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EARLY PERMIAN FLORAL DIVERSITY AND PALAEOENVIRONMENT OF THE WEST BOKARO COALFIELD, DAMODAR BASIN, INDIA

SRIKANTA MURTHY*, NEHA AGGARWAL and ANJU SAXENA

BIRBAL SAHNI INSTITUTE OF PALAEOSCIENCES, 53 UNIVERSITY ROAD, LUCKNOW-226007, INDIA

*Corresponding author e-mail: srikanta_murthy22@rediffmail.com

ABSTRACT

The coal-bearing sequence of the Barakar Formation exposed in Tapin North open cast mine West Bokaro Coalfield, Jharkhand state is analyzed for miofloral, palynofacies and macrofloral study with the objective to infer the floral composition, palynostratigraphic status and depositional environment of the area. The miofloral study reveals single palynoassemblage, which is characterized by the predominant occurrence of non striate bisaccate *Scheuringipollenites* and striate bisaccate *Faunipollenites* pollen and infers the Artinskian age (late Early Permian) to this stratum. The recovered palynoassemblage shows over all dominance of Glossopteridales (*Scheuringipollenites, Faunipollenites, Striatopodocarpites, Striasulcites* and *Weylandites*) followed by Cordaitales (*Barakarites, Parasaccites, Plicatipollenites, Potonieisporites, Striamonosaccites* and *Caheniasaccites*), Coniferales (*Crescentipollenites, Distriatites, Rhizomaspora* and *Dicappipollenites*), Filicales (*Microfoveolatispora*) and one unidentified megaspore. Besides, the mioflora, a number of *Vertebraria* (root of *Glossopteris* plant) axes are also recorded from the shale intercalation. On the basis of the recovered dispersed organic matter counts, three distinct palynofacies (I-III) have been identified. Palynofacies-I is characterized by the dominance of spore-pollen; Palynofacies-II is demarcated by the abundance of opaque phytoclasts alongwith the high value of the opaque/translucent phytoclast ratio and Palynofacies-III is distinguished by the dominance of opaque phytoclasts with a low value of the opaque/translucent phytoclast ratio. Palynofacies analysis of the whole succession indicates swamp-dominated phase alongwith the intraseam parting of river and lake deposits which diretly corroborates with the palynofloral studies.

Keywords: Barakar Formation, Bokaro Coalfield, Palynofacies, Palynology, Permian, *Vertebraria.*

INTRODUCTION

Damodar Basin is the most important storehouse of the Indian coal, and it spreads in the territory of Jharkhand and West Bengal states of India. The important coalfields in this basin are Raniganj, Jharia, East Bokaro, West Bokaro, Ramgarh, South, and North Karanpura. The Bokaro Coalfield is located in Jharkhand, and it is the chain of the Damodar Valley basins from east to west. The Lugu hill (978.40 m) is the most important landmark of the area that divides the Bokaro basin into two parts viz., East Bokaro and West Bokaro coalfields. The West Bokaro Coalfield, covering an area of 207 km^2 falls in Hazaribagh and Ramgarh districts in the state of Jharkhand (23º 48´ N and 85º 45´ E).

Diversified elements of *Glossopteris* flora have been recorded from these basins, of which the Damodar Basin is significantly explored. However, in comparison to the Raniganj, Jharia, Giridih and Karanpura coalfields, the West Bokaro Coalfield is least explored for its Permian floral diversity. Some of the pioneer palynological study carried out from the West Bokaro Coalfield includes the work of Surange *et al.* (1953a, b) who had reported lycopods megaspore, palynofossils, cuticles and wood pieces from the Pindra coal seam of the Lower Gondwana sediments.

Srivastava (1954) has described four new types of megaspores and one seed from Mangardaha coal. Ghosh (1962) have recovered the dominance of *Callumispora* followed by *Granulatisporites* pollen grains, these resemble the Barakar (late Early Permian) palynomorphs from the Gondwana rocks. Lele (1975) has recorded the early and late Talchir age (Earliest Permian) palynomorphs from the sequence of the Dudhi River section. Anand-Prakash *et al.* (1979) recorded palynotaxa viz. *Callumispora, Microbaculispora* and *Parasaccites* were representing the lower Karharbari and Talchir (Earliest Permian) from the Dudi River section of the West Bokaro Coalfield. Murthy (2017) has assigned the late Permian age to the sediments of Bokaro River section near Danea area. A recent study based on palyno- and megafloral assemblages form this coalfield (Jarangdih coal mine), suggest late Early Permian (Kungurian) age to the Barakar strata and prevalence of moderately warm climate during their deposition (Saxena *et al*., 2019). In addition to these, a few studies pertaining to megafossil remains have also been carried out (Hughes, 1867; Lele, 1966; Surange and Singh, 1951) long back which have reported diverse megafossil assemblages. The remains of *Vertebraria* axes are reported by Lele (1966) and Singh (2000). More recently, a very rich and diverse Glossopterid assemblage (16 *Glossopteris* species) with poor occurrence of *Vertebraia* has been recovered from the Jarandih Coal mine of this coalfield (Saxena *et al*., 2019). Palynofacies analysis is an interdisciplinary approach in which the complete dispersed organic matter is investigated toward palaeoenvironmental reconstruction. Dispersed organic matter is observed as a sedimentary constituent that replicates the original circumstances of the source area and in the depositional setting.

The majority of the palynological studies carried out from the West Bokaro Coalfield either present only palynostratigraphic interpretations or morphotaxonomy regarding biostratigraphic units and their ages or description of the palynoassemblages. But, a precise correlation with their equivalents across the Indian peninsula has hardly been attempted. Similarly, the megafloral studies have also been done in isolation with rare attempts to infer the palaeoenvironmental implications. The main purpose of the present investigation is to carry out floristic analyses, palynofacies, and emphasis on palynological dating of the sediments as well as discuss and highlight its significance to biostratigraphic correlation. Hence, the present work focuses on

Table 1. Generalised stratigraphy of the West Bokaro Coalfield (Raja Rao 1987).

Age	Formation	Lithology	thickness
Recent Jurassic?		Alluvium and Laterite. Basic and ultra basic dykes and sills	----
Upper Triassic	Supra Panchet (Mahadeva?)	Conglomerate, ferruginous sandstone and siltstones.	600 m
Lower Triassic	Panchet	Fine grained sandstone, green shales and red and chocolate coloured shale and clay.	450 m
Upper Permian	Raniganj	Fine grained sandstone, siltstone, carbonaceous and grey shales with thin coal seams.	550 m
Middle Permian	Barren Measures	Carbonaceous shales, grey micaceous shales with ironstones.	300 m
Lower Permian	Barakar	Conglomerate, pebbly sandstones, very coarse grained to fine grained sandstones, grey shales, carbonaceous shales, fire clay and coal seams.	610 m
	Karharbari	Conglomerates, very coarse grained sandstone, carbonaceous at places and thin coal seams.	40-60 m
	Talchir	Diamictie, fine to medium grained greenish and buff coloured sandstones, shales, rhythmites, turbidites etc.	160 m
Precambrian		Granites, gneisses, amphibolities, quartiztes, pegmatites, etc.	

the correlation with the late Early Permian palynoassemblages from other Indian basins. The scope of this paper is to link floristic diversity, palynostratigraphy, palynofacies, and their implications to palaeoenvironmental interpretations.

GENERAL GEOLOGY OF THE STUDY AREA

West Bokaro Coalfield unconformably overlies the Precambrian Basement represented by granitoids and amphibolites. This coalfield represents the early Permian (Talchir, Karharbari and Barakar formations); late Permian (Barren Measures and Raniganj formations); lower Triassic (Panchet Formation) and middle and upper Triassic (Supra Panchet Formation) sequences (Raja Rao, 1987). The generalized stratigraphic sequence is shown in Table 1.

The Talchir beds are well exposed in the western part of the coalfield. Typical section of the Talchir Formation is well exposed in the Dudhi Nala sediments which comprise tillites, conglomerates, sandstones with huge dropstones, turbidites sequence comprising siltstones and shales. The Karharbari sediments are recognized only in the Dudhi Nala section and western part of the coalfield. These sediments are comprised of carbonaceous sandstones, coarse to very coarse-grained sandstones with mottled appearance, shales, and thin coal seams. The Barakar Formation covers a major part of the coalfield and formation is characterised by a thick sequence of conglomeratic sandstone, fine to coarse-grained sandstones, carbonaceous grey shales, fire clay, and coal seams. The Barren Measures strata are exposed along the northern boundary, and it comprises sandstone and shale. The Raniganj beds occur as a narrow strip in the northern part of the field near Basantpur and as a small patch in the middle part of the field. The Raniganj Formation is overlain by a thick sequence of fine-grained, dirty green micaceous sandstones, intercalated with greenish and chocolate coloured shale beds of the Panchet Formation. The Panchet strata are exposed only in the basal part of the Lugu Pahar Hill. The contact of the Panchet beds with underlying the Raniganj beds is seen in the area south of Chorpaiatoli. The youngest strata in this coalfield, the Supra-Panchet Formation, consists of coarse clastics and rests over the Panchet Formation. The composition of this formation is mostly coarse-grained ferruginous sandstones with lenses of pebbles, interbedded within the sandstones and few thin beds of red clays (Raja Rao, 1987).

