale along with impersistent coal seams
Middle Permian	Barren Measures	110-300 m	Dark brown to brownish yellow to greenish grey, medium- to coarse-grained flaggy sandstone with thin grey clay bands in between
Early Permian	Barakar	325-550 m	Dirty white fine- to coarse-grained sub-arkosic to arkosic sandstone along with siltstone, shale, carbonaceous shale and coal seams
Early Permian	Talchir	75-230 m	Dark greenish grey to grey shale, fine-grained sandstone diamictite, siltstone pebbly sandstone and boulder bed
--------------------------------------*Unconformity*---			
Precambrian	Mahakoshal		Granite, gneiss, quartzite, phyllite, schist and pegmatite

EXPLANATION OF PLATE I

Fig. 1. ***Glossopteris arberi*** Srivastava, BSIP Museum Specimen No. 41687; Fig. 2. ***Glossopteris longicaulis*** Feistmantel BSIP Museum Specimen No. 41688; Fig. 3. ***Glossopteris communis*** Feistmantel, BSIP Museum Specimen No. 41689; Fig. 4. ***Glossopteris nautiyalii*** Pant and Singh BSIP Museum Specimen No. 41688; Fig. 5. ***Glossopteris indica*** Schimper, BSIP Museum Specimen No. 41690; Fig. 6. ***Euryphyllum*** sp., BSIP Museum Specimen No 41691.

Plate I



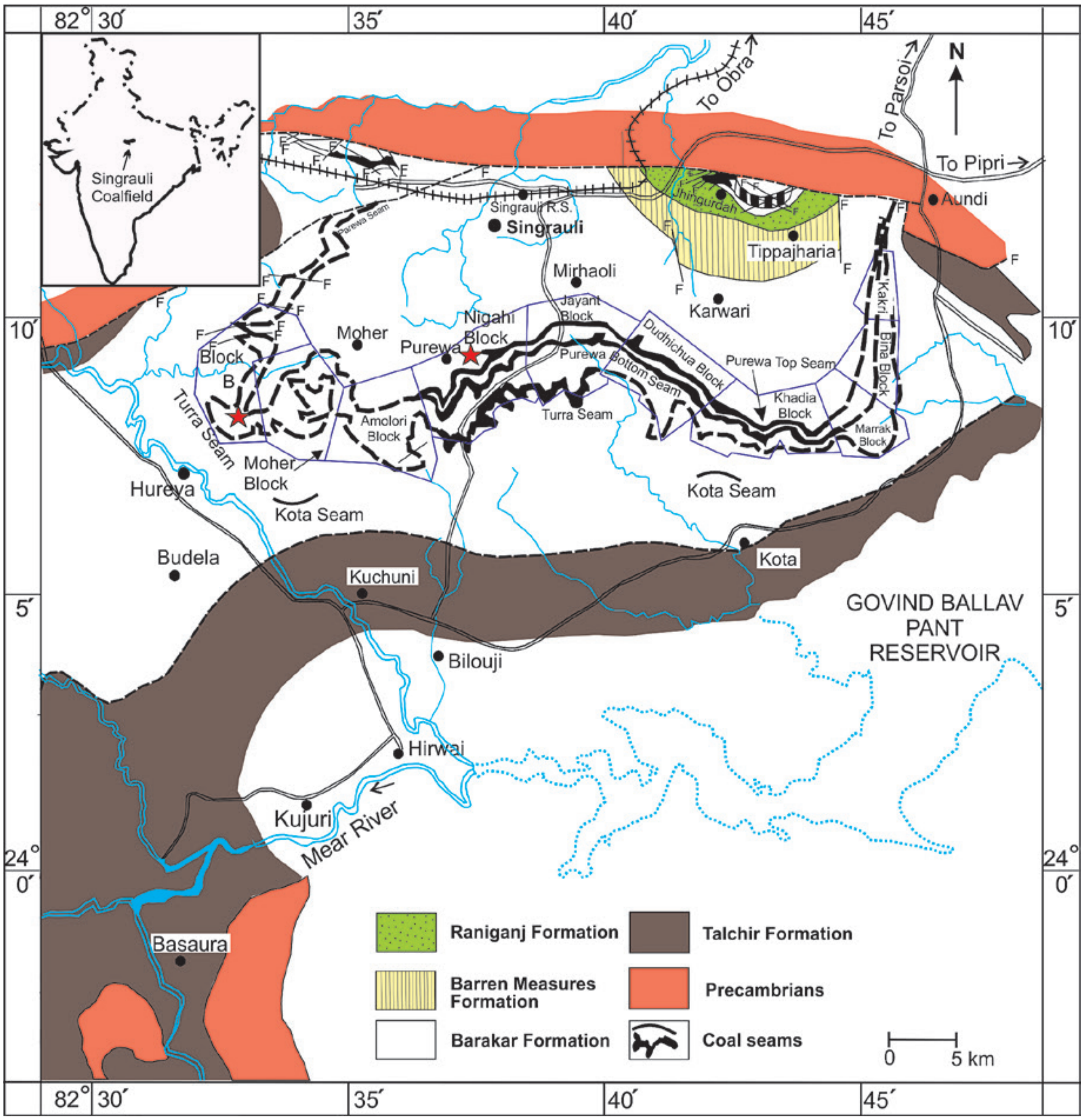


Fig. 1. Location map of the Singrauli Coalfield showing Block-B and Nigahi collieries (after Raja Rao, 1983).

residue was treated with concentrate nitric acid (63.01% HNO_3) followed by alkali treatment (10% KOH solution) to remove the humic contents. Five slides per sample were prepared from each productive sample and the palynofossils were examined under a standard light microscope (Olympus BX61 with the DP-20 camera using Cell A software). A maximum of 200 palynomorphs were counted per sample for ascertaining their percentage frequency distribution (Figs. 3 and 4).

