Palynostratigraphy of Permian succession in the Mand–Raigarh Coalfield, Chhattisgarh, India and phytogeographical provincialism

Srikanta Murthy*, Ram-Awatar and Saurabh Gautam

Birbal Sahni Institute of Palaeobotany, 53 University Road, Lucknow 226 007, India.
**Corresponding author. e-mail: Srikanta_murthy22@rediffmail.com*

Palynofloras have been recorded from the Barakar Formation in the Borehole MBKW-3, Barpali–Karmitikra Block, Mand–Raigarh Coalfield, Chhattisgarh. Three distinct palynoassemblages have been identified and referred to the following palynoassemblage zones – *Gondisporites raniganjensis* (Latest Permian); *Faunipollenites varius* (latest Early Permian), and *Scheuringipollenites barakarensis* (late Early Permian). It is inferred that these deposits contain the representative palynoassamblages of Early to Late Permian in age. The First Appearance Datum (FAD)s of *Arcuatipollenites pellucidus, A. ovatus, Guttulapollenites hannonicus, Lundbladispora microconata, Alisporites opii*, *Klausipollenites* sp., and *Goubinispora indica* (at 41.95, 45.90, 98.35 m depths), indicate the closing phase of Permian, as these elements are the key species that mark a transition from Permian to the Lower Triassic. An attempt has been made here to reconstruct the phytogeographical provincialism on the basis of *Guttulapollenites* recorded in this basin.

1. Introduction

The Mand–Raigarh Coalfield is located in the central part of the Upper Mahanadi Gondwana Master Basin (figure 1) and extends over a vast stretch from Sambalpur district of Orissa in the southeast, to the Surguja district of Chhattisgarh in the northwest. The Gondwana sediments here have been subdivided into different coalfields, e.g., Ib-River, Mand–Raigarh, Korba and Hasdo-Arand. The state boundary between Chhattisgarh and Orissa is generally considered to mark the southeastern limit of Mand–Raigarh Coalfield. This coalfield actually covers the areal extents of three initially assigned coalfields, the North Raigarh, South Raigarh, and Mand River coalfields (Raja Rao 1983). Later, on the basis of tectonic and lithostratigraphic modelling, Chakraborti (2001) revised the geology of Mand Coalfield.

The north and western parts of the Mand–Raigarh Coalfield have been referred to Mand sub-basin. It is separated from the Raigarh and Ib river basin in the east by a N–S to NNE–SSW trending lineament passing the Konkori–Gersa–Sirsinga area. On the west, it is separated from the Korba–Basin by the NW–SE trending Mauhari–Machida lineament, and from the Hasdo-Arand Basin in the north by the well defined E–W trending Dhirpada–Kedma–Chornai shear zone. Within these structural boundaries, the Mand sub-basin acquired NNW–SSE to NW–SE trending asymmetrical shape, with an aerial extent of about 2000 km^2. The area is bounded by latitudes 22°05′00″–22°47′00″N and longitudes 82°55′00″–83°15′00″E (figure 2).

Palaeobotanical data from this coalfield are meagre and scattered. Though different species of *Glossopteris, Schizoneura, Vertebraria* and

Keywords. Palynology; Permian; phytogeography; Mand–Raigarh Coalfield.

J. Earth Syst. Sci. **123**, No. 8, December 2014, pp. 1879–1893

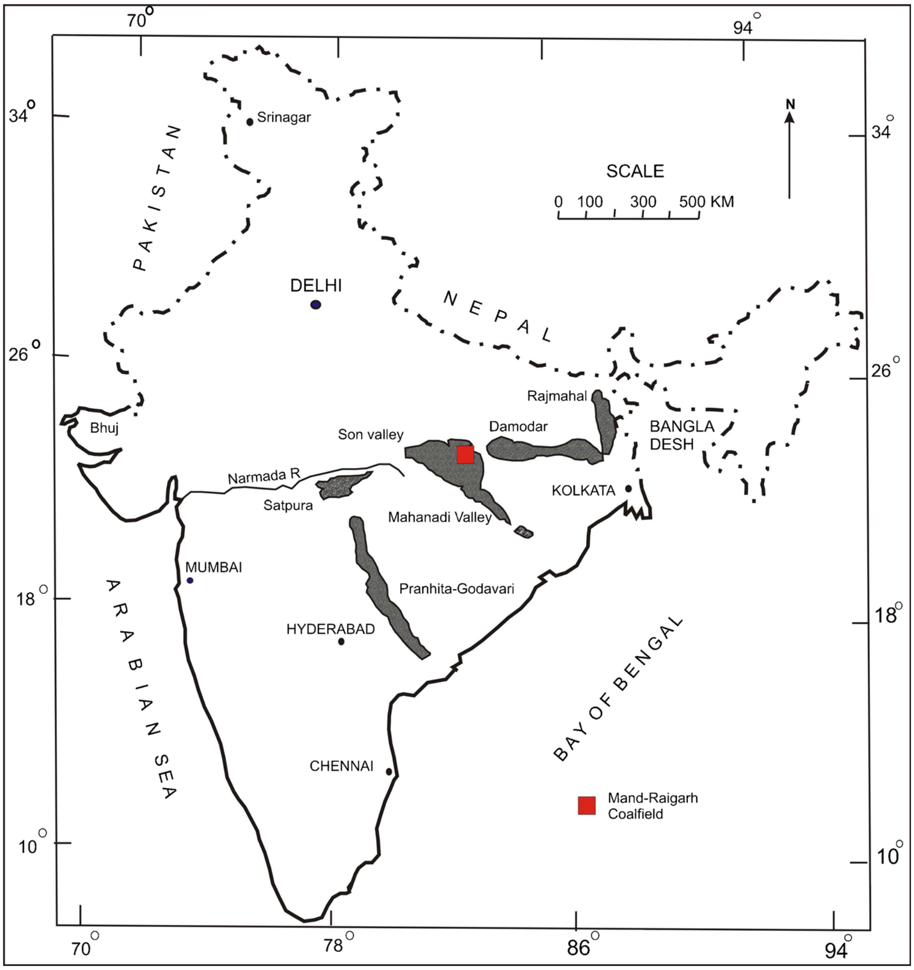

Figure 1. Map showing the study area and principal Gondwana basins of India.

