Journal of the Palaeontological Society of India
Volume 64(2), December 31, 2019: 241-255

ISSN 0552-9360

ARTINSKIAN PALYNOFLORA AND PALAEOCLIMATE OF NAND–BESUR BLOCK, BANDAR COALFIELD WARDHA BASIN, INDIA

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ABSTRACT

Palynofloral and palynofacies investigations have been carried out in borehole NP-74 from a Nand–Besur Block of the Nagpur District, Bandar Coalfield, Wardha Basin, Maharashtra. Palynofloral qualitative and quantitative analysis has revealed two distinct palynoassemblages I and II. The abundance of *Scheuringipollenites* spp. (40-51%) and sub dominance of *Parasaccites* spp. (25-30%) characterizes Palynoassemblage-I (277-283m). The dominance of *Scheuringipollenites* spp. (30-78%) along with *Faunipollenites* spp., *Striatopodocarpites* spp. and taeniates (13-28%) demarcates Palynoassemblage-II (102.5-271m). Palynoassemblage-I and II show its resemblance to the upper Karharbari and lower Barakar palynoflora of the early Permian age, respectively. On the basis of the recovered palynoflora, Artinskian age is assigned to these palynoassemblages (I and II). Four genera of megaspores have also been recovered at a depth of 202 m. By the palynofacies investigations, five distinct Palynofacies Association (A-E) has been identified. Palynofacies Association A is demarked by the predominance of the spore-pollen; Palynofacies Association B is characterized by the dominance of structured terrestrial; Palynofacies Association C is dominated by charcoal; Palynofacies Association D is distinguished by the dominance of degraded organic matter and Palynofacies Association E is marked by the predominance of amorphous organic matter. Palynofacies Association A—E is deposited in the peat-forming setting; fairly dense vegetation in the proximal settings; oxidizing conditions in exposed areas of flood plains; slight flow/ waterlogged settings and oxygen-deficient conditions in low energy settings respectively.

Keywords: Palynofacies, Palynology, megaspore, palaeoenvironment, Permian.

INTRODUCTION

In peninsular India, Gondwana deposits occur in a triangular pattern distributed along four major river valleys, *viz*., Damodar, Son-Mahanadi, Godavari and Satpura Basin. Wardha Basin is the North-western extension of the Godavari Graben which is situated in the State of Maharashtra, Central India. This basin covers an area of 4150 sq.km, marked between 19^0 30' and 20^0 27' latitudes and 78^0 50' and 79^0 45' longitudes. Main parts of the Wardha Basin are constituted by the Gondwana sediments exposed in the state of Maharashtra. The Gondwana sediments are represented by the Talchir, Barakar, Kamthi, and Maleri formations resting over the basement constituted by Archaean gneisses, Proterozoic Pakhal, and Sullavai sequences. After the cessation of the Gondwana sedimentation, the marine incursion in the form of the Bagh and Lameta beds has also been documented in parts of Nagpur and Chandrapur districts. This is followed by the huge flood of lava during the Upper Cretaceous. These lava flows were known as Deccan traps which cover up to two-thirds of the state of Maharashtra.

Both macro and micro plant fossils are well documented from the different four coalfields of the Wardha Basin. Macro fossil reports are documented by various workers (Bunbury, 1861; Feistmantel, 1881; Varadpande, 1977a, b; Chitnis and Vagyani, 1979; Chandra and Prasad, 1981; Raja Rao, 1982; Sundaram and Nandi, 1984; Agashe and Prasad, 1989; Agashe and Shashi Kumar, 1996, 2001; Agashe, 2001; Tewari and Rajanikanth, 2001; Agarwal *et al*., 2007; Tewari, 2007, 2008; Singh *et al*., 2005; Tewari *et al*., 2012a, b). Palynological investigation of the Gondwana sediments of the Wardha Basin has confirmed the presence of abundant palynomorphs by different palynologists (Srivastava and Bhattacharyya, 1996; Kumar and Jha, 2000; Jha *et al*., 2007; Kalkar *et al*., 2010; Mahesh *et al*., 2007, 2011, 2014; Murthy and Sarate, 2016; Sarate *et al*., 2016). First preliminary palynological record from Bandar Coalfield has been documented by Pauline *et al*., 2007, and recently Murthy *et al*., 2017 reported both microspores and megaspores from this coalfield. Previous records of megaspores from the Wardha Basin are also available (Agashe, 1979; Tewari *et al*., 2004).

Although two palynofloral reports from the Bandar Coalfield have been documented but the present work is the first palynofacies studies from this coalfield. The purpose of the present investigation is to focus on the palynostratigraphic construction, comparison of the recovered palynoassemblages with their equivalents palynozones (India and the other Gondwana continents) and the palaeoenvironment construction through palynofacies studies. The present work defines palynological records of the Barakar sediments of the Nand–Besur Block, Bandar Coalfield, Nagpur District, Wardha Basin, Maharashtra to evaluate the palynofloral and palaeoenvironmental conditions during the early Permian periods. This combined research will refine the biostratigraphy and palaeoenvironmental history of a relatively poorly studied area, which is of immense local economic significance. As India was part of the Gondwana supercontinent during the Permian Period, present work would also provide some significant evidence in framing the regional palynostratigraphic and palaeoclimatic interpretations of the Gondwana supercontinent during the Permian Period.

GEOLOGY OF THE AREA

The Wardha Basin is one of the important lower Gondwana basins of India and is confined to the northeastern part of the Maharashtra State. It includes four coalfields (Raja Rao, 1982) namely, Umrer, and Kamptee of Nagpur District, Wardha Valley

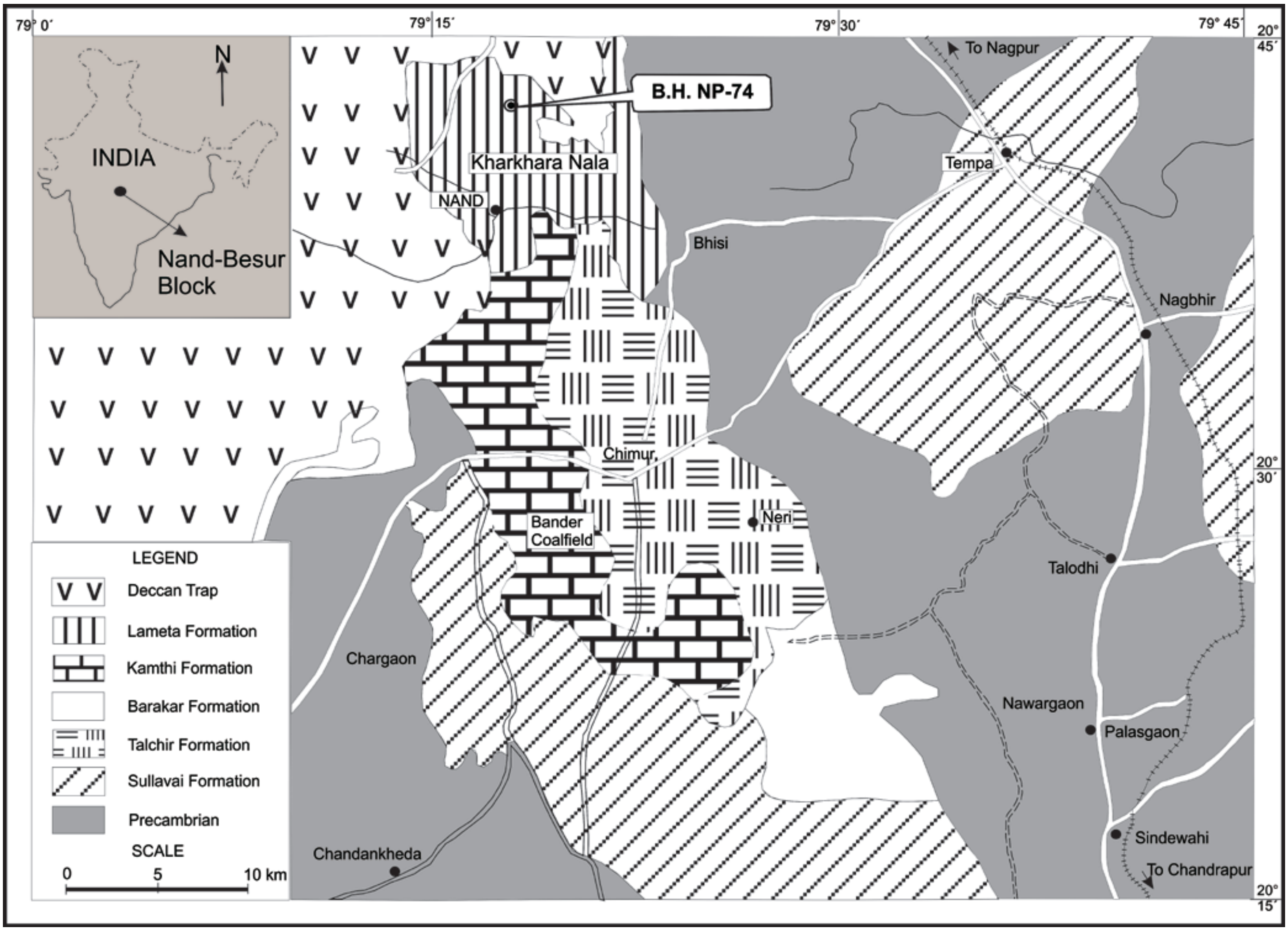

Fig. 1. Map of the Wardha Basin showing the location of borehole NP-74.

of Chandrapur District, and the Bandar coalfield, which is situated towards the north of the Wardha Valley coalfield and spreads over a part of both Nagpur and Chandrapur districts, Maharashtra.

