



## The First Report of *Gangamopteris rajaensis* from Rajmahal Gondwana Basin (Jharkhand, India)

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**Abstract:** The present study deals with the systematic description of macro and microfossil analysis of *Gangamopteris rajaensis* and *Glossopteris indica* from the carbonaceous shale-coal bearing sequences of the Rajmahal Open Cast Mine, Rajmahal Basin, Jharkhand, India. The floral diversity, age correlation, and the paleoenvironment of the Barakar Formation were well described. Morphological analysis revealed the reticulate venation pattern, anastomosing of veins, and the absence of the midrib in *Gangamopteris rajaensis*. The recovered megafossil assemblages of *Gangamopteris rajaensis* and *Glossopteris indica* suggest a late early Permian (Artiskian-Kungurian) age for the Barakar strata of Rajmahal coal mine and the prevalence of a moderately warm climate during their deposition. Earlier the species was reported from the Barakar Formation of Damodar and Mahanadi Gondwana basins in India. However, this is the first detailed systematic investigation of this species from the Rajmahal Gondwana Basin, Jharkhand, India.

**Keywords:** Barakar Formation, Early Permian, *Gangamopteris rajaensis*, Rajmahal Gondwana Basin.

### INTRODUCTION

The warm and humid climate after the Late Paleozoic glaciations (Permo-Carboniferous) prepared the way for the great expansion of plant life (Chandra & Chandra, 1988). Floral remnants in the form of mold fossils excited the geoscientific community and the richness of flora and its diversity allowed recreation of a scenario for the paleoclimatic conditions. Enormous amounts of fossil evidence were recovered from the Indian Lower Gondwana basins and other parts of the world. The Gondwana basin of India (i.e., Son-Mahanadi basin, Damodar basin, Pranhita–Godavari basin, and Purnea-Rajmahal-Galsi basin) was one of the hotspots for the growth of significant floral assemblages during

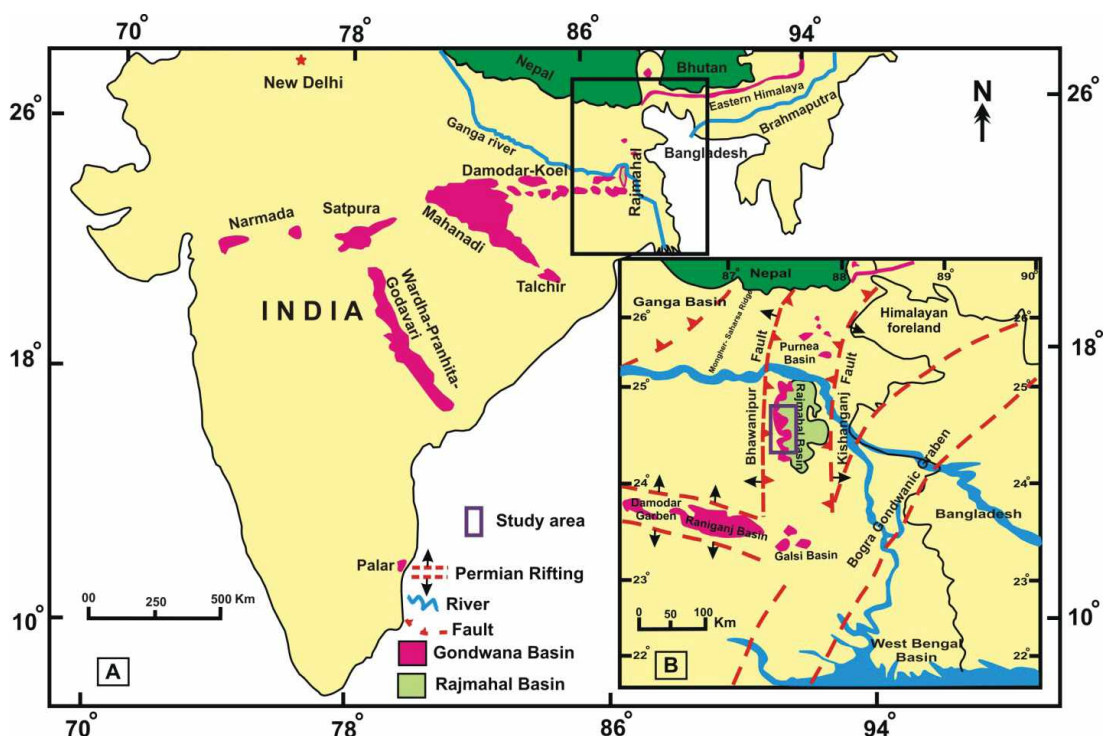
the Permo-Carboniferous period (Mukhopadhyay et al., 2010). The Rajmahal Gondwana basin also contains a variety of floral species from the Barakar Formation. The present species *Gangamopteris rajaensis* was not reported before from the Rajmahal Basin. *Gangamopteris* was first reported by McCoy (1847) from New South Wales, Australia as *Cyclopteris*, a leaf showing netted venation without a midrib. Different species of *Gangamopteris* are well-reported and documented in almost all parts of Gondwanaland, i.e., Australia, Antarctica, Argentina, Brazil, India, Madagascar, and South Africa (McCoy, 1847; Feistmantel, 1890; Dolianiti, 1954; Pant & Singh, 1968; Srivastava, 1992; Singh, 2000). The leaves of *Gangamopteris* McCoy are the dominant constituent of *Glossopteris* flora in the Early

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Permian sequences of Gondwana (Srivastava and Agnihotri, 2010). Morphologically leaves are similar to *Glossopteris* Brongniart in having reticulate venation pattern but differ in the absence of a midrib (Chandra & Surange, 1979). The present communication deals with the first report of *Gangamopteris rajaensis* from the Rajmahal Open Cast Mine, Rajmahal Area, Rajmahal Basin, Jharkhand India (Figure 1A, B). The assemblage recovered from the area is represented by species of *Glossopteris* namely *Glossopteris communis*, *G. damudica*, *G. gigas*, *G. indica*, *G. lanceolatus*, *G. longicaulis*, *G. oldhamii*, *G. taenioides*, *G. tenuifolia*, and *Vertebraria indica* belonging to the order Glossopteridales and *Noeggerathiopsis hislopi* of order Cordaitales. The present work is significant as it represents the presence of *Glossopteris* flora (250-290 ma) which is mainly responsible for the formation of coal in the area.

## MATERIAL AND METHODS

Fossils were collected from the carbonaceous shale (Thick Seam) of Barakar Formation, Rajmahal Open Cast Mine, Coal Mine Zone- 57, Rajmahal Basin (Figure 1B). The specimens are preserved as impressions and were studied with the help of a hand lens and low-power binocular microscope Olympus 20 iH under incident light for morphotaxonomical characteristics. Various morphological characters like the shape of leaf, nature of apex, base, margin, midrib, and venation pattern were considered. Lawrence (1955), Melville (1969) and Chandra & Surange (1979) were followed for exact descriptions. The specimens are deposited in the Botany Department, S.G.R.R. (P.G.) College, Dehradun.



**Figure 1.** A) Gondwana basin of peninsular India with fossil location (after Mukhopadhyay et al., 2010). B) Generalized tectonic map of North-eastern Gondwana basin of India showing various tectonic zones in Purnea-Rajmahal- Galsi Gondwana basins with the study area (after Prasad & Pundir, 2020). The study area is marked by the rectangular box and its coordinates lie between 24°01'12" to 25°01'15" North latitudes and 87°24'52" to 87°25'00" East longitudes.