Phyllotheca have been recorded by Raja Rao (1983), Chakraborti and Chakraborty (2001) have recorded Early and Middle Triassic plant megafossils from the Kamthi Formation. They also reported *Alisporites, Falcisporites, Klausipollenites* and *Weylandites* from the Kamthi Formation, near the Baronakund area, Raigarh Coalfield, Chhatisgarh. In addition, Jana *et al.* (2002), Ram-Awatar (2007) and Chakraborti and Ram-Awatar (2006) have also recorded Early–Late Permian palynoflora from this coalfield. In the present investigation, Early and Late Permian palynofossils have been recorded from subsurface (MBKW-3) samples which have an important bearing on the correlation of coal seams in the area.

2. General geology

The Gondwana sediments of the Mand–Raigarh Coalfield are classified into the Talchir, Barakar, and Kamthi formations. The geology of the Mand–Raigarh Basin has undergone a major change when regional exploration and large scale mapping was carried out over a large part of the basin by Chakraborti *et al.* (2002). On the basis of lithological attributes, the total sedimentary package of the basin has been recategorized into Talchir, Barakar, Barren Measures, Raniganj, and Kamthi formations.

In the Mand Basin, Gondwana sediments are juxtaposed with quartzites of the Chandrapur Group (Chhattisgarh Supergroup) in the southwest, and metamorphic rocks of Raigarh–Sundargarh schist belt in the northwest. The contact between the Gondwana strata and the metamorphics is faulted in nature. The general stratigraphic succession in the Mand–Raigarh Coalfield is shown in table 1.

3. Materials and methods

The samples for the present study were collected from borecore MBKW-3, located in the exploration blocks of Barpali–Karmitikra, in the northwestern part of the Mand Basin (figures 2 and 3). A total of 83 samples of varied lithofacies, comprising

Table 1. *Generalized lithostratigraphy of the Mand–Raigarh Coalfield, Chhattisgarh (after Chakraborti et al. 2002).*

Age	Formation		Thickness	Lithology
Recent to sub-Recent				Alluvial soil, pebbly to bouldery bed with silty clay band, laterite, etc.
Cretaceous	Deccan Trap		200 m+	Basaltic and doleritic flows, dykes and sills.
Lower to Middle Triassic	Supra-Panchet/ Kamthi Formation		280 m+	Buff coloured, coarse to pebbly, cross bedded, reworked shaly clasts bearing sandstone with abundant ferruginous sandstone bands with/without red claystone to siltstone or white marl bed at the base.
Upper Permian to Lower Permian	Raniganj Formation		180 – 250 m	Cyclic sequence of fine to medium grained sandstone, grey shale, claystone, carbonaceous shale and two coal seams.
	Barren Measures		280 –350 m	Interbeded sequence of sideritic claystone, grey shale, siltstone and fine grained sandstone; carbonaceous shale and some medium grained sandstone bands in the east to dominantly medium to coarse grained sandstone with interbanded sequence of sideritic claystone, grey shale, siltstone and fine grained sandstone; carbonaceous shale and light green siltstone to sandstone bands.
	Barakar Formation	Upper	180 – 220 m	Mostly medium to coarse grained sandstone with subordinate very coarse to pebbly massive arkosic sandstone. This fining upward sequence includes five regional coal seams (No. V to IX) and one local coal seam (No. VIIL). Grey claystone to siltstone bands are common at the top and bottom.
		Middle	140 – 200 m	Mostly coarse to very coarse grained sandstone with granule to pebbly sandstone at the base of each depositional sequence. Fine grained sandstone and siltstone are rarely present. It contains five to six local seams (Nos./ bands IVL1 TO IVL6).
		Lower	280 – 400 m	Mostly very coarse grained to granule sized arkosic sandstone with pink quartz and garnet grains and also with subordinate medium to coarse grained sandstone. It includes four regional coal seams (No. I – IV). Pebbly to matrix-based conglomerate bands are common. Basal 40–50 m zone is fine to medium grained with minor siltstone.
Lower most Permian to Upper Carboniferous	Talchir Formation		150 m+	Khaki to brownish green, siltstone, shale and fine grained sandstone with two boulder beds.
------------------------------------Unconformity--				
Late Proterozoic	Chandrapur Group			Variegated quartzose sandstone, calcareous, variegated shale.
------------------------------------Unconformity--				
Early Proterozoic	Bilaspur, Raigarh, Sundargarh Complex.			Vein quartz, pegmatite, granite gneiss, massive granite, etc.

mudstones, silty shales, shales, coaly shales and coal horizons from the borecore MBKW-3 (41.95–640.00 m depth) were processed for spore-pollen study. Only 75 samples have yielded rich and diverse palynotaxa. For palynological preparations, 50 gm of sediments were crushed and treated with 40% hydrofluoric acid for 3–4 days to remove silica. This was followed by treatment with nitric acid for 5 days to digest the organic matter. The residue was treated with 10% potassium hydroxide to release the humus. After thorough wash with distilled water, the residues were mixed with polyvinyl alcohol, smeared over cover glasses and kept to dry at room temperature. After complete drying, the cover glasses were fixed to slides with Canada balsam. Five slides were prepared for each sample. Microscopic observation (Olympus BX61model) was done at species level for microfloral analysis.