The Bandar Coalfield is one of the prominent coalfields located in the Vidarbha region of Maharashtra. It was first discovered by Hughes (1877) who reported the existence of the Barakar Formation here. The coal-bearing blocks established through exploration from the south to north are Bandar, Murpar, Surmanjiri, Bhagwanpur, Gokul, Nand and Khandalzari (CMPDI, unpublished report). The Bandar coalfield is located at a distance of nearly 42 km east of the Warora Town and 80 km SSE of Nagpur. The lower Gondwana sediments in the Bandar coalfield occur in an area of 295 sq. km within the latitudes 20°20’ to 20°38’N and longitudes 79°14’ to 79°30’E and are deposited in a depression with metamorphic rocks exposed in the eastern and the western sides. On the southern side, the Gondwana sediments are exposed on a hilly region formed by the rocks of the Sullavai Group and on the northern side they are capped by the Lameta Formation and Deccan Traps.

The Barakar Formation in the Bandar Coalfield is composed of fine to coarse-grained white, grey, yellowish coloured micaceous sandstones and oftenly present carbonaceous shales. The thickness of the Barakar Formation, as intersecting in various boreholes the Bandar Coalfield, ranges from 9.15 to 76.77 m. Barakars are underlined by Talchir Formation and overlapped by the Kamthi Formation. Kamthi Formation is represented by the reddish yellow to buff coloured, medium to coarse-grained sandstone with a variable proportion of shale and yellow buff clay and at few places fine-grained micaceous sandstone (Table 1).

EXPLANATION OF PLATE I

Fig. 1. ***Horriditriletes*** sp., Fig. 2. ***Parasaccites korbaensis*** Bharadwaj 1964, Fig. 3. ***P. talchirensis*** Lele and Makada, 1972, Fig. 4. ***P. plicatus*** Lele and Makada, 1972, Fig. 5. ***P. abscurus*** Tiwari, 1965, Fig. 6. ***Potonieisporites neglectus*** Potonie and Lele, 1961, Fig. 7. ***Potonieisporites lelei*** Maheshwari, 1967, Fig. 8. ***Plicatipollenites indicus*** Lele, 1964, Fig. 9. ***Striomonosaccites ovatus*** Bharadwaj, 1962, Fig. 10. ***Densipollenites indicus*** Bharadwaj and Srivastava, 1969, Fig. 11. ***Crucisaccites indicus*** Srivastava, 1970, Fig. 12. ***Arcuatipollenites (=Lunatisporites)*** sp., Fig. 13. ***Arcuatipollenites ovatus*** (Goubin) Tiwari and Vijaya, 1995, Fig. 14. ***Dicappipollenites crasus*** (Sinha) Tiwari and Vijaya, 1995, Fig. 15. ***Sahniles barrelis*** (Tiwari) Tiwari and Singh, 1984, Fig. 16. ***Scheuringipollenites tentulus*** (Tiwari) Tiwari, 1973, Fig. 17. ***Scheuringipollenites maximus*** (Hart) Tiwari, 1973, Fig. 18. ***Scheuringipollenites barakarensis*** (Tiwari) Tiwari, 1973, Fig. 19. ***Faunipollenites varius*** Bharadwaj, 1962, Fig. 20. ***Primuspollenites levis*** Tiwari, 1964, Fig. 21. ***Striatopodocarpites magnificus*** Bharadwaj and Salujha, 1964, Fig. 22. ***Rhizomaspora indica*** Tiwari, 1965, Fig. 23. ***Tiwariasporis simplex*** (Tiwari) Maheshwari and Kar, 1967, Fig. 24. ***Alisporites asansolensis*** Maheswari and Banerji, 1975.

Plate I

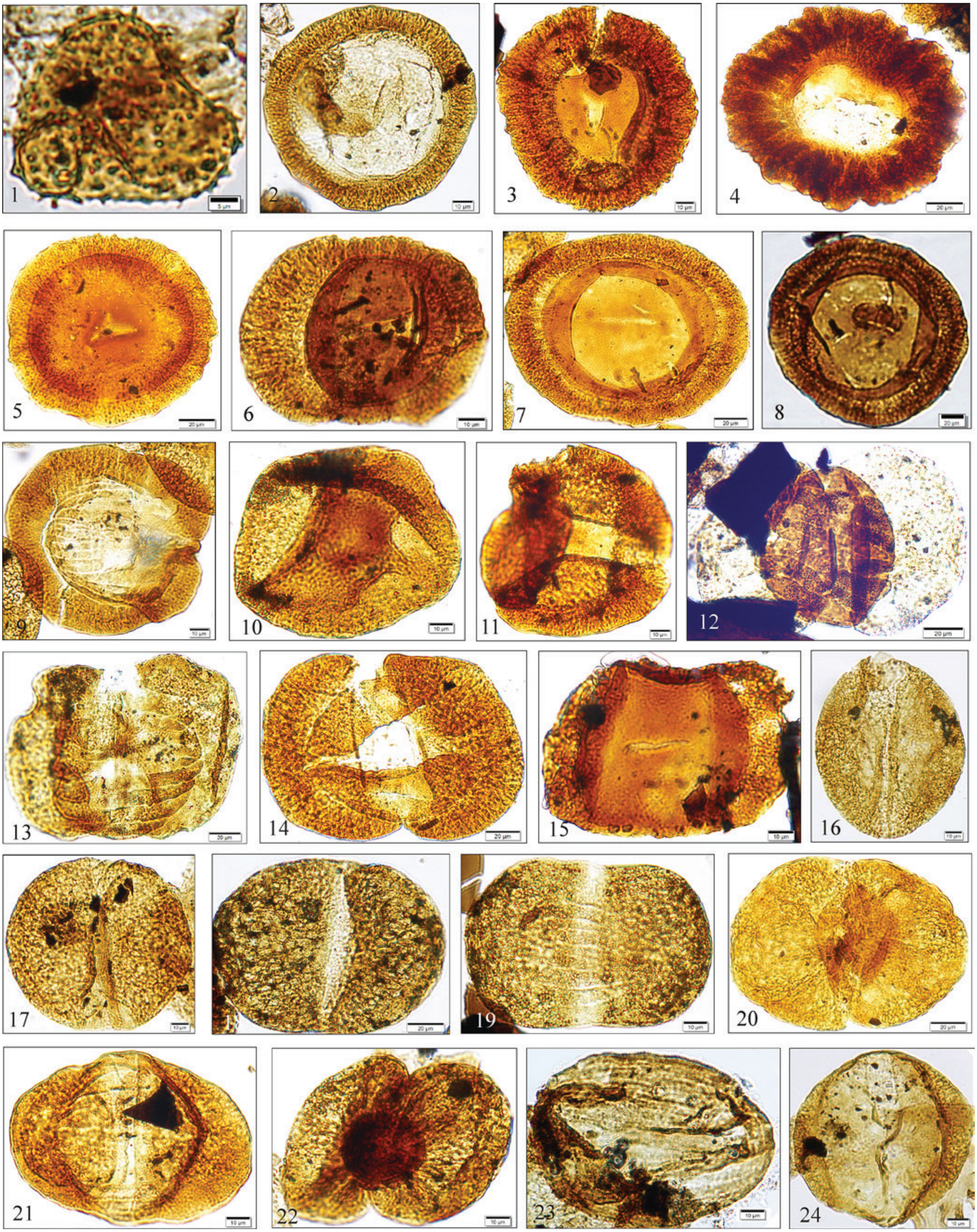

Table 1. Stratigraphy of Bandar coalfield (*after* C.S. Raja Rao, 1982).

Age	Group/Formation	Bandar coalfield
Recent		Soil and Alluvial gravel
Eocene	Deccan Trap	Thoeliitic basalt
~~**Unconformity**~~~~~~~~~~		
Cretaceous	Lameta	Chert, Limestone, Silicified Sandstone
~~**Unconformity**~~~~~~~~~~		
Upper Permian to Lower Triassic	Kamthi	Yellow and buff sandstone, Yellowish clay
~~**Unconformity**~~~~~~~~~~		
Lower Permian	Barakar	Fine to coarse grained Sandstone, grey shales, coal seams
Upper Carboniferous to Lower Permian	Talchir	Fine grained sandstone and shales
~~**Unconformity**~~~~~~~~~~		
Archaean	Pakhal	Metamorphics

The study area represents the northeastern continuity of the main Bandar Coalfield known as the Nand–Besur Block and displays similar geographical features as witnessed in the Bandar Coalfield. The Nand Block is adjacent to and lies on the northern margin of the Gokul Block. Both these blocks are spread in the Nagpur District of Maharashtra. Detailed exploration in the Nand Block has established the existence and continuity of the prominent coal seams. Accordingly, three coal seams Seam–II, Seam–V and Seam VII) are present in the Nand Block, out of these only Seam-II and Seam-V are workable

MATERIAL AND METHODS

Microspores

Twenty-five subsurface samples were collected from borehole NP-74 drilled (Fig. 1) to a depth of 290 m in the Nand-Panjrepar block, at a distance of around five km north of the Besur Village in Bhivapur Taluk of the Nagpur District, Maharashtra. Borehole NP-74 (Locality no. BSIP 8800, dated 02.01.2015) was collected by Dr. O.S. Sarate from Nand area of Nagpur. Samples collected from shale were processed by following a standard palynological method called maceration (Bhardwaj, 1962; Bhardwaj and Saluja, 1964). For the removal of silica, first, the material (50 gm) was crushed to 2mm-4mm size and subjected to Hydrofluoric Acid (HF, 40%) for two to three days. After thorough washing, the resultant acid–free residue was treated with concentrated nitric acid (HNO_3) for 3-4 days for the digestion of humic matter followed by alkali treatment (10% KOH solution) to bleach the organic matter. The materials were sieved through a 400 micro mesh, and finally, the residue was mounted in the Canada balsam with the help of Poly Vinyl Chloride (PVC). Five slides per sample were prepared from each productive sample. All samples were studied using an Olympus BX61 microscope and photographs were taken with a DP-25 camera using Cell A software. For frequency analyses, spore/pollen counts of a total of 200 grains were conducted for each sample (Fig. 2). Stratigraphically significant taxa are shown in Plate I.

Table 2. showing recovered percentage of different type of the recovered organic matter

S.N.	Depth	SP	ST	CH	AOM+DT
1	102	0.943396	0	26.72956	72.32704
2	102.5	49.8615	31.85596	12.46537	5.817175
3	104	0.497512	0	74.62687	24.87562
4	104.5	1.993355	0	23.25581	74.75083
5	122	0.795756	1.591512	27.32095	70.29178
6	155	27.11864	35.25424	22.0339	15.59322
7	157	11.73021	62.46334	6.744868	19.06158
8	163	15.15152	81.81818	0	3.030303
9	166	5.070423	28.73239	46.47887	19.71831
10	178	0.561798	0	84.26966	15.16854
11	181	8	31	37.33333	23.66667
12	190	8.411215	35.20249	26.47975	29.90654
13	202	13.09524	62.79762	12.5	11.60714
14	223	52.94118	44.70588	1.176471	1.176471
15	226	34.48276	56.73981	2.507837	6.269592
16	229	0	0.425532	48.93617	50.6383
17	253	4.6875	12.5	65.625	17.1875
18	265	1.162791	5.813953	45.05814	47.96512
19	268	0	3	87	10
20	271	54.3131	9.584665	15.97444	20.1278
21	272	41.9708	11.31387	19.34307	27.37226
22	280	52.79503	26.08696	9.31677	11.80124
23	283	28.73563	24.13793	18.3908	28.73563
24	286	26.36656	17.36334	32.15434	24.11576
25	290	12.1519	46.07595	16.4557	25.31646

SP spore-pollen, ST Structured terrestrial, CH charcoal, AOM Amorphous Organic Matter, DT Degraded terrestrial

Megaspores

For the recovery of megaspores, the samples were first treated with 40% hydrofluoric acid (HF) for 5–7 days and washed thoroughly with water for retrieval of megaspores. When the megaspores were released, they were picked individually. The megaspores were kept in conc. HNO_3 for 10–12 hours along with a pinch of potassium chlorate ($KClO_3$) to catalyze the reaction. The megaspores were washed with water thoroughly when they turned brown. Then megaspores were treated with 5% of potassium hydroxide (KOH) solution. The megaspores revealed the exosporium features (shape, nature of triradiate and contact ridges and ornamentations). After that, individual megaspores were placed on a slide. The light microscopic studies and photography were carried out with an Olympus BX61 microscope with DP-20 camera attachment. The megaspores were picked up and mounted over stubs. The stubs were coated with gold-palladium and examined using a Field Emission Electron Microscope (Model JEOL 7610F). In the case of megaspores of SEM, the mesosporium could not be studied. Hence, it was not possible to assign them to define species. Though this is the first record of the megaspores of the early Permian Barakar Formation of the Bandar Coalfield, all of them are well known from other Gondwana basins (Tewari *et al*., 2009; Govind *et al*., 2014) of India (Plate II). Hence, a detailed description of these is not given here.

Palynofacies

The samples for palynofacies were prepared using the standard non-oxidative palynological procedure (Faegri and Iversen, 1989; Tyson 1995; Traverse, 1994; Prasad *et al*., 2013).

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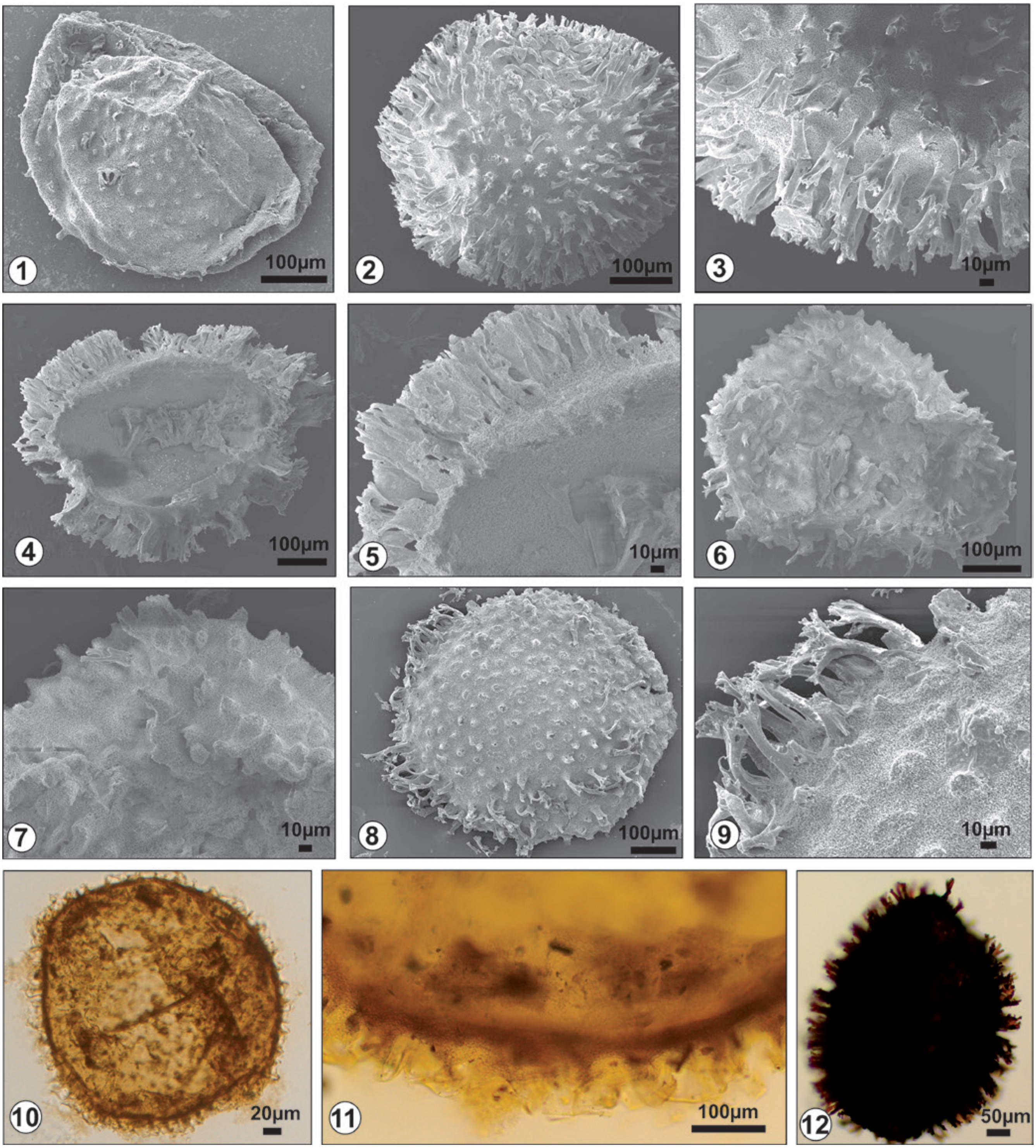
Plate II