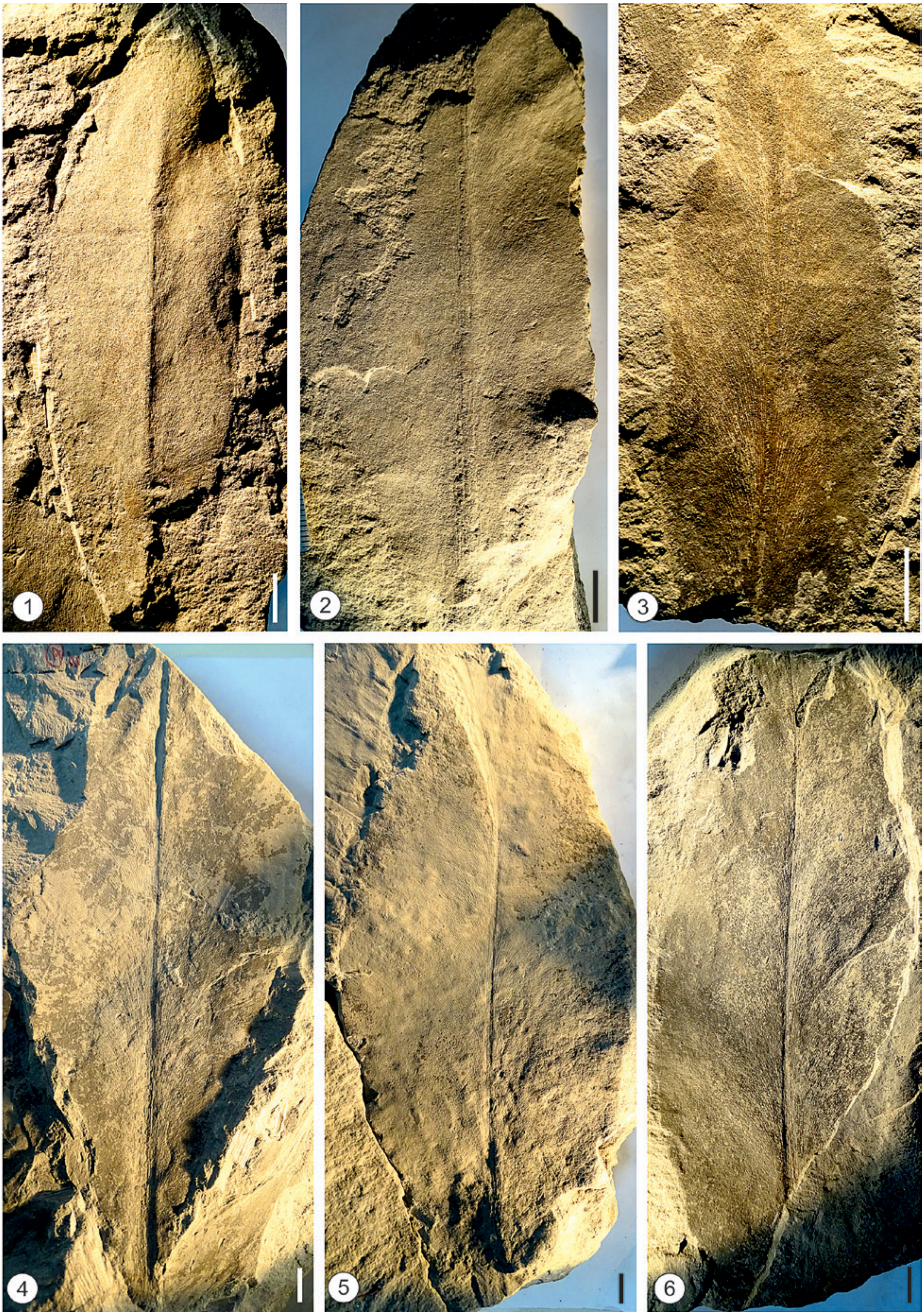
The details of the sequence yielding megafossil specimens and palynological samples are given in Figs. 2 and 3. Some of the significant and well preserved megafossils are shown in Plates I, II and III. Similarly the key palynomorphs are shown in Plate IV.

All the figured specimens are deposited in the repository of Birbal Sahni Institute of Palaeoesciences, vide statement number 1509, museum specimen numbers (megafossils) 41687 to 41700 and palynological slides numbers 16417-16421.

EXPLANATION OF PLATE II

Fig. 1. ***Glossopteris spatulata*** Pant and Singh BSIP Museum Specimen No. 41692; Fig. 2. ***Glossopteris spatulata*** Pant and Singh BSIP Museum Specimen No. 41693; Fig. 3. ***Glossopteris spatulata*** Pant and Singh BSIP Museum Specimen No. 41694; Fig. 4. ***Glossopteris gigas*** Pant and Singh BSIP Museum Specimen No. 41695; Fig. 5. ***Glossopteris gigas*** Pant and Singh BSIP Museum Specimen No. 41698; Fig. 6. ***Glossopteris raniganjensis*** Chandra and Surange, BSIP Museum Specimen No. 41697.

Plate II



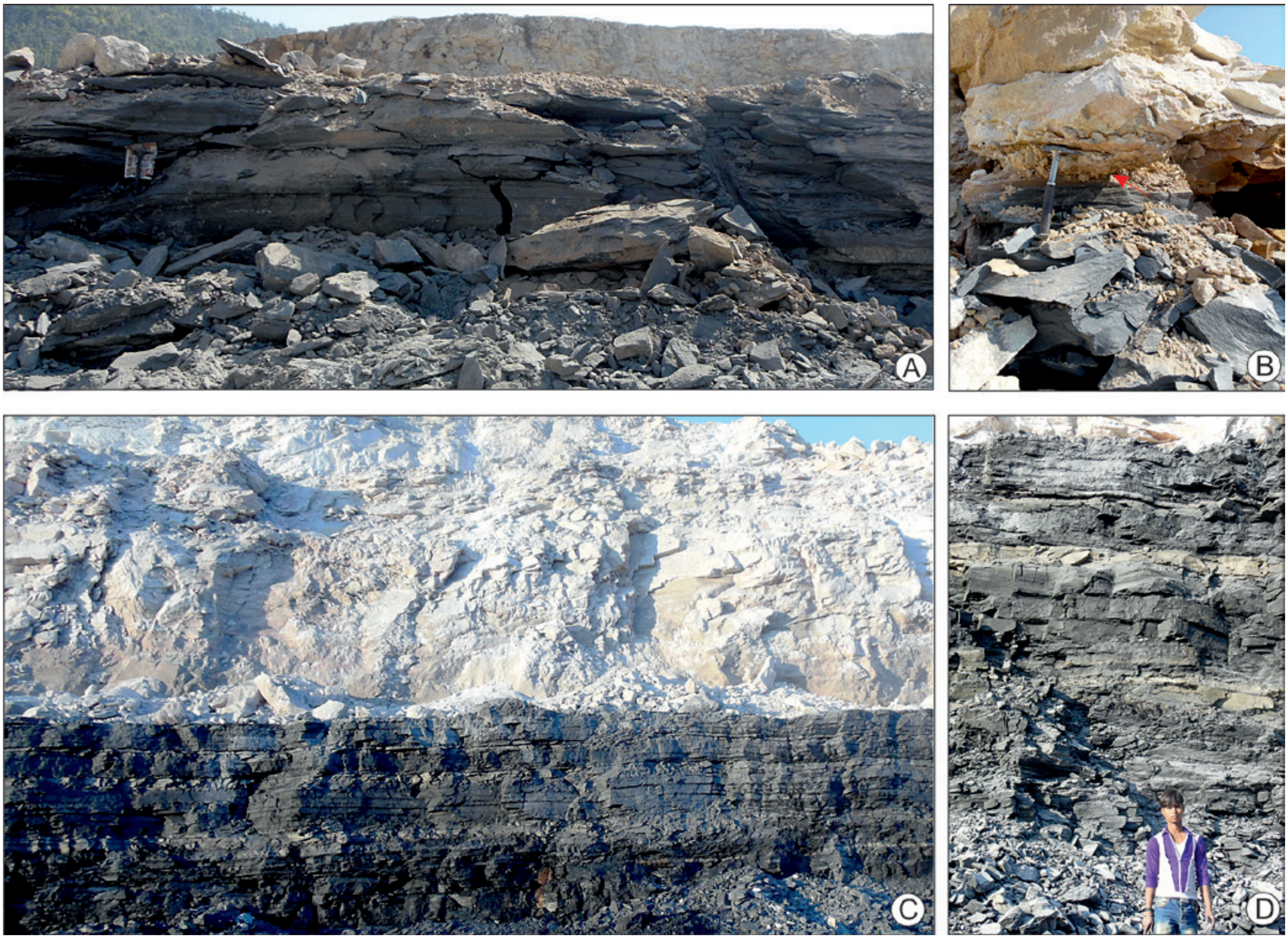


Fig. 2: (A). An overview of a part of Turra Seam of Block B colliery, showing the grey shale, mudstone and sandstone successions. (B). Close view of the Fig. 2A, showing mudstone and shale contact of the section. (C). An overview of a part of Purewa Top Seam of Nigahi colliery showing the grey shale, mudstone and sandstone successions. (D). Close view of the section shown in Fig. 2C.

SYSTEMATIC PALAEOBOTANY

Order Equisetales
Genus ***Paracalamites*** Zalessky, 1932

Paracalamites sp.
(Pl. III, fig. 3)

Description: One specimen in the collection, axis measures 10.3 cm in length and 4.8 cm in width. Nodes and internodes are present. 11 ridges and 10 furrows are present throughout the length of the axis. Ridges and furrows are spaced at less than 1 mm distance.

Remarks: The present remain of equisetalean stem is classified as Genus *Paracalamites* as proposed by Rigby (1966) in having the alternate ridges and furrows, and nodes and internodes.

Division **Gymnospermophyta**
Order **Glossopteridales** Plumstead, 1956
Genus ***Glossopteris*** Brongniart, 1828

Glossopteris arberi Srivastava, 1956
(Pl. I, fig. 1)

Description: One incomplete specimen, lower half of the specimen preserved, leaf small to medium sized, shape oblong, measures 8.5 cm in length and 3.3 cm in width. Apex and base not preserved; midrib broad, flat, persistent, tapering upwards; secondary veins arise at acute angles, arching outwards near midrib, meet margins at 60º-70º. Veins dichotomise and anastomose 4-6 times to form narrow elongated meshes, vein density 22-28 veins/cm^2.

Remarks: Specimen shows close resemblance with the holotype *G. arberi* as described by Srivastava (1956, Pl. 9, fig.

EXPLANATION OF PLATE III

Fig. 1. ***Glossopteris gigas*** Pant and Singh BSIP Museum Specimen No. 41696; Fig. 2. ***Glossopteris mohudaensis*** Chandra and Surange, BSIP Museum Specimen No. 41698; Fig. 3. ***Paracalamites*** sp. BSIP Museum Specimen No. 41696; Fig. 4. ***Glossopteris communis*** Feistmantel BSIP Museum Specimen No. 41699; Stem impression from Nighai colliery; Fig. 5. ***Glossopteris*** sp. BSIP Museum Specimen No. 41700.

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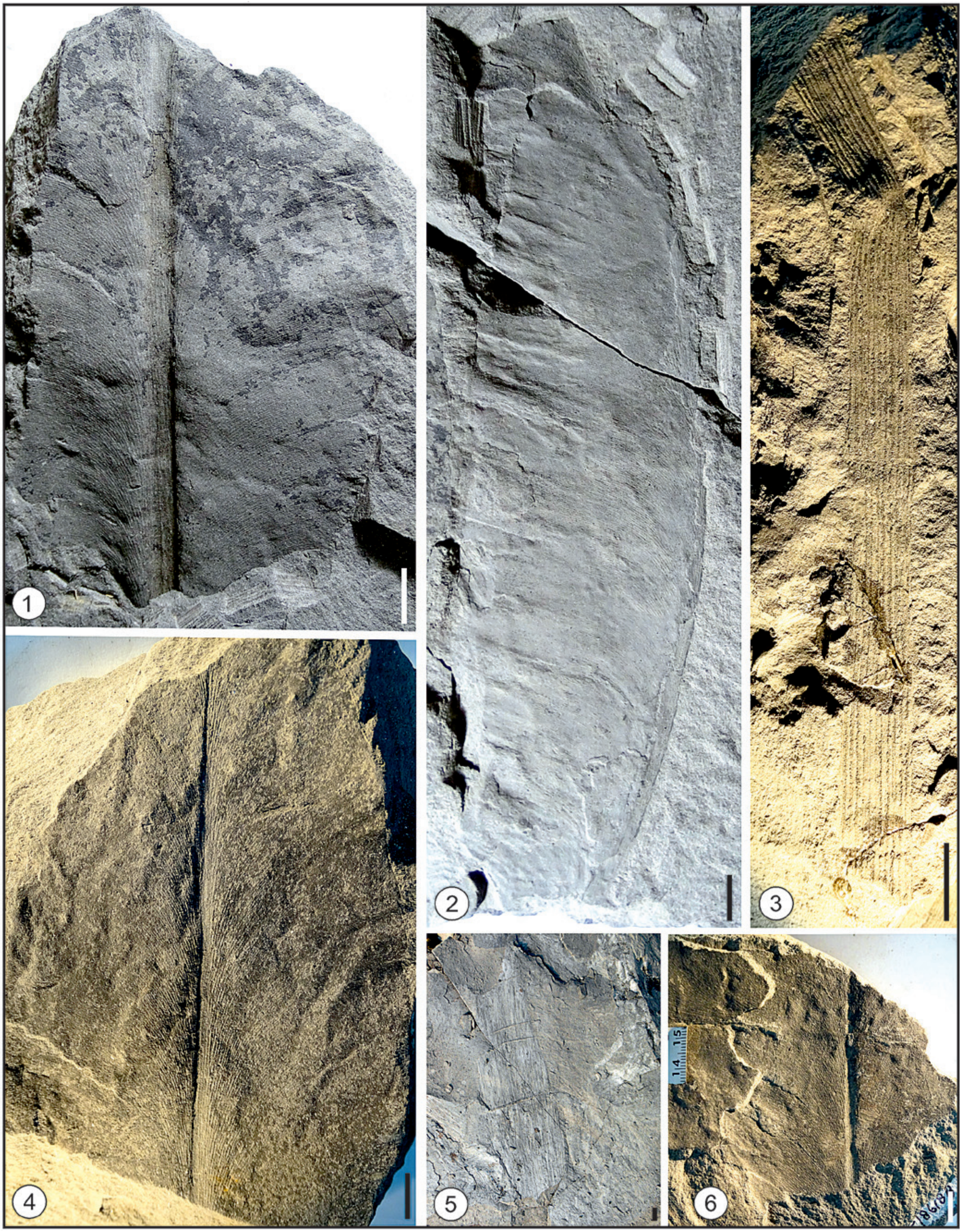
Plate III



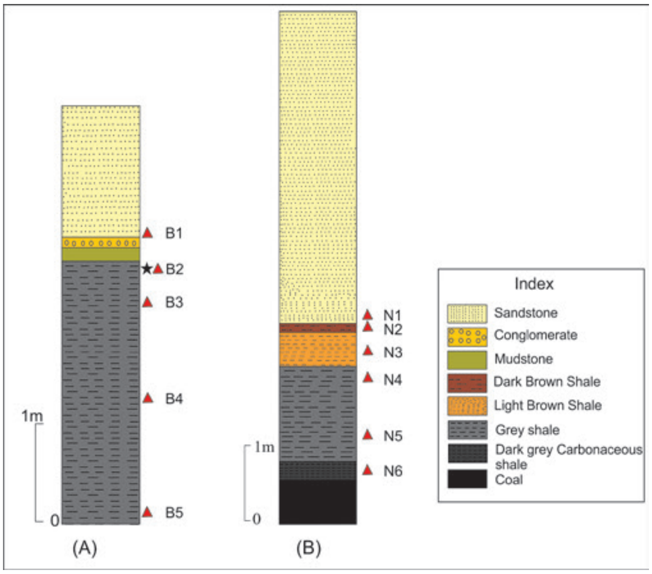


Fig. 3: (A). Litholog of the part of Turra seam section yielding megafossil and palynological assemblages, (B). Litholog of the part of Purewa Top seam section of Nigahi colliery; (* indicate megafossil bearing horizon, Δ indicate positions of palynological samples).

57) in length to width ratio, nature of midrib and venation pattern. The specimen is also comparable in its shape and venation pattern with *G. arberi* as described by Chandra and Surange (1979, Pl. 7, figs 4, 7; Pl. 8, fig. 6; Pl. 17, fig. 2), Chandra and Singh (1992, Pl. 7, fig. 3; Pl. 8, fig. 2), Singh *et al*. (2006b, Pl. 2, fig. 3), Tewari (2007, Pl. 1, fig. 6; Pl. 4, figs. 3, 4) and Tewari *et al*., (2012, Fig. 5, E and F).

Glossopteris communis Feistmantel, 1879
(Pl. I, fig. 3)

Description: The species is represented by 7 specimens of which one is complete. Leaves medium to large, broad in the middle and tapering towards apex, measuring 7.5 to 17 cm in length and 4 to 8 cm in width. The complete specimen exhibits narrow elliptic shape, length/ width ratio 4:1, obtuse apex, acute-cuneate base. Margin entire; midrib 3- 4 mm wide, strong, distinct and tapers towards the apex. Lateral veins emerge from the midrib at 15º-25º, arched towards the margin and meet it at 50º-65º. Veins dichotomize and anastomose to form dense elongate meshes, meshes are 4-6 mm in length and .0.3-0.7 mm in width. Vein density is 22-27 veins/cm^2 near midrib and 24-30 veins/cm^2 near the margin.

Remarks: The present specimens resemble with the holotype of *Glossopteris communis* Feistmantel (1879, Pl. 17, figs. 1, 2)

Table 2: Distribution of *Glossopteris* species recorded from Singrauli Coalfield in the Barakar Formation of other Indian Gondwana coalfields/basins (indicate new contribution from the present study).

Coalfields/Basins ↓ / ***Glossopteris* species** →	**Singrauli**	**Ib-River**	**Talchir**	**Tatapani-Ramkola**	**Korba**	**Sohagpur/Johilla**	**Pathakhera/Pench/ Kanhan/**	**Mohpani**	**Auranga**	**Raniganj**	**Karanpura**	**Bokaro**	**Giridih**	**Rajmahal Basin**	**Wardha/Godavari**	**Kashmir**
*G. arberi**	+	+			+		+				+	+			+	
G. browniana	+	+	+	+	+		+		+	+	+	+		+	+	
*G. communis**	+	+	+	+	+	+	+	+	+	+		+	+	+	+	+
G. cf. G. cordatifolia	+						+				+	+		+	+	+
*G. gigas**	+	+	+		+	+	+								+	
*G. indica**	+	+	+	+	+	+	+	+	+	+	+	+		+	+	+
G. leptoneura	+	+	+						+			+				
*G. longicaulis**	+		+			+	+			+					+	+
*G. mohudaensis**	+											+			+	
G. nakkarea	+	+					+									
*G. nautiyalii**	+	+														
G. pantii	+	+			+											
*G. raniganjensis**	+	+		+	+					+	+					
G. recurva	+	+										+				
*G. spatulata**	+	+			+	+				+						
G. sp. *cf. taeniopteroides*	+	+				+	+							+	+	+
G. tenuifolia	+	+	+	+			+			+		+			+	
Glossopteris species	+	+	+	+	+	+	+			+	+	+				+

EXPLANATION OF PLATE IV

Fig. 1. ***Parasaccites korbaensis*** Bharadwah and Tiwari 1964, Slide no. 16417, Q51/2; Fig. 2. ***Parasaccites obscurus*** Tiwari 1965, Slide no. 16418, W50; Fig. 3. ***Plicatipollenites indicus*** Lele 1964, Slide no. 16417, K45; Fig. 4. ***Potonieisporites*** sp. Slide no. 16418, W52/2; Fig. 5. ***Densipollenites*** sp. Slide no. 16418, O63; Fig. 6. ***Tiwariasporis simplex*** (Tiwari) Maheshwari and Kar 1967 Slide no. 16418, P48/4; Fig. 7. ***Scheuringipollenites tentulus*** Tiwari ememd. Tiwari 1973, Slide no. 16421, S61/1; Fig. 8. ***Scheuringipollenites maximus*** (Hart) Tiwari 1973, Slide no. 16419, G62/2; Fig. 9. ***Scheuringipollenites barakarensis*** Tiwari ememd. Tiwari 1973, Slide no. 16421, M45/3; Fig. 10. ***Faunipollenites varius*** Bharadwaj 1964, Slide no. 16421, E53/1; Fig. 11. ***Faunipollenites singrauliensis*** Sinha 1972, Slide no. 16418, W54/4; Fig. 12. ***Sahnites barrelis*** (Tiwari) Tiwari & Singh 1984, Slide no. 16417, M59/1; Fig. 13. ***Crescentipolenites fuscus*** Bharadwaj, Tiwari & Kar 1974, Slide no. 16417, M59/2, 3; Fig. 14. ***Primuspollenites levis*** Tiwari 1964, Slide no. 16417, M59/1-3; Fig. 15. ***Rhizomaspora indica*** Tiwari 1964, Slide no. 16420 , P37/Q37/1.

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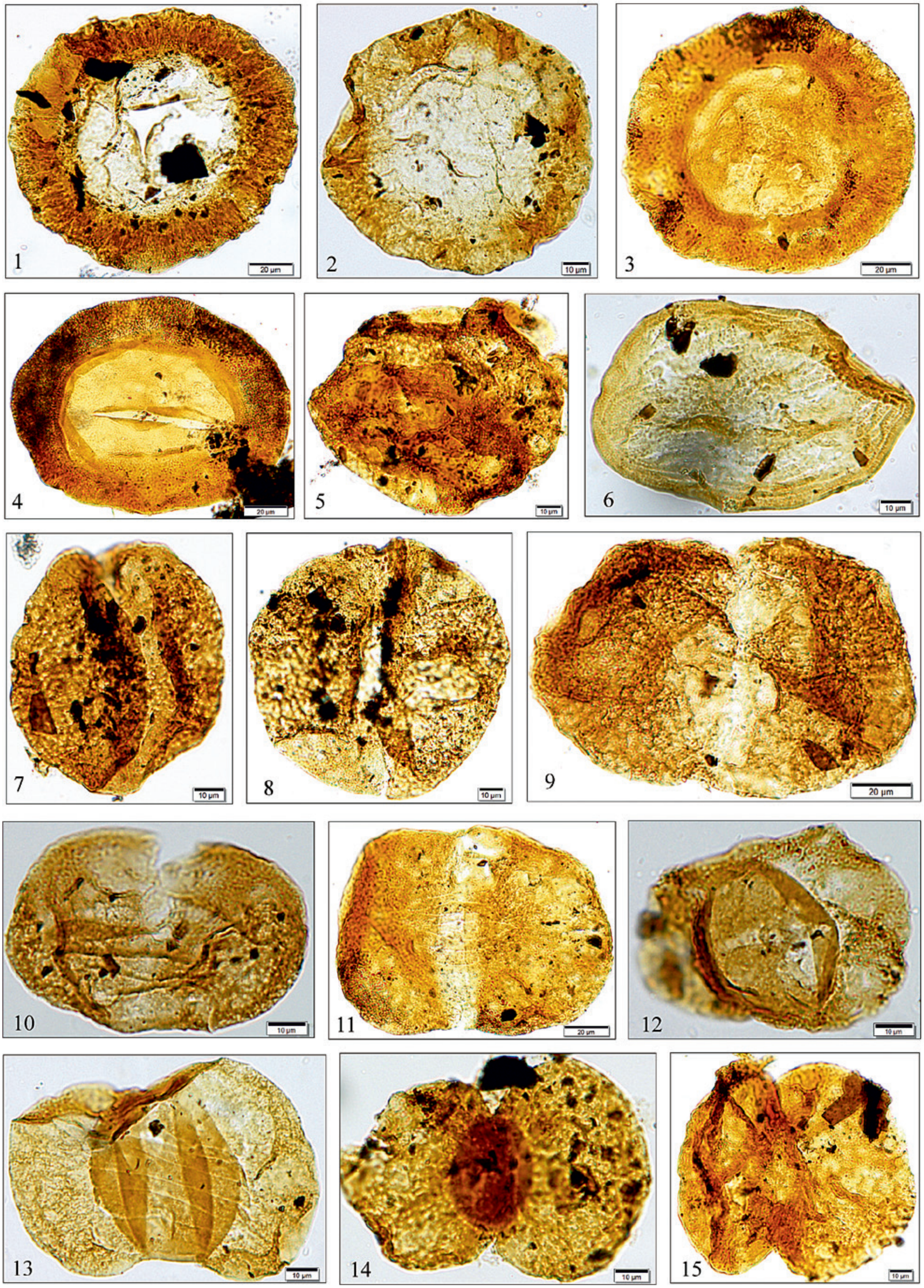
Plate IV



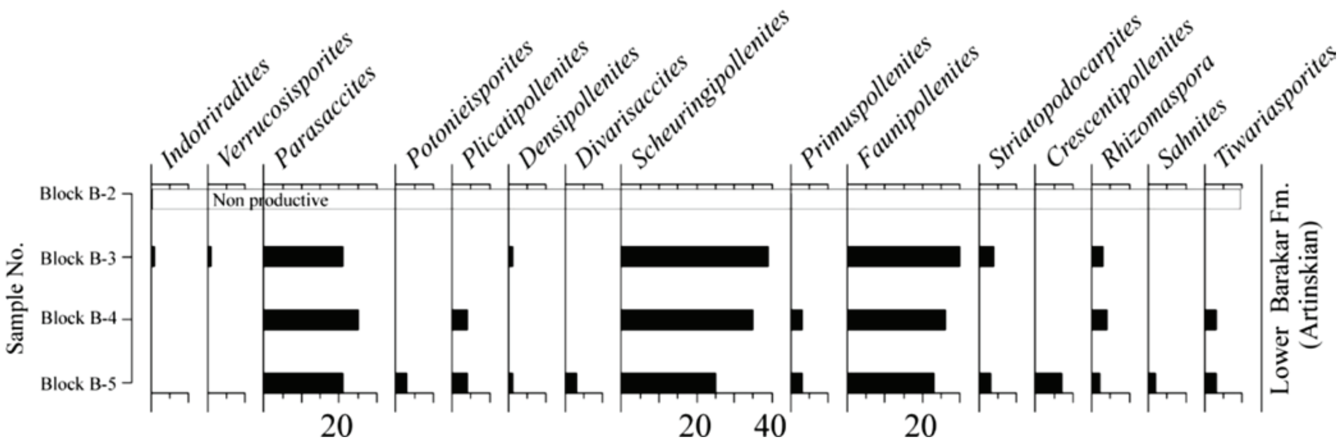


Fig. 4. Distribution of palynotaxa recovered from the Turra Seam of Block B section.

Table 3. List of spore-pollen taxa identified in Block B and Nigahi sections and their botanical affinity based on the compilation of various authors (Balme, 1970, 1995; Grauvogel-Stamm, 1978, 1999; Retallack, 1975, 1997; Hochuli *et al*., 2010; Zavada, 1991; Lindström *et al*., 1997; Looy *et al*., 1999; Mishra and Jha 2017)

Filicales	**Cordaitales**
Microfoveolatispora sp.	*Parasaccites korbaensis* Bharadwah and Tiwari, 1964
Lycopsidales	*Parasaccites obscurus* Tiwari, 1965
Indotriradites sp.	*Plicatipollenites sp.*
Glossopteridales	*Plicatipollenites indicus* Lele, 1964
Faunipollenites sp.	*Densipollenites* sp.
Faunipollenites varius Bharadwaj, 1964	*Densipollenites magnicorpus*
Faunipollenites singrauliensis Sinha, 1972	**Coniferales**
Scheuringipollenites tentulus Tiwari ememd. Tiwari, 1973	*Potonieisporites* sp.
Scheuringipollenites maximus (Hart) Tiwari, 1973	*Potonieisporites lelei* Maheshwari
Scheuringipollenites barakarensis Tiwari ememd. Tiwari, 1973	*Sahnites barrelis* (Tiwari) Tiwari and Singh, 1984
Others	*Crescentipolenites fuscus* Bharadwaj, Tiwari and Kar, 1974
Tiwariasporis simplex (Tiwari) Maheshwari and Kar, 1967	*Primuspollenites levis* Tiwari, 1964
Tiwariasporis indicus Srivastava, 1970	*Rhizomaspora* sp.
	Rhizomaspora indica Tiwari, 1964

in their overall shape and venation pattern, and specimens of *G. communis*, re-described by Chandra and Surange (1979, Pl. 1, figs. 2, 3) (Geological Survey of India specimen nos. 5022 and 5087). The specimens are also comparable with the specimens described by Singh and Chandra 1992 (Pl. 1, fig. 5; Pl. 2, fig. 5), Singh *et al*. (2006b, Pl. 4, fig. 6), Singh *et al*., 2011 (Pl. 1, fig. 1; Pl. 5, fig. 1) and Srivastava *et al*. (2012, Pl. 1, fig. e) and Singh and Saxena (2015, Pl.3, fig. 4) in their overall shape and venation pattern.

Glossopteris gigas Pant and Singh, 1971
(Pl. II, figs. 4, 5; Pl. II, fig. 1)

Description: Nine incomplete specimens are present in the collection. Leaves are large and very broad, elliptic to wide elliptic in shape. Leaves measure 13.4 to 23.4 cm in length and 7.1 to 10 cm in width. One specimen is almost complete with the median and upper half of the lamina preserved. In one specimen obtuse . Midrib very wide, 2 to 7 mm thick, strong in the basal region, persistent, gradually tapering towards the apex. Margin entire, lateral veins emerge at about 40-45º, arch a little outwards and then pass to the margin in gentle curves, meshes long and narrow.

Comparison and remarks: Specimens are comparable with the holotype of *G. gigas* Pant and Singh (1971, Pl. 3, Fig. 14, specimen no. 3034A) in shape and venation pattern of the leaf. The specimens are also comparable with *G. gigas* as figured by Chandra and Singh (1992, Pl. 6, Fig. 1), Singh *et al.* (2011, Pl. 6, Figs 2, 4), Saxena *et al*., 2016a (Pl. 1, fig. 6) and Agnihotri *et al*. (2016, Pl. 2, figs. 1, 3). In general, *Glossopteris gigas* resembles *Glossopteris major* and *Glossopteris raniganjensis* in venation pattern but theshape of both these leaves is distinct. *Glossopteris major* and *Glossopteris raniganjensis* are much more long than broad; and *Glossopteris major* is oblanceolate and *Glossopteris raniganjensis* is narrow elliptic with acute apex (Chandra and Surange, 1979).

Glossopteris indica Schimper, 1869
(Pl. I, fig. 5)

Description: The species is represented by one incomplete leaf specimen in the collection. Only the lower middle part of the lamina about 13 cm long and 4 cm wide is preserved. Leaf appears to be oval-lanceolate in shape. Midrib flat, striated, tapers towards the apex. Secondary veins arise from midrib at acute angles, and arch towards the margin, meeting it at obtuse angles. Veins dichotomize and anastomose to form meshes. Meshes are small, broad near the midrib narrow, elongate near the margin. Vein density is 14-18 veins/cm^2 near midrib and 20-25 veins/cm^2 near the margin.

Remarks: The present leaf is comparable with the lectotype of *G. indica* Schimper (1869) designated by Rigby *et al*. (1980; Figs. 38, 39, 40, 41) in having ovate-lanceolate shape; distinct midrib, mesh and venation pattern. The leaf is also comparable

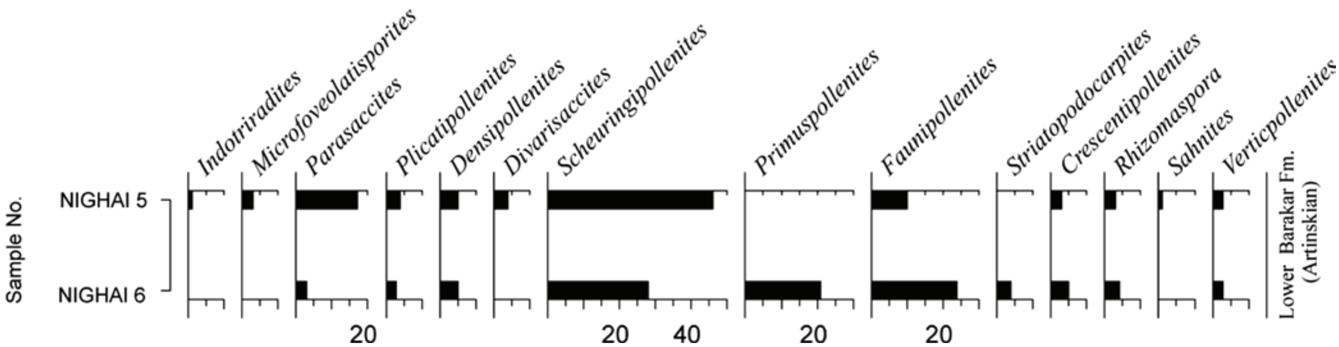


Fig. 5. Distribution of palynotaxa recovered from the Purewa Top Seam of Nighai section.

with *G. indica* as described by Srivastava *et al*., 2012 (Pl. 1, fig. f), Srivastava and Agnihotri (2010, Pl. 2, fig. 4), Singh and Saxena (2015, Pl. 2, fig. 3) and Agnihotri *et al*. (2016, Pl.2, figs, 5,7).

Glossopteris longicaulis Feistmantel, 1879
(Pl. I, fig. 2)

Description: One incomplete specimen in the collection, only the lower half of the leaf is preserved, measures 11.2 cm in length and 4.1 cm in width, base attenuate with long petiole. Margin entire, midrib distinct, flat striated, 4-6 mm broad in basal part, persistent into the petiolar part. Secondary veins numerous, thin, arise from the midrib at an angle of about 45º or less, then arch out to the margin. Meshes are long, polygonal, vein density16-20 per cm^2.

Remarks: The present specimen is in accordance with the specimen described by Feistmantel (1879, Pl. 31, figs. 1, 3) and Chandra and Surange (1979, Pl. 1, fig. 4; Pl. 15, fig. 13) in having a distinct petiolar base and venation pattern. The leaf also shows resemblance to the specimens described from the Bhareli Formation, Arunachal Pradesh Tewari and Srivastava (2000b, Pl. 1, fig. 3), from the Barakar Formation of Sohagpur Coalfieled, South Rewa Gondwana Basin (Agnihotri *et al*. 2016, Pl. 3, fig. 1), Manuguru Area, Godavari graben (Tewari *et al*. 2017, Pl. 4, figs. 4,5) and from the Pali Formation, South Rewa Gondwana Basin Pillai *et al*. (2018, Pl. 2, Fig. 4).

Glossopteris mohudaensis Chandra and Surange, 1979
(Pl. III, fig. 2)

Description: The species is represented by a single incomplete specimen with half lamina preserved, leaf measures 19.5 cm in length, width of half lamina is 5.1 cm, margin entire, shape appears to be obovate, midrib thick, lateral veins arise at acute angles, arched slightly to meet the margin, veins dichotomize and anastomose to form broad polygonal meshes.

Remarks: The present leaf resembles the specimen described by Chandra and Surange (1979, Pl. 11, fig. 2; Pl. 18, fig. 14) in its overall shape and nature of venation pattern. The specimen is also comparable with *G. mohudaensis* described by Chandra and Singh (1992, Pl. 11, fig. 4), Tewari (2008, Pl.4, fig. 7), Singh and Saxena (2015, Pl. 2, fig. 7) and Tewari *et al*. (2017, Pl. 4, fig 6).

Glossopteris nautiyalii Pant and Singh, 1971
(Pl. I, fig. 4)

Description: One incomplete specimen is present in the collection. Leaf is of medium size, 9.4 cm long and 5.2 cm wide, shape appears to be narrow elliptic, Apex acute, base not preserved. Midrib narrow, persistent, 2-3 mm wide. Lateral veins arise at an angle of less than 45º and travel straight to the margin. In apical region, veins are steeper. Meshes long and narrow. Cross connections are frequent.

Remarks: The specimen resembles in its shape and venation pattern with the holotype specimen described by Pant and Singh (1971, fig. 69. Specimen no. 3074) and specimens described and discussed by Chandra and Surange (1979, Pl. 8, fig. 4; Pl. 18, fig. 3; Pl. 23, figs 8, 14; Pl. 46, fig. 1) and Singh *et al*. (2006b, Pl. 4, fig. 1).

Glossopteris raniganjensis Chandra and Surange, 1979
(Pl. II, fig. 6)

Description: Two incomplete specimens are present in the collection. Leaves large, longer than broad; shape narrow elliptic to lanceolate, measuring 15-19.1 cm long and 7.3 to 7.6 cm wide; apex and base not preserved. Midrib wide strong and persistent, gradually tapering upwards; veins thin, venation dense; veins arise at an angle of less than 45º and pass out to margin in sweeping arcs; meshes very long and narrow.

Remarks: The leaves show resemblance to the holotype specimens described by Chandra and Surange (1979, Pl. 3, figs 3, 8; Pl. 4, fig. 4; Pl. 5, fig. 2. Pl. 10, fig. 1) in having long narrow shape and dense venation pattern. The leaves are also similar to the specimens described by Singh *et al*. (2011; Pl. 4, fig. 2; Pl. 8, figs. 2, 4) from Korba Coalfield and Singh and Maheshwari (2000, Pl. 10, fig. 1) from South Karanpura Coalfield.

Glossopteris spatulata Pant and Singh, 1971
(Pl. II, figs. 1-3)

*Description***:** Five specimens are present in the collection of which one is nearly complete. Leaves are medium to large, broad, oblanceolate to spatulate in shape and measure 8.4-14.1 cm in length and 3.3-5 cm in width. The upper middle part is broader than the basal part. Apex obtuse and the base acute-cuneate, margin entire. Midrib distinct, striated and broad, 3-4 mm wide, gradually tapers towards the apex. Secondary veins arise at acute angles around 35-40º, arch outwards and meet the margin at 60-70º. Meshes elongate and narrow, become narrower and smaller near the margin, venation dense, vein density 15-18 per cm^2 near the midrib and 18-24 near the margin.

Remarks: Leaves show close resemblance in shape and venation pattern with the holotype specimen of Pant and Singh (1971, Pl. 10, fig. 60, specimen no. 3043, Pant collection, Botany Department, Allahabad University, Allahabad); specimens described by Singh *et al*. (2006b; Pl. VII, figs. 1, 3), Agnihotri *et al*. (2016, Pl. 3, figs. 2, 4) and Pillai *et al*. (2018, Pl. 2, fig. 6).

Glossopteris sp.
(Pl. II, fig.6)

Remarks: There are 5 incomplete specimens in the collection. The midrib and reticulate venation pattern is clearly discernible. However, owing to incomplete specimen and poor preservation, species is not assigned to these specimens.

Division ***Coniferophyta***
Class ***Pinopsida***
Order **Cordaitales** Unger, 1850
Genus ***Euryphyllum*** Feistmantel, 1879

Euryphyllum sp.
(Pl. I, fig. 6)

Description: Only one incomplete specimen in the collection. Leaf simple, asymmetrical obovate shape, apex and base not preserved, preserved part measures 4 cm in length and 3 cm in width, 5–6 strong veins emerge from the base of the leaf, run sub-parallel in the median region but slightly arch towards the margin in the upper portion of the lamina and meet it at an angle of 15-20º. The veins arising near the margin arch more. Veins dichotomize without forming meshes.

Remarks: The present specimen resembles the holotype specimen of *Euryphyllum* described by (Feistmantel 1879, Pl. 21, fig. 1) in having obovate shape, and similar venation pattern. It also exhibits similarity with the specimen characteristics described by Chandra (1974, p. 134, 135) and by Maithy (1965, Pl. 1, fig. 9). Although, the morphological characters of the present specimen clearly assign it to *Euryphyllum* the generic level but due to incomplete and distorted preservation its species level could not be ascertained.

Palynological Observations:

The palynological analyses of the coal bearing sequences of Turra Seam of Block-B and Nigahi collieries have yielded two palynoassemblages namely, Palynoasasemblage-I and Palynoassemblage-II. The vertical distributions of different palynomorphs iof both these assemblages have been shown in the frequency chart (Figs. 4, 5) and indicated as dominant (more than 20%), sub-dominant (between 10–20%), common (between 5–9%), fair (between 2–4%) and poor (less than 2%). List of recovered spore-pollen species has been summarized in Table 3. The palynofossils preservation is variable within the samples and the recovery is low to moderate, light yellowish to dark brown, broken to fairly well–preserved. Stratigraphically significant taxa are shown in Plate IV.

Palynoassemblage-I

Out of five samples, only three (B 3, 4 and 5) were found to be rich in palynomorphs along with plant debris. The remaining samples (B1 and B2) are unproductive. Palynologically studied succession reveals that the pollen grains are predominant over the spores. Quantitative and qualitative palynological analysis of sediments has revealed one palynoassemblage in Block B section of Turra seam. Recovered palynoassemblage is characterized by the dominance of non-striate bisaccate *Scheuringipollenites* (25-39%) and sub-dominance of striate bisaccate pollen *Faunipollenites* (23-30%). Other palynomorphs present in the palynoassemblage are *Parasaccites* (21-25%), *Plicatipollenites* (0-4%), *Potonieisporites* (0-3%), *Densipollenites* (0-1%), *Divarisaccites* (0-3%), striate bisaccate pollen grains viz. *Striatopodocarpites* (3-4%), *Crescentipollenites* (0-7%), *Rhizomaspora* (2-4%), *Sahnites* (0-2%), *Primuspollenites* (0-2%), *Tiwarisporis* (0-3%), sporidic presence of triletes are *Verrucosiporites* (0-1%), and *Indotriradites* (0-1 %) is observed.

Palynoassemblage II

Out of six samples, only two (N5 and N6) are rich in palynomorphs and others (N1, 2, 3 and 4) are devoid of palynomorphs but have granular dark plant debris which could not be identified. The palynoassemblage shows the dominance of non striate bisaccate pollen *Scheuringipollenites* (28-46%) and sub dominance of striate bisaccate polen *Faunipollenites* (10-24%), other palynomorphs in the assemblage are *Parasaccites* (3-17%), *Plicatipollenites* (3-4%), *Densipollenites* (5%), *Divarisaccites* (0-4%), *Primuspollenites* (0-21%), *Striatpodocarpites* (0-4%), *Crescentipollenites* (3-5%), *Rhizomaspora* (3-4%), *Sahnites* (0-1%), *Verticipollenites* (3%) and includes a few triletes spores including *Indotriradites* (-1%) and *Microfoveolatispora* (0-3%).

Palynodating: The palynoassemblages recovered from the Turra seam of Block- B Colliery and Nighai Colliery of the Singrauli Coalfield are well correlated with the *Scheuringipollenites barakarensis* palynoassemblage zone (zone V) of the lower Barakar Formation of the Damodar Basin (Tiwari and Tripathi, 1992).

DISCUSSION

The flora of Turra Seam of Block B comprises mainly of equisetales, Glossopteridales, and Cordaitales. The megafloral assemblage comprises of four genera and 17 species. The genus *Glossopteris* dominates the assemblage and is represented by 10 species, namely *G. arberi, G. communis, G. gigas, G. indica, G. longicaulis, G. mohudaensis, G. nautiyalii, G. raniganjensis G. spatulata* and *Glossopteris* species. The genus *Gangamopteris* is represented by five species namely *G. angustifolia, G. cyclopteroides, G. karharbariensis, G. major* and *Gangamopteris* sp. In addition to these, equisetalean axis namely *Paracalamites* sp. and cordaitalean genus *Euryphyllum* sp. are also recorded. Interestingly, the procured fossil leaves of *Glossopteris* and *Gangamopteris* are fairly large and broad as evidenced by the abundance of *Glossopteris gigas* and *Gangamopteris cyclopteroides* which are large leaf forms; their abundance in the assemblage suggests the existence of low light or the shady conditions in and around the vegetated area. This admixture of *Glossopteris* and *Gangamopteris* leaves suggests the sediments to be of Early Permian age. Further, the presence of cuticles in these megafossil specimens is very less, only observed in patchy flakes in some of the specimens, which indicates the partial oxidation of the carbon content of the preserved fossils at least in these facies.

The abundance and diversity of the megaflora in the Barakar Formation of Block B colliery is moderate. So far the comprehensive data of Barakar sediments is available from Bina colliery (Singh *et al*., 2017), Block B colliery (present study) and from few outcrops of this coalfield (Lele, 1966). The diversity of the genus *Gangamopteris* reported so far from this coalfield is represented by five species, namely, *Gangamopteris angustifolia, G. cyclopteroides, G. karharbariensis, G. major* and *Gangamopteris* sp., of which *G. karharbarensis* and *G. major* are reported for the first time from Block B colliery in Singrauli coalfield. The diversity of the genus *Gangamopteris* and its stratigraphical significance has been discussed in detail by Saxena *et al*. (2019b). Similarly, the genus *Glossopteris* is represented by 18 taxa in this coalfield. Moreover, the abundance of the genus *Glossopteris* and subdued occurrence of *Gangamopteris* is typical of Lower Barakar affinity.

The diversity of *Glossopteris* in the Singrauli coalfield is comparable with that of the Barakar Formation of Talcher Coalfield, which possesses only 16 species of *Glossopteris*. However, except for the Talcher Coalfield, other coalfields/basins are quite high in *Glossopteris* diversity for example 52 species in the Ib River Coalfield (Goswami *et al*., 2018), 22 species in Korba Coalfield (Singh *et al*., 2011), 18 species in Tatapani-Ramkola Coalfield (Saxena *et al*., 2019a) of the Son-Mahanadi Basin. 20 species of *Glossopteris* are present in Raniganj Coalfield (Maheshwari and Tewari, 1992; Srivastava, 1992) whereas, in Auranga Coalfield, Damodar Basin, *Glossopteris* is represented by 15 species (Srivastava, 1977; Srivastava and Tewari, 1996). 12 species of *Glossopteris* are recorded from Pachwara Coalfield and 5 species from Pali area. Bokaro, Chirimiri, Karanpura, Singrauli, Hutar and Hura coalfields/areas show presence of 34, 3, 2, 2, 2 and 1 *Glossopteris* species each, respectively (Maheshwari, 1992; Saxena *et al*., 2019c). A more or less similar Glossopteris flora is recorded from the Sharda open cast mine, Shoahgpur Coalfield, comprising *Gangamopteris intermedia* and seven species of *Glossopteris* of which, except for *Glossopteris giridihensis,* other species are common to Singrauli coalfield (Agnihotri *et al*., 2016). A rich and diverse assemblage of Glossopterid flora is recorded from the Barakar Formation of the Manuguru area of Wardha Godavari Basin consisting of *Gangamopteris cyclopteroides*, 21 species of *Glossopteris* in association with Equisetales and Cordaitales (Tewari *et al*., 2017). Total number of *Glossopteris* species in the Barakar Formation of India is 80 (Saxena *et al*., 2014).

Palynoassemblages retrieved from the present study is dominated by *Scheuringipollenites barakarensis* and are comparable with those known from the early Permian Barakar Formation (lower part) of the Raniganj Coalfield of Damodar Basin (Palynoassemblage II of Borehole RT-4, Murthy *et al*., 2010) in having a combination of *Scheuringipollenites* and *Faunipollenites*. They also show similarity with palynoassemblage-II of the Mand-Raigarh Coalfield of Mahanadi Gondwana Basin (Murthy *et al*., 2014) in the presence of *Scheuringipollenites barakarensis, S. maximus, Faunipollenites varius,* and other palynotaxa *Striatopodocarpites magnificus*, *Rhizomaspora indica, Crescentipollenites fuscus*, and *Parasccites obscurus* palynotaxa.

The palynoassemblages recorded here are comparable with those known from the early Permian Barakar Formation of Wardha Valley Coalfield, Hindustan Lalpeth Colliery (Agashe and Chitnis, 1970, 1972) and Assemblage–B of boreholes MWS 23 and MWS 33 (Bhattacharyya, 1997) in the presence of genera *Scheuringipollenites, Faunipollenites Plicatipollenites*, *Potonieisporites*, *Striatopodocarpites*, *Rhizomaspora*, and trilete spore *Microfoveolatispora.* The present assemblage is also similar to the Palynoassemblage–2 of borecore CMWNM–57, Majri Open Cast Mine (Jha *et al.,* 2011); Palynoassemblage A retrieved from the borecore MGE–15 (Mahesh *et al.,* 2008) and palynomorphs recorded from the sediments of the New Majri Open Cast Mine (Mahesh *et al.,* 2014) of Wardha Valley Coalfield, and the borecore MBG–23 of Gokul block of the Bandar Coalfield (Sabina *et al.,* 2007) in presence of the palynotaxa *Scheuringipollenites–Faunipollenites* complex along with pollen *Plicatipollenites, Potonieisporites*, *Striatopodocarpites, Rhizomaspora* and spores *Microfoveolatispora*.

The palynoassemblage-III of Jhingurdah bottom coal seam (Singh *et al*., 2017) and palynoassemblage-II of borecore SMJS-2 (Vijaya *et al*., 2012) along with palynoassemblage recovered from the Turra Seam of Bina colliery (Saxena *et al*., 2016b), of Singrauli Coalfield, Son-Mahanadi Basin, central India is also closely correlated with the presently studied palynoassemblages (*Scheuringipollenites–Faunipollenites*) in having the palynotaxa *Scheuringipollenites* spp., *Faunipollenites* spp., *Striatopodocarpites* spp., *Crescentipollenites fuscus*, *Rhizomaspora indica*, *Parasaccites* spp. and *Microfoveolatispora* sp.

Present palynoassemblages are also similar with Early Permian (Barakar) palynoassemblages of Godavari Valley Basin viz. Assemblage-2 of borehole GRK-1 in Ramakrishnapuram (Srivastava and Jha, 1989), Assemblage-C of Ramagundam (Srivastava and Jha, 1989), Barakar palynoassemblage (Palynozone-4) of Ramakrishnapuram (Srivastava and Jha, 1992b), Manuguru area (Srivastava and Jha, 1992a), Budharam area (Srivastava and Jha, 1995), Palynozone-2 of Koyagudem (Srivastava and Jha, 1996); Palynozone-3 (borecores CAM-6 and CAM-8) of Mailaram area (Jha *et al*., 2012); palynozone-4 of Lingala-Koyagudem coalbelt (Aggarwal and Jha, 2013) and Palynoassemblage-4 of Chinatalapudi sub-basin (Jha *et al*., 2018). All of these palynoassemblages comprise similar palynotaxa with present palynoassemblage such as *Scheuringipollenites* spp*., Faunipollenites* spp*.,* along with *Striatopodocarpites* spp*., Crescentipollenites*, *Parasaccites, Plicatipollenites*, *Potonieisporites,* and *Microfoveolatispora* spp.

Botanical affinities of the palynotaxa recorded from these palynoassemblages is given in Table-3. Palynocomposition have the dominance of Glossopteridales represented by *Scheuringipollenites,* and *Faunipollenites*, followed by sub-dominance of group coniferales comprising of*, Crescentipollenites, Primuspollenites,* and *Sahnites,* and *Rhizomaspora.* Cordaitales are also frequently represented in palynoassemblages by *Parasaccites, Plicatipollenites* and *Densipollenites*. Spores are very few in numbers and are represented by Filicales (*Microfovelatispora*) and Lycopsidales (*Indotriradites*).

A late early Permian (Artinskian) age has been assigned to the studied sections of Block B and Nighai –colliery as these sections are palynologically correlated with the *Scheuringipollenites barakarensis* Assemblage zone of Damodar Basin (Tewrai and Tripathi, 1992).

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