4. Palynological observations

The preservation of the palynomorphs is variable within the samples. Recovery is frequently very good, can be low to moderate. Specimens are yellowish–dark brown in colour, distorted, and broken to fairly well-preserved (Plates I and II; table 2). The relative occurrences of the taxa vary from rare (<1%), common (1–5%), fair (5–10%) to an abundance (11–25%) and dominant (>25%) in an assemblage, and based on changes in the palynomorphs of characteristic genera and species

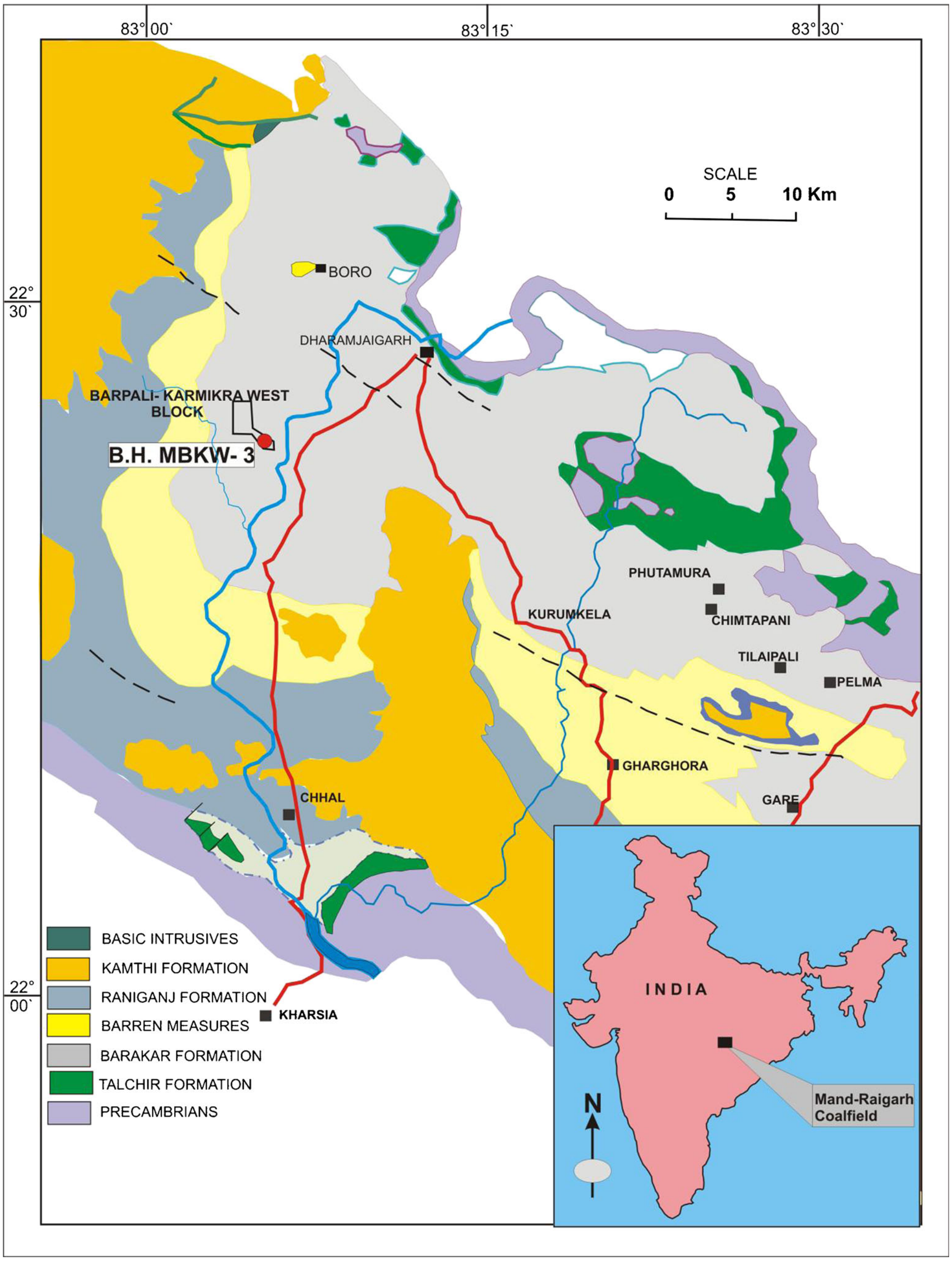

Figure 2. Geological map of Mand–Raigarh Coalfield showing location of borehole MBKW-3.

(tables 3 and 4), three palynoassemblage zones were identified in the 598.05 m thick strata of Permian successions of borecore MBKW-3. The species identified herein are listed in table 5.

4.1 *Palynoassemblage-I; Depth 41.95–98.35 m (table 4)*

Dominant: *Striatopodocarpites*
Subdominant: *Gondisporites*

The assemblage recovered from the shales, carbonaceous shales, and coal in 242.94-m thick strata is characterised by a dominance of *Striatopodocarpites* and *Gondisporites,* along with fair occurrence of *Faunipollenites* spp., *Guttulapollenites hannonicus*, *Arcuatipollenitess* spp., *Lundbladispora micorconata*, *Goubinispora indica*, *Alisporites opii* and *Klausipollenites* spp. Some palynomorphs, such as, *Microbaculispora, Microfoveolatispora, Crescentipollenites, Weylandites, Distriatites, Didecitriletes* and *Scheuringipollenites* are rare in occurrence. The FADs of *Arcuatipollenites pellucidus, Guttulapollenites hannonicus, Lundbladispora microconata* and *Klausipollenites* sp. at 41.95 m are significant,

