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DEVELOPMENT OF *GLOSSOPTERIS* FLORA IN INDIAN GONDWANA SEQUENCE

DESENVOLVIMENTO DA FLORA DE GLOSSOPTERIS NA SEQÜÊNCIA GONDVÂNICA DA ÍNDIA

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Resumo: O desenvolvimento da Flora de *Glossopteris* no Gondwana tem sido considerado através de fases florísticas de *Gangamopteris* e *Glossopteris* desde o Permiano inferior ao Permiano superior. Entretanto, aparecimento, desaparecimento, continuidade e afiliação de diferentes taxa em formações do Gondwana Inferior da Índia indicam que a flora atingiu sua maturidade e diversidade com associação específica de gêneros e espécies durante Permiano inferior (transição Karharbari-Barakar), Permiano inferior final (Formação Barakar-Barren Measures), Permiano superior incial (Formação Raniganj) e Permiano superior (Formação Kamthi). Em outras regiões gondvânicas, América do Sul, África do Sul, Austrália e Antártica, os gêneros e espécies, associados são diferentes, mas eles também demonstram padrão de desenvolvimento comparativo da Flora de *Glossopteris*.

Palavras-Chave: Flora de *Glossopteris;* Seqüência Gondvânica; Gondwana; Índia.

Abstract: Development of *Glossopteris* flora in Gondwana has been considered through *Gangamopteris* and *Glossopteris* floral phases from Early Permian to Late Permian. However, appearance, disappearance, continuance and affiliation of different taxa in Lower Gondwana formations of India indicate that flora attained its maturity and diversity with specific association of genera and species during Early Permian (Karharbari-Barakar transition), Late Early Permian (Barakar-Barren Measures Formation), Early Late Permian (Raniganj Formation) and Late Permian (Kamthi Formation). In other Gondwana regions, South America, South Africa, Australia and Antarctica associated genera and species are different, but they also demonstrate comparative development pattern of *Glossopteris* flora.

***Keywords*:** *Glossopteris* Flora; Gondwana Sequence; Gondwana; India.

INTRODUCTION

Complete sequence of Indian Gondwana from Permian to Jurassic-Lower Cretaceous mainly derived from fresh water sediments is divided on the basis of plant fossils. Traditionally, there were Lower and Upper divisions characterised by *Glossopteris* and *Ptilophyllum* floras (Oldham 1893, Cotter 1918, Fox 1931, Krishnan 1982). However, occurrence of *Dicroidium* flora in Triassic (Vredenberg 1914, Wadia 1961, Lele 1964, Saksena 1974) demarcates the Middle Gondwana flora. Generalised sequence of Indian Gondwana is as follows:

GO	**UPPER**	**Cretaceous Jurassic**		Rajmahal Formation Jabalpur Formation	*Ptilophyllum* Flora
NDW	**MIDDLE**	**Triassic**	Late / Upper	Mahadeva Formation	*Dicroidium* Flora
			Early / Lower	Panchet Formation	
ANA	**LOWER**	**Permian**	Late / Upper	Kamthi Formation Raniganj Formation	*Glossopteris* Flora
			Early / Lower	Barren Measures Formation Barakar Formation Karharbari Formation Talchir Formation	

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	Name of the plant fossil	Name of the Horizon					
		Talchir	Karharbari	Barakar	Barren Measures	Raniganj	Kamthi
1.	*Paranocladus*	■					
2.	*Birsinghia*		■				
3.	*Botrychiopsis*		■				
4.	*Chirimiria*		■				
5.	*Dolianitia*		■				
6.	*Ginkgophyton*		■				
7.	*Paliandrolepis*		■				
8.	*Rubidgea*		■				
9.	*Barakaria*			■			
10.	*Birbalsahnia*			■			
11.	*Diphyllopteris*			■			
12.	*Ginkgoites*			■			
13.	*Gondwanophyllites*			■			
14.	*Gondwanophyton*			■			
15.	*Lelstotheca*			■			
16.	*Maheshwariphyllum*			■			
17.	*Pachlwarophyllum*			■			
18.	*Palasthalia*			■			
19.	*Santhalea*			■			
20.	*Saportaea*			■			
21.	*Veekaysinghia*			■			
22.	*Walkomiella*			■			
23.	*Belemnopteris*					■	
24.	*Bengalea*					■	
25.	*Cuticulatopteris*					■	
26.	*Damudopteris*					■	
27.	*Damudosauras*					■	
28.	*Dichotomopteris*					■	
29.	*Jambadostrobus*					■	
30.	*Kendostrobus*					■	
31.	*Leleopteris*					■	
32.	*Lithangium*					■	
33.	*Mahudaea*					■	
34.	*Pantopteris*					■	
35.	*Plumsteadia*					■	
36.	*Plumsteadiostrobus*					■	
37.	*Pteronilsonia*					■	
38.	*Raniganjia*					■	
39.	*Searsolia*					■	
40.	*Surangephyllum*					■	
41	*Trithecopteris*					■	
42	*Venustostrobus*					■	
43	*Benlightfootia*						■
44	*Denkania*						■
45	*Glossotheca*						■
46	*Handapaphyllum*						■
47	*Khania*						■
48	*Lidgettonia*						■
49	*Nesowalesia*						■
50.	*Utkalia*						■
51.	*Arberia*	■	■				
52.	*Gangamopteris*	■	■	■	■	■	
53.	*Ottokaria*	■	■	■		■	
54.	*Cordaites*	■	■	■		■	■
55.	*Phyllotheca*		■	■		■	■
56.	*Giridia*		■	■			
57.	*Psygmophyllum*		■	■			
58.	*Euryphyllum*		■	■			
59.	*Buriadia*		■	■			
60.	*Cyclodendron*		■		■		■
61.	*Rhipidopsis*		■	■		■	■
62.	*Schizoneura*		■	■	■	■	■
63.	*Neomariopteris*		■	■	■	■	■
64.	*Rhabdotaenia*			■	■	■	■
65.	*Dizeugotheca*			■		■	
66.	*Eretmonia*			■		■	
67.	*Palaeovittaria*			■		■	
68.	*Scutum*			■		■	
69.	*Senotheca*			■		■	
70.	*Sphenophyllum*			■		■	■
71.	*Trizygia*			■		■	■
72.	*Asansolia*			■		■	■
73.	*Pterophyllum*			■		■	■
74.	*Dictyopteridium*			■		■	■
75.	*Partha*			■			■
76.	*Pseudoctenis*			■			■
77.	*Glossopteris*	■	■	■	■	■	■
78.	*Noeggerathiopsis*	■	■	■	■	■	■