Tapin North Open Cast Mine (OCM) is situated in the near Tapin Village of Ramgarh District of Jharkhand state and is located between latitude 23º 83' 05" N and longitude 85º 49' 51" E (Figs. 1 and 2). The litho-sequence in the Tapin North OCM comprises sandstone, shale, and coal intercalations (Fig. 3).

MATERIAL AND METHODS

The studied material comprises of twelve samples (TN-1 to TN-12) which were collected from the sedimentary sequence of the Tapin North Open Cast Mine (OCM) which is situated in southern margin of the Tapin Village (Figs. 1 and 2). The succession is approximately 75 m thick, and the lithofacies comprises mainly of sandstone, dark-grey shales, and coal seam (Fig. 3). The samples were taken from the shale and coal intervals only. In addition to these samples, in order to assess the effect of intrusion on the palynomorphs, three coal samples (TN-IT-1, TN-IT-2, and TN-IT-3) were also collected at the same coal seam horizon, at two meter interval distance from the igneous intrusion. For palynological analysis, 100 grams of each sample were taken and crushed (2-4 mm) and treated with 40% Hydrofluoric acid (HF) for 2-4 days to remove the silica content. Thereafter, the samples were washed thoroughly with distilled water to remove the acid content. The resultant residue was treated with 63.01% Nitric acid (HNO_3) to release the palynomorphs from the rest of the organic debris. Five slides were prepared from each residue, and the palynofossils were examined under a standard light microscope (Olympus BX61 with the DP-25 camera using Cell A software). Out of the twelve samples, six yielded pollen-spores which have been used for palynodating of the sequence.

The samples for palynofacies were prepared using the standard non-oxidative palynological procedure (Faegri and Iversen, 1989; Tyson, 1995; Prasad *et al*., 2013). Qualitative and quantitative measures of various types of dispersed organic matter were used for the palaeoclimatic construction of NT beds. The quantitative studies comprised of at least 500 counts of dispersed organic matter particles per sample. However, to attain a better resolution, three to five slides per sample have been studied. Presently studied dispersed organic matter was classified into four major categories (palynomorphs, structured terrestrial phytoclasts, opaque phytoclasts, and biodegraded organic matter) including further minor categories using terminology modified by various researchers (Batten, 1996;

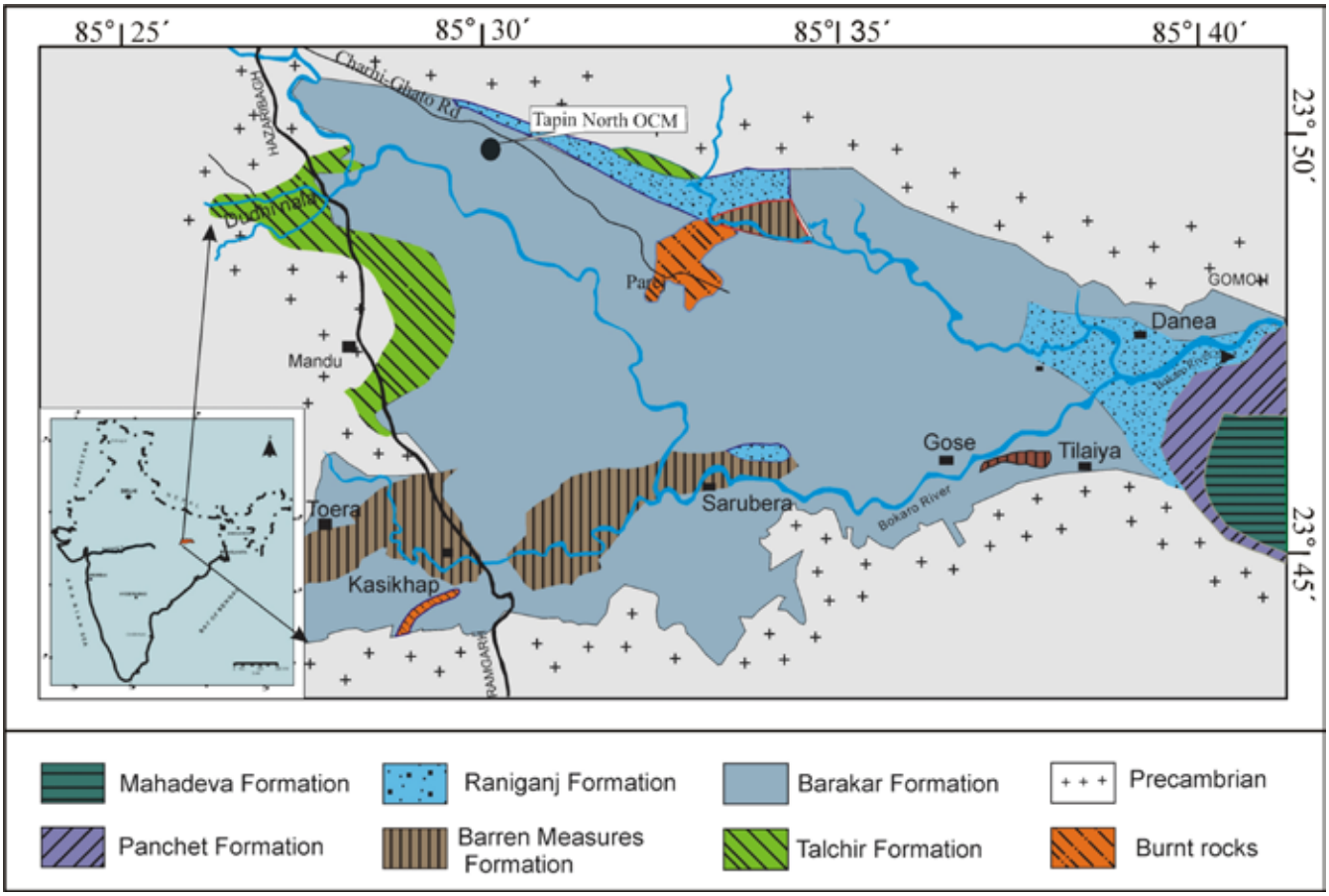

Fig. 1. Geological map of West Bokaro Coalfield showing the location of Tapin North OCM.

Tyson, 1995; Oboh-Ikuenobe and Yepes, 1997; Oboh - Ikuenobe and de Villiers, 2003; Aggarwal *et al.*, 2017). 1. Palynomorphs of our study include mainly gymnospermous pollen grains and scanty presence of spores. 2. Structured terrestrial phytoclast (ST) includes woody tracheids and plant cuticles. 3. Opaque phytoclasts (CH) comprises of all opaque black remains with irregular shape under a light microscope. 4. Biodegraded matter comprises two categories, i) Degraded organic matter (DOM) is formed as a result of bacterial and fungal activities. ii) Amorphous organic matter (AOM) due to fungal and bacterial activities partly degraded organic matter change to entirely brown to orange structureless, porous/spongy, dark or slightly translucent amorphous mass.

The recovered macroflora from this sequence comprises of 12 axes of *Vertebraria indica* (root axes of *Glossopteris* plant) and a wood impression and a stem cast and is devoid of any fossil leaf forms. The *Vertebraria* axes are preserved as impressions on the topmost shale unit of the sequence. Since these specimens were preserved on very large surface area of a big shale unit, they could not be collected from the field, but their photographs were taken in the field itself.

Repository

The palynomorphs documented in this paper are deposited in the repository of the Birbal Sahni Institute of Palaeosciences (BSIP), Lucknow vide Statement No.1506 with Museum slide numbers16407-16411.

RESULTS

Palynological analysis

Out of twelve samples, only six samples (NT-3, 5, 6, 7, 11 and 12) have been used for palynological dating due to the dominance of palynomorphs (Fig. 3). The remaining samples (NT- 1, 2, 4, 8, 9 and 10) comprise dark colours, structure to spindle-shaped plant remains along with sporadic palynotaxa. On the basis of the quantitative and qualitative analysis of recovered palynotaxa, one distinct palynoassemblage has been identified, which is characterized by the predominance of non striate bisaccate and subdominance of striate bisaccates pollen grains (Fig. 4). Some of these palynomorphs are shown in Plate-I. The palynoassemblage has low taxonomical diversity with 16 genera and 26 species (Table 2) belong to Cordaitales (11 taxa), Glossopteridales (10 taxa), Coniferales (4 taxa) and Filicales (1 taxon).

This palynoassemblage is characterized by the dominance of non striate bisaccate *Scheuringipollenites* (29-39%) and subdominance of striate bisaccate *Faunipollenites* (19-26%) along with monosaccate mainly *Parasaccites* (14-21%) pollen. The other palynotaxa includes in this palynoassemblage are represented by: monosaccate - *Barakarites* (7-14%), *Potonieisporites* (0-3%), *Plicatipollenites* (0-2%), *Striomonosaccites* (0-3%) and *Caheniasaccites* (0-2%); striate bisaccates - *Striatopodocarpites* (0-5%), *Rhizomaspora* (2-5%), *Crescentipollenites* (0-4%) and *Distriatites* (0-2%); taeniate –

Fig. 2. Field photographs showing the overview and section of Tapin North OCM . 1. Overview of the coal mine. 2. Photograph of a part of the section. 3, 4. Photographs of igneous intrusion.