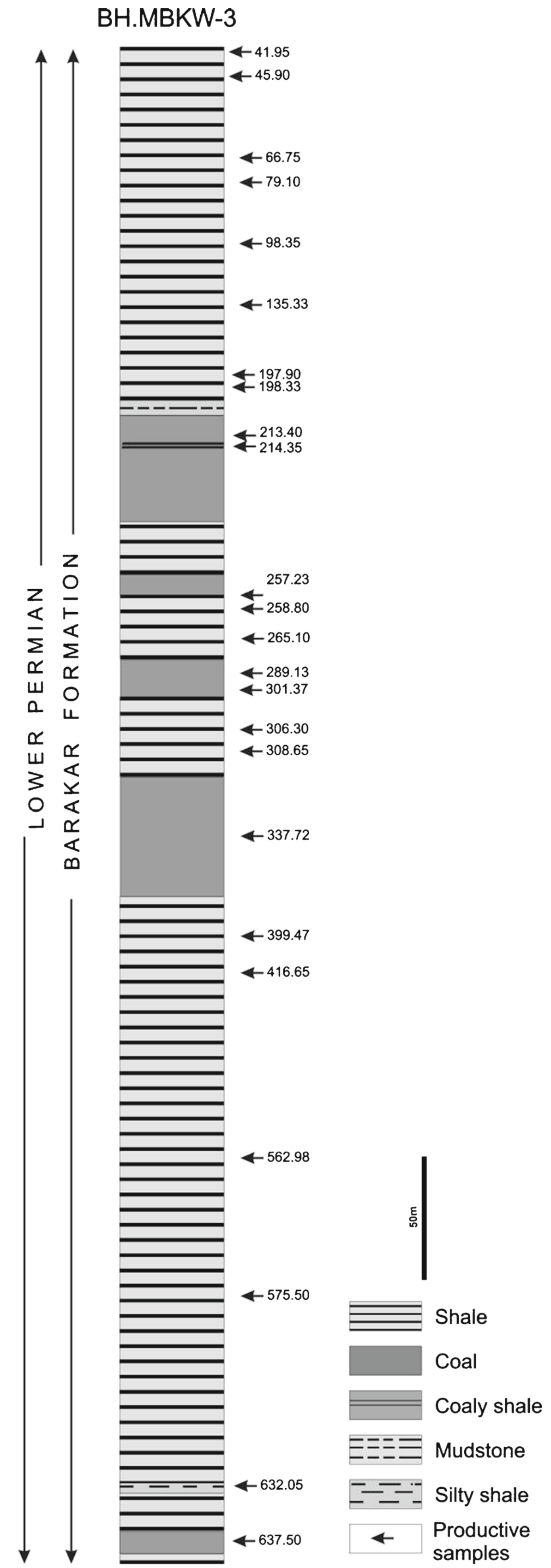

Figure 3. Lithologic column of borehole MBKW-3, Mand–Raigarh Coalfield showing individual lithofacies, and location of productive samples in the succession.

because they represent the terminal phase of Late Permian sedimentation on the Indian peninsula (Vijaya and Tiwari 1987; Tiwari and Tripathi 1992).

This composition of palynoassemblage-1 is very similar to the known palynoflora from the upper part of the Raniganj Formation in Damodar Basin in having an abundance of *Gondisporites, Striatopodocarpites,* and *Faunipollenites.* Hence, palynoassemblage-I is placed in the *Gondisporites raniganjensis* assemblage zone of Tiwari and Tripathi (1992), dated as Late Permian in age.

Palynodating: Late Permian (Raniganj Formation).

4.2 *Palynoassemblage-II; Depth 135.55–284.89 m (table 4)*

Dominance: *Faunipollenites*
Subdominance: *Scheuringipollenites*

Palynomorphs were recovered from mudstones, micaceous siltstones, shales, coaly shales and coal horizons in 149.34-m thick strata of the Barakar Formation. The striate bisaccate pollen grain *Faunipollenites* was dominant in the assemblage, while nonstriate bisaccate pollen, e.g., *Scheuringipollenites* was subdominant in this assemblage zone. Moderate to low occurrence of striate bisaccate palynomorphs like *Verticipollenites, Rhizomaspora, Dicappipollenites, Platysaccus, Striasulcites, Tiwariasporis, Weylandites, Parasaccites, Striamonosaccites* sp., *Guttulapollenites* sp., *Barakarites* sp., *Potonieisporites* sp., and nonstriate bisaccates is also recorded. Trilete spores are infrequent but are represented by *Microfeveolatispora, Microbaculispora, Brevitriletes* and *Horriditriletes.*

Palynoassemblage-II correlates with the generic acme-zone of the *Faunipollenites–Scheuringipollenites* zone in the Barakar Formation of the Damodar Basin which is late Early Permian in age (Tiwari and Tripathi 1988, 1992).

Palynodating: Late Early Permian (Upper Barakar Formation).