TABLE 1: Range chart of genera in different Lower Gondwana formations of India.
QUADRO 1: Carta de distribuição de gêneros em diferentes formações do Gondwana Inferior da Índia.

The presence of *Glossopteris* flora in all the Lower Gondwana formations of different basins in India signifies its distribution in time and space (Surange 1966, 1975; Lele 1976; Srivastava 1997). Recent additions of genera and species with characteristic morphology having restricted stratigraphic range have provided us an insight to examine the developmental stages of *Glossopteris* flora in India.

COMPOSITION OF THE FLORA VIS-A-VIS DEVELOPMENTAL STAGES

Geological history of *Glossopteris* flora in India is not known before Permian due to non-availability of Carboniferous deposits. Earliest assemblage is recorded from Talchir Formation (beginning of Permian) and flora developed in successive horizons of Karharbari, Barakar, Barren Measures, Raniganj and Kamthi Formations covering the entire period of Permian.

The composition of *Glossopteris* flora in different formations is compiled in table 1, diversity of flora in increasing order of genera and species in different Lower Gondwana formations of India are plotted in figures 1-6 and graphic representation of different plant groups and appearance and disappearance of major taxa are shown in figure 7 (source of information is derived from-A Catalogue of Indian Fossil Plants, Lakhanpal *et al*. 1976 and A Catalogue of Fossil Plant from India-Palaeozoic and Mesozoic: Megafossils, Chandra & Tewari 1992). Kamthi Formation of Late Permian has been correlated with Raniganj Formation, but the appearance of new genera and new species of *Glossopteris* (14 spp) suggests different composition of flora beyond the range of Raniganj Formation (Chandra & Prasad 1981, Singh & Chandra 1987, Chandra & Singh 1992). On palynological evidences, Kamthi Formation has been dated as the end phase of Permian (Srivastava & Jha 1996).

The flora of Talchir Formation is known by the species of *Gangamopteris, Glossopteris, Noeggerathiopsis, Arberia, Ottokaria, Paranocladus* and seeds (Chandra *et al*. 1992). Limited number of plant fossils indicates that glossopterids, cordaites and conifer were the earliest stock of *Glossopteris* flora in India (Figures 1,7). The emergence of new floral elements, i.e. glossopterid leaves, *Rubidgea, Euryphyllum,* glossopterid fructification, *Dolianitia*, pteridosperm foliage of *Botrychiopsis*, lycophytic axes of *Cyclodendron*, equisetales *Phyllotheca, Schizoneura, Giridia;* filicales *Neomarioptoeris;* ginkgopsid *Ginkgophyton, Rhipidopsis, Psygmophyllum, Chirimiria;* conifers *Buriadia, Birsinghia, Paliandrolepis* and increased diversity of *Gangamopteris-Noeggerathiopsis* complex in Karharbari Formation reflect significant development and diversification of *Glossopteris* flora during early Permian (Figures 2,7). The assemblage continues in lower part of Barakar Formation but occurrence of new elements, e.g. glossopterid leaves, *Gondwanophyllites, Maheshwariphyllum, Palaeovittaria;* glossopterid fructification *Scutum, Partha;* filicales *Palasthalia* and absence of typical Karharbari forms, e.g. *Botrychiopsis, Buriadia, Cyclodendron, Chirimiria,* suggests a changing phase of flora (Figures 3,7).