Dicappipollenites (0-2%); sulcate - *Weylandites* (0-4) and trilete spore - *Microfoveolatispora* (0-2%).

The palynocomposition recovered from the Tapin North OCM (Open Cast Mine) section of the West Bokaro Coalfield is well correlated with the *Scheuringipollenites barakarensis* palynoassemblage zone (zone V) of the lower Barakar Formation of the Damodar Basin (Tiwari and Tripathi, 1992). A comparison of this palynoassemblage with other previous known palynological assemblage in Indian Gondwana also indicates an early Permian (Artinskian) age.

Palynocorrelation

Present *Scheuringipollenites barakarensis* palynoassemblage zone is comparable with known from the early Permian Barakar Formation (lower part) of the Raniganj Coalfield of Damodar Basin (Palynoassemblage II of Borehole

EXPLANATION OF PLATE I

Fig. 1. ***Microfoveolatispora*** sp., Fig. 2. Unidentified megaspore, Fig. 3. ***Parasaccites obscurus*** Tiwari, 1965, Fig. 4. ***Parasaccites bilateralis*** Tiwari, 1965, Fig. 5. ***Plicatipollenites gondwanensis*** (Balme and Henn.) Lele, 1964, Fig. 6. ***Plicatipollenites indicus*** Lele, 1964, Fig. 7. ***Barakarites indicus*** Bharadwaj and Tiwari, 1964, Fig. 8. ***Barakarites decorus*** Tiwari, 1965, Fig. 9. ***Barakarites implicatus*** Tiwari, 1965, Fig. 10. ***Striomonosaccites circularis,*** Fig. 11. ***Striasulcites*** sp., Fig. 12. ***Weylandites magnus*** (Bose and Kar) Backhouse, 1991, Fig. 13. ***Weylandites*** sp., Fig. 14. ***Scheuringipollenites barakarensis*** Tiwari, 1973, Fig. 15. ***Scheuringipollenites maximus*** Tiwari, 1973, Fig. 16. ***Scheuringipollenites tentulus*** Tiwari, 1973, Fig. 17. ***Dicappipollenites singrauliensis*** (Sinha) Tiwari and Vijaya, 1995, Fig. 18. ***Potonieisporites magnus*** Lele and Karim, 1971, Fig. 19. ***Rhizomaspora indica*** Tiwari, 1965, Fig. 20. ***Faunipollenites varius*** Bharadwaj, 1962, Fig. 21. ***Striatopodocarpites circularis*** Sinha, 1972, Fig. 22. ***Crescentipollenites fuscus*** (Bharadwaj) Bharadwaj, Tiwari and Kar, 1974.

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Plate I

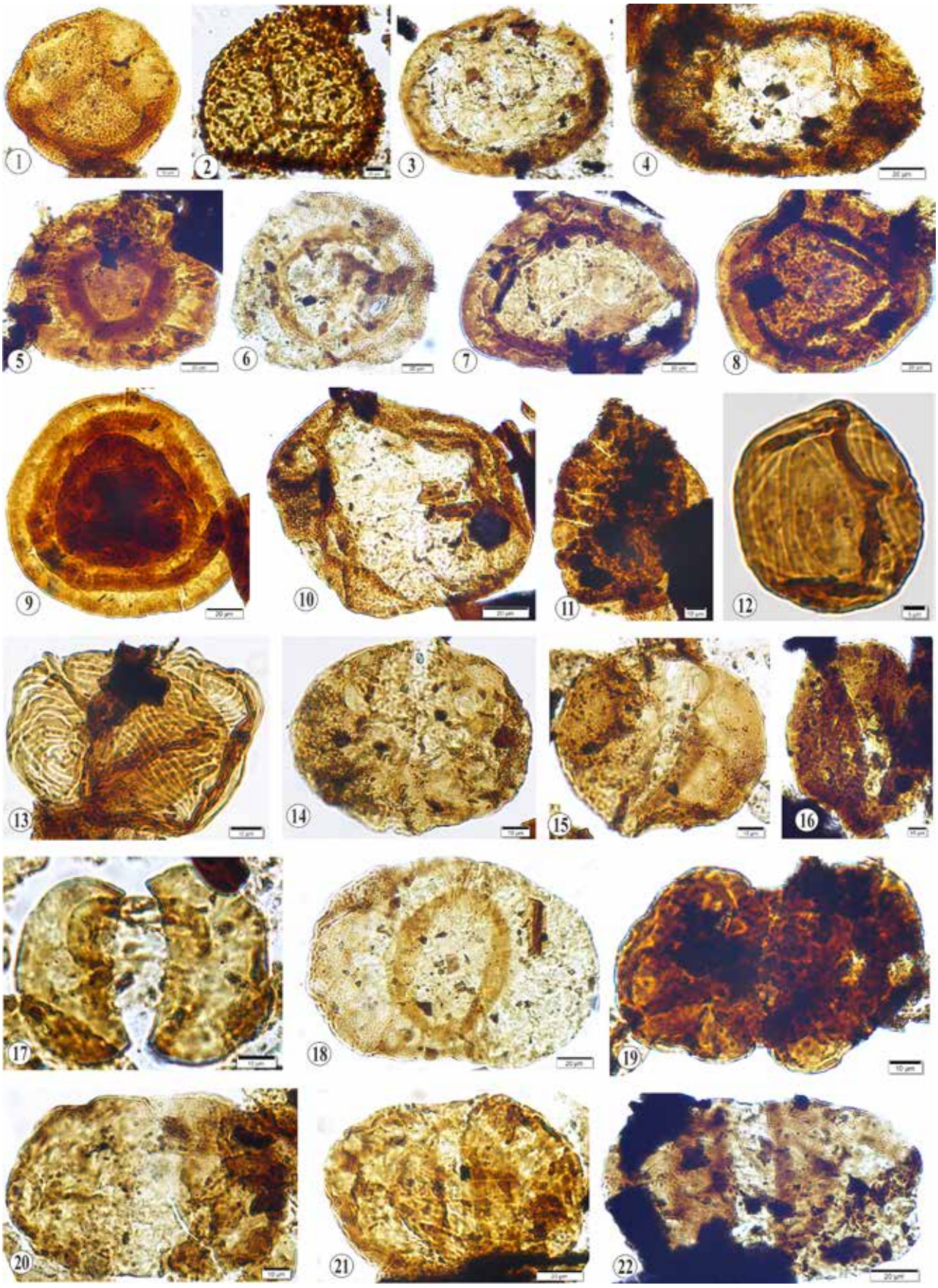

Table 2. List of taxa recorded at Tapin North OCM sequence of West Bokaro Coalfield, Damodar Basin (Balme,1995; Gould and Delevoryas, 1977; Lindström and McLoughlin, 2007; Jha and Aggarwal, 2015).

Palynotaxa identified in the present study	Botanical Affinity
Microfoveolatispora sp.	Filicales
Barakarites indicus	Cordaitales
Barakarites decorus	Cordaitales
Barakarites implicatus	Cordaitales
Parasaccites obscurus	Cordaitales
Parasaccites ovatus	Cordaitales
Parasaccites bilateralis	Cordaitales
Plicatipollenites gondwanensis	Cordaitales
Plicatipollenites indicus	Cordaitales
Potonieisporites magnus	Cordaitales
Striomonosaccites circularis	Cordaitales
Caheniasaccites distinctus	Cordaitales
Crescentipollenites fuscus	Coniferales
Distriatites sp.	Coniferales
Rhizomaspora indica	Coniferales
Dicappipollenites singrauliensis	Coniferales
Faunipollenites varius	Glossopteridales
Faunipollenites sigrauliensis	Glossopteridales
Striatopodocarpites subcircularis	Glossopteridales
Striatopodocarpites magnificus	Glossopteridales
Striasulcites sp.	Glossopteridales
Scheuringipollenites barakarensis	Glossopteridales
Scheuringipollenites maximus	Glossopteridales
Scheuringipollenites tentulus	Glossopteridales
Weylandites simplex	Glossopteridales
Weylandites sp.	Glossopteridales
Megaspore unidentified	

RT-4, (Murthy *et al*., 2010) in having *Scheuringipollenites barakarensis, Faunipollenites varius*, *Barakarites indicus*, *Rhizomaspora indica,* and *Striomonosaccites* sp. It also shows its equivalence 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*, *Weylandites* sp. and *Parasccites obscurus*.

The palynoassemblage recorded herein, is 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*, *Caheniasaccites*, *Barakarites*, *Striatopodocarpites*, *Rhizomaspora* and trilete spore *Microfoveolatispora.* The present assemblage is also akin 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

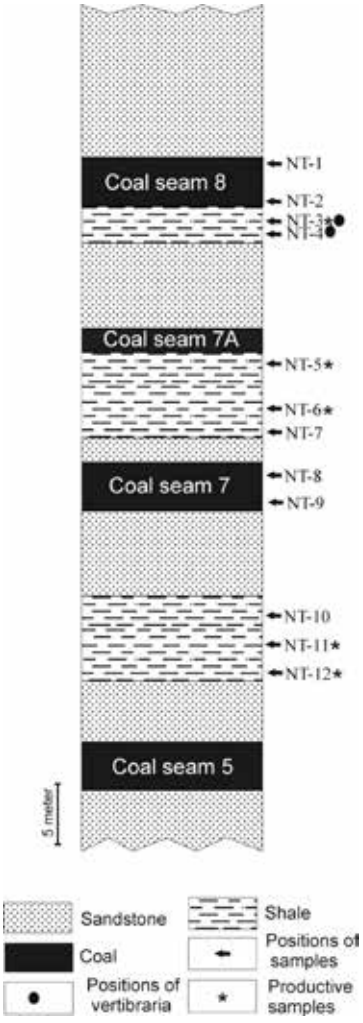

Fig. 3. Litholog showing sequence of Tapin North OCM, West Bokaro Coalfield and the position of samples. * indicates the samples yielding pollen and spores.

Majri Open Cast Mine (Mahesh *et al.,* 2014) of Wardha Valley Coalfield, and the borecore MBG–23 of Gokul block of the Bandar Coalfield **(**Pauline *et al.,* 2007) in presence of the palynotaxa *Scheuringipollenites–Faunipollenites* complex as along with *Plicatipollenites, Potonieisporites*, *Caheniasaccites*, *Barakarites*, *Striatopodocarpites, Rhizomaspora, Weylandites* and *Microfoveolatispora*.

The palynoassemblage-II of borecore SMJS-2 (Vijaya *et al*., 2012) and palynoassemblage-III of Jhingurdah bottom coal seam (Singh *et al*., 2017) from the Singrauli Coalfield, Son-Mahanadi Basin, central India is also closely correlated with the presently studied palynoassemblage in having the palynotaxa such as *Scheuringipollenites* spp., *Faunipollenites* spp., *Striatopodocarpites* spp., *Crescentipollenites fuscus*, *Barakarites indicus*, *Dicappipollenites singrauliensis*, *Rhizomaspora indica, Striomonosaccites* sp., *Parasaccites* spp. and *Microfoveolatispora* sp.

EXPLANATION OF PLATE II

Microphotographs of palynomorphs. Figs. 1, 2. Palynomorphs liberated from (sample TN-3) unaffected shale and coal: palynomorphs along with cuticle and tracheids are clear, Figs. 3, 4. organic matter derived from (sample no. TN-IT-1, very close to igneous intrusion) intrusion affected coal, Figs. 5, 6. Palynomorphs derived from (samples TN-IT-2, TN-IT-3) intrusion affected coal, distinct charred effect can be seen.

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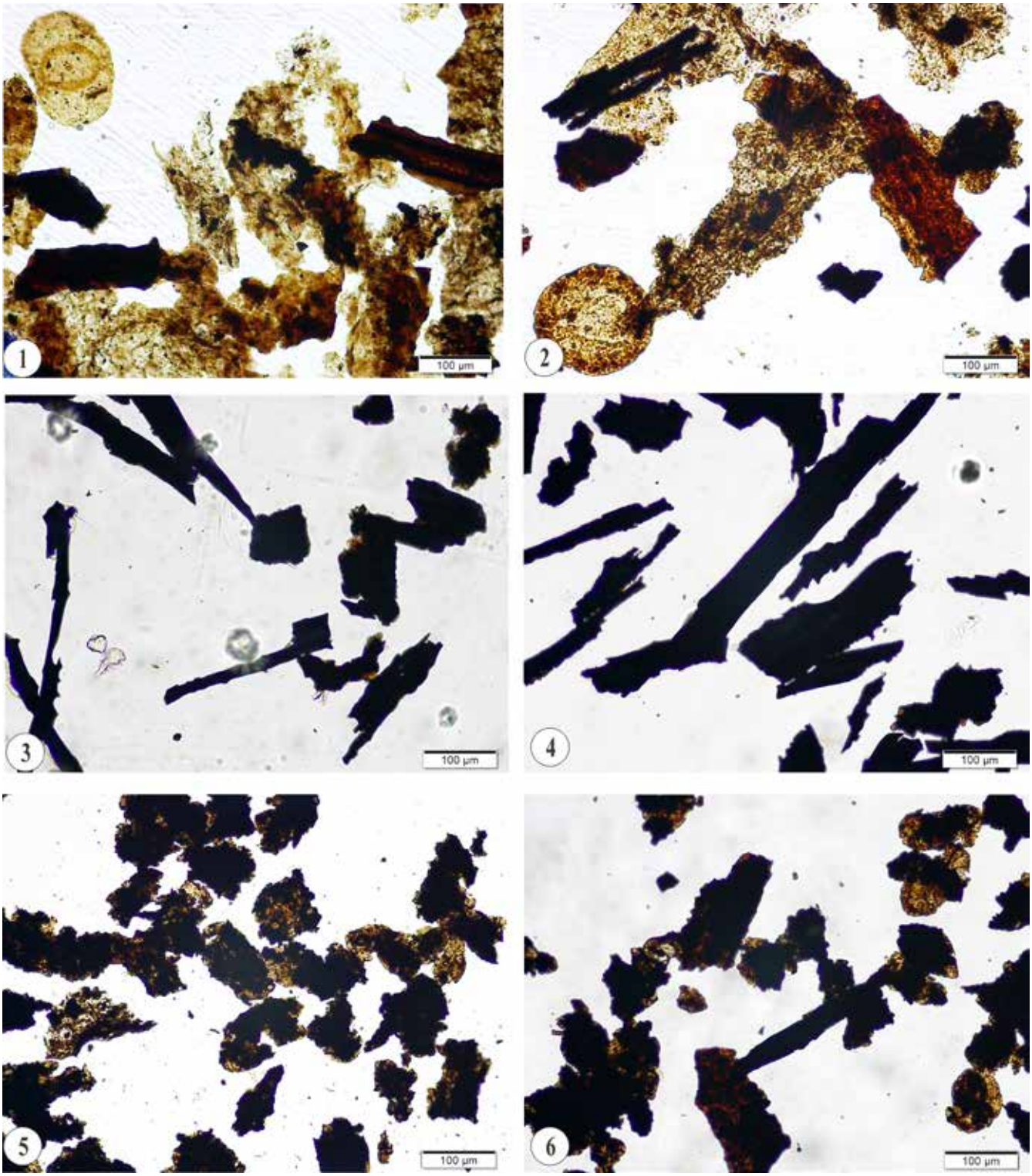
Plate II



This palynoassemblage also show its resemblance with the early Permian Barakar palynoassemblages of Godavari Valley Basin viz., palynozone- 4 of Lingala- Koyagudem coalbelt (Aggarwal and Jha, 2013); Palynoassemblage-4 of Chinatalapudi sub-basin (Jha *et al*., 2018); 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) and Palynozone-3 (borecores CAM-6 and CAM-8) of Mailaram area (Jha and Aggarwal, 2012). These palynoassemblage comprises similar palynotaxa with present palynoassemblage such as *Scheuringipollenites* spp., *Faunipollenites* spp., along with *Striatopodocarpites* spp., *Crescentipollenites*, *Parasaccites, Barakarites, Plicatipollenites*, *Potonieisporites, Caheniasaccites* and *Microfoveolatispora*.

In addition to the floristics and palynofacies observations, an igneous intrusion in the form of the dyke is also noticed in the southern side of the mine, cutting through the sequence of sandstone, shale, and coal seams. Near the igneous intrusion, three coal samples (TN-IT-1 to TN-IT-3) were collected to assess the affect of heat on palynomorphs, tracheids and other structures in the sediments. The palynomorphs, tracheids, and cuticles recovered from these three samples are darker and opaque showing distinct burn/charring effect of thermal alteration (Plate II, figs. 3-6). The obvious effect of heat can be seen in samples TN-IT-1 which is nearest to the intrusive, comprising only tracheids which are completely opaque. The palynomorphs in the samples TN-IT-2 and TN-IT-3 are dark, blackish brown in colour and phytoclasts are almost opaque with translucent edges or borders (Plate II, figs. 3-6). The palynomorphs, another structured recovered from the samples collected from the sequence (Fig. 2) are well preserved and are light brown to dark brown in colour with clearly visible internal structures in comparison to the palynomorphs recovered from the samples near to the igneous intrusion (Plate I).

Palynofacies analysis

On the basis of the recovered dispersed organic matter counts, three distinct palynofacies have been identified (Fig. 5, Plate III).

Palynofacies-I

This palynofacies is distinguished by well preserved palynomorphs (range 5.9-26%, avg. 17.37%) in the low energy environment (carbonaceous shale, Fig. 3). The overall decrease in energy level is distinguished by increase of translucent material (range 20-68%, avg. 39.6%) including structured organic matter (range 3-19%, avg. 8.33%), degraded organic matter (range 12-48.5%, avg. 30.72%) and AOM (range 0-2.%, avg. 0.6%) along with decrease in the opaque phytoclast (range 16-65%, avg. 43%). This palynofacies has the majority of occurrence in succession and has been documented in sample nos. NT 3-7 and NT11-12.

Palynofacies-II

This palynofacies has been observed in three samples (1, 8, 10) of the succession and composed of coal and carbonaceous shale (Fig. 5). This palynofacies is characterized by the abundance of opaque phytoclasts (range 91-95%, avg. 94%) and a high value of the opaque/translucent ratio (23.91%). Other faintly present constituents of this palynofacies are structured terrestrial (range 0-2.9%, avg. 1.3%), degraded organic matter (range 1.7-2.5%, avg. 2.1%), and AOM (range 0-1.5%, avg. 0.5%). This palynofacies represents very poor preservation of the palynomorphs (range 0.6-3.5%, avg. 1.9%).