EXPLANATION OF PLATE II

Fig. 1. ***Duosporites*** sp., Fig. 2. ***Singhisporites*** sp., Fig. 3. The enlarged part of ***Singhisporites*** sp., Fig. 4. ***Manumisporites*** sp., Fig. 5. The enlarged part of ***Manumisporites*** sp., Fig. 6. ***Singhisporites*** sp., Fig. 7. The enlarged part of ***Singhisporites*** sp., Fig. 8. ***Singhisporites*** sp., Fig. 9. The enlarged part of ***Singhisporites*** sp., Fig. 10. ***Jhariatriletes filiformis*** Tewari and Maheshwari, 1992, Fig. 11. The enlarged part of ***Jhariatriletes filiformis*** Tewari and Maheshwari, 1992, Fig. 12. ***Singhisporites radialis*** Bharadwaj and Tiwari, 1970.

A total of at least 300 particles were counted only for dispersed organic matter from each sample preparation at variable magnifications to generate a qualitative assessment for the palynofacies. The identification of the palynofacies was carried out with the classical literature by Tyson (1993, 1995), Traverse (1994), Oboh- Ikuenobe *et al*. (2005), Carvalho *et al*. (2006). Photography and counting of the palynofacies association were done with the help of BX61 Olympus microscope and DP25 camera. After calculating the percentage of each category (Table 2), for each palynofacies association average of each group is calculated (Fig. 3). Recovered palynofacies are shown in Plate III. All microscopic slides are kept in the repository of the Birbal Sahni Institute of Palaeosciences, Lucknow.

Spore and pollen (SP) are recognized merely by their specific morphology. Different types *viz.,* triletes, monosaccates, non-striate bisaccates, striate bisaccates, and taeniates have been identified. The presence of different kinds of palynomorphs reveals different palaeofloral or palaeoenvironmental patterns. The organic matter with a lath-shaped/blocky outline, pale yellow to brown/dark brown, and well to moderately preserve considered under structured terrestrial particles (ST) category. Tracheids, wood fragments, and cuticles are a more common component of this category. Cuticles exhibited pale yellow to pale brown/dark brown in colour, thin, rounded, or polygonal-shaped cells. In many cases, cuticle preserved the innermost part of the epidermis showing a rectangular and cellular structure which may indicate a gymnosperm origin (Tyson, 1995). Degraded terrestrial particles (DT) are formed due to fungal or bacterial activity. Fungi act as a degrading agent which converts vegetal parts into various organic types with the help of biochemical mechanisms. Diverse states of preservation partial to completely deteriorated have been observed in this category. Opaque and black particles with and without noticeable structures are incorporated into the charcoal category (CH). Amorphous organic matter (AOM) is characterized by its structureless, heterogeneous aggregates, and a porous, spongy appearance. Different stages of AOM ranging from partial to complete degradation have been observed under this category.

RESULTS

Palynomorph Analysis

Microspores: Quantitative and qualitative palynological analysis of sediments has revealed two palynoassemblage in borehole NP-74. The vertical distribution of different palynomorphs in the borehole NP-74 has been shown in the frequency chart (Fig. 2) and a list of recovered spore-pollen species has been summarized in Table 3. The palynofossils preservation is variable within the samples, and recovery is low to moderate, light yellowish to dark brown, broken to fairly well–preserved.

Palynocomposition: Out of 25 samples processed, only nine samples were rich in palynomorphs. Palynologically studied succession reveals that the pollen grains are predominant over the spores. Palynocomposition of two different palynoassemblage are as follows:

Palynoassemblage-I (283-277m): Recovered palynoassemblage is characterized by the dominance of nonstriate bisaccate *Scheuringipollenites* (40-51%) and subdominance of monosaccates *Parasaccites* (30-32%), *Plicatipollenites* (6–11%), *Potonieisporites* (3-4%). Other associated taxa of the palynoassem-

Table 3. list of recovered spore-pollen species and their botanical affinity based on the compilation of Balme 1995; Lindström and Mc Loughlin 2007; di Pasquo and Grader 2012; Mishra *et al*. 2017).

Botanical affinity	Palynotaxa
Filicopsid	*Horriditriletes ramosus* (Balme and Hennelly) Bharadwaj and Salhjha, 1964
	Horriditriletes sp.
Lycopsids	*Duosporites* sp.
	Manumisporites sp.
	Jhariatriletes filiformis Tewari and Maheshwari, 1992
	Singhisporites radialis Bharadwaj and Tiwari, 1970
	Singhisporites sp.
Cordaitales	*Barakarites* sp.
	Crucisaccites indicus Srivastava, 1970
	Parasaccites talchirensis Lele and Makada, 1972
	Parasaccites plicatus Lele and Makada, 1972
	Parasaccites perfectus Bose and Maheshwari, 1968
	Parasaccites korbaensis Bharadwaj and Tiwari, 1964
	Parasaccites ovatus Kar, 1968
	Parasaccites obscrus Tiwari, 1965
	Plicatipollenites gondwanensis (Balme and Hennely) Lele, 1964
	Plicatipollenites trigonalis Lele, 1964
	Plicatipollenites indicus Lele, 1964
Glossopteridales	*Faunipollenites varius* Bharadwaj, 1962
	Funipollenites singrauliensis Sinha, 1972
	Faunipollenites perexiguus Bharadwaj and Salujha, 1965
	Sriatopodocarpites globosus Maheshwari, 1967
	Striatopodocarpites magnificus Bharadwaj and Salujha, 1964
	Striatopodocarpites sp.
	Scheuringipollenites barakarensis Tiwari, 1973
	Scheuringipollenites tentulus Tiwari ,1973
	Scheuringipollenites maximus Tiwari, 1973
	Verticipollenites sp.
Coniferales	*Potonieisporites neglectus* Potonie and Lele, 1961
	Potonieisporites lelei Maheshwari, 1967
	Striomonosaccites ovatus Bharadwaj, 1962
	Crescentipollenites talchirensis Lele, 1975
	Lunatisporites ovatus (Goubin) Tiwari and Vijaya, 1995
	Lunatisporites sp.
	Tiwarisporis indicus Srivastava, 1970
	Sahnites barrelis (Tiwari) Tiwari and Singh, 1984
	Sahnites methois (Hart) Tiwari and Singh, 1984
Peltaspermales	*Alisporites asansolensis* Maheswari and Banerji, 1975
	Primuspollenites levis Tiwari, 1964
Unknown affinity	*Dicapipollenites* Tiwari and Vijaya, 1995
	Dicappipollenites crasus (Sinha) Tiwari and Vijaya, 1995
	Densipollenites indicus Bharadwaj and Srivastava, 1969
	Rhizomaspora indica Tiwari, 1965
	Rhizomaspora sp.