The dominance of *Glossopteris* species in upper part of Barakar Formation (Srivastava 1992) and appearance of equisetales *Trizygia, Sphenophyllum, Lelstotheca, Barakaria, Pachhwarophyllum;* glossopterid leaves, *Rhabdotaenia, Diphyllopteris;* glossopterid fructification *Plumsteadia, Dictyopteridium, Eretmonia, Senotheca;* conifer *Walkomiella; ginkgopsid Saportaea, Gingkoites, Gondwanophyton;* filicales *Santhalea, Dizeugotheca; Cycads Pseudoctenis, Pterophyllum;* fructifications of unknown affinities *Veekaysinghia, Birbalsahnia* and absence of *Gangamopteris, Noeggerathiopsis* spp. suggest a new direction of flora from *Gangamopteris* to *Glossopteris* floral phase (Figure 7). Although new taxa which emerged in Barakar Formation are not recorded in the overlying flora of Barren Measures Formation, but the dominance of *Glossopteris* species corresponds with the Upper Barakar Flora (Figure 7).

Rapid development of *Glossopteris* species is evident in Early Late Permian Sequence of Raniganj Formation where the flora is represented by 78 species of *Glossopteris* along with new glossopterid leaf forms of *Belemnopteris, Pteronilssonia;* glossopterid fructifications *Kendostrobus, Mahudaea, Plumsteadiostrobus, Venustostrobus, Jambadostrobus;* equisetales *Raniganjia, Bengalea;* conifer *Searsolia;* sterile and fertile foliage of filicales *Damudosorus, Asansolia, Leleopteris, Trithecopteris, Dichotomopteris, Cuticulatopteris.* The flora also shows the widespread occurrence of equisetales and filicales, e.g. *Trizygia, Phyllotheca, Schizoneura, Neomariopteris* which were the part of earlier strata (Figure 7). Complete association of the flora in terms of number of genera and species suggests the acme of *Glossopteris* flora in Raniganj Formation (Early Late Permian). The records of new glossopterid fructifications in Kamthi Formation, e.g. *Denkania, Glossotheca, Lidgettonia, Nesowalesia;* new leaf of *Surangephyllum,* reported occurrence of new species (14) of *Glossopteris*, and new forms of unknown affinities, e.g. *Khania, Utkalia, Handapaphyllum, Senia, Pantopteris, Benlight* footia even after Raniganj Formation demonstrate the developmental trend of flora. The continuation of *Glossopteris* species (11) recorded only from Kamthi Formation, in Lower Triassic beds of India, suggests distinction of *Glossopteris* flora of Kamthi Formation with that of Raniganj Formation (Figures 5,6) (Chandra & Singh 1986). In all likelihood Kamthi Formation represents the penultimate development of *Glossopteris* flora in Indian Gondwana succession. The appearance of *Dicrodium*-frond and new elements in Early Triassic signifies the beginning of *Dicroidium* flora in Panchet Formation of India (Lele 1964, Saksena 1974).

COMPARATIVE DEVELOPMENT OF GLOSSOPTERIS FLORA IN OTHER GONDWANA COUNTRIES

Successive development of *Glossopteris* flora in Permian Gondwana of Brazil, Argentina, South Africa, Antarctica and Australia has been sorted out on the basis of associated plant taxa. Roslër (1973, 1975) identified four to five stages in Parana Basin of Brazil, six zones have been marked in Carboniferous-Permian sequence of Paganzo Basin, Argentina. The flora in ascending order is known as Malimaniense, Tupense, Trampeaderense, Lubeckense A, Lubeckense B and Bonetense (Archangelsky 1986). Anderson & Anderson (1985) have also distinguished six assemblages in Karroo Basin of South Africa. Although understory vegetation of Antarctica is not known but on the basis of available records of *Gangamopteris, Glossopteris* (leaves and fructifications), *Cordaites (Noeggerathiopsis),* petrified woods and in situ preservation of *Vertebraria* in southern Victoria

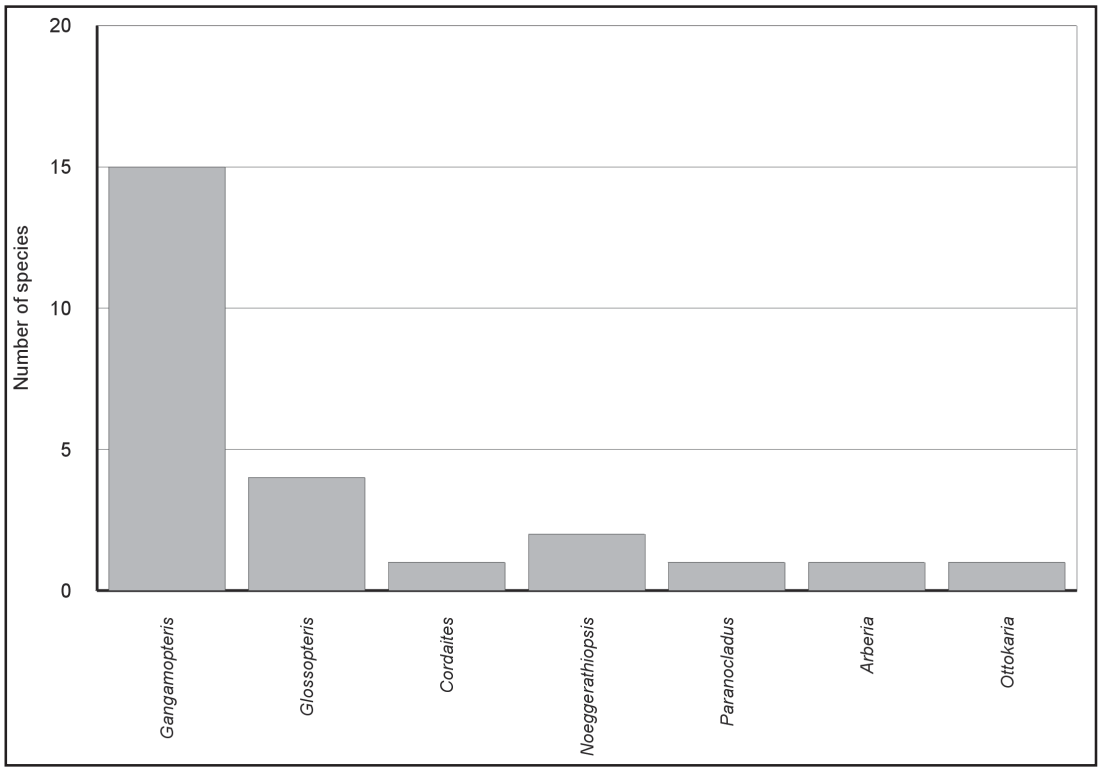


FIGURE 1: Distribution of plant fossils in Talchir Formation.
FIGURA 1: Distribuição de fitofósseis na Formação Talchir.

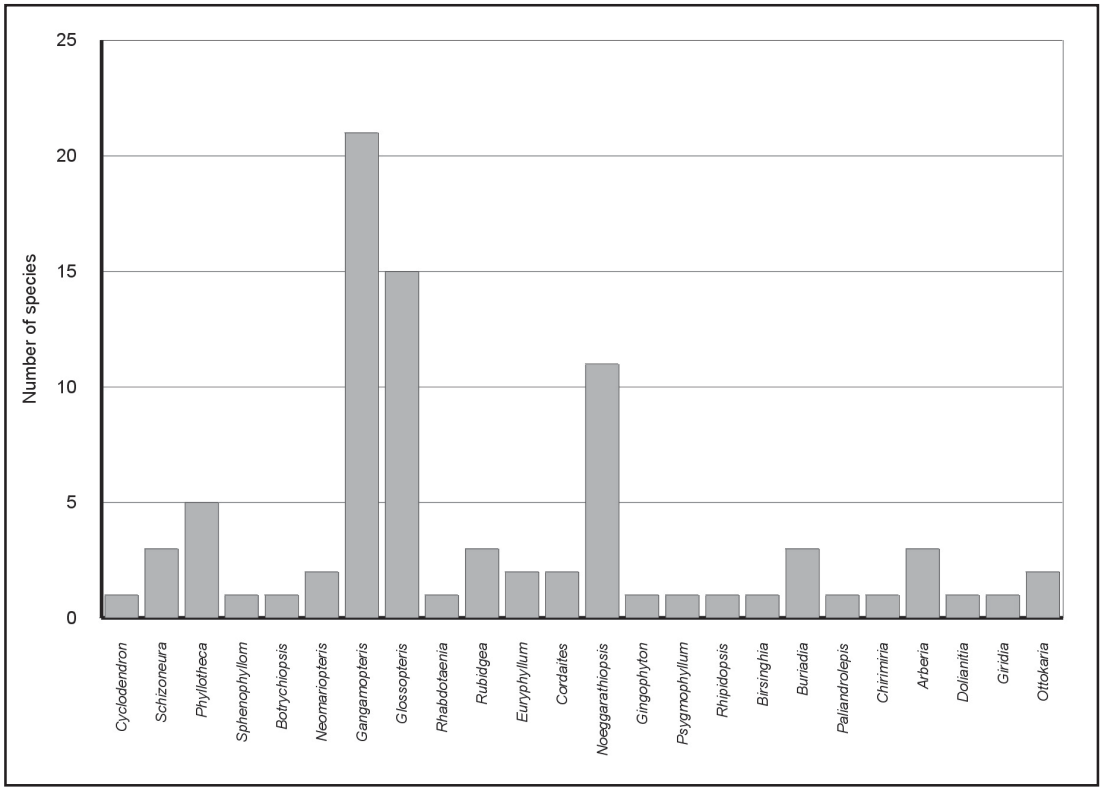


FIGURE 2: Distribution of plant fossils in Karharbari Formation.
FIGURA 2: Distribuição dos fitofósseis na Formação Karharbari.