Palynofacies-III

This palynofacies has been documented in two samples (2, 9) of the succession and composed of coal only (Fig. 5). It is characterized by the abundance of opaque phytoclast (range 77-80% avg. 78%) and a low value of the opaque/translucent ratio (4.23). Other constituents of this palynofacies are structured terrestrial (range 1.8-22%, avg. 11.5%), degraded organic matter (range 0.25-13%, avg. 6.84%), and AOM (range 0-0.8%, avg. 0.4%). This palynofacies also represents very poor preservation of the palynomorphs (range 0.5-3.2%, avg. 1.8%).

Macrofloral Observations: The macrofloral assemblage comprises 12 axes of *Vertebraria indica*, a wood impression, and a stem cast. These axes are found on the lateral extension of topmost shale band of the sequence and are preserved as impressions (Plate IV). These axes are generally characterized as an elongate, branched or unbranched axes with two or more longitudinal series of rectangular areas. Most of the axes preserved are biseriate. One specimen (Plate IV, fig. 5) shows the definite branching. The specimens are 20 to 78 cm long, and 3 to 10 cm wide. The preserved stem cast is 68 cm long and 11.8 cm wide. The specimens do not exhibit any preferred orientation and seem to be randomly preserved. Therefore, it can be inferred that these are drifted ones.

DISCUSSION

Floristic Diversity and Palynodating

The available palynological data from the deposits of the early Permian Barakar Formation exhibits that the composition of the palynoassemblage analyzed herein is relatively homogeneous in the studied section. The palynological and palaeobotanical analyses have been carried out to assess the age and floral diversity for deposition of the Barakar strata in the West Bokaro Coalfield. The complete 75 m deep sedimentary sequence represents only one palynoassemblage which is dominated by non striate bisaccate pollen grain *Scheuringipollenites* and sub dominance of striate bisaccate mainly *Faunipollenites*. The statistical analyses of the studied sequence reveal that the pollen grains are predominant over trilete spores. The qualitative analyses of palynotaxa of the present study show over all dominance of Glossoptridales elements in this palynoassemblage, representing 2 species of each *Faunipollenites* and *Striatopodocarpites*, 3 species of *Scheuringipollenites*, 2 species of *Weylandites* and

EXPLANATION OF PLATE III

Fig. 1. Palynofacies recovered from a sequence of Tapin North OCM. Palynomorphs along with opaque phytoclast, NT-5, 1, H46-4, Fig. 2. Structured terrestrial phytoclast (wood) with other types of organic matter (opaque phytoclast and degraded organic matter), NT-5, 1, Q19, Fig. 3. Amorphous organic matter along with opaque phytoclast, NT-4, A, G37-4, Fig. 4. Palynomorphs alongwith opaque phytoclast and degraded organic matter, NT-4, A, R-43, Fig. 5. Monosaccate palynomorph, NT-4, A, X38-4, Fig. 6. Degraded organic matter alongwith opaque phytoclast NT-4, B, F33-3.

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Plate III

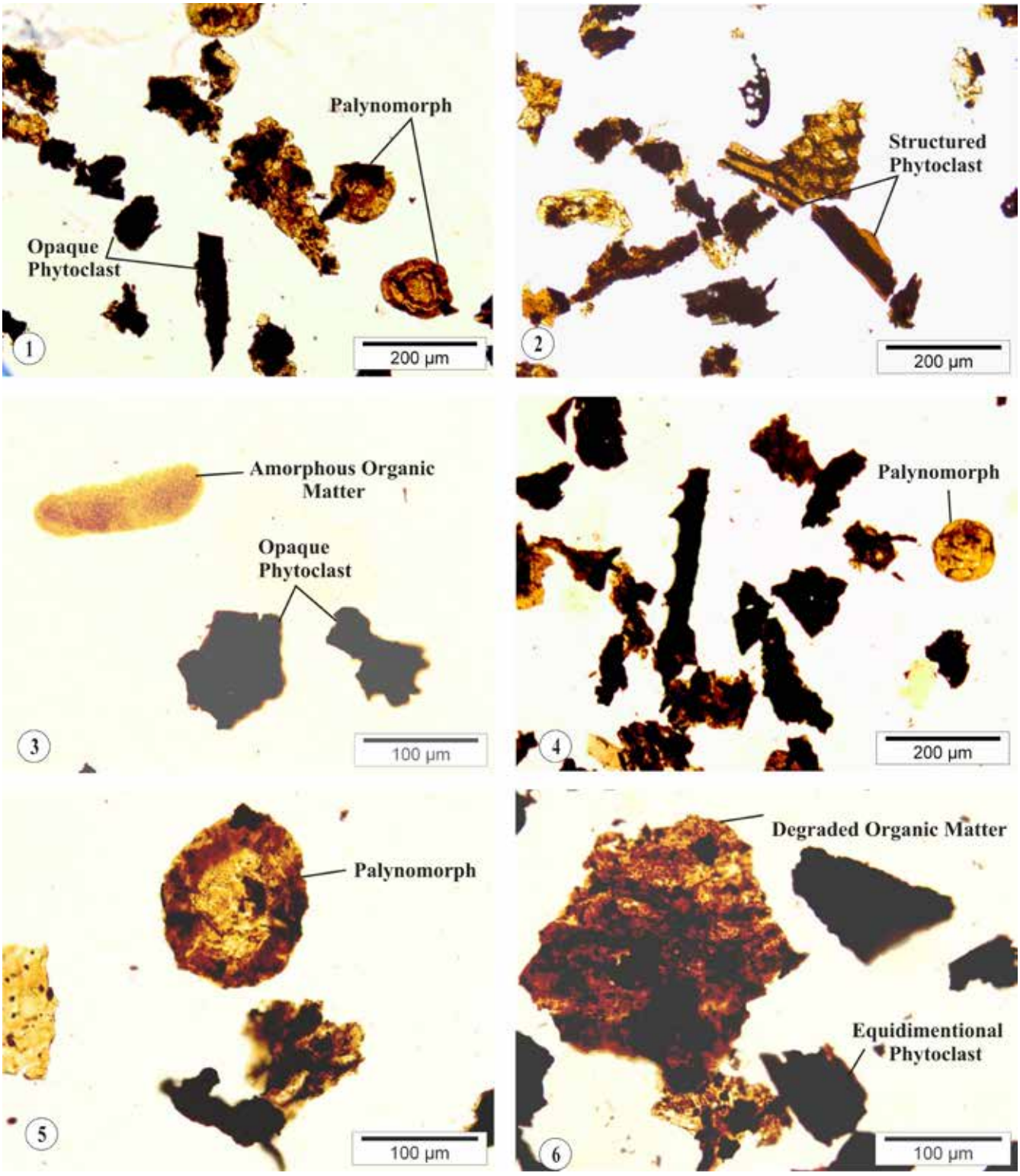
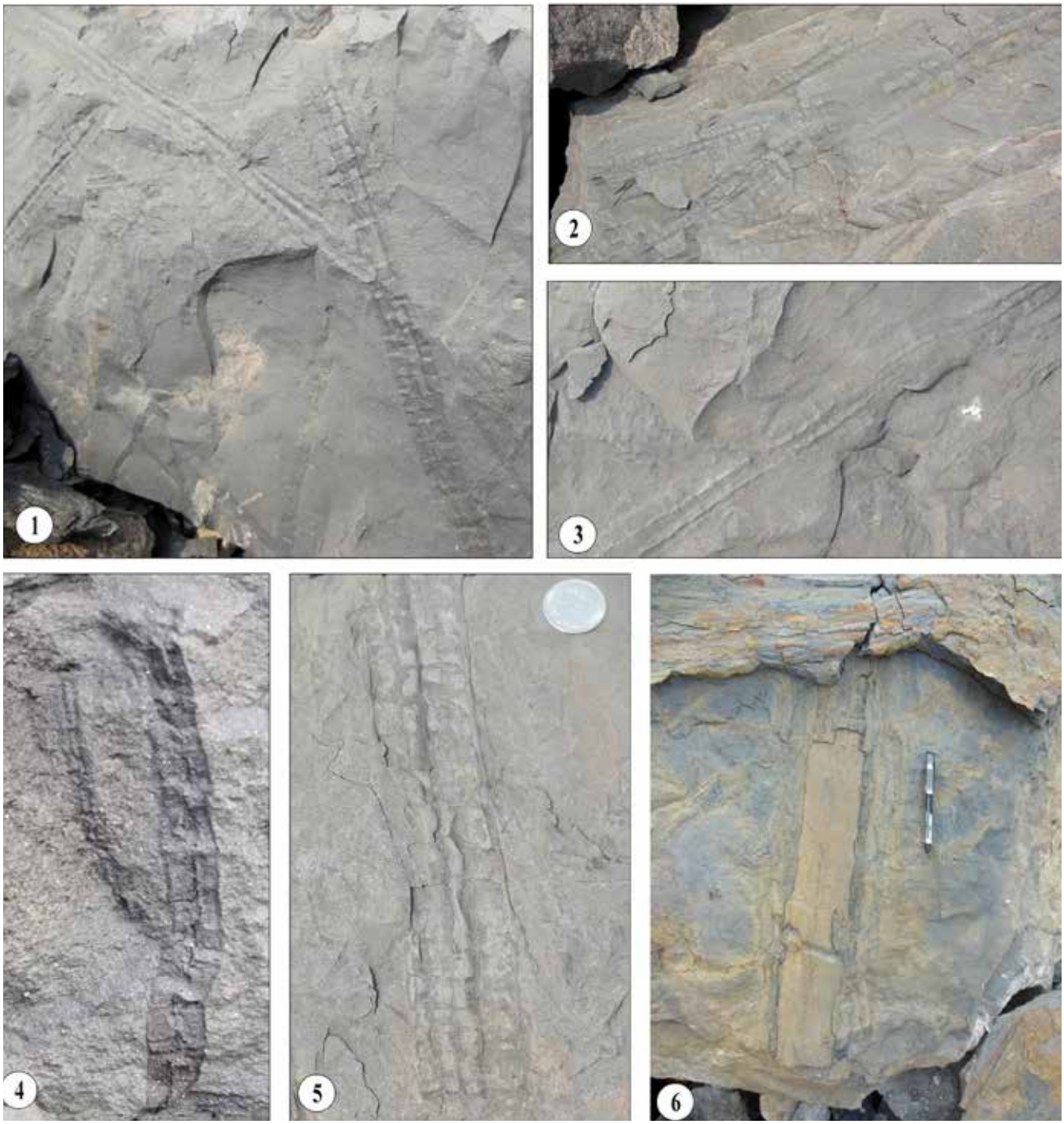