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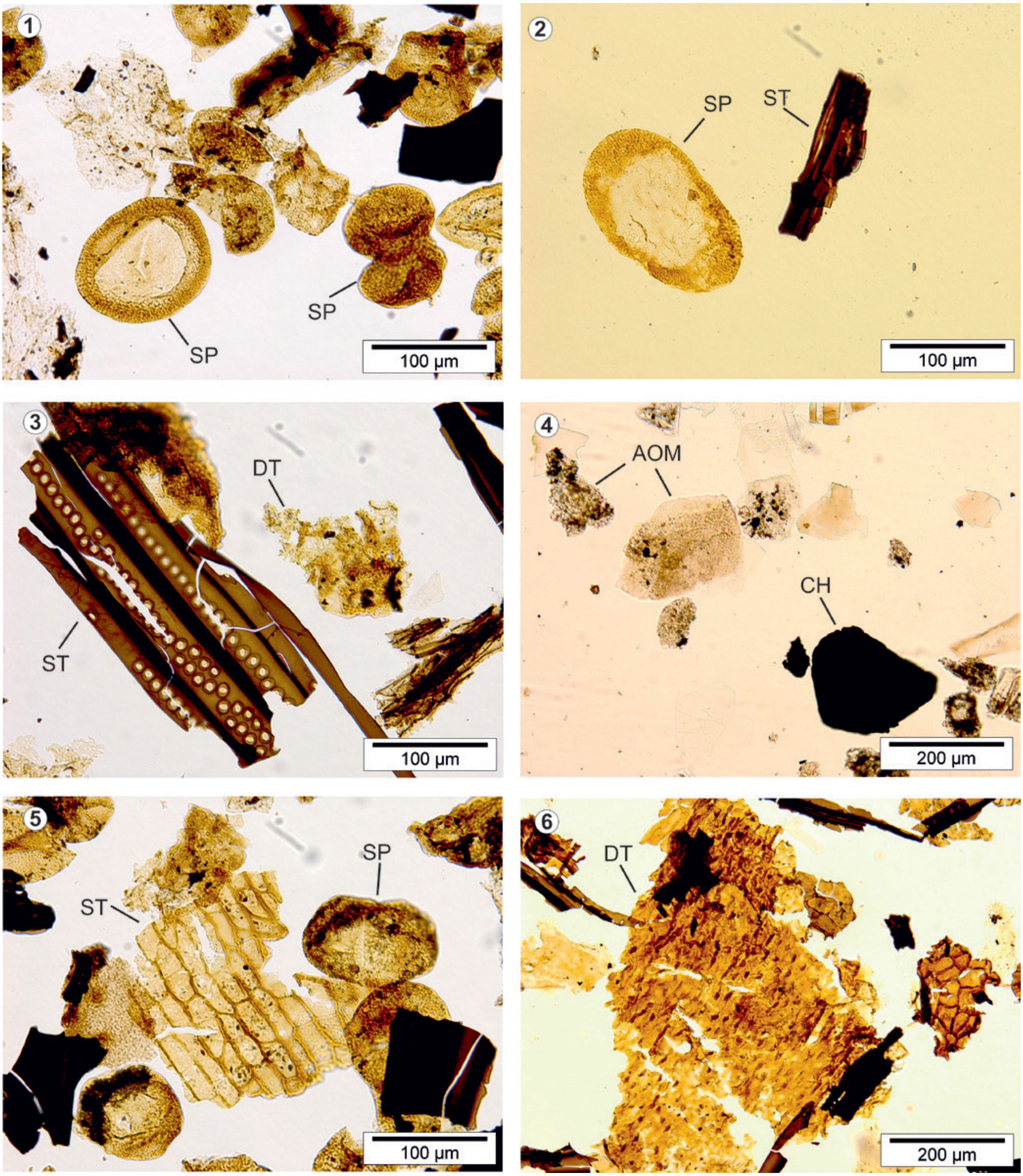
Plate III



EXPLANATION OF PLATE III

Palynofacies recovered from borehole NP-74; Fig. 1. Monosaccate and bisaccate pollen grains, Fig. 2. Monosaccate pollen grains in association with structured terrestrial organic matter, Fig. 3. Structured terrestrial organic matter in association with degraded terrestrial organic matter, Fig. 4. Amorphous Organic matter in association with Charcoal, Fig. 5. Structured terrestrial organic matter in association with pollen grains, Fig. 6. Degraded terrestrial organic matter.

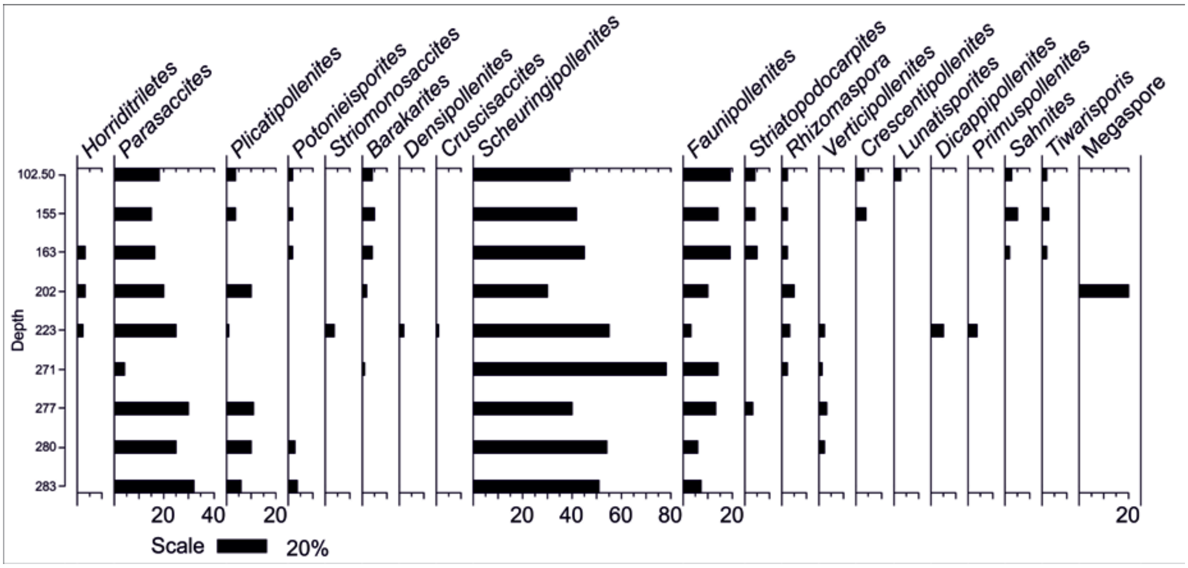


Fig. 2 Histogram showing vertical distribution and percentage frequencies of various palynotaxa in borehole NP-74, Wardha Basin, Maharashtra

blage are *Faunipollenites* (6–13%), *Striatopodocarpites* (3%), and *Verticipollenites* (2–3%). Recovered palynoflora compares well with the upper Karharbari palynoflora.

Age span: Artinskian age (Aggarwal and Jha, 2013).

Lithostratigraphic distribution: Barakar

Comparison: Recovered palynocomposition shows its close resemblance with Palynozone-2 of the Mailaram area (Jha and Aggarwal, 2012); Playnozone-3 of the Lingala-Koyagudem coalbelt (Aggarwal and Jha, 2013) of the Godavari Graben. The Palynoassemblage also seems to be equivalent Zone-2 of the Raniganj Coalfield (Tiwari, 1973), Korba Coalfield (Bharadwaj and Srivastava, 1973), Umaria Coalfield (Srivastava and Anand-Prakash, 1984) and the Johilla Coalfield (Anand-Prakash and Srivastava, 1984). The palynoflora also shows its similarity with Biozone-II and III of the Umrer Quarry, Nagpur (Bharadwaj and Anand-Prakash, 1974); Zone-1 of the Shobhapur block (Srivastava and Sarate, 1989); Assemblage-A of the Wardha Coalfield (Bhattacharyya, 1997) and the Umrer Coalfield (Jha *et al*., 2007). This palynoassemblage has never been traced in the Damodar Basin.

Palynoassemblage-II (271-102.5m): Recovered palynoassemblage is characterized by the dominance of nonstriate bisaccate *Scheuringipollenites* (30-78%) along with striate bisaccates *Faunipollenites* (3-19%), *Striatopodocarpites* (4-5%), *Crescentipollenites* (3-4%), *Verticipollenites* (1-2%), *Rhizomaspora* (2-5%). Other associated monosaccate taxa, which discriminate the palynoassemblage, include species of *Parasaccites* (4-25%), *Potonieisporites* (2%), *Barakarites* (1–5%), *Plicatipollenites* (1–10%), *Striomonosaccites* (4%), *Densipollenites* (2%), *Crucisaccites* (1%). Taeniate genera include *Lunatisporites* (3%) *Dicapipollenites* (5%), *Sahnites* (2-5%), *Primuspollenites* is 4%. and *Tiwariasporis* (2-3%). Spores are represented by the single genus *Horriditriletes* (2–3%). A good percentage of megaspores (20%) are also present at a depth of 202m. The composition of this palynoassemblage corresponds to the lower Barakar palynoflora.

Age span: Artinskian age (Aggarwal and Jha, 2013).

Lithostratigraphic distribution: Barakar

Comparison: Palynoassemblage-II shows its equivalence with the *Scheuringipollenites barakarensis zone* (Zone III-A) of the Damodar Basin (Tiwari and Tripathi, 1992). The present palynoassemblage compares well with the lower Barakar palynoflora of several areas of the Godavari Basin such as Mamakannu area (Palynoassemblage-III: Jha and Aggarwal, 2010); Gundala area (Palynoassemblage-D: Jha and Aggarwal, 2011); Kachinapalli area (Palynoassemblage-I: Jha *et al*., 2011); Mailaram area (Palynozone-3: Jha and Aggarwal, 2012) in having the predominance of *Scheuringipollenites* and sub-dominance of striate bisaccates. Palynoassemblage-II also correlates well with the Barakar palynoflora of other coalfields viz., Umaria Coalfield (Zone-3: Srivastava and Anand-Prakash, 1984); Johilla Coalfield (Zone-3: Anand-Prakash and Srivastava, 1984); Pathakhera Coalfield (Assemblage-B: Sarate, 1986; Zone-2: Srivastava and Sarate, 1989); Wardha Coalfield (Assemblage-B: Bhattacharyya, 1997); Talcher Coalfield (Assemblage- II: Tripathi, 1997); Ib River Coalfield (Palynozone-2: Meena, 2000), Pali sediments of the Sohagpur Coalfield (Palynoassemblage-I: Ram-Awatar *et al*., 2003) and Palynozone-2 of the Tatapani-Ramkola Coalfield (Kar and Srivastava, 2003).

Megaspores

Genus— ***Duosporites*** Høeg *et al*., 1955 emend. Bharadwaj and Tiwari,1970 *Duosporites* sp.

Genus—***Jhariatriletes*** Bharadwaj and Tiwari, 1970 *Jhariatriletes filiformis* Tewari and Maheshwari, 1992

Genus: ***Manumisporites*** Bharadwaj and Tiwari, 1970 *Manumisporites* sp.

Genus—***Singhisporites*** (Potonié, 1956) Bharadwaj and Tiwari, 1970 *Singhisporites radialis* Bharadwaj and Tiwari, 1970 and *Singhisporites* sp.

The present record is a further signature of megaspores from this basin. The megaspores from the present study of borehole NP-74 at a depth of 202 m includes *Duosporites* sp., *Manumisporites* sp., *Jhariatriletes filiformis, Singhisporites radialis Singhisporites* sp. which include four genera and five species. *Duosporites* sp. and *Manumisporites* sp. are reported only from the Umrer Coalfield and *Jhariatriletes filiformis, Singhisporites radialis, Singhisporites* sp. is reported from the Bandar Coalfield of the Wardha Basin. The present megaspores are diversified with ornamentations of the exosporia including

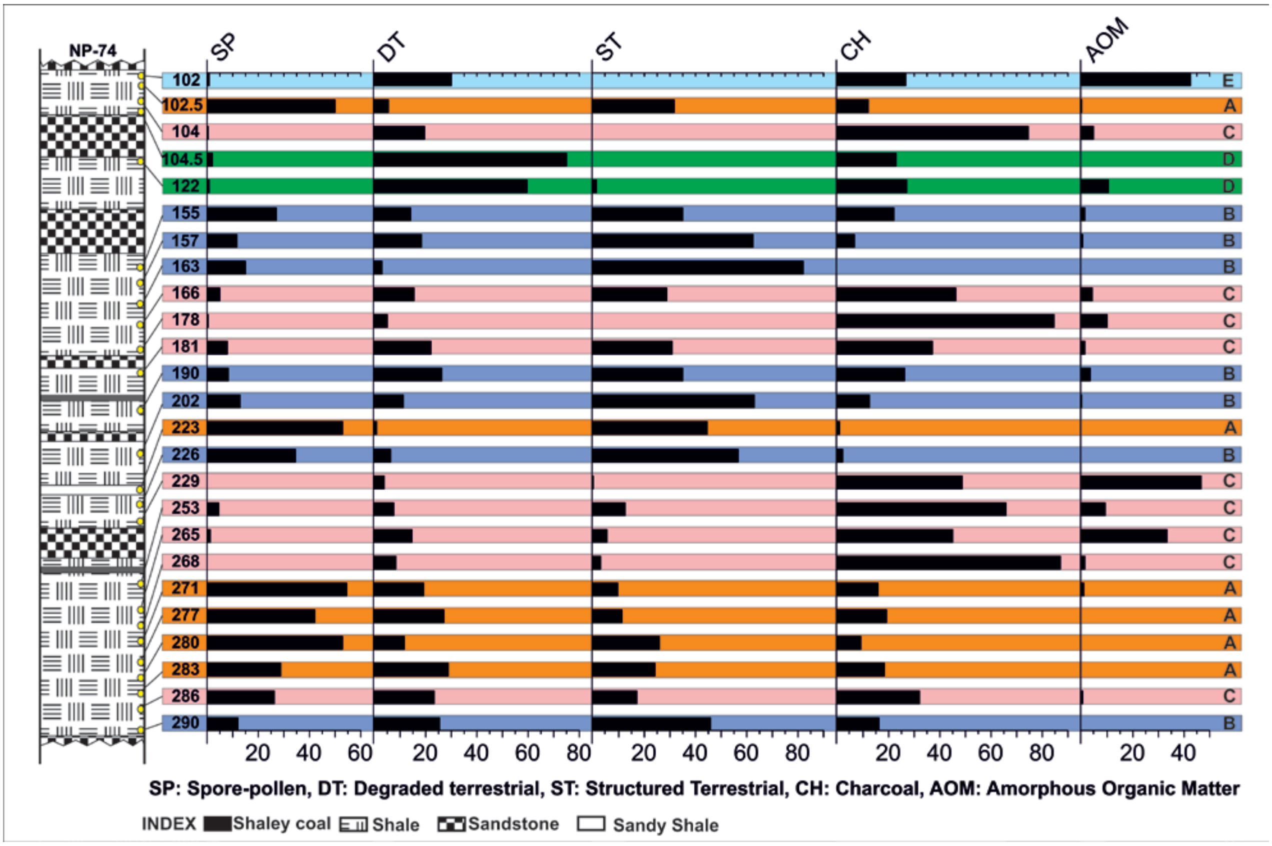


Fig. 3. Histogram along with lithological details showing the distribution of various palynofacies in borehole NP-74, Wardha Basin, Maharashtra.

granulate/verrucate (*Duosporites*), spinate with multifurcate spines (*Manumisporites, Singhisporites radialis,* and *Singhisporites)* and baculate (*Jhariatriletes filiformis*). The megaspores with spinate exosporia appeared in the Barakar Formation and continued up to the late Permian. In general development pattern of the exosporia (laevigate, verrucate, baculate and rarely spinate) are common during the Talchir and Karharbari formations while, spinate developed during the Barakar and Raniganj formations. The present study also reveals the predominance of spinate genera. This feature indicates the occurrence of a variety of heterosporous source vegetation, mainly the lycopsids. The spinate outer walls indicate aquatic conditions which facilitate fertilization.

PALYNOFACIES ANALYSIS

Palynofacies components in the Permian sediments of the Wardha Basin have been studied for palaeoclimatic reconstruction. The elements comprise of plant remains (spore/pollen, cuticles, woods, tracheids) and other degraded organic matter which have been categorized under five categories: spore-pollen, structured terrestrial particles, degraded terrestrial particles, opaque particles (charcoal) and amorphous organic matter. In the present investigation, the palynofacies components are primarily of continental origin as marine elements (i.e., acritarchs, foraminiferal test linings, etc.) are missing. Previous workers (Bhattacharya *et al*., 2012, 2018) identified a marine incursion in the Barakar sedimentation on the basis of sedimentary structures such as cross-strata bundles with intermittent reactivation surfaces, bidirectional cross-strata sets, sigmoidal cross-strata bundles along with heterolithic strata (alternate sand and mud dominated units). However, in the present study sedimentological analysis could not be undertaken due to the unavailability of the complete succession of the borehole and the samples for the present palynological study have been taken only from the palynofossil yielding beds (carbonaceous shales, grey shales, coaly shales, etc.).

Based on the quantitative and qualitative deviations in the dispersed organic matter, content five (A—E) distinct palynofacies associations (Fig. 3) linked to depositions and palaeoenvironmental distinctions are documented and described as follows:

Palynofacies Association A

This palynofacies association represents 24% (occurred in six samples) in all studied samples. It is the most abundant palynofacies in the lower part of the section. This palynofacies association is characterized by the dominance of the spore-pollen (46.76%) and sub-dominance of structured terrestrial (24.61%). Other components of this palynofacies association are degraded terrestrial (15.63%) and charcoal (12.77%). Scanty presence of amorphous organic matter (0.2%) has also been recorded. This palynofacies association has been identified at the depths of 102.5m, 223m, 271m, 277m, 280m and 283m (Table 4).

Palynofacies Association B

This palynofacies association represents 28% (occurred in seven samples) in all studied samples. This palynofacies association is characterized by the dominance of structured

Table 4. Summarized table of the list of samples, recovered palynostratigraphy and identified palynofacies.

<table>
<tr><th>S.N.</th><th>Depth (m)</th><th>Lithology</th><th>Formation</th><th>Palynostratigraphy</th><th>Age</th><th>Identified Palynofacies</th></tr>
<tr><td>1</td><td>102.00</td><td>Shale</td><td rowspan="25">BARAKAR</td><td rowspan="20">Palynoassemblage-II: distinguished by the dominance of nonstriate bisaccate Scheuringipollenites (30-78%) along with striate bisaccates Faunipollenites (3-19%), Striatopodocarpites (4-5%) Crescentipollenites (3-4%).</td><td rowspan="20">Artinskian (Lower Barakar palynoflora)</td><td>Palynofacies-E</td></tr>
<tr><td>2</td><td>102.50</td><td>Shale</td><td>Palynofacies-A</td></tr>
<tr><td>3</td><td>104.00</td><td>Shale</td><td>Palynofacies-C</td></tr>
<tr><td>4</td><td>104.50</td><td>Shale</td><td rowspan="2">Palynofacies-D</td></tr>
<tr><td>5</td><td>122.00</td><td>Shale</td></tr>
<tr><td>6</td><td>155.00</td><td>Shale</td><td rowspan="3">Palynofacies-B</td></tr>
<tr><td>7</td><td>157.00</td><td>Shale</td></tr>
<tr><td>8</td><td>163.00</td><td>Shale</td></tr>
<tr><td>9</td><td>166.20</td><td>Shale</td><td rowspan="3">Palynofacies-C</td></tr>
<tr><td>10</td><td>178.00</td><td>Shale</td></tr>
<tr><td>11</td><td>181.00</td><td>Shale</td></tr>
<tr><td>12</td><td>190.00</td><td>Shale</td><td rowspan="2">Palynofacies-B</td></tr>
<tr><td>13</td><td>202.10</td><td>Shale</td></tr>
<tr><td>14</td><td>223.20</td><td>Sandy Shale</td><td>Palynofacies-A</td></tr>
<tr><td>15</td><td>226.00</td><td>Shale</td><td>Palynofacies-B</td></tr>
<tr><td>16</td><td>229.00</td><td>Shale</td><td>Palynofacies-C</td></tr>
<tr><td>17</td><td>253.00</td><td>Shale</td><td rowspan="3">Palynofacies-C</td></tr>
<tr><td>18</td><td>265.00</td><td>Shale</td></tr>
<tr><td>19</td><td>268.00</td><td>Shale</td></tr>
<tr><td>20</td><td>271.00</td><td>Shale</td><td rowspan="4">Palynofacies-A</td></tr>
<tr><td>21</td><td>277.00</td><td>Shale</td><td rowspan="3">Palynoassemblage-I: characterized by the abundance of non striate bisaccate Scheuringipollenites (40-51%) and subdominance of monosaccate Parasaccites (30-32%)</td><td rowspan="3">Artinskian (Upper Karharbari palynoflora)</td></tr>
<tr><td>22</td><td>280.00</td><td>Shale</td></tr>
<tr><td>23</td><td>283.00</td><td>Shale</td></tr>
<tr><td>24</td><td>286.00</td><td>Shale</td><td rowspan="2">Frequency of spore-pollen is very low</td><td></td><td>Palynofacies-C</td></tr>
<tr><td>25</td><td>290.00</td><td>Shale</td><td></td><td>Palynofacies-B</td></tr>
<tr><td colspan="7">Palaeoenvironmental interpretation of the different palynofacies:
Palynofacies-A: Deposited in peat-forming setting with humid palaeoclimatic conditions which supports the coal formation.
Palynofacies-B: Fairly dense vegetation in the proximal settings.
Palynofacies-C: Implies oxidizing conditions in exposed areas of flood plains.
Palynofacies-D: Slight flow/ waterlogged (oxygen-depleted) settings.
Palynofacies-E: Implies oxygen-deficient conditions and low energy settings.</td></tr>
</table>

terrestrial (54.33%) and sub-dominance of spore-pollen (17.44%). Other components of this palynofacies association are degraded terrestrial (15.01%) and charcoal (12.38%). The amorphous organic matter is only 0.8%. This palynofacies association has been identified at the depths of 155m, 157m, 163m, 190m, 202m, 226m, and 290m (Table 4).

Palynofacies Association C

This palynofacies association represents 36% (occurred in nine samples) in all studied samples which are the most occurred palynofacies associations in succession. This palynofacies association is characterized by the predominance of the charcoal (57.94%). Other components of this palynofacies association are degraded terrestrial (13.38%), spore-pollen (5.14%), structured terrestrial (10.98%), and amorphous organic matter (12.94%). This palynofacies association has occurred at the nine depths of 104m, 166m, 178m, 181m, 229m, 253m, 265m, 268m, and 286m (Table 4).

Palynofacies Association D

This palynofacies association represents 8% (occurred in two samples) in all studied samples. This palynofacies association is characterized by the dominance of degraded terrestrial (67.21%) and sub-dominance of charcoal (25.28%). Other components of this palynofacies association are spore-pollen (1.3%), structured terrestrial (0.79%) and amorphous organic matter (5.3%). This palynofacies association has occurred at the two depths of 104.5m and 122m (Table 4).

Palynofacies Association E

This palynofacies association has been identified only at the depth level of 102m. This palynofacies association is characterized by the dominance of amorphous organic matter (42.45%) along with sub-dominance of degraded terrestrial (29.87%) and charcoal (26.72%). Spore-pollen is just 0.94% while the absence of structured terrestrial has been documented (Table 4).

DISCUSSION

Palynofloral turn over in the Indian Lower Gondwana succession

Quantitative variations and morphographic features of the palynomorphs of different palynozones help in the interpretation of their sensitivity towards climate (Tiwari and Tripathi, 1987). On the basis of the palynoflora four distinct palaeoenvironmental phases have been documented in the Indian Lower Gondwana which are as follows:

Phase-I: Asselian–early Sakmarian palynoflora (Talchir palynoflora) characterized by the predominance of diverse forms of radial monosaccates pollens (Cordiates) along with the minor constituent of pteridosperms (represented by Coniferales, Glossopteridales, Peltaspermales) indicate arid and cool climate (Bussert and Schrank, 2007; Stephenson *et al*., 2007; Aggarwal and Jha, 2013). Glacial events during the Asselian–early Sakmarian have also been documented worldwide (Isbell *et al*., 2003; 2012).

Phase-II: Late Sakmarian-early Artinskian palynoflora (Karharbari palynoflora) documented by the abundance of pteridophytic spores (*Callumispora* spp., *Brevitriletes* spp.) and subdominance of monosaccates (chiefly *Parassacites* spp. and *Plicatipollenites* spp.) suggests the cooler climate with high humidity which is also favorable for the formation of thin bands of coal (Aggarwal and Jha, 2013).

Phase-III: Indian late Artinskian-Kungurian palynoflora (Barakar palynoflora) shows the increased abundance of gymnospermoid non-striate bisaccate predominantly *Scheuringipollenites* spp. (di Pasquo and Grader, 2012) diverse types of Cordaites (*Parasaccites* spp., *Plicatipollenites* spp., *Potonieisporites* spp., *Crucisaccites* spp., *Barakarites* spp.) and along with few striate bisaccates (*Striatopodocrpites* spp., *Faunipollenites* spp.). The profusion of non-striate bisaccates recommends Araucarioxylon forest community or floodplain swamp (Dunay and Fisher, 1979; Scott 1982), which reveals the inception of coal vegetation. In India, nearly 99% of coal is found within the Barakar Formation (Mukhopadhyay *et al*., 2010). Formation of coal during the Artinskian is supported due to the extended transgressive phase of the Sakmarian resulting in well-sorted and clastic sediments, which are usually present in the deeper parts of the Indian Gondwana basins (Mukhopadhyay *et al*., 2010). Cool to moderately warmer conditions has been interpreted during the Barakar palynoflora of India (Tiwari and Tripathi, 1987).

Phase-IV: Roadian -Lopingian palynoflora (Barren Measures and Raniganj palynoflora) is dominated by the predominance of striate bisaccates chiefly *Striatopodocarpites* spp., *Faunipollenites* spp. (Glossopteridales) along with some stratigraphically significant forms (*Corisaccites* spp., *Lunatisporites* spp., *Guttulapollenites* spp., *Hamiapollenites* spp., *Falcisporites* spp. *Weylandites* spp., etc.). Ubiquitous Permian striate bisaccates are usually considered as an upland gymnospermous group which represents a seasonally arid climate with low humidity (Jha *et al*., 2018). Oxygen isotopic studies carried out by Chen *et al*. (2011) also suggests warm climatic conditions during the Guadalupian-Lopingian boundary.

Comparison of recovered palynoflora with other Gondwana continents

Implementation of diverse methodology such as concurrent range (South Africa), a FAD (Australia), acme zone (India) in the identification of the Gondwanan palynozones results in an only speculative connection between the palynoflora of the Gondwana continents. Besides, it the international stages are mainly based on the marine fossil (conodonts, ammonoids, foraminifers, etc.) records and radiometric dates, but, most of the Indian Gondwana sequences lack marine fossils and radiometric dates due to which accurate dating and correlation remain uncertain. Therefore, the age for the presently studied sequence is inferred by comparison with other Gondwana palynofloras and thus remains tentative. The study reveals that the palynoassemblages recorded from the present research typify the palynoassemblages of the early Permian (Artinskian) age.

The Artinskian palynoflora of the present study predominated by non-striate bisaccates *Scheuringipollenites* spp. could be tentatively equivalent to OSPZ4 of Arabia in having *Plicatipollenites* spp., *Barakarites* spp., *Striatopodocarpites* spp. (Stephenson 2016). It is also tentatively akin to the lower part of the *Striatites* Zone (Table 5) of Argentina (Playford and Dino, 2002; Souza *et al*., 2007), and lower part of the *Lueckisporites virkkiae* palynozone (LvZ) of the Parana Basin, Brazil (Souza *et al*., 2007; Mori *et al*., 2012). Presently studied palynoflora is also found tentatively akin to stage -3 of the eastern Australia (Kemp *et al*., 1977), *Striatopodocarpites fusus* zone of the Western Australia (Backhouse, 1991), *Vesicaspora* zone in having the dominance of bisaccates (Manum and Tien, 1973) and palynoassemblage of the Luwumbu Coal Measures Formation in having bisaccates (non-striate and striate) along with few monosaccates (Utting, 1976), Namwele-Mkomolo and the Moze Coalfield in Tanzania (Semkiwa *et al*., 1998).

Palaeoenvironmental interpretations inferred by palynofacies

Palynofacies Association A, which is characterized by the predominance of conifers and glossopterids along with a few spores (lycopsids, sphenopsids, and filiciopsids) in peat-forming setting during the deposition of these sediments and reflects the flourishing vegetation which bloomed in the vicinity implying the occurrence of humid palaeoclimatic conditions which also, supports the coal formation. Glossopterids grew in hygrophilous to mesophilous climate (Closas *et al*., 2005), and coniferous plants flourished in upland conditions with a temperate climate (Götz and Ruckwied, 2014, Ruckwied *et al*., 2014). The high percentage of glossopterids and conifers co-occurring with lycopsids, sphenopsids, and filiciopsids are indicative of hypo autochthonous sedimentation (Jha *et al*., 2014).

Palynofacies Association B represents the shallowest environment as dominated by structured terrestrial particles (average 54.33%) including wood fragments mainly tracheids and cuticles along with the low percentage of spore-pollen, degraded terrestrial and charcoal implies the fairly dense vegetation in the proximal settings of the site of the deposition (Marson and Pocock, 1981; Tyson, 1995; Ercegovas *et al*., 1997; McCarthy and Rubidge, 2005; Peters *et al*., 2013). Thus humid palaeoclimatic conditions support the development of the forest that likely existed in the palaeomire during the deposition of the studied borehole. The presence of lycopsids (megaspores) at the depth level of 202 m also supports the aquatic conditions.

Palynofacies Association C is characterized by the domination of black-brown oxidized particles (57.94%) along with a small percentage of degraded organic matter. Charcoal is formed as a result of oxidizing conditions of wood fragments with normal or elevated temperature (Closas *et al*., 2005; Cincotta *et al*., 2015). The abundance of charcoal implies oxidizing conditions in exposed areas of flood plains (Batten and Stead, 2002) which directly replicates the flooding episodes (Tyson, 1989; Cincotta *et al*., 2015).

Palynofacies Association D is characterized by the dominance of degraded terrestrial (67.21%) and sub-dominance of charcoal (25.28%). The preeminence of degraded terrestrial is produced as the result of fungal/bacterial degradation of woody material/cuticles/plant tissues, etc. under slight flow/waterlogged (oxygen-depleted) water settings (Tyson, 1993; 1995; Peters *et al*., 2013).

Palynofacies Association E is characterized by the dominance of amorphous organic matter (42.45%) along with

Table 5. correlation of the Artinskian palynoflora of the present study with the zonations from the other Gondwana continents.

This study borehole NP-74 Wardha Basin, India			Australia Collie Basin (Backhouse, 1991)	Tanzania (Manum and Tien, 1973)	Zambia (Utting, 1976)	South America Parana Basin, Brazil (Souza et al., 2007)	Argentina (Playford and Dino, 2002; Souza et al., 2007)
Artinskian palynoflora (Aggarwal and Jha, 2013)	Barakar Formation	*Scheuringipollenites* assemblage zone	*Praecolpatites sinuosus* Zone (basal part)	*Vesicaspora* Zone	Palynoassemblage of disaccates and few monosaccates	*Lueckisporites virkkiae* Interval Zone (basal part)	*Striatites* Zone (basal part)
	Upper Karharbari Formation	*Parasaccites-Scheuringipollenites* assemblage zone	*Striatopodocarpites fusus* Zone				

subdominance of degraded terrestrial (29.87%) and charcoal (26.72%). Spongy and membranous AOM have probably resulted from vascular land plants suggests a nonmarine origin (Batten, 1983). The oxygen-deficient conditions and low energy settings can also be inferred by the presence of AOM (Jones and Demaison, 1982; Jones, 1983; Powell *et al*., 1990).

Palaeodepositional settings in the studied sequence

In borehole NP-74 sequence, the sedimentation reflects a cyclic deposition. This repetition of carbonaceous shale with the small intercalation s of the fine-grained sandstones along with few shaley coals (Fig. 3) is presumed to suggest either an escalated rate of subsidence leading to the sinking of peat or hindered subsidence causing desiccation of the well-drained peat-forming swamps (Tavener-Smith *et al*., 1988). Similar conditions are also suggested through palynofacies studies (Palynofacies-A and B). Gradually, the deposition style changes to deposit shaley coal materials in a short moderately to poorly drained and densely vegetated peat-forming flood plain. The succession also shows an increase clastic fining upward sequences which were built up by various flooding events, which is also supported by the abundant presence of the charcoal (Palynofacies-C) the palynofacies analysis.

The principal coal-bearing unit, the Barakar Formation is extensively developed in all the Indian Gondwana coalfields. The Barakar sediments were formerly interpreted as lacustrine/ fluvial deposits (Raja Rao, 1987; Casshyap and Tewari, 1988; Bandhyopadhyay, 1996; Tewari, 1998 and many others). However, later many workers (Dutt and Mukhopadhyay, 2001; Chakraborty *et al*., 2003; Ghosh *et al*., 2004; Bhattacharya *et al*., 2012; 2018) identified possible fluvial-marine interactions from the Barakar sedimentations in some basins (Raniganj Coalfield, Damodar Basin and Mohapani Coalfield, Satpura Basin) based on trace fossils, tide-wave influence, high boron and sulfur content, etc. However, due to the unavailability of the detailed sedimentary structures, the present study did not incorporate lithofacies analysis into the palaeoenvironmental interpretation, but palynofacies studies are effective for the preliminary palaeoclimatic reconstruction.

CONCLUSIONS

1. The palynological investigation of borehole NP-74 from the Barakar Formation of the Bandar Coalfield revealed two distinct palynoassemblages and new records with palaeoclimatic significance.
2. Palynoassemblage-I (*Parasaccites-Scheuringipollenites* assemblage zone) and Palynoassemblage-II (*Scheuringipollenites* assemblage zone) show its resemblance with the upper Karharbari and the lower Barakar palynoflora of the Artinskian (early Permian) age respectively.
3. Present palynoflora supports the correlation to the Artinskian *Lueckisporites virkkiae* palynozone (LvZ) of the Parana Basin, Brazil, *Striatopodocarpites fusus* zone of Western Australia, *Vesicaspora* zone of Zambia.
4. Diverse plant deposits composed of lycopsids, filicopsids, Cordaites, conifers and glossopterids recorded in our palynoassemblages of Barakar Formation represent in a broad sense, swampy vegetation in the Lower Gondwana developed under cool-temperate and humid conditions.
5. A low energy depositional settings such as marsh/peat/ swamp has been attributed to the studied sequence as recovered palynofacies has been characterized by the dominant occurrence of well-preserved palynomorphs assemblages along with less altered woody material (structured terrestrial particle).

The palynodata available here provides significant information for palaeoenvironment reconstruction, palaeofloral diversity pattern and climate change within the early Permian sediments of the Wardha Basin. Ongoing studies will also address basin-wide palynofacies investigation of the Wardha Basin and palynostratigraphic construction of the early Permian succession.

ACKNOWLEDGEMENTS

Authors are thankful to the Director, Birbal Sahni Institute of Palaeosciences, Lucknow for providing the necessary facilities and permitting to publish the present work. The author (OS) expresses his gratitude to the Ex-Director Shri V.S. Sawakhande and the present Director Shri R. S. Kalamkar (Directorate of Geology and Mining, Govt. of Maharashtra, Nagpur) for his permission to collect the borehole samples for providing the related information. Authors also express their sincere thanks to the anonymous reviewers, for their valuable suggestions to improve the quality of this manuscript.

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Manuscript received : October 2018

Manuscript accepted : October 2019