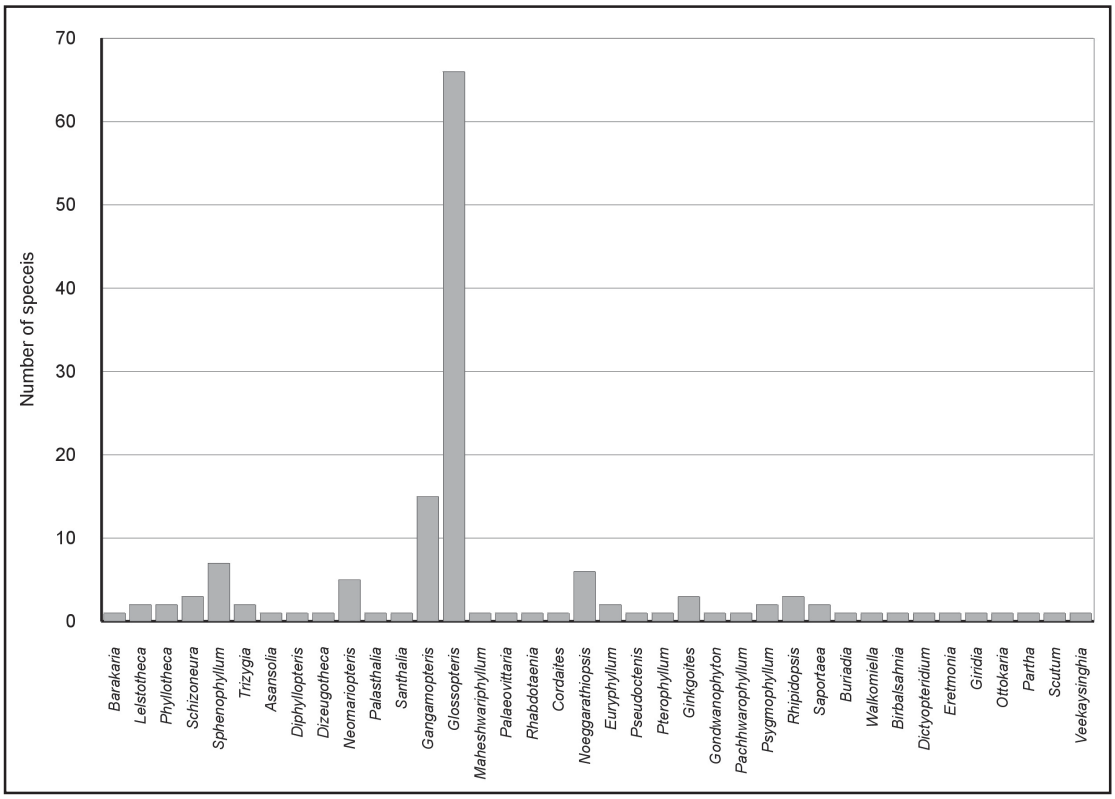


FIGURE 3: Distribution of plant fossils in Barakar Formation.
FIGURA 3: Distribuição de fitofósseis na Formação Barakar.

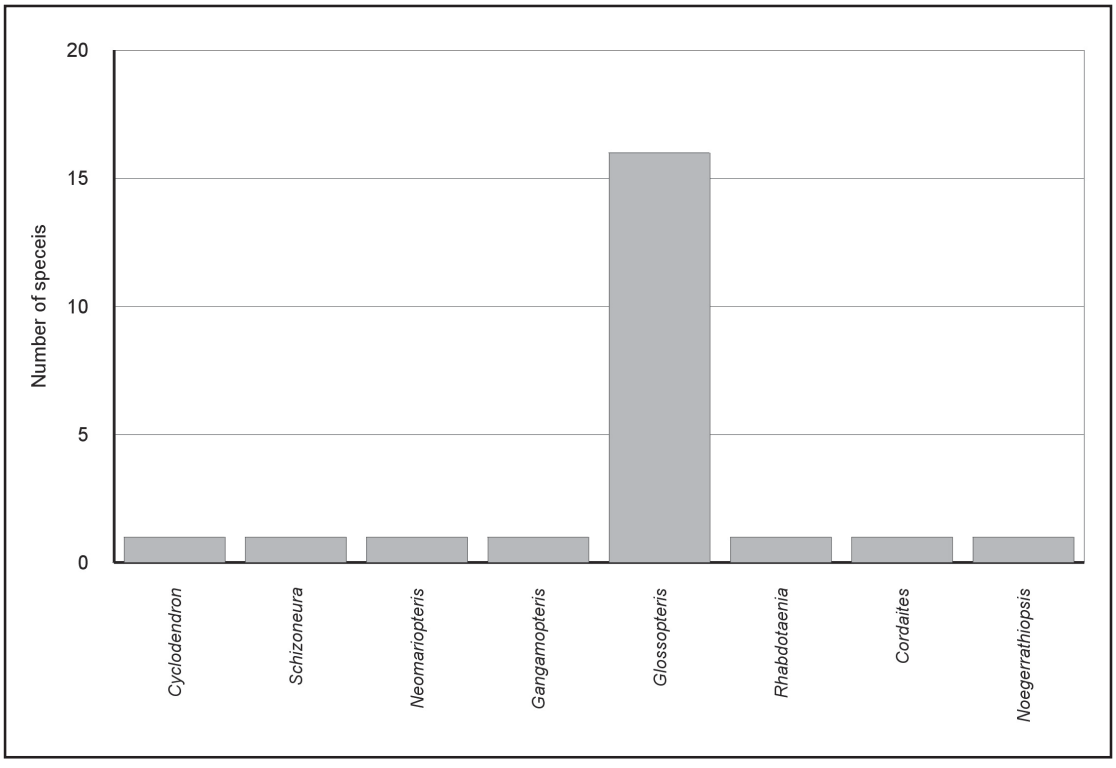


FIGURE 4: Distribution of plant fossils in Barren Measures Formation.
FIGURA 4: Distribuição de fitofósseis na Formação Barren Measures.

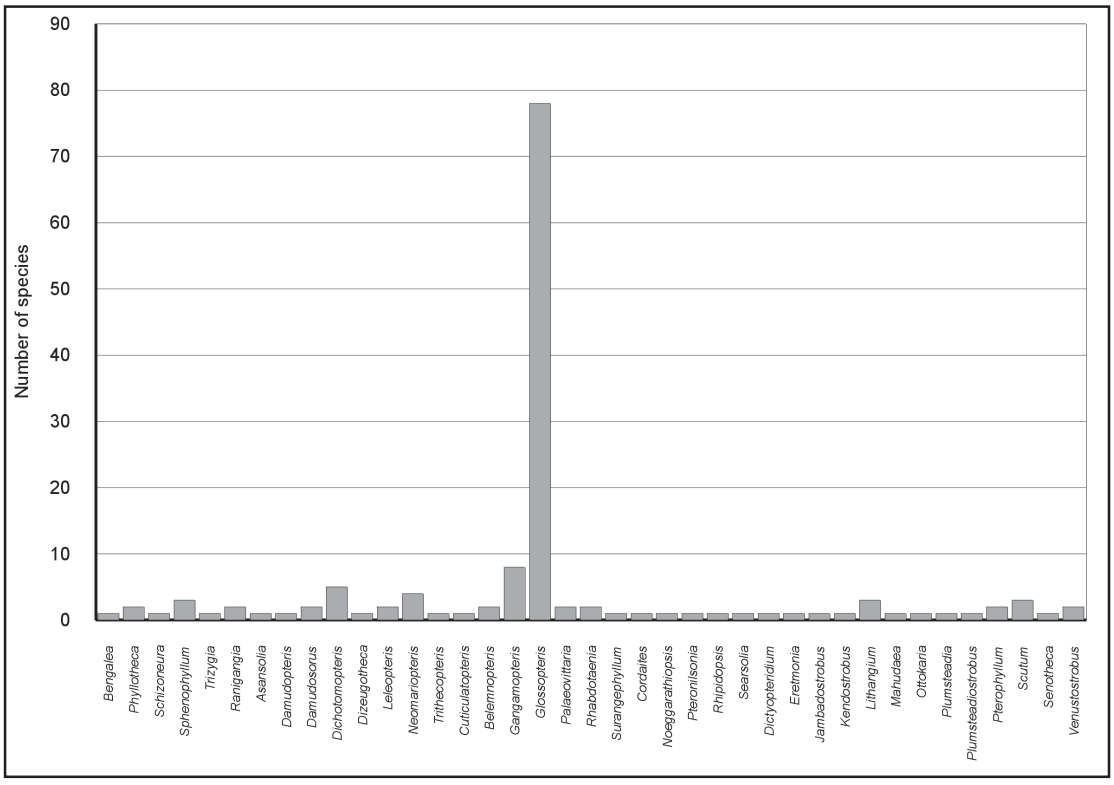


FIGURE 5: Distribution of plant fossils in Raniganj Formation.
FIGURA 5: Distribuição de fitofósseis na Formação Raniganj.

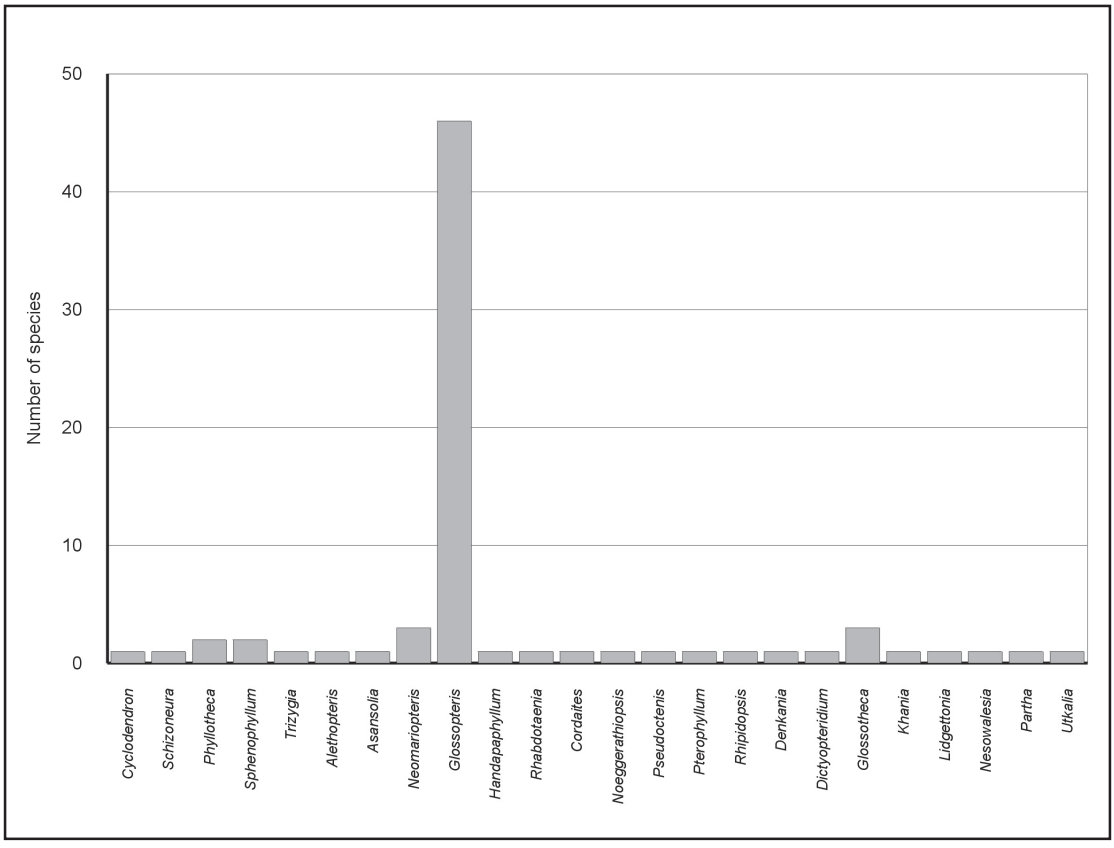
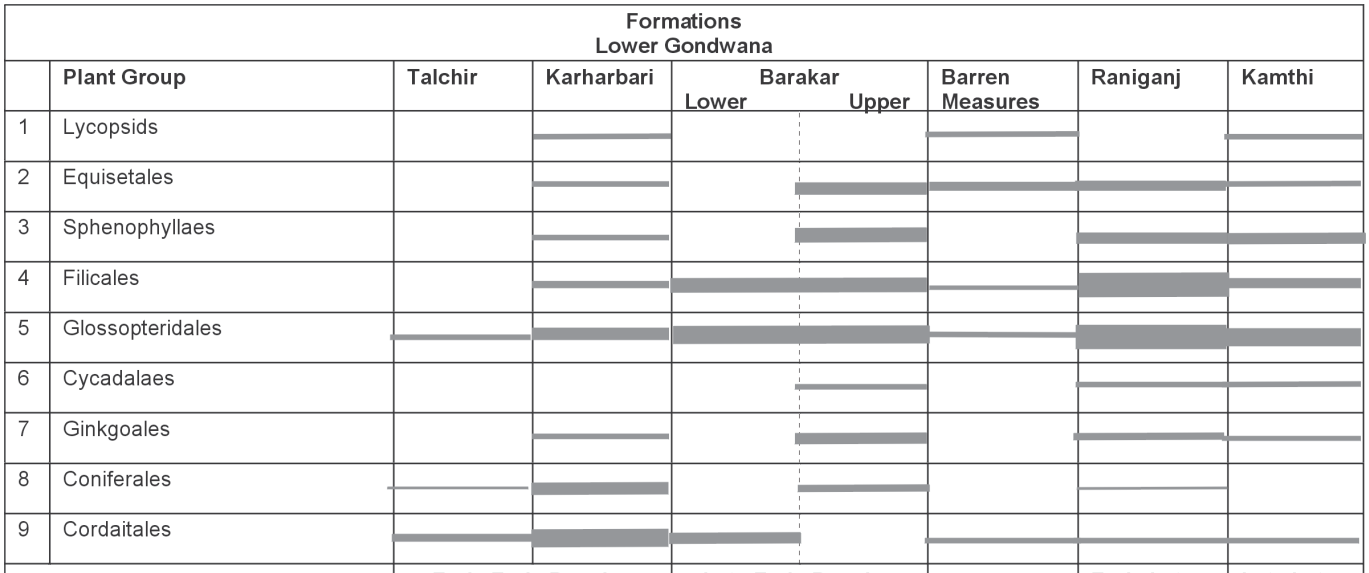


FIGURE 6: Distribution of plant fossils in Kamthi Formation.
FIGURA 6: Distribuição de fitofósseis na Formação Kamthi.



Significant Taxa		Early Early Permian		Late Early Permian			Early Late Permian	Late Late Permian
	Appearance of Taxa	*Gangamopteris, Glossopteris, Noeggerathiopsis, Ottokaria, Arberia, Paranocladus*	*Rubidgea, Eurynhyllum, Dolianta, Botychiopsis, Cyclodendron, Phyllotheca, Schizoneura, Neomariopteris, Rhipidopsis, Ginkgophyton, Psygmophyllum, Chirimiria, Buriadia, Birsinghia, Pallandrolepis*	*Trizygia, Sphenophyllum, Palasthalia, Gondwanophyllites, Maheshwariphyllum, Scutum, Partha, Plumsteadia, Senotheca, Dictyopteridium, Walkomiella, Ginkgoites, Saportaea*	*Barakaria, Pachhwaraophyllum, Santhalea, Dizeugotheca, Pseudoctenis, Pterophyllum, Veekaysinghia, Birbalsahnia*	*Rhabdotaenia*	*Belemnopteris, Pteronilssonia, Kendostrobus, Mohudaea, Venustostrobus, Searsolia, Damudosorus, Asansolia, Trithecopteris, Raniganjia*	*Denkania, Glossotheca, Lidgettonia, Khania, Handapaphyllum, Utkalia*
	Disappearance of Taxa		*Paranocladus*	*Rubidgea, Botrychiopsis, Buriadia, Chirimiria*	*Gangamopteris, Eurynhyllum, Walkomiella, ondwanophyllites, Maheshwariphyllum, Senotheca*	*Barakaria, Pachhwaraophyllum, Santhalea, Dizeugotheca, Pseudoctenis, Pterophyllum, Veekaysinghia, Birbalsahnia*	*Cyclodendron*	*Searsolia, Damudosorus, Trithecopteris*
		I		II		III	IV	V
	Significant Association	*Gangamopteris – Noeggerathiopsis*	*Gangamopteris – Noeggerathiopsis – Buriadia*	*Gangamopteris – Noeggerathiopsis – Glossopteris*	*Glossopteris – Equisetales*	*Glossopteris species*	*Glossopteris – Pteridophytes*	*Glossopteris*

*FIGURE 7: Graphic representation of plant groups in different formations showing appearance, disappearance and significant association of plant fossils. Assemblages I – V show the development of **Glossopteris** flora in Early Permian, Late Early Permian, Early Late Permian and Late Permian. FIGURA 7: Representação gráfica dos grupos vegetais em diferentes formações mostrando aparecimento, desaparecimento e associação significativa de fósseis vegetais. Assembléias I – V mostram o desenvolvimento de flora de **Glossopteris** no Permiano inicial, Permiano inicial final, Permiano final inicial e Permiano final.*

land and Beardmore glaciation area, Cuneo *et al.* (1993) have visualized three stages of development in Antarctica. In Australia, Gould (1975) has observed three floral phase but Retallack (1980) considers only *Gangamopteris* and *Glossopteris* florules in Early and Late Permian sequences. However, the study of Bowen Basin flora of Queensland suggests two pulses of floristic diversification in Late Permian *Glossopteris* flora (McLoughlin 1994), the first in the mid Late Permian (Moranbah Coal Measures, Macmillan Formation, Tomago Coal Measures and equivalent) which contains *Surangephyllum, Dictyopteridium, Rigbya, Senotheca* and increased abundance of pteridophytes and the second pulse is represented by *Schizoneura gondwanensis, Trizygia speciosa, Raniganjia bengalensis, Dictyopteridium walkomii, Cometia* spp. *Partha* spp. *Glossopteris grandis* and *G. Truncata*, although specific genera and species are not associated in Indian and Australian flora but floristic zones identified in Late Permian flora of Raniganj and Kamthi Formations of India showing distinct assemblages correspond with two stage development of *Glossopteris* flora in Late Permian sequences of Australia.

CONCLUSION

Glossopteris flora came into existence after the onset of glaciation, during late Carboniferous or early part of Permian. The floristic assemblages of different formations in Lower Gondwana Succession of India indicate the development of flora through different stages in successive horizons of Permian Period.

It has been observed that transition from *Gangamopteris* to *Glossopteris* floral phase is a notable development of *Glossopteris* flora from Early to Late Permian in all the Gondwana countries. However, further developmental stages are evident with the development of new forms and extinction of earlier forms. The incoming of *Dicroidium* - fronds in Early Triassic marks the end phase of *Glossopteris* flora. Nevertheless, continuation of few species of *Glossopteris, Noeggerathiopsis, Rhabdotaenia, Trizygia* suggest the tarrying of *Glossopteris* floral elements across Permian-Triassic.

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