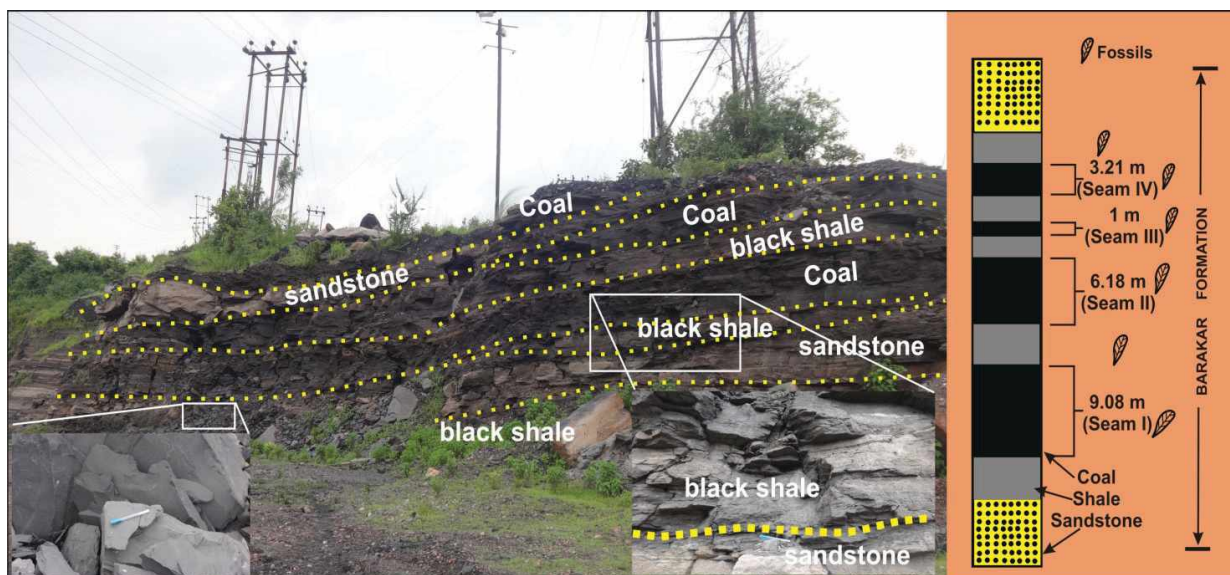
## GEOLOGICAL SETTING OF THE STUDY AREA

The biostratigraphy of the study area (i.e., Rajmahal basin) is part of the N-S trending Gondwana Graben, referred to as the Purnea-Rajmahal-Galsi Gondwana Graben as shown in Figure 1.B (Prasad & Pundir, 2020). The Rajmahal Basin is a master basin that encompasses a large area of Bengal Basin, north Bengal and Purnea Basin (Joshi, 2018a). The Rajmahal Basin consists of a series of Lower Gondwana exposures aligned roughly in N-S direction along the foot of the Rajmahal hills. The sedimentary succession of Rajmahal Basin is given in Table-1. The presence of thick sedimentary sequences from Gondwana is categorized into Upper and Lower Gondwana groups (Table 1). The Lower Gondwana rock groups mainly consist of two formations – (1) Talchir Formation and (2) Barakar Formation. The Talchir Formation is composed of diamictite, coarser sandstone, pebbly sandstone and shale, while the Barakar Formation consists of an alternate band of sandstone and carbonaceous shale. The variable width of coal seams is prominent in this Formation and it is popularly known as the storehouse of coal. The Barakar Formation, which

conformably overlies the Talchir Formation, is a uniform set of fining-upward cycles of coarse to medium sandstone, interbedded fine sandstone or siltstone carbonaceous shale, and coal. The sandstone is channel-shaped below and sheet-like above, with planar and trough cross-bedding, and is attributed to channel shifting and the lateral accretion of point bars. The interbedded sandstone and shale correspond to vertical accretion in levees and the coal to deposition in peat swamps in distal floodplains and lakes of meandering streams. Carbonaceous shale and coal are abundant with different species of plant fossils. The Gondwana sequences of Rajmahal are deposited over the Chhotanagpur Granitic Complex and mainly capped by the post-Gondwana Rajmahal trap (Prasad & Pundir, 2017 and 2020). The Rajmahal traps capping the Rajmahal hills receded considerably towards the north-east near the Ganges, exposing large areas of the coal-bearing Barakar Formation. In addition to these lithostratigraphic units, Talchir (underlying the Barakar) and Dubrajpur (underlying the Rajmahal traps) are exposed in the Basin (Figure 1B). The Rajmahal Open Cast Mine forms the northernmost part of Hura Coalfield.