Plate IV



EXPLANATION OF PLATE IV

Field photographs of ***Veretebraria*** axes (roots of the Glossopterid plant). Figs.1, 2, 3 and 5. ***Vertebraria*** axes with biseriate rectangular areas, axes arranged in haphazard pattern, Fig. 4. Branching in ***Vertebraria*** root, Fig. 6. Stem cast.

1 species of *Striasulcites*. The rest of the palynoassemblage belongs to Cordaitales (3 species each of *Barakarites* and *Parasaccites*, 2 species of *Plicatipollenites* and 1 species each of *Potonieisporites*, *Striomonosaccites,* and *Caheniasaccites*); Conifers (1 species each of *Crescentipollenites*, *Distriatites*, *Rhizomaspora,* and *Dicappipollenites*) and only one species of *Microfoveolatispora* that belongs to Filicales.

In the Damodar Basin, Tiwari and Tripathi (1992) presented a palynostratigraphic Zonation for the Permian sequences based on consecutive assemblage zones defined by the first and last consistent occurrence of key taxa. Six palynoassemblage zones (I-VI) are established in the early Permian, namely the

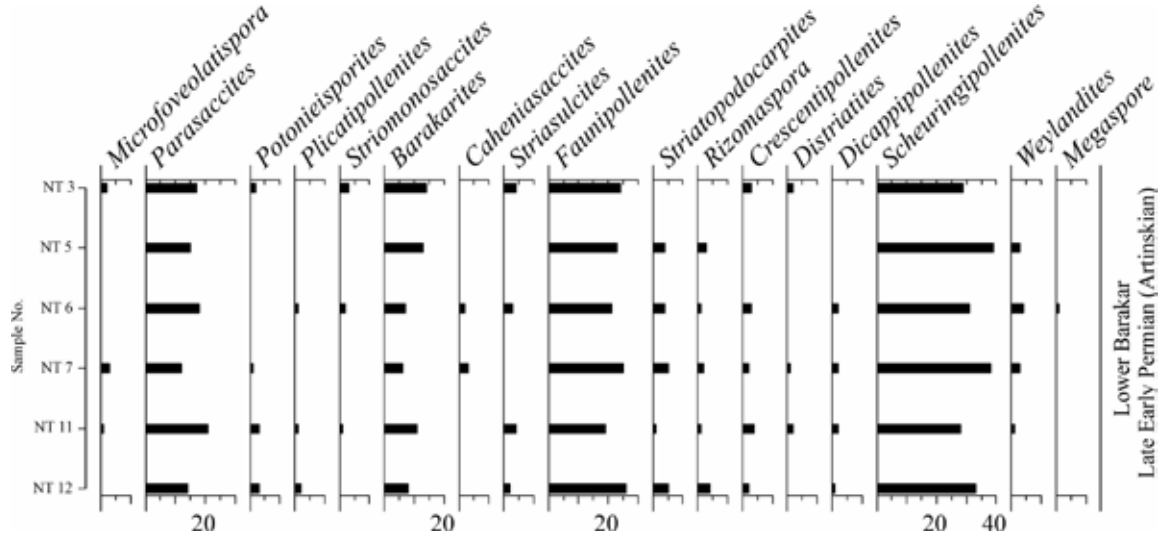


Fig. 4. Frequency chart showing the distribution of palynotaxa in the Tapin North OCM, West Bokaro Coalfield.

Potonieisporites neglectus zone, *Plicatipollenites gondwanensis* zone and the *Parasaccites korbaensis* zone, *Crucisaccites monoletes* Zone, *Scheuringipollenites barakarensis* zone and *Faunipollenites varius* zone. Zone I-III belongs to the Talchir Formation, Zone-IV belongs to the Karharbari Formation, and Zone V-VI belongs to the Barakar Formation. The palynologically studied sequence equates with *Scheuringipollenites barakarensis Assemblage* zone–V, belonging to the lower part of the Barakar Formation, which is of the late Early Permian (Tiwari and Tripathi, 1992). The overall palynotaxa recorded from the Tapin North OCM, West Bokaro Coalfield correlates well with the palynoassemblages of the lower Barakar Formation described from the most of the coalfields of Peninsular India. Thus, the studied sequence is palynologically dated as the early Permian (Artinskian) in age.

In terms of the occurrence of megafloral assemblage, the outcrop of the studied sequence has yielded a poor assemblage in the form of *Vertebraria* roots only and a complete absence of leaf forms and seeds. In the Peninsular Gondwana records, it is a general observation that the genus *Vertebraria* is either absent or, if present, it is less common in the beds where prolific numbers of *Glossopteris* leaves are found (Goswami *et al.,* 2006). However, there are few records where such roots have been recorded in abundance in association with the *Glossopteris* leaves (Singh and Saxena, 2015; Singh *et al.,* 2016). In general, it has been found that the coal beds rest on a bed of carbonaceous clay, or sheet earth and this floor bed is often characterized by the root beds (*Vertebraria* in case of the Gondwana coal) and sometimes with fossil leaves of Glossopteridales or other plants (Fox, 1931; Schopf, 1982; Srivastava, 1995; Banerjee, 2005; Singh *et al*., 2016). The occurrence of horizontally preserved (parallel to the bedding plane) and randomly arranged root axes in the shale bed beneath the topmost coal seam of this sequence indicate their drifted nature and allocthonous origin of the coal.

Palaeoenvironment

In the Palynofacies-I, the presence of a significant amount of degraded organic matter and a low ratio of opaque/ translucent phytoclasts (Fig. 5) suggests the low rate of sedimentation (Carvalho *et al*., 2013). Presence of good diversity of palynomorphs including glossopterids and conifers alongwith scanty presence of spores (Fig. 4) and a low ratio of equidimensional/lath phytoclasts represent low water level and proximal deposition in high sedimentation rate for this palynofacies. Thus Palynofacies-I has been deposited in oxidized swamps dominated environments (Mendonça Filho *et al*., 2011, Wheeler and Götz, 2016) with a high rate of sedimentation in low energy settings.

In Palynofacies-II higher ratio of equidimensional/lath phytoclast (6.66) along with high ratio of opaque/translucent phytoclast (23.91, Fig. 5) represents the deposition of the sediments in distal settings probably occurred due to repeated cycles of the deposition alongwith the long transportation (Wheeler and Götz, 2016; Batten and Stead, 2005; Tyson, 1995). Opaque phytoclasts are the results of the semi-oxygenated to oxygenated environmental conditions of woody material in elevated or normal temperatures (Cincotta *et al.,* 2015). In the palynological slides, opaque fragments (elongated/sharp) appear mainly highly corroded homogeneous, and often break up into smaller particles during transportation. The high value of the opaque phytoclasts represents oxic environment and its deposition by fluvio-deltaic sources (Ercegovac and Kostic, 2006). Highly oxidizing conditions resulted in the dilution of other types of the organic matter like degraded organic matter, structured organic matter and AOM thus this palynofacies has been deposited in oxic environment with relatively high energy level (Wheeler and Götz, 2017). The results suggest the interpretation of extensive river dominated phase for this palynofacies in which coal deposition occurs.

In Palynofacies-III low ratio of equidimensional/lath phytoclast (0.41) and the moderate presence of transluscent organic matter (range 16.12-22.2%, avg.19.2%) including structured organic matter and degraded organic matter along with high abundance of opaque phytoclast (78.92%) suggests proximal post-depositional oxidation of the sediments in low energy settings (Wheeler and Götz, 2016). Thus this palynofacies is deposited under oxic conditions with dominant lake depositional phase.

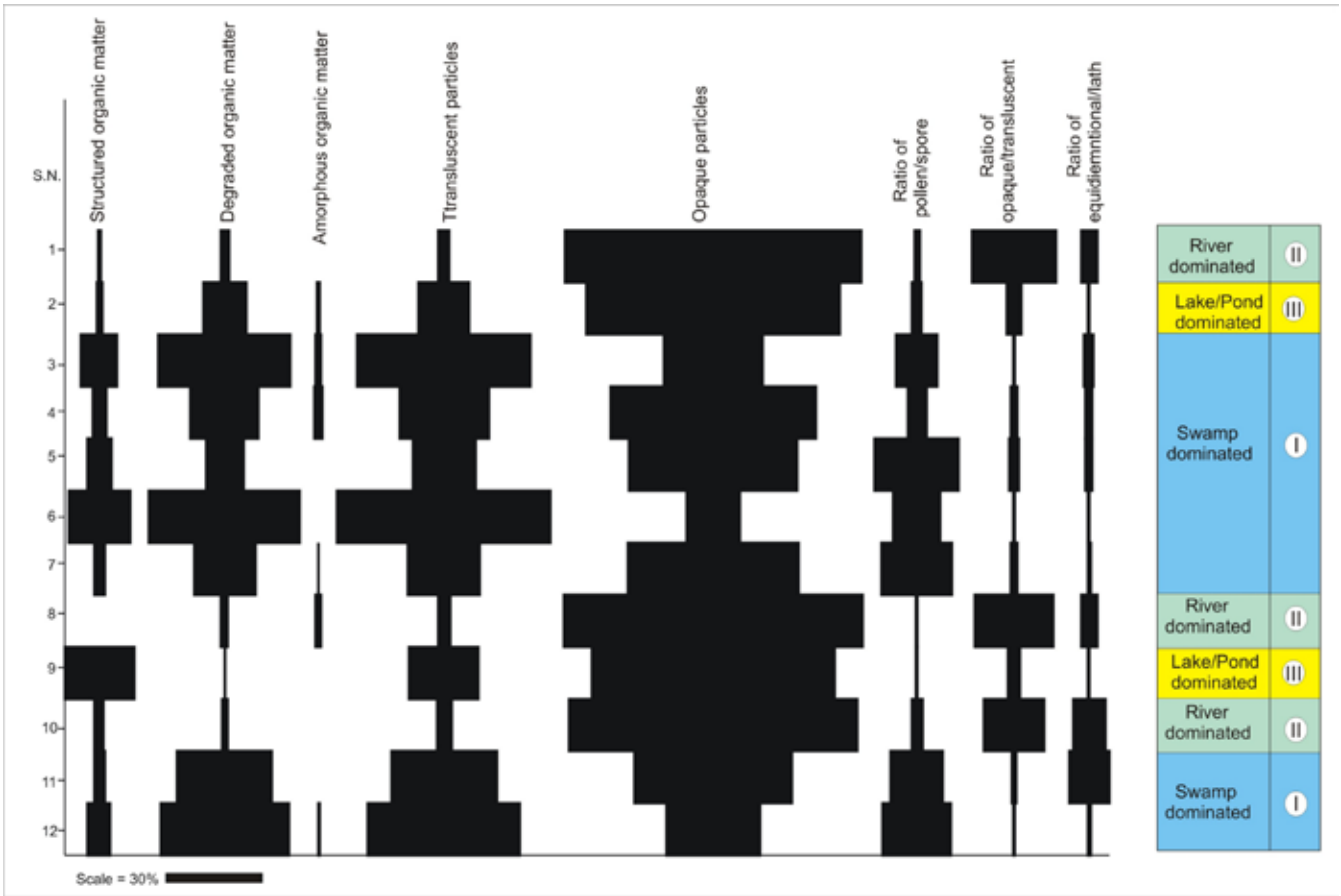


Fig. 5. Palynofacies distribution in the sequence of Tapin North OCM, alongwith inferred depositional environments.

CONCLUSIONS

The palynofloral assemblage recorded in the present study indicates an age equivalent to the early Permian Barakar Formation (Artinskian) to the strata of Tapin North OCP.

On an average, palynofacies analysis of the whole succession indicates swamp-dominated phase alongwith the intraseam parting of deposited coal sequence due to riverine and lacustrine phases.

The occurrence of horizontally preserved dispersed *Vertebraria* axes indicates allocthonous deposition of the coal sequence.

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REFERENCES

Agashe, S. N. and Chitnis, S. R. 1970. Palynological investigation of coal seams of Lower Gondwana strata from Maharashtra, India–A preliminary report. *Palynological Bulletin*, **6**: 6–9.

Agashe, S. N. and Chitnis, S. R. 1972. Palaeopalynology of a Permian coal seam from the Hindustan Lalpeth Colliery, Chandrapur District, Maharashtra, India, pp. 21–29. In: *Proceedings of Seminar on Palaeopalynology Indian Stratigraphy* (Eds. Ghosh A. K. *et al.*), Calcutta.

Aggarwal, N. and Jha, N. 2013. Permian palynostratigraphy and palaeoclimate of Lingala-Koyagudem Coalbelt, Godavari Graben, Andhra Pradesh, India. *Journal of Asian Earth Sciences*, **64**: 38-57.

Aggarwal, N., Jha, N., Jayasena, H. A. H. and Weerakoon, W. A. P. 2017. Palynofacies of Gondwana sediments of Godavari sub basin: Implications for the palaeoenvironment of continental source. *Geophytology*, **47**: 49–57.

Anand-Prakash, Srivastava, S. C. and Tiwari, R. S. 1979. The nature of groove pavement and palynology of overlying Talchir and Karharbari sediments in West Bokaro Coalfield, Bihar, India. *Palaeobotanist,* **26**(1): 63–71.

Balme, B. E. 1995. Fossil in situ spores and pollen grains: an annotated catalog. *Review of Palaeobotany and Palynology,* **87**: 81–323.

Banerjee, M. 2005. Autochthonous deposition of Indian coal beds with palaeobotanical evidences of *in situ* plants from Saharjuri Basin, Jharkhand. *Current Sciences*, **88**(9): 1487–1490.

Batten, D. J. 1996. Palynofacies and palaeoenvironmental interpretation, pp. 1011–1064. In: Palynology: principles and applications (Eds. Jansonius, J. and McGregor, D. C.), American Association of Stratigraphic Palynologists Foundation, **3**.

Batten, D. J. and Stead, D. T. 2005. Palynofacies Analysis and its Stratigraphic Application, pp. 203–226. In: Applied Stratigraphy (Ed. Koutsoukos, E.A.M.), Springer Netherlands, Dordrecht.

Bhattacharyya, A. P. 1997. Palynological recognition of the Karharbari–Barakar Formation in the sub–surface sediments of Wardha Coalfield, Maharashtra, India. *Palaeobotanist,* **46**: 217–219.

Carvalho, M. D. A., Ramos, R. R. C., Crud, M. B., Witovsik, L., Kellner, A. W., Silva, H. D. P., Grillo, O. N., Riff, D. and Romano, P. S.

2013. Palynofacies as indicators of palaeoenvironmental changes in a Cretaceous succession from the Larsen Basin, James Ross Island, Antarctica. *Sedimentary Geology*, **295**: 53–66.

Cincotta, A., Yans, J., Godefroit, P., Garcia, G., Dejax, J., Benammi, M., Amico, S. and Valentin, X. 2015. Integrated Paleoenvironmental Reconstruction and Taphonomy of a Unique Upper Cretaceous Vertebrate-Bearing Locality (Velaux, Southeastern France). *PLoS One,* **10**(8): 1-20.

Ercegovac, M. and Kostic, A. 2006. Organic facies and palynofacies: nomenclature, classification and applicability for petroleum source rock evaluation. *International Journal of the Coal Geology*, **68**: 70–78.

Faegri, K. and Iversen, J. 1989. Textbook of pollen analysis (fourth edition). New York: Wiley.

Fox, C. S. 1931. Coal in India II. The Gondwana System related formations. *Memoir Geological Survey f India*, **58**: 1–241.

Ghosh, T. K. 1962. Study of the Gondwana rocks with notes on the coal and fireclay deposits of Kuju, West Bokaro Coalfield, District Hazaribagh, Bihar. *Quarterly Journal of the Geological Mining and Metallurgical Society of India,* **34**(2–3): 57–73.

Goswami, S., Singh, K. J. and Chandra, S. 2006. Pteridophytes from the Lower Gondwana Formations of IB-River Coalfield, Orissa and their diversity and distribution in the Permian of India. *Journal of Asian Earth System Science,* **28**: 234-250.

Gould, R. E. and Delevoryas, T. 1977. The biology of Glossopteris: evidence from petrified seed-bearing and pollen-bearing organs. *Alcheringa*, **1**: 87–399.

Hughes, T. W. H. 1867. The Bokaro Coalfield. *Memoir Geological Survey of India*, **6**(2): 1-70.

Jha, N. and Aggarwal, N. 2012. Permian-Triassic palynostratigraphy in Mailaram area, Godavari Graben, Andhra Pradesh, India. *Journal of Earth System Science*, **121**:1257-1285.

Jha, N. and Aggarwal, N. 2015. Peat-forming environment of coal-bearing Permian sediments in Kachinapalli area of Godavari Graben, India. *Revista Brasileria De Paleontologia,* **18** (2): 239–250.

Jha, N., Aggarwal, N. and Mishra, S. 2018. A review of the palynostratigraphy of Gondwana sediments from the Godavari Graben, India: Global comparison and correlation of the Permian- Triassic palynoflora. *Journal of Asian Earth Sciences,* **163**: 1–21.

Jha, N., Pauline Sabina, K., Tewari, R. and Mehrotra, N. C. 2011. Palynological dating and correlation of surface and subsurface sediments from Wardha Valley Coalfield, Maharashtra. *Journal of the Geological Society of India,* **77**: 137–148.

Lele, K. M. 1966. Studies in Talchir flora of India-4. Quest for the early traces and subsequent development of the Glossoptris flora in the Talchir stage, pp. 85-97. In: Symposium on floristics and stratigraphy of Gondwana. Lucknow: Birbal Sahni Institute of Palaeobotany.

Lele, K. M. 1975. Studies in the Talchir flora of India–10. Early and Late Talchir miofloras from the West Bokaro Coalfield, Bihar. *Palaeobotanist*, **22**(3): 219–235.

Lindström, S. and McLoughlin, S. 2007. Synchronous palynofloristic extinction and recovery after the end-Permian event in the Prince Charles Mountains, Antarctica: implications for palynofloristic turnover across Gondwana. *Review of Palaeobotany and Palynology,* **145**: 89–122.

Mahesh, S., Pauline Sabina, K. and Bilwa, M. L. 2008. Permian palynomorphs from the subsurface sediments of lower Gondwana of Wardha Valley Coalfield, Maharashtra, India. *Gondwana Geological Magazine*, **23**: 63–67.

Mahesh, S., Pauline Sabina, K. and Bilwa, M. L. 2014. Palynology and depositional facet of lower Permian (Artinskian) sediments from New Majri Open Cast Mine, Wardha Basin, India. *Journal of the Geological Society of India,* **83**: 697–708.

Mendonça Filho, J. G., Menezes, T. R. and Mendonça, J. O. 2011. Organic composition (palynofacies analysis), p. 33–81. In: ICCP Training Course on Dispersed Organic Matter, Porto.

Murthy, S. 2017. Late Permian palynomorphs from the West Bokaro Coalfield, Damodar Basin, Jharkhand, India. *Palaeobotanist,* **66**: 201-209.

Murthy, S., Chakraborthi, B. and Roy, M. D. 2010. Palynodating of subsurface sediments, Raniganj Coalfield, Damodar Basin, West Bengal. *Journal of Earth System Sciences,* **119**(5): 701- 710.

Murthy, S., Ram-Awatar and Saurabh, G. 2014. Palynostratigraphy of Permian succession in the Mand-Raigarh Coalfield, Chhattisgarh, India. *Journal of Earth System Sciences,* **123**: 1879-1893.

Oboh-Ikuenobe, F. E. and De Villiers, S. E. 2003. Dispersed organic matter in samples from the western continental shelf of South Africa: palynofacies assemblages and depositional environments of Late Cretaceous and younger sediments. *Palaeogeography Palaeoclimatology Palaeoecology*, **201**: 67–88.

Oboh-Ikuenobe, F. E., Yepes, O. and Leg, O. D. P. 1997. Palynofacies analysis of sediments from the Côte d'Ivoire-Ghana Transform Margin: Preliminary correlation with some regional events in the eastern Equatorial Atlantic. *Palaeogeography Palaeoclimatology Palaeoecology*, **129**: 291–314.

Pauline Sabina, K., Bilwa, M. L. and Mahesh, S. 2007. A palynostratigraphic study of lower Gondwana sediments from Bandar Coalfield, Nagpur District, Maharashtra. J*ournal of the Geological Society of India,* **69**: 834–840.

Prasad, V., Singh, I. B., Bajpai, S., Garg, R., Thakur, B., Singh, A., Saravanan, N. and Kapur, V. V. 2013. Palynofacies and sedimentology-based high-resolution sequence stratigraphy of the lignite-bearing muddy coastal deposits (early Eocene) in the Vastan Lignite Mine, Gulf of Cambay, India. *Facies,* **59**(4): 737-761.

Raja Rao, C. S. 1987. Coalfields of India. *Bulletin of Geological Survey of India,* A–IV **45**(I): 1–60.

Saxena, A., Murthy, S. and Singh, K. J. 2019. Floral diversity and environment during the Early Permian: A case study from Jarangdih Colliery, East Bokaro Coalfield, Damodar Basin, India. *Palaeobiodiversity and Palaeoenvironments, https://doi.org.10.1007/s12549-019-003175-6*.

Schopf, J. M. 1982. Forms and facies of *Vertebraia* in relation to Gondwana Coal. Americal Geophysical Union. *Antarctica Research Series*, **36**: 37-62.

Singh, K. J. and Saxena, A. 2015. End Permian (Lopingian) floral diversity in Singrauli coalfield: Evidences from Jingurdah colliery, Son-Mahanadi basin, India. *Journal of the Palaeontological Society of India*, **60**: 97-112.

Singh, K. J., Murthy, S., Saxena, A. and Shabbar, H. 2017. Permian macro- and miofloral diversity, palynodating and palaeoclimate implications deduced from the coal-bearing sequences of Singrauli coalfield, Son–Mahanadi Basin, central India. *Journal of Earth System Sciences,* **126**: 25-41. DOI 10.1007/s12040-017-0809-z.

Singh, K. J., Saxena, A. and Goswami, S. 2016. In situ occurrence of *Vertebraria* roots in the Raniganj Formation of Singrauli Coalfield and its palaeoecological significance. *Current Science*, **110**(3): 299-301.

Singh, S. M. 2000. Glossoptris flora from the Early Permian Karanpura and Bokaro Coalfields, India. *Geophytology,* **29**:69-80.

Srivastava, A. K. 1995. Nature and preservation of *Vertebraria* axes in the Lower Gondwana beds of India. *Acta Palaeobotanica*, **35**: 189–193.

Srivastava, P. N. 1954. On some Lower Gondwana megaspores and seeds from Mangardaha Coal West Bokaro, Bihar. *Palaeobotanist,* **3**: 113–115.

Srivastava, S. C. and Jha, N. 1989. Palynology of Lower Gondwana sediments in the Godavari Graben, Andhra Pradesh, India. *Palaeobotanist*, **37**: 199–209.

Srivastava, S. C. and Jha, N. 1992a. Palynostratigraphy of Permian sediments in Manuguru area, Godavari Graben, Andhra Pradesh. In: *Proceedings of Birbal Sanhi Birth Centenary Palaeobotanical Conference* (Eds. Venkatachala, V.S., Jain, K.P. and Awasthi, N.) *Geophytology*, **22**: 103–110.

Srivastava, S. C. and Jha, N. 1992b. Permian palynostratigraphy in Ramakrishnanpuram area, Godavari Graben, Andhra Pradesh, India. *Geophytology,* **20**: 83–95.

Srivastava, S. C. and Jha, N. 1995. Palynostratigraphy and correlations of Permian-Triassic sediments in Budharam Area, Godavari Graben, India. *Journal of the Geological Society of India,* **46**: 647-653.

Srivastava, S. C. and Jha, N. 1996. Palynology of sub-surface Permian sediments in Koyagudem area, Godavari Graben, Andhra Pradesh. *Geophytology,* **25**: 131–136.

Surange, K. R. and Singh, P. 1951. Walkomiella indica, a new conifer from the Lower Gondwanas of Indiaa. *Journal of Botanical Society of India*, **30**: 143-147.

Surange, K. R., Singh, P. and Srivastava, P. N. 1953a. Megaspores from West Bokaro Coalfield (Lower Gondwanas) of Bihar. *Palaeobotanist*, **2**: 9–13.

Surange, K. R., Srivastava, P. N. and Singh, P. 1953b. Microfossils analysis of some lower Gondwana coal seams of West Bokaro, Bihar. *Bulletin of National Institute of Science, India,* **2**: 111–127.

T**iwari, R. S. and Tripathi, A.** 1992. Marker assemblage zones of spore and pollen species through Gondwana Palaeozoic and Mesozoic sequence in India. *Palaeobotanist,* **40**: 194–236.

Tyson, R. V. 1995. Sedimentary Organic Matter: Organic Facies and Palynofacies, p. 615. Kluwer Academic, Dordrecht, Holland.

Vijaya, Tripathi, A., Roy, A. and Mitra, S. 2012. Palynostratigraphy and age correlation of subsurface strata within the sub-basins in Singrauli Gondwana Basin, India. *Journal of Earth System Sciences,* **121**(4): 1071–1092.

Wheeler, A. and Götz, A. E. 2016. Palynofacies patterns of the Highveld coal deposits (Karoo Basin, South Africa): clues to reconstruction of palaeoenvironment and palaeoclimate. *Acta Palaeobotanica*, **56**: 3–15.

Wheeler, A. and Götz, A. E. 2017. Palynofacies as a tool for high-resolution palaeoenvironmental and palaeoclimatic reconstruction of Gondwanan postglacial coal deposits: no. 2 Coal Seam, Witbank Coalfield (South Africa). *Palaeobiodiversity and Palaeoenvironment*s, **97**: 259–271.

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