4.3 *Palynoassemblage-III; Depth 287.15–640.00 m (table 4)*

Dominant: *Scheuringipollenites*
Subdominant: *Faunipollenites*

The siltstones, shales, coaly shales, and coal horizons of the Barakar Formation yielded abundant and qualitatively diversified spore-pollen assemblages. Nonstriate bisaccate pollen taxon *Scheuringipollenites* was most abundant, followed by *Faunipollenites* spp., *Striatopodocarpites* and *Horriditriletes* palynotaxa recorded between the depths 287.15–337.72 m. Less common monosaccate

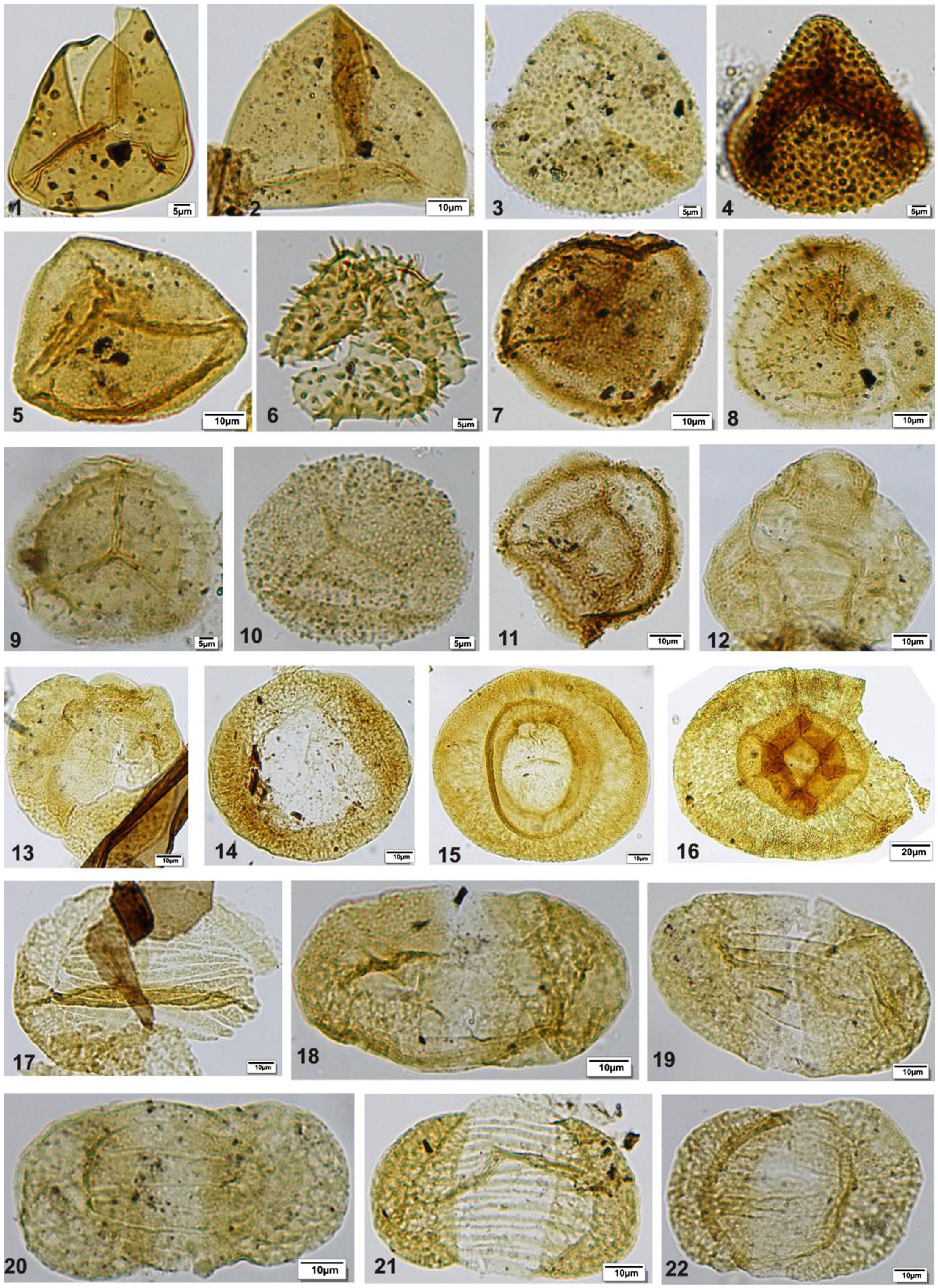

PLATE I. 1. *Lacinitriletes badamensis* Venkatachala and Kar emend. Tiwari and Singh (1981). 2. *Microbaculispora barakarensis* Tiwari emend. Tiwari and Singh (1981). 3. *Microbaculispora indica* Tiwari emend. Tiwari and Singh (1981). 4. *Didecitriletes horridus* Venkatachala and Kar emend. Tiwari and Singh (1981). 5. *Microfoveolatispora foveolata* Tiwari emend. Tiwari and Singh (1981). 6. *Acantotriletes filiformis* (Balme and Hennelly) Tiwari (1965). 7. *Gondisporites raniganjensis* Bharadwaj (1962). 8. *Lundbladispora warti* Tiwari and Rana (1981). 9. *Lundbladispora raniganjensis* Tiwari and Rana (1981). 10. *Lundbladispora willmotti* Balme emend. Playford (1965). 11. *Gondisporites* sp. 12. *Goubinispora morondavensis* (Goubin) Tiwari and Rana (1981). 13. *Goubinispora indica* Tiwari and Rana (1981). 14. *Parasaccites obscures* Tiwari (1965). 15. *Potonieisporites* sp. 16. *Potonieisporites neglectus* Potonie and Lele (1961). 17. *Striomonosaccites ovatus* Bharadwaj (1962). 18. *Faunipollenites varius* Bharadwaj emend. Tiwari *et al.* (1989). 19. *Faunipollenites singrauliensis* Sinha (1972). 20. *Striatites levistriatus* Bharadwaj and Tiwari (1977). 21. *Striatopodocarpites magnificus* Bharadwaj and Tiwari (1964). 22. *Striatopodocarpites antiques* (Leschik) Soritschewa and Sedova (1954).

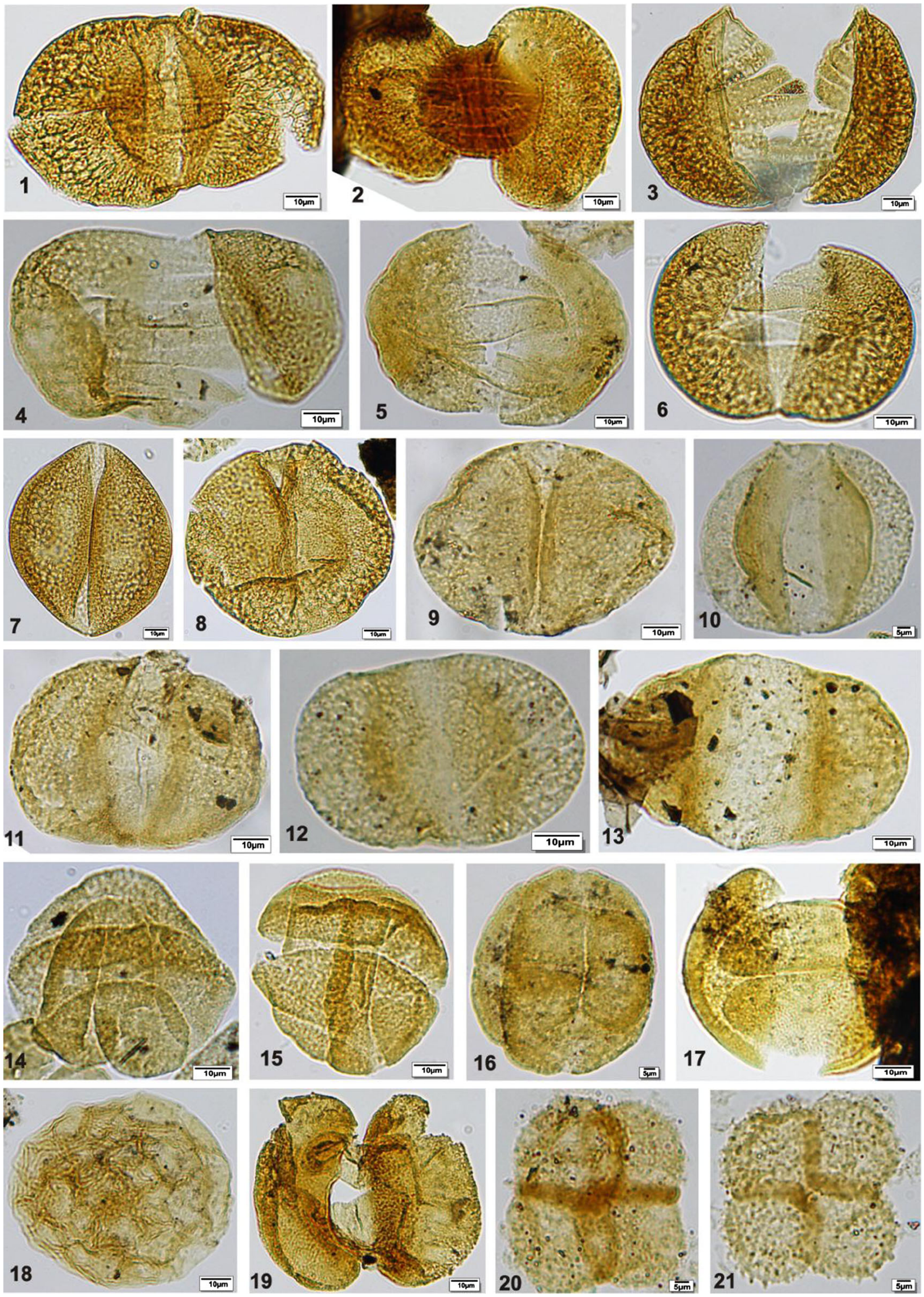

PLATE II. 1. *Crescentipollenites fuscus* Bharadwaj, Tiwari and Kar (1974). 2. *Verticipollenites gibbosus* Bharadwaj (1962). 3. *Arcuatipollenites asansoliensis* (Tiwari and Rana) Tiwari and Vijaya (1995). 4. *Arcuatipollenites pellucidus* (Goubin) Tiwari and Vijaya (1995). 5. *Arcuatipollenites paliensis* (Tiwari and Ram-Awatar) Tiwari and Viajaya (1995). 6. *Arcuatipollenites tethysensis* (Vijaya and Tiwari) Tiwari and Vijaya (1995). 7. *Scheuringipollenites tentulus* Tiwari ememd. Tiwari (1973). 8. *Scheuringipollenites maximus* (Hart) Tiwari (1973). 9. *Scheuringipollenites barakarensis* Tiwari ememd. Tiwari (1973). 10. *Alisporites ovalis* Kumar (1973). 11. *Alisporites plicatus* Kar *et al.* (1972). 12. *Falcisporites zapfei* Leschick emend. Klaus (1963). 13. *Klausipollenites schaubergeri* Potonie and Klaus emend. Jansonius (1962). 14 and 15. *Guttulapollenites hannonicus* Goubin (1965). 16. *Guttulapollenites* sp. 17. *Dicappipollenites crassus* (Sinha) Tiwari and Vijaya (1995). 18. Cf. *Maculatisporites* sp. 19. *Lueckisporites virkkiae* Potonie and Klaus in Leschic (1956). 20 and 21. *Qudrisporites horridus* Hennelly emend. Potonie and Lele (1961).

Table 2. *Details of lithofacies and spore-pollen content and composition of dispersed organic matter at different depths in Borehole MBKW-3, Mand–Raigarh Coalfield.*

Depth (m)	Lithology	Remarks
41.95	Shale	Preservation good, rich in palynomorphs and diversified, less amorphous and plant debris
45.90	Shale	Preservation bad, medium palynomorphs, exine peeled out, much plant debris-cuticle, cells and wood splinters
66.75	Shale	Preservation bad, rich palynomorphs, broken, granular sized amorphous present
79.10	Shale	Preservation bad, very less palynomorphs, much amorphous present, less plant debris
98.35	Shale	Preservation good, rich palynomorphs, less amorphous and plant debris
145.30	Shale	Preservation bad, no palynomorphs, abundance of amorphous and woody splinters
156.19	Shale	Preservation bad, medium palynomorphs, broken, exine peeled out, granular sized amorphous matter and less woody splinters present
162.10	Shale	Preservation good, rich palynomorphs, rich dark, uneven, plant debris present
197.90	Mudstone	Preservation good, rich palynomorphs, less amorphous and plant debris present
198.33	Micaceous siltstone	Preservation good, rich palynomorphs, less amorphous matter present
213.40	Coal	Preservation bad, rich palynomorphs, abundance of amorphous matter present
214.35	Shale	Preservation bad, less palynomorphs, full of dark to brown amorphous matter and woody splinters present
257.23	Coal	Preservation bad, rich palynomorphs, broken, exine peeled out, full of amorphous matter present
289.15	Coal	Preservation is bad, very less palynomorphs, full of amorphous matter present
289.60	Coal	Preservation is good, medium palynomorphs, broken, exine peeled out, granular sized, dark to dark brown amorphous matter present
300.49	Coal	Preservation is bad, less palynomorphs, less amorphous and plant debris present
301.35	Coal	Preservation is bad, less palynomorphs, broken, amorphous matter is dominance
306.30	Shale	Preservation good, rich palynomorphs, less amorphous matter and plant debris present
308.65	Shale	Preservation good, rich palynomorphs, less amorphous matter and plant debris present
315.05	Shale	Preservation is bad, medium palynomorphs, broken, exine peeled out, granular sized amorphous matter present
332.81	Coal	Preservation is bad, less palynomorphs, granular dark plant debris overlapped and woody splinter dominated
335.05	Coal	Preservation is bad, less palynomorphs, broken, exine peeled out, amorphous matter present
336.81	Coal	Preservation is bad, no palynomorphs, amorphous matter and woody shreds present
337.64	Coal	Preservation is bad, no palynomorphs, full of amorphous matter present
337.72	Shale	Preservation is good, rich in palynomorphs, less in amorphous and woody shreds
358.55	Coal	Preservation is bad, less palynomorphs, granular sized, black amorphous matter abundant
379.74	Coaly shale	Preservation is bad, less palynomorphs, granular sized, black amorphous matter abundant
381.72	Coal	Preservation is bad, no palynomorphs, full of amorphous matter present
383.03	Shale	Preservation is bad, no palynomorphs, full of amorphous matter present
384.73	Shale	Preservation is bad, no palynomorphs, full of amorphous matter present
385.53	Shale	Preservation is bad, no palynomorphs, full of amorphous matter and woody shreds present
386.73	Coal	Preservation is bad, no palynomorphs, full of amorphous matter and woody shreds present
396.38	Shale	Preservation is bad, no palynomorphs, full of dark coloured debris present
399.47	Shale	Preservation is good, less palynomorphs, dark coloured dominant
416.15	Shale	Preservation is good, no palynomorphs, abundance of quadrisporites, no woody and amorphous matter
411.93	Shale	Full of woody shreds
413.05	Shale	Preservation bad, no palynomorphs, quadrisporites dominant (distinct algae)
442.10	Silty shale	Preservation good, no palynomorphs, full of plant remains
508.70	Shale	Preservation good, no palynomorphs, full of plant remains
530.65	Shale	Preservation good, no palynomorphs, full of plant remains
561.50	Shale	Preservation good, no palynomorphs, full of plant remains
562.98	Shale	Preservation is good, rich palynomorphs, small to granular, dark amorphous matter present
575.50	Shale	Preservation bad, medium palynomorphs, broken, exine peeled out, less amorphous present
632.05	Silty shale	Preservation is good. Less palynomorphs, broken, less dark debris present
633.60	Silty shale	Preservation is good. Less palynomorphs, broken, less dark debris present
637.50	Coal	Preservation is good. Less palynomorphs, broken, less dark debris present
638.75	Coal	Full of woody shreds
640.00	Coaly shale	Full of woody shreds
641.00	Shale	Preservation is good. Less palynomorphs, broken, less dark debris present
643.84	Shale	Preservation is good. Less palynomorphs, broken, less dark debris present

Table 3. *Composition of palynoassemblages identified in borehole MBKW-3, Mand–Raigarh Coalfield, Chhattisgarh.*

Assemblage zone identified (after Tiwari and Tripathi 1992)	Lithology	Depth (m)	Palynocomposition	Significant age marker species	Age
Gondisporites raniganjensis	Shale and coal	41.95–98.35	Dominance of *Gondisporites* spp., *Striatopodocarpites* spp., *Faunipollenites* spp. and fair appearance of *Guttulapollenites* spp., *Arcuatipollenites* spp., *Lundbladisporites*, *Goubinispora* spp., and nonstriated bisaccates pollens – *Alisporites* spp., *Klausipollenites* spp. Triletes are less but represents *Microbaculispora*, *Microfoveolatispora*. Some palynomorphs less in number are *Cresentipollenites*, *Weylandites, Distriatites, Didecitriletes* and *Scheuringipollenites*	*Guttulapollenites hanonicus*, *Arcuatipollenites pellucidus*, *Goubinispora indica*	Latest Permian
Faunipollenites varius	Shale	258.8	Dominance of *Faunipollenites* spp. and *Scheuringipollenites* spp., and subdominance of *Striatopodocarpites* spp., and fair occurrence of nonstriated bisaccate. Other palynomorphs recovered are *Parasaccites*, *Striasulcites, Weylandites, Tiwariasporites* and *Microfoevolatispora*	*Faunipollenites varius* and *Scheuringipollenites gondwanensis*,	Late Early Permian
Scheuringipollenites barakarensis	Coal	289.60	Dominance of *Scheuringipollenites* spp., *Faunipollenites* spp., and *Striatopodocarpites* spp. Other palynomorphs recovered are *Crescentipollenites, Weylandites,* and fair occurrence of Triletes namely *Microbaculispora* spp., *Microfoevolatispora*	*Faunipollenites varius* *Scheuringipollenites gondwanensis* and *Striatopodocarpites*	Late Early Permian
Scheuringipollenites barakarensis	Shale	306.30	Dominance of *Scheuringipollenites* spp., subdominance of *Faunipollenites* spp., *Striatopodocarpites* spp., and *Parasaccites*. Less in count but stratigraphically important genus are *Arcuatipollenites, Weylandites* sp., triletes are less but represented by *Microfoveolatispora, Barakarites, Tiwarisporis*	*Scheuringipollenites gondwanensis* and *Faunipollenites varius*	Late Early Permian
Scheuringipollenites barakarensis	Coal	337.72	Dominance of *Scheuringipollenites* spp., subdominance of *Faunipollenites* spp., *Striatopodocarpites* spp., and *Parasaccites*. Less in count but stratigraphically important genus are *Arcuatipollenites, Weylandites* sp., triletes are less but represented by *Microbaculispora* and *Microfoveolatispora*	*Scheuringipollenites gondwanensis* and *Faunipollenites varius* and *Arcuatipollenites* sp.	Late Early Permian
	Shale	399.47	Fair occurrence of *Parasaccites*, *Plicatipollenites, Sahnites, Corricasaccites*, *Rhizomaspora, Dicappipollenites*	*Parasaccites*	
	Shale	416.65	Dominance only quadrisporites	*Qudrisporites horridites*	
		442.10–640.00	Less occurrence of nonstriate bisaccate-*Scheuringipollenites* and radial monosaccates	*Scheuringipollenites barakarensis, Parasaccate* spp.	

Table 4. *Palynologic dating in Borehole MBKW-3 (41.95–640.00 m depth), Mand–Raigarh Coalfield.*

Age/ formation		Palynoassemblages identified (Tiwari and Tripathi 1992)	Characteristics	Present status	
EARLY PERMIAN	BARAKAR	41.95–98.35 *Gondisporites raniganjesis* Assemblage Zone	Dominance of zonate spore, striate bisaccate and fair occurrence of Taeniate, nonstriate bisaccate pollen	Raniganj Formation	Latest Permian
		135.33–284.89 *Faunipollenites varius* Assemblage Zone	Dominance of striate bisaccate and subdominance of nonstriate bisaccate pollen	Barakar Formation	Late Early Permian
		287.15 – 337.72 *Scheuringipollenites barakarensis* Assemblage Zone	Dominance of nonstriate bisaccate and subdominance of striate bisaccate pollen		
		358.55 – 396.20	Very low spore pollen, rich in amorphous and plant debris		
		416.65	Dominance of Qudrisporites		
		442.10 – 640.00	Fair occurrence of radial monosaccites and nonstriate bisaccates		

taxa include *Parasaccites* spp. Other stratigraphically significant taxa in this assemblage are *Microbaculispora indica, Micorbaculispora tentula, Microfoveolatispora foeveolata, Verticipollenites* sp., *Tiwariasporis gondwanensis, Rizomaspora indica, Crescentipollenites* sp., and *Weylandites* sp.

The spore/pollen composition of palynoassemblage-III correlates with the *Scheuringipollenites barakarensis* palynozone of Barakar Formation, Damodar Basin, which is of Early Permian age (Tiwari and Tripathi 1988, 1992).

Strata between 358.55 and 640.00 m depths, which include shales, silty shales, siltstones, coaly shales, and coal, had poor spore and pollen yields (especially, *Scheuringipollenites* and radial monosaccates). Macerations contained an abundance of black woody splinters, plant tissues, and amorphous matter.

Palynodating: Late Early Permian (Lower Barakar Formation).

5. Discussion

The 598.05-m thick interval of Barakar Formation strata encountered in Borecore MBKW-3, Barpali–Karmitikra block, Mand–Raigarh Coalfield was investigated palynologically. In this litho-succession, three palynozones were identified based upon the dominance, and sub-dominance of palynotaxa, stratigraphic importance of key taxa, and their relative occurrence along with other associated significant species. Based on these palynozones, the biostratigraphic status, age and phytogeographical provincialisms of the palynoflora are discussed (table 6).

In the younger part (41.95–98.35 m) of the borecore, abundant striate bisaccate pollen taxa with zonate spores, such as *Gondisporites* (79.10–98.35 m depth) are common. These elements indicate a younger age for this part of the borecore than that of the Barakar Formation. The introduction of *Arcuatipollenites pellucidus, A. ovatus, Guttulapollenites hannonicus*, and *Lundbladispora microconata* at 41.95, 45.90, 98.35 m, and *Alisporites opii*, *Klausipollenites* sp., and *Goubinispora indica* at 41.95 m, indicate the closing phase of Permian, as presence of these key species mark a transition from Permian to the Lower Triassic.

The strata at 135.55–284.89 m had yielded very low spore and pollen grain and abundant woody and amorphous organic matters (table 2). Variants of striate and nonstriate bisaccate pollