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Advent and decline of the genus *Glossopteris* Brongniart in the Talcher Coalfield, Mahanadi Basin, Odisha, India

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ABSTRACT

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The paper deals with the distribution of the genus *Glossopteris* and its fructifications in different Lower Gondwana formations of Talcher Coalfield of Odisha State. We demonstrate how this taxon appeared in this basin in the earliest Permian Talchir Formation and evolved and diversified through the Karharbari, Barakar, Barren Measures and lower part of Kamthi formations and ultimately vanished in the early Triassic in the upper part of Kamthi Formation. Amongst fifty one species of the genus *Glossopteris* recorded in all, one species each has been found in the Talchir and upper part of Kamthi formations and two, sixteen and forty seven species respectively are represented in Karharbari, Barakar and the lower part of Kamthi formations. Barren Measures Formation is devoid of any megaplant fossil. Similarly, out of twenty seven taxa of fertile organs belonging to the *Glossopteris*, two each are found in the Talchir and Barakar formations respectively, whereas twenty four are recorded from the lower part of Kamthi Formation. It is observed that *Glossopteris* is less diversified in Early Permian Karharbari Formation. However, it diversified and proliferated during Barakar and Late Permian lower part of Kamthi formations. Further, it shows declination in the Early Triassic upper part of Kamthi Formation. The study shows that the lower part of Kamthi Formation of Talcher Coalfield has the maximum diversity of *Glossopteris* (forty seven species) among all the known localities of this formation exposed in Indian Gondwana.

The existence of meagre *Glossopteris* species against many *Gangamopteris* species in the needle shale confirms its association with the lower floral zone of Talchir Formation instead of the upper floral zone established by previous workers in this basin. Very low diversity of *Glossopteris* in the upper part of Kamthi Formation of Talcher Basin demonstrates that this palaeogeographic area would have experienced more arid conditions in early–middle Triassic period as compared to the mellowing climatic conditions prevailing during the same time period in the Panchet Formation (=Upper Kamthi Formation) of other areas of Son–Mahanadi Basin and the Damodar Basin.

Key–words—*Glossopteris*, Diversity, Talcher Coalfield, Son–Mahanadi Basin.

भारत में उड़ीसा की महानदी द्रोणी के तालचीर कोयलाक्षेत्र में ग्लॉसॉप्टेरिस ब्रॉगनियार्ट वंश का आगमन एवं अंत

अंजू सक्सेना, कमलजीत सिंह एवं श्रीरूप गोस्वामी

सारांश

यह शोध–पत्र उड़ीसा राज्य में तालचीर कोयलाक्षेत्र की विभिन्न निम्न गोंडवाना शैलसमूहों में *ग्लॉसॉप्टेरिस* वंश और इसके फल के वितरण से संबंधित है। हम प्रदर्शित करते हैं कि कैसे प्रारंभिकतम् पर्मियन तालचीर शैलसमूह में इस द्रोणी में यह वर्गक दिखायी दिया एवं इसका विकास हुआ तथा यह करहरबाड़ी, बराकार, बैरन मैजर्स तथा निम्न भाग कामथी शैलसमूहों में परिवर्तित हुआ और अंततः कामथी शैलसमूह के ऊपरी भाग के प्रारंभिक ट्रायसिक में इसका अंत हुआ। *ग्लॉसॉप्टेरिस* वंश की कुल 51 प्रजातियों में तालचीर शैलसमूह और कामथी शैलसमूहों के ऊपरी भाग में एक प्रजाति प्रत्येक में पाई गई है। दो, सोलह तथा सैंतालिस प्रजातियाँ क्रमशः करहरबाड़ी, बराकार तथा कामथी शैलसमूहों के निम्न भाग में

पाई गई हैं। बैरन मैजर्स शैलसमूह किसी भी गुरूपादप जीवाश्म से रहित है। इसी तरह, *ग्लॉसॉप्टेरिस* से संबंधित उर्वर अंगों के 27 वर्गकों में से तालचीर व बराकार शैलसमूहों में प्रत्येक के दो वर्गक पाए गए हैं जबकि कामथी शैलसमूहों के निम्न भाग से 24 वर्गक अभिलिखित किए गए हैं। यह देखा गया है कि *ग्लॉसॉप्टेरिस* प्रारंभिक पर्मियन करहरबाड़ी शैलसमूह में अल्प परिवर्तित है। यद्यपि, यह कामथी शैलसमूहों के निम्न भाग के बराकार तथा अंतिम पर्मियन के दौरान परिवर्तित हुए तथा उनमें वृद्धि हुई। इसके आगे, कामथी शैलसमूह के ऊपरी भाग के प्रारंभिक ट्रायसिक में इसका पतन प्रदर्शित होता है। यह अध्ययन प्रदर्शित करता है कि तालचीर कोयलाक्षेत्र के कामथी शैलसमूह के निम्न भाग में भारतीय गोंडवाना में अनावरित यह शैलसमूह सभी ज्ञात संस्थितियों में *ग्लॉसॉप्टेरिस* (47 प्रजातियॉं) की अधिकतम विभिन्नता है।

नीडल शेल में कई *गंगामॉप्टेरिस* प्रजातियों के प्रतिकूल दुर्बल *ग्लॉसॉप्टेरिस* प्रजातियों की विद्यमानता, इस द्रोणी में पूर्व कार्मिकों द्वारा स्थापित किए गए ऊपरी वनस्पति क्षेत्र की बदले तालचीर शैलसमूह के निम्न वनस्पति क्षेत्र के साथ इसका सहयोग प्रमाणित करता है। तालचीर द्रोणी के कामथी शैलसमूह के ऊपरी भाग में *ग्लॉसॉप्टेरिस* की अत्यंत निम्न विभिन्नता प्रदर्शित करती है कि पुराभौगोलिक क्षेत्र को सोन–महानदी द्रोणी तथा दामोदर द्रोणी के अन्य क्षेत्रों के पंचेत शैलसमूह (= ऊपरी कामथी शैलसमूह) में तत्कालीन अवधि के दौरान प्रचलित आर्द्र जलवायवी परिस्थितियों की तुलना में प्रारंभिक–मध्य ट्रायसिक अवधि में अधिक शुष्क परिस्थितियों का अनुभव हुआ होगा।

सूचक शब्द– *ग्लॉसॉप्टेरिस*, विभिन्नता, तालचीर कोयलाक्षेत्र, सोन–महानदी द्रोणी।

INTRODUCTION

THE Mahanadi Basin, one of the five major sedimentary basins of Peninsular India is located on the east coast of India. The Gondwana sediments deposited in the states of Chhattisgarh and Odisha constitute this master basin and are restricted to five major sub basins, viz. Mand–Raigarh, Hasdo–Arand, Korba, Talcher and Ib–River.

The Talcher Coalfield or the Talcher sub basin, occupying an area of over 1800 sq km constitutes the south–eastern most part of the Mahanadi Basin and its major portion is covered in Dhenkanal and Angul districts while a small part in the adjoining Sambalpur District of Odisha State. This sub basin mainly occupies the Brahmani River Valley and is bounded by latitudes 20°50' and 21°15' N and longitudes 84°20' and 85°23' E (Fig. 1). In the general geological sequence of Talcher Coalfield, the sediments of Lower Gondwana rest on Precambrian base and are distinguished into the lowermost Talchir Formation, and coal bearing Karharbari and Barakar formations, and non–coaliferous Barren Measures and uppermost Kamthi formations (Raja Rao, 1982; Manjrekar *et al.,* 1995; Table 1). Plant megafossils are reported from the Talchir, Karharbari, Barakar and Kamthi formations. Barren Measures Formation is completely barren of coal as well as of the megafossils whereas, palynological assemblages are known from all these formations (Das, 1958; Bhattacharya *et al*., 2001; Bharadwaj & Srivastava, 1969a, b; Meena, 2003; Navale & Srivastava, 1971; Srivastava, 1970, 1984; Tiwari *et al*., 1991; Tripathi, 1993, 1996, 1997, 2001, 2009; Tripathi & Bhattacharya, 2001).

Blanford *et al*. (1859) carried out the first ever palaeobotanical investigation in this coalfield and reported the Lower Gondwana fossils, viz. *Dizeugotheca* (*Pecopteris*), equisetaceous forms and the *Glossopteris*. Later, Feistmantel (1880) recorded the megafossils from the Barakar rocks exposed in and around Gopal Prasad Village near Talcher Town. During subsequent years many palaeobotanical investigations were carried out from a number of localities belonging to Talchir, Karharbari, Barakar and Kamthi formations that range in age from Early Permian to Late Triassic {Subramanian and Rao (1960); Roy and Bhattacharya (1967); Khan (1969); Surange and Maheshwari (1970); Surange and Chandra (1973a, b, c, 1974a, b, c, d, 1978); Chandra and Rigby (1981, 1983); Chandra (1984); Pant *et al.* (1985); Chandra and Singh (1986, 1988, 1989, 1992, 1995, 1996a, b); Patra and Panigrahi (1988); Patra and Swain (1991); Pant (1995); Singh (1985, 2000); Srivastava *et al*., (1996); Singh and Chandra (1987, 1996, 2000); Pal and Ghosh (1997); Pal *et al*. (1991); Bhattacharya *et al.* (2001); Singh *et al.* (2003, 2006); Goswami *et al.* (2006a, b) and Tiwari *et al*. (2009)}.

The complete diversity of the genus *Glossopteris* and its associated fructifications is analyzed and compared with the diversity found in the contemporaneous formations exposed in other Lower Gondwana basins of India. The reasons for the low diversity in the Talchir and upper part of the Kamthi formations have been discussed. It is revealed that the lower part of the Kamthi Formation of this basin has the highest diversity of *Glossopteris* (47 species as sterile leaves and 24 taxa of its associated fructifications) among all the known localities of this formation in Indian Gondwana.

GEOLOGICAL SETTING

The Permian–Triassic sedimentary rocks in Talcher sub basin belong to the Talchir, Karharbari, Barakar and Post–Barakar formations and are generally fluvial in origin (Sastry *et al.*, 1977; Bhattacharya *et al.*, 2002). The Talchir Formation is generally regarded as the continental facies deposit as is evidenced by the presence of plant megafossils in the needle shales (Chandra & Singh, 1996b; Singh *et al.*, 2005), the glacial nature of the basal boulder bed, ripple marks, hummocky cross–stratification, and the presence of cross–bedded sandstone and pebbly conglomerate in the overlying unit. The plant fossils and the above mentioned sedimentary features indicate that sedimentation took place in a huge water body. The stable isotopic analyses recently (Bhattacharya *et*

al., 2002) carried out on the carbonate nodules present in the siltstone bed of the Talchir Formation exposed near Bedasar Village near Angul Town indicate that this phase of Talchir sedimentation took place in a fresh water environment, most probably in lakes formed by the water supplied by melting of the glaciers from the nearby hills. The type locality of Talchir Formation also exists in the eastern part of Talcher Coalfield in and around Sarang Village.

According to Subramanian (1962) and Chakraborty *et al.* (1967), the huge post–Barakar Formation sedimentary pile can be divided into the Raniganj, Panchet and Mahadeva formations, based on the lithology and palaeontology. However, the entire sequence was retained in a single lithostratigraphic unit, i.e. the Kamthi Formation by Raja Rao (1982). The Kamthi sediments exposed in the west–central part of Talcher Basin were mapped by Chakraborty (1989) and differentiated into the Lower and Upper members (Table 1). CMPDI (1986) and Mohanty and Chaudhury (1989) demarcated the Barren Measures Formation from the Kamthi Formation in the central part of this basin on the basis of lithology. Tripathi and Bhattacharya (2001) also confirmed the presence of the Barren Measures Formation on the basis of miofloral assemblage. In the present scenario, the rocks of Lower Gondwana period in Talcher Basin are differentiated as Talchir, Karharbari, Barakar, Barren Measures, Lower Kamthi and Upper Kamthi formations (Goswami & Singh, 2013). The stratigraphic sequence encountered within the Talcher sub basin along with the lithology and fossil elements of different assemblage zones is presented in Table 1.

FLORAL DIVERSITY IN TALCHER COALFIELD

1. Talchir Formation (Early Permian, Asselian–Sakmarian)

Glossopteris is represented by a single species, i.e. *Glossopteris longicaulis* recorded in the needle shales exposed near Dereng and Patharmunda villages in Talcher Coalfield (Roy & Bhattacharyya, 1967). However, other forms, viz. annelid impressions, insect wings, nematodes, bryophytic remains, equisetaceous stems, ichno genus *Talchirichnus gondwanensis,* four species of *Gangamopteris*, *Noeggerathiopsis hislopi*, *Arberia surangei*, *Ottokaria bengalensis, Cardaicarpus* seeds and *Vertebraria indica* have been reported from the Talchir Formation (Roy & Bhattacharyya, 1967; Chandra & Singh, 1996b; Srivastava *et al.,* 1996).

Records of *Glossopteris* from Talchir Formation of other coalfields are likewise sporadic. One species, viz. *G. communis* has been reported from Chirimiri Coalfield in

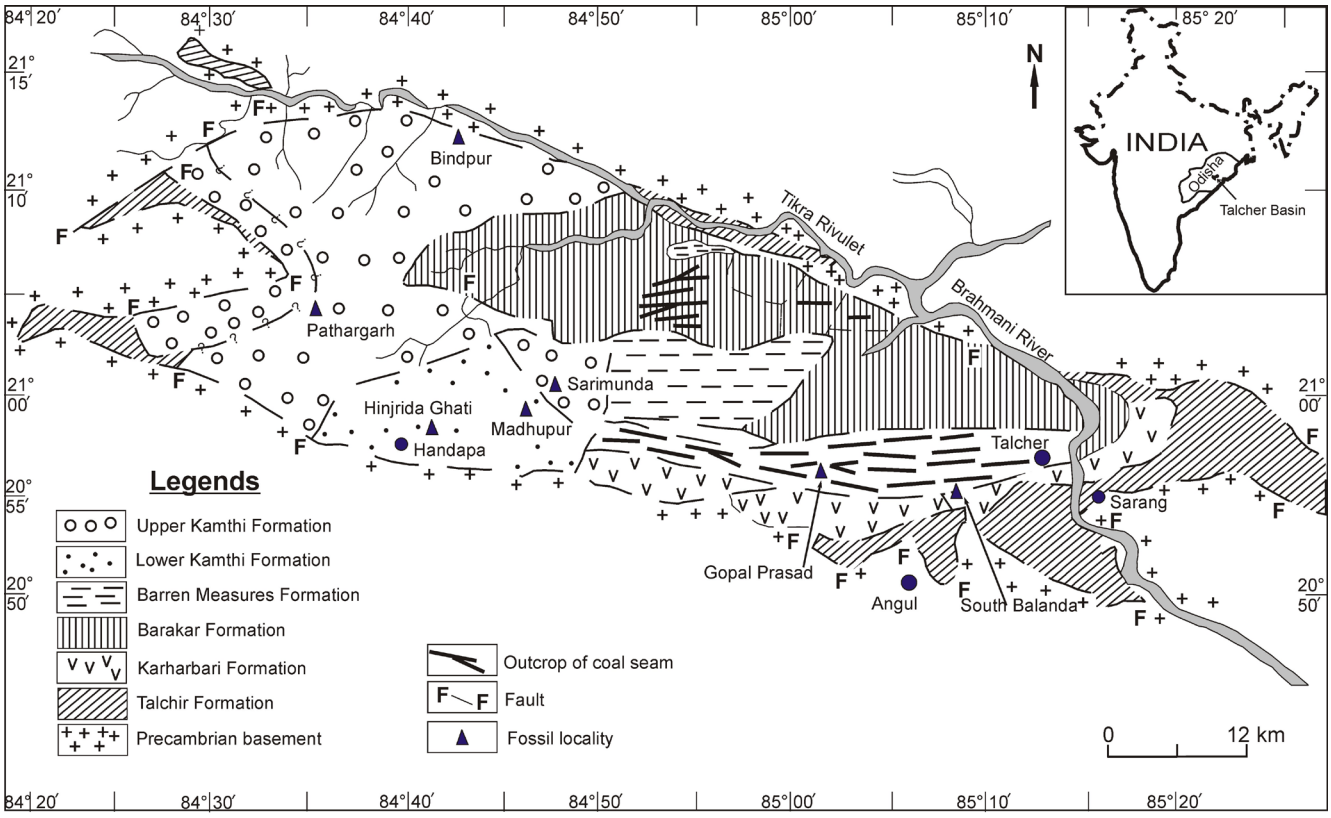

Fig. 1—Location Map of Talcher Basin of Odisha (modified after Manjrekar *et al*., 2006; Pal *et al*., 1991; Raja Rao, 1983).

central India and *G. talchirensis* is recorded from South Rewa Gondwana Basin. Two species of *Glossopteris*, viz. *G. communis* and *G. indica* are known from the North Karanpura Coalfield (Chandra & Surange, 1979). Recently, Tewari and Srivastava (2000) reported six species of *Glossopteris*, viz. *G. talchirensis*, *G indica*, *G. communis*, *G. stenoneura*, *G. tenuifolia* and *G. spatulata* from the Talchir Formation exposed in Jaitri River section near Latehar Town, Auranga Coalfield, Jharkhand State. This is the highest diversity of *Glossopteris* in any locality of the Talchir Formation in India. The maximum diversity of *Glossopteris* in the Talchir Formation of India is seven species.

2. Karharbari Formation (middle Early Permian, Sakmarian–Artinskian)

Sediments of Karharbari Formation are exposed at many places but the megafossils were recovered only from the carbonaceous shale horizons exposed in South Balanda open cast colliery near Talcher Town. Like Talchir Formation, the representation of *Glossopteris* is again very poor in Karharbari Formation of Talcher Coalfield. Only two species, viz. *G. communis* and *G. browniana* are recorded. Rest of the flora recorded in this formation is comparatively well diversified and represented by *Phyllotheca westensis*, *Schizoneura gondwanensis*, *Noeggerathiopsis hislopi*, two species of *Euryphyllum* (*E. maithyi* and *E. whittianum*), two species of *Gangamopteris* (*G. angustifolia* and *G. cyclopteroides*), *Surangephyllum elongatum*, *Macrotaeniopteris feddeni*, *Vertebraria indica* and *Buriadia heterophylla* {Chandra and Singh (1996a) and Singh *et al*. (2003, 2006)}.

In comparison to the Talcher Coalfield, the Karharbari Formation exposed in other basins of Peninsular India exhibits more diversity in the genus *Glossopteris*. Giridih Coalfield has the maximum number of *Glossopteris* species (eleven species, viz. *G. angusta, G. angustifolia, G. browniana, G. communis, G. damudica, G. decipiens, G. giridihensis, G. longicaulis, G. pandurata, G. recurva* and *G. spathulato–cordata* (Maithy, 1965; Pant & Gupta, 1968, 1971). Similarly, eight species of *Glossopteris* (*G. communis*, *G. gigas*, *G. indica*, *G. major*, *G. angusta*, *G. spatulata*, *G. browniana* and *G. spathulato–cordata*) are reported from the Karharbari Formation (= Basal Barakar) of Nand Coalfield in Wardha Basin (Singh *et al*., 2005). The other coalfields/localities that possess characteristic megafossils of the Karharbari Formation are Deogarh, Karanpura and Auranga which have one species each, Daltonganj, Umaria and Chirimiri have four species each and Pali is represented by five species of *Glossopteris* (Maheshwari, 1992). Total number of *Glossopteris* species in the Karharbari Formation of India is 19 (Singh *et al*., 2006).

3. Barakar Formation (late Early Permian, Artinskian–Kungurian)

A rich and diversified megafossil assemblage has been recorded from the Barakar sediments exposed in the vicinity of Gopal Prasad Village near Talcher Town and near Koshala Village in Angul District (Feistmantel, 1880; Patra & Panigrahi, 1988; Patra & Swain, 1991; Singh & Chandra, 1996; De, 2003). The assemblage is dominated by the genus *Glossopteris* with 16 species (*G. angustifolia, G. browniana, G. communis, G. conspicua, G. damudica, G. decipiens, G. gigas, G. indica, G. intermedia, G. intermittens, G. leptoneura, G. longicaulis, G. stenoneura, G. subtilis, G. tenuifolia* and *G. tenuinervis*) along with other genera which include: *Gangamopteris, Merianopteris, Neomariopteris*, *Schizoneura*, *Raniganjia*, *Sphenophyllum*, *Trizygia*, *Rhipidopsis*, *Dictyopteridium, Eretmonia*, *Vertebraria*, equisetaceous spikes, stems and *Paracuneatochara talchirensis* and *P. kosalensis*.

As compared to the Barakar Formation of the Talcher Coalfield which possesses only 16 *Glossopteris* species, this formation in other basins/coalfields of peninsular India shows much more diversity in the genus *Glossopteris*. For instance, 52 species are known from various collieries and adjoining areas of Ib–River Coalfield, Odisha (Singh *et al*., 2006). This is the highest diversity of this genus in any locality of Barakar Formation in India.

The *Glossopteris* diversity in the Barakar sediments of Mand–Raigarh Coalfield is also very high (29 species) representing *G. gondwanensis*, *G. raniganjensis*, *G. communis*, *G. barakarensis*, *G. arberi*, *G. feistmantelii*, *G. indica*, *G. karanpurensis*, *G. spatulata*, *G. tenuifolia*, *G. nimishea*, *G. tenuinervis*, *G. churiensis*, *G. damudica*, *G. stenoneura*, *G. pandurata*, *G. leptoneura*, *G. major*, *G. lanceolatus*, *G. bosei*, *G. angustifolia*, *G. stricta*, *G. browniana*, *G. intermedia*, *G. spathulato–cordata*, *G. karharbariensis*, *G. gopadensis*, *G. senii* and *G. tortuosa.* (Singh *et al*., MS). Singh *et al*. (2011) reported 22 species of *Glossopteris* from the Korba Coalfield, Mahanadi Basin. 20 species of *Glossopteris* are present in Raniganj Coalfield, Damodar Basin (Maheshwari & Tewari, 1992; Srivastava, 1992). In Auranga Coalfield, *Glossopteris* is represented by 15 species (Srivastava, 1977; Srivastava & Tewari, 1996). 15 *Glossopteris* species are recorded from Tatapani–Ramkola Coalfield (Singh *et al*. 2012). 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 4, 3, 2, 2, 2 and 1 *Glossopteris* species each, respectively (Maheshwari, 1992). Total number of *Glossopteris* species in the Barakar Formation of India is 80 (Singh *et al*., 2006).

4. Barren Measures Formation (Middle Permian–Guadalupian)

The sediments of this formation are exposed in the central part of the Talcher Basin, however they are completely barren of mega plant fossils including *Glossopteris*.

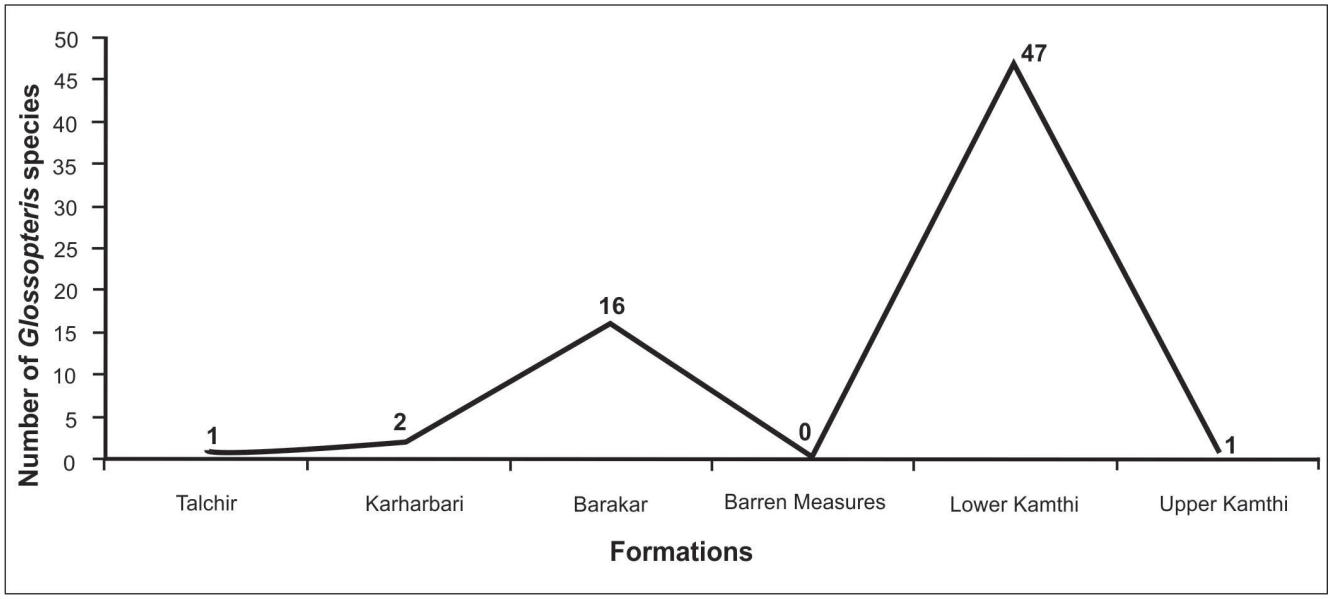

Fig. 2—Diversity of the genus *Glossopteris* in Talcher Basin during Permian–Early Triassic.

5. Lower part of the Kamthi Formation (Late Permian–Lopingian)

The Kamthi Formation is divided into lower and upper members in Talcher sub Basin. The Lower member exposed near Madhupur Village and in the Hinjrida Ghati Section near Handapa Village is of Late Permian age and contains a distinct megaflora similar to the flora found in the Raniganj Formation of the Damodar Basin of equivalent age (Chandra & Singh, 1992; Singh & Chandra, 2000). These two sedimentary deposits have been worked out by a number of workers mentioned in the introduction. The genus *Glossopteris* flourished very well in the lower part of the Kamthi Formation in this basin representing 47 species in the form of leaves and 24 taxa as associated fructifications (Table 2). Besides *Glossopteris*, other plant groups with their representative genera, viz. Lycopodiales (*Cyclodendron*), Sphenophyllales (*Trizygia* and *Sphenophyllum*), Equisetales (*Schizoneura*, *Phyllotheca*, *Lelstotheca* and *Raniganjia*), Filicales (*Asansolia*, *Dizeugotheca*, *Neomariopteris*, *Pantopteris* and *Damudopteris*), Cycadales (*Pseudoctenis*), Ginkgoales (*Handapaphyllum*) and Glossopteridales (*Glossopteris*, *Surangephyllum*, *Vertebraria*, *Cistella*, *Denkania*, *Dictyopteridium*, *Eretmonia*, *Glossotheca*, *Indocarpus*, *Khania*, *Lidgettonia*, *Nesowalesia*, *Partha*, *Scutum, Utkalia* and *Samaropsis*) also grew luxuriantly in the lower part of the Kamthi Formation. 20 species of *Glossopteris* are recorded from the Madhupur Locality (Singh & Chandra, 2000). With 42 *Glossopteris* species, Hinjrida Ghati Section is the only locality in India that has the highest specific diversity in the genus *Glossopteris* in the Lower Kamthi Formation (Chandra & Singh, 1992). The data from Hinjrida Ghati and Madhupur villages demonstrate that the Kamthi Formation in Talcher Coalfield has the highest diversity in *Glossopteris* (47 species as sterile leaves and 24 taxa of fructifications) among all the Kamthi Formation localities exposed in India.

In comparison to the vast diversity in the genus *Glossopteris* in the Kamthi sediments of Talcher Basin of Mahanadi Master Basin, its diversity is comparatively low in the Kamthi Formation of Wardha Basin (36 species) and it is very poor in the Godavari Basin (4 species) (Tewari, 2008). Total number of *Glossopteris* species in the Lower part of the Kamthi Formation of India is 54 (Singh *et al*., 2006).

6. Upper part of the Kamthi Formation (Early–Late Triassic–Anisian)

The sediments of upper part of the Kamthi Formation are exposed in the central and western parts of the Talcher Coalfield near Sarimunda, Pathargarh and Bindpur villages (Fig. 1). This formation is very poor in *Glossopteris* diversity (only one species as *Glossopteris* sp. is present), but it is comparatively rich in elements of Triassic age like *Dicroidium zuberi*, *D. superbum*, *D. giarensis*, *Lepidopteris* sp. cf. *L. stormbergensis*, *Elatocladus* sp., *Yabiella* sp. and *Desmiophyllum* sp. It also possesses few specimens of *Neomariopteris hughesii* and equisetaceous stems (Pal *et al*., 1991; Pal & Ghosh, 1997; Bhattacharya *et al*., 2001). These authors found this assemblage quite comparable with that of the Panchet Formation of Triassic age.

The Panchet sediments of Tatapani–Ramkola Coalfield which are equivalent in age to the upper part of the Kamthi Formation, possess a magnificent *Glossopteris* diversity representing 12 species, viz. *G. indica, G. senii, G. gopadensis, G. recurva, G. communis, G. angustifolia, G. retifera, G. tortuosa*, *G. tenuifolia, G. barakarensis, G. pandurata* and

G. browniana (Singh *et al*., 2012). Similarly, the Nidpur beds in Singrauli Coalfield have 6 species of *Glossopteris* along with *Scutum* sp., scale leaves, seeds and many species of *Dicroidium.* Another section of Panchet Formation exposed in Nonia Rivulet near Asansol Town in West Bengal State also contains six species of *Glossopteris* and *Cordaicarpus* seeds along with *Schizoneura gondwanensis*, *Macrotaeniopteris* and typical Triassic elements, viz. *Dicroidium*, *Lepidopteris*, *Podozamites*, *Cyclopteris* and *Taeniopteris* (Singh *et al*., 2012).

DISCUSSION

Fifty one species of the genus *Glossopteris* have been recorded in all from the Talcher Coalfield/sub basin, of which one species each has been found in the Talchir Formation and in the upper part of the Kamthi Formation and two, sixteen and forty seven species are represented in the sediments of Karharbari, Barakar and lower part of the Kamthi formations respectively. Barren Measures Formation is devoid of any *Glossopteris* species. Similarly, out of twenty seven taxa of fertile organs belonging to the *Glossopteris*, two each are found in the Talchir and Barakar formations respectively whereas, twenty four taxa are recorded from the lower part of the Kamthi Formation (Table 2). The data show that the apparent diversity of *Glossopteris* was minimum up to the Karharbari Formation (only three species) in this basin and was highest (47 species) during the deposition of lower part of the Kamthi Formation and again it decreased to its lowest level in the upper part of the Kamthi Formation (Fig. 2).

Very poor representation of the genus *Glossopteris* in the Talchir Formation of Talcher Coalfield may be related to its association with one of the two lower floral zones of the Talchir Formation which is dominated by *Gangamopteris* leaves instead of the upper floral zone that has distinct presence of *Glossopteris* along with *Gangamopteris* (Chandra *et al*., 1992). Rikba beds of North Karanpura Coalfield (Lele, 1966) containing many *Glossopteris* species and the Talchir Formation of the Auranga Coalfield having six species of *Glossopteris* and seven species of *Gangamopteris* (Tewari & Srivastava, 2000) fits into the hypotheses of Chandra *et al.* (1992). Similarly, the presence of four species of *Gangamopteris* and a single *Glossopteris* species in the Talchir needle shale in Talcher Basin again points out that these beds belong to the lower floral zone. The vegetation of Talchir Formation seems to be meagre, as only a few specimens were found preserved in the type locality of this formation near Sarang Village (Chandra & Singh, 1996b).

From Sakmarian onwards, the floral diversity amplified with increased sunlight and a rise in temperature that resulted in the development of a slightly more diverse flora in the Karharbari Formation (total taxa 13, including 2 species of *Glossopteris*). The climate during the deposition of the Barakar and lower part of the Kamthi formations was quite conducive for the fast development and diversification of the *Glossopteris* flora (Chandra & Singh, 1992; Singh & Chandra, 1996, 2000). This is reflected in the assemblages recovered from the Barakar Formation of the Gopal Prasad area and the Koshala Village (total taxa–34; charophytes–2, pteridophytes–10, Ginkgoales–1, Glossopterids–21) and in the assemblages found in the Handapa and Madhupur areas belonging to the lower part of the Kamthi Formation (total taxa–95; pteridophytes–18, Cycadales–1, Ginkgoales–1, Glossopterids–75) of this basin (Goswami & Singh, 2013).

There is no record of any megaplant fossil in the Barren Measures Formation, however striate disaccate pollen grains are recorded from this formation. The total absence of megafossil remains in the Barren Measures of the Talcher Basin can be attributed mostly to a facies change. It is observed that the genus *Glossopteris* flourished luxuriantly in the lower part of the Kamthi Formation (Late Permian) in both the Handapa and Madhupur areas with a diversity of 42 and 20 species respectively (Chandra & Singh, 1992; Singh & Chandra, 2000). In all, 47 *Glossopteris* species have been reported from the lower part of the Kamthi Formation of the Talcher Basin. This is again the largest report of specific diversity in the genus *Glossopteris* occurring in the Kamthi Formation of the Indian subcontinent.

The abrupt decline in the *Glossopteris* diversity in the upper part of the Kamthi Formation of Talcher Basin can be related with extreme arid conditions in this palaeogeographic area that probably did not allow the *Glossopteris* plants to produce reproductive structures (seeds and pollen) needed for the propagation and survival of the plants in the next generation. This assumption is supported by the fact that even a single fructification of *Glossopteris* is not reported from the rocks of upper part of the Kamthi Formation in this basin. Tewari (2001) suggested prevalence of unfavourable conditions during the early Triassic as one of the reasons for the sterility of seeds leading to extinction of *Glossopteris*. In contrast, the lower part of the Kamthi Formation in this basin not only possesses the highest diversity of *Glossopteris* (47 species) but also of its fructifications (24 taxa). Such a vast diversity during Late Permian certainly points out towards the conducive climatic conditions for the healthy growth of the *Glossopteris* plants with seasonal blossoming.

In comparison to the upper part of the Kamthi Formation of Talcher Basin which is supposed to be of early to middle Triassic in age, the equivalent formation, i.e. Panchet Formation in the Tatapani–Ramkola Coalfield and in the Singrauli Coalfield (Nidpur beds) of the same Son–Mahanadi Master Basin, has better diversity in the genus *Glossopteris* (12 and 6 species respectively, Singh *et al*., 2012). The Nidpur beds also possess the fertile organ *Scutum*, scale leaves and seeds along with many species of *Dicroidium.* Similarly, the Panchet Formation exposed near the Asansol Town in Damodar Basin in West Bengal State also contains six species of *Glossopteris, Cordaicarpus* seeds along with *Schizoneura*

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

Table 1—Stratigraphic nomenclature of Talcher Basin, Odisha (Modified after Manjrekar *et al*., 1995).

FORMATIONS → / PLANT TAXA ↓	A. Talchir Formation (Early Permian)	B. Karharbari Formation (Early Permian)	C. Barakar Formation (Early Permian)	D. Barren Measures Formation (Middle Permian)	E. Lower Kamthi Formation (Late Permian)	F. Upper Kamthi Formation (Triassic)
Glossopteris (51)	1	2	16	0	47	1
Glossopteris acuminata					+	
G. angusta					+	
G. angustifolia			+		+	
G. arberi					+	
G. barakarensis					+	
G. bosei					+	
G. browniana		+	+		+	
G. communis		+	+		+	
G. conspicua			+		+	
G. damudica			+		+	
G. decipiens			+			
G. dhenkanalensis					+	
G. divergens					+	
G. feistmantelii					+	
G. fluctuosa					+	
G. gigas			+		+	
G. gondwanensis					+	
G. gopadensis					+	
G. hinjridaensis					+	
G. indica			+		+	
G. inaequalis					+	
G. intermedia			+		+	
G. intermittens			+			
G. kamthiensis					+	
G. lanceolatus					+	
G. leptoneura			+		+	
G. longicaulis	+		+			
G. maheshwarii					+	
G. mohudaensis					+	
G. nautiyalii					+	
G. nimishea					+	
G. obscura					+	
G. oldhamii					+	
G. pandurata					+	
G. radiata					+	
G. retifera					+	

G. sastrii					+	
G. spatulata					+	
G. stenoneura			+		+	
G. stricta					+	
G. subtilis			+		+	
G. syaldiensis					+	
G. taeniensis					+	
G. tenuifolia			+		+	
G. tenuinervis			+		+	
G. tortuosa					+	
G. utkalensis					+	
G. varia					+	
G. vulgaris					+	
G. zeilleri					+	
Glossopteris sp.						+
Fertile forms (27)	2	0	2	0	24	0
Arberia surangei	+					
Plumsteadia pretiosa (*Cistella ovata*)					+	
Plumsteadia sp. (*Cistella* sp.)					+	
Denkania indica					+	
Dictyopteridium sporiferum			+		+	
Eretmonia utkalensis					+	
E. hinjridaensis					+	
E. ovata					+	
E. karanpuraensis					+	
Eretmonia sp.			+			
Glossotheca utkalensis					+	
G. immanis					+	
G. orissiana					+	
Indocarpus elongatus					+	
Khania dhenkanalensis					+	
Lidgettonia indica					+	
L. mucronata					+	
Lidgettonia sp.					+	
Nesowalesia indica					+	
Ottokaria bengalensis	+					
Partha indica					+	
P. spathulata					+	
Scutum sahnii					+	
S. elongatum					+	
S. indicum					+	
Scutum sp.					+	
Utkalia dichotoma					+	

Table 2—Comparative analyses of *Glossopteris* and allied fructifications in Talcher Basin of Odisha.

gondwanensis, *Macrotaeniopteris* and typical Triassic elements, viz. *Dicroidium*, *Lepidopteris*, *Podozamites*, *Cyclopteris* and *Taeniopteris* (Singh *et al*., 2012). Such a big difference in the diversity trend of *Glossopteris* occurring in the upper part of the Kamthi Formation of Talcher Basin that exists almost in the eastern part of Son–Mahanadi Master Basin, in the Panchet Formation of Tatapani–Ramkola and Singrauli coalfields located in the northern–westernmost end of this Master Basin, and in the Panchet Formation of Nonia Nala near Asansol in Damodar Basin situated in the north of Talcher Basin points out more arid and non–conducive conditions in Talcher Basin as compared to the slightly mellowing climate in the Tatapani–Ramkola Coalfield, Singrauli Coalfield and Nonia Nala Section during Early–Middle Triassic period.

CONCLUSIONS

The needle shales of the Talchir Formation in Talcher Coalfield may belong to the lower floral zone of earlier workers (Chandra *et al*., 1992) instead of the upper floral zone, as is evidenced by the presence of meagre number of *Glossopteris* species against many *Gangamopteris* leaves in the assemblage. The lower part of the Kamthi Formation of the Talcher Basin possesses the highest diversity in the genus *Glossopteris* (47 species) and in its fructifications (24 taxa) as compared to the known localities of this formation of Indian Gondwana.

Very low diversity of *Glossopteris* in the upper part of the Kamthi Formation of Talcher Basin demonstrates that this palaeogeographic area might have experienced more arid conditions as compared to the mellowing climatic conditions prevailing during the deposition of the sediments of Panchet Formation (= Upper part of Kamthi Formation) in Tatapani–Ramkola and Singrauli coalfields and in and around Nonia rivulet section near Asansol Town which allowed *Glossopteris* to grow more comfortably. Based on the varying diversity patterns in the genus *Glossopteris* during Upper Kamthi / Panchet Formation in the above mentioned four areas, i.e. Talcher Basin, Tatapani–Ramkola Coalfield, Singrauli Coalfield and the Nonia Section that existed quite apart from each other, it is inferred that latitude and longitude might have also played vital role in regulating the climatic conditions of these areas.

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