**Table 1.** General stratigraphy of the study area (after Prasad & Pundir, 2017).

Period / Group	Formation	Lithology	Thickness Range (in meter)
Recent to Subrecent	Alluvium	Soil cover with vegetation	0-15
		---Unconformity---	
Cretaceous	Rajmahal Traps	Rajmahal volcanic and intertrappean sandstone and shale	50
		---Unconformity---	
Lower Gondwana Group	Barakar	Coarse to medium grained sandstone, a variable width of coal seam, carbonaceous shale, fossils bearing coal and shale	25-350
	Talchir	Diamictite, Coarse arkosic sandstone, pebbly sandstone, shale	15-150
		---Unconformity---	
Precambrian	Chhotanagpur Granitic Complex	Granite genesis, hornblende Schists and pegmatites	10-20



**Figure 2.** A field photograph showing alternate bands of sandstone, shale and coal with the stratigraphic column. Carbonaceous shale and coal seam contain plant fossils.

### SYSTEMATIC DESCRIPTION OF THE MEGAFLORAL ASSEMBLAGE

Division: Gymnospermophyta

Order: Glossopteridales

Genus: *Gangamopteris* McCoy, 1847

Type species: *Gangamopteris angustifolia*  
McCoy, 1847

*Gangamopteris rajaensis* Srivastava, 1992  
(Figure 3 a-d)

**Description:** There are two leaf specimens in the collection. The complete leaf measures 4.4 cm in length and 1.9 cm in width at its maximum, i.e., near the apical margin of the leaf. Apex is broad, a small protuberance makes it mucronate, and the base is broadly contracted. The median region is occupied by 4-6 parallel running veins, dichotomizing frequently during their upward course and form 2-2.5 mm long and 0.5-1 mm broad, linear hexagonal meshes, and fiber-like structures are present in between the veins. Lateral veins arise at acute angle and form 2-3.5 mm long

and 0.6-1.8 mm broad, hexagonal meshes in the centre and 1-1.5 mm long and 0.5 mm broad meshes towards the margin. The density of veins is 12-14 veins per cm.

**Pictured specimens:** Specimens nos. RJ/GANG/1 and RJ/GANG/2.

**Horizon:** Barakar Formation

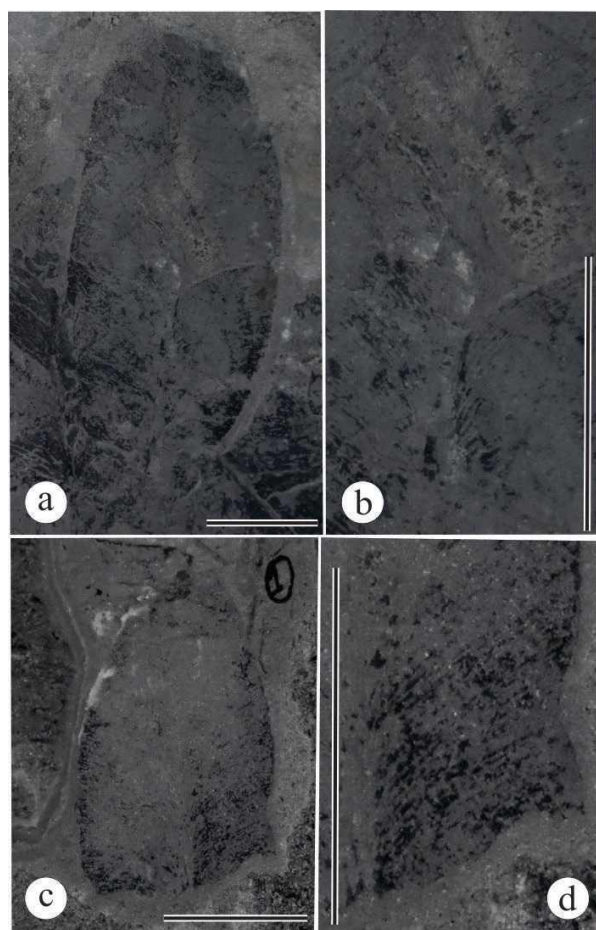
**Locality:** Rajmahal Open Cast Mine, Rajmahal Basin, Jharkhand, India

**Age:** Early Permian (Cisuralian)

**Number of specimens studied:** Two

**Remarks:** The present specimens resemble *Gangamopteris rajaensis* by Srivastava (1992, pl. 5, Figs. 1-2) and Singh et al. (2006, pl. 2, Figs. 3 and 5) in their shape, size and venation pattern.

It differs from other prominent species of *Gangamopteris*, namely *G. angustifolia*, *G. cyclopteroides* and *G. major*, which are prominent species of the Early Permian in Barakar Formation with respect to their comparatively small size and narrow meshes.



**Figure 3.** Megafloral assemblages recovered from the Barakar Formation of the Rajmahal Open Cast Mine, Rajmahal Basin, Jharkhand, India, **a)** *Gangamopteris rajaensis* specimen no. RJ/GANG/1, **b)** Middle portion of the leaf enlarged ( $\times 3$ ) to show vein density at the middle part of the leaf, **c)** *Gangamopteris rajaensis* specimen no. RJ/GANG/2, **d)** Margin of leaf enlarged ( $\times 3.5$ ) to show vein density near the margin. Scale bar = 1 cm.

Genus: *Glossopteris* Brongniart, 1828

Type species—: *Glossopteris browniana*  
Brongniart, 1828

*Glossopteris indica* Schimper, 1869  
(Figure 4 A)

Description: There are twelve specimens of this species in the collection. Leaves are lanceolate in shape with the entire margin. Apex is acute and

preserved in four specimens, whereas bases are absent in all of them. Leaves measure 8–22 cm in length and 3–5.2 cm in width at their widest part which is the middle portion. Midrib is distinct, persistent, elevated, striate (having 3–4 deep striations), and measures 1–2 mm in width. The secondary veins arise at angles of about  $40^{\circ}$ – $45^{\circ}$  from the midrib and after successive dichotomies and anastomoses form polygonal, short, and broad meshes near the midrib and narrow–elongate meshes near the margin. The secondary veins meet the margin at angles of about  $65^{\circ}$ – $75^{\circ}$ . Meshes measure 2–3 mm long and 0.3–0.5 mm wide near the midrib and 2–3.5 mm long and 0.2–0.4 mm wide near the margin. The vein density is 16–20 per cm near midrib and 16–26 per cm near the margin.

Pictured specimens: Specimens No. RJ  
10/2019

Horizon: Barakar Formation

Locality: Rajmahal Open Cast Mine,  
Rajmahal Basin, Jharkhand, India

Age: Early Permian (Cisuralian)

Number of specimens studied: Twelve

Remarks: Leaves are identical to *Glossopteris indica* (Chandra & Surange, 1979, pl. 5, fig. 1, pl. 10, fig. 4, pl. 15, fig. 11, pl. 28, fig. 1, pl. 29, fig. 1; Tewari and Srivastava, 2000, pl. 1, fig. 4; Tewari 2008, pl. 4, fig. 4) in shape, nature of midrib and venation pattern.

It is different from *Glossopteris damudica* and *G. gigas*, the markers of the Early Permian, in lower Barakar Formation with respect to their small size.

*Glossopteris lanceolatus* Pant and Singh,  
1974

(Figure 4 B-C)

Description: There are three leaf specimens in the collection. Leaves are narrow, oblong in shape, measure 7–12.2 cm in length and 3–4 cm in width, apex acute, base absent and margin

slightly undulating. Midrib striate is 0.7 mm wide and gradually tapers towards apex. Secondary veins arise at about 45° from midrib and after dichotomization and anastomoses, meet the margin at about 85°. Meshes are broad, elongate, 3.5–5 mm long and 0.5–0.6 mm wide near the midrib, and short and narrow, 2–2.5 mm long and 0.3–0.4 mm wide near the margin. Vein density is 16–21 per cm near the midrib and 23–32 per cm near the margin.

Pictured specimens: Specimens nos. RJ 11/2019 and RJ 12/2019.

Horizon: Barakar Formation

Locality: Rajmahal Open Cast Mine, Rajmahal Basin, Jharkhand, India

Age: Early Permian (Cisuralian)

Number of specimens studied: Three

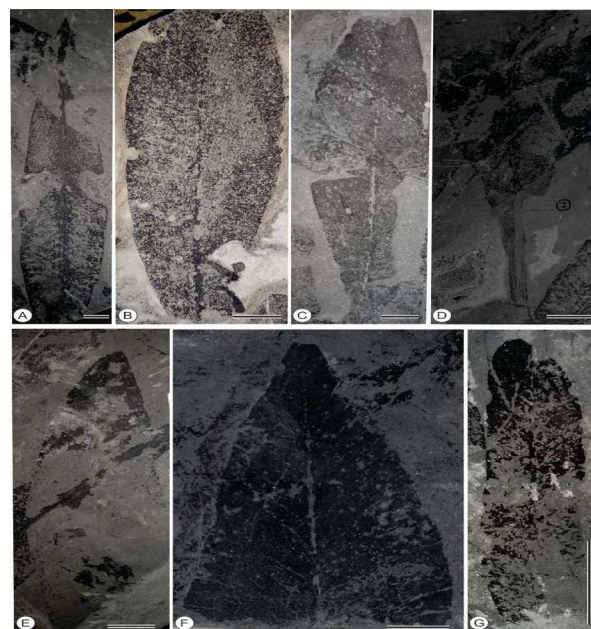
Remarks: Present leaves resemble *G. lanceolatus* described by Chandra & Surange 1979 (pl. 7, fig. 2, pl. 19, fig. 2, pl. 40, fig. 2) and Tewari et al., 2017 (pl. 4, fig. 3) with similar shape and venation pattern.

However, it differs from other species of *Glossopteris*, namely *G. taenioides*, *G. longicaulis*, and *G. arberii*, with respect to their oval shape and broad meshes.

## PALEOENVIRONMENT

The temporal, geographical and environmental distribution pattern of *Glossopteris* and *Gangamopteris* are closely related to the evolution of the Late Paleozoic glaciation during the Permo-Carboniferous period (Chandra & Chandra, 1988; Goswami, 2006). There was a great expansion of plant life after the Permo-Carboniferous cryospheric event. In the early period of the Permian as the climate was warming, the floral remnants that survived the ice age gave rise to different species of *Glossopteris* and *Gangamopteris* flora (Goswami et al., 2006). This floral species equivocally supports the continental drift theory, which advocates that the Indian subcontinent was

an integral part of Gondwanaland along with other continents. Furthermore, different fossil evidence recorded from the Indian Gondwana basin infers the paleoenvironmental conditions for the growth of this species (Tewari 2007; Srivastava & Agnihotri, 2010; Tewari et al., 2017; Joshi, 2014, 2018a & 2020; Joshi et al., 2015). After a thorough study of the fossil evidence from Indian Gondwana it is evident that the environment was moist temperate during the Permo-Carboniferous period where forest type vegetation was dominated by gymnospermous plants probably belonging to *Glossopteris* (Pant & Singh 1968; Joshi, 2018a, b & 2020; Prasad & Pundir, 2020). The *Glossopteris* flora flourished during the Permo-Carboniferous and is mostly preserved in the alternate bands of carbonaceous shale and coal in the Barakar Formation formed in a warm temperate climate (Srivastava, 1997; Joshi, 2014, 2018a, b & 2020; Joshi et al., 2015; Tewari et al., 2015, 2017).



**Figure 4.** Megaflores recovered from the Barakar Formation of the Rajmahal Open Cast Mine, Rajmahal Basin, Jharkhand, India, **A)** *Glossopteris indica*, specimen no. RJ 10/2019. **B-C)** *Glossopteris lanceolatus*, specimens nos. RJ 11/2019 and RJ 12/2019. **D)** *Glossopteris longicaulis*, specimen no. RJ

13/2019. **E-F)** *Glossopteris oldhamii*, specimens nos. RJ 14/2019 and RJ 15/2019. **G)** *Glossopteris taneioides*, specimen no. RJ 16/2019. Scale bar= 1 cm. climate

## DISCUSSION AND CONCLUSION

The recovered species in the present study, *Gangamopteris rajaensis*, from the Gondwana basin in Rajmahal coal mines, is a biostratigraphic marker in the Late Paleozoic of Gondwana (Srivastava, 1992 and Singh et al., 2006). The signature of this particular species also infers the warm and humid climate after the deglaciation phase of the Gondwana icehouse (Tewari et al., 2015, 2017). Records of mega fossils from the Rajmahal Basin are scarce (Ball 1877; Maheshwari & Prakash 1965; Prasad et al., 1987; Maheshwari & Bajpai 1992; Joshi, 2018a, b, 2020; Pillai et al., 2020). The present record is significant as it shows the presence of *Glossopteris* flora responsible for the formation of coal in the basin as evinced by the production of coal (10.5 million tons per annum) from different coalfields. Therefore, it is necessary to study this coal-forming vegetation from the area to generate a new palaeobotanical database. Earlier *Gangamopteris rajaensis* was reported from Raniganj Coalfield, Damodar (Srivastava, 1992) and Ib-River Coalfield, Mahanadi (Singh et al., 2006) basins. Report of this species from the Rajmahal Basin widens its phytogeographical distribution and the scope of this species as one of

the characteristic forms of the Barakar Formation of Early Permian age. There is diversity in the flora represented by the presence of both narrow (*Glossopteris oldhamii*, *G. tenuifolia*, *G. taenioides*) and broad leaves (*Glossopteris damudica*, *G. indica*, *G. gigas*, *G. lanceolatus*) in the collection. It justifies the favorable environmental conditions, i.e., warm and humid, suggested by previous workers (Lele, 1976; Chandra & Chandra, 1988) for the development of such rich *Glossopteris* flora. The presence of Genus *Gangamopteris* and *Noeggerathiopsis* advocates for the Lower Barakar Formation (Tewari, 2007; Tewari et al., 2015 and 2017), while the smaller size leaves (*Glossopteris oldhamii*, *G. tenuifolia* and *G. taenioides*) represent the flora of the Upper Barakar Formation (Srivastava and Agnihotri, 2010; Tewari et al., 2017). In general, the *Glossopteris* flora is comparable with the flora known from other Gondwana basins in India (namely Damodar, Mahanadi, South Rewa, Satpura, Wardha and Godavari basins) (Table 2). More efforts are required for better recovery of the *Glossopteris* flora that is mainly responsible for the production of coal in the area. However, there are fears of fossils disappearing from this area as the state government of Jharkhand has assigned a mining lease in the area to private companies. Hence, it is very necessary to study this coal-forming vegetation and its distribution to generate a new palaeobotanical database from the area.

**Table 2.** Distribution of plant fossil taxa in the present study of Rajmahal Open Cast Mine, Barakar Formation in other lower Gondwana basins of India.


Name of Taxa	Lower Gondwana basins of India					
	Damodar	Mahanadi	Wardha	Satpura	South Rewa	Godavari Graben
<i>Gangamopteris rajaensis</i>	+	+	-	-	-	-
<i>Glossopteris indica</i>	+	+	+	+	+	+
<i>Glossopteris lanceolatus</i>	-	+	-	-	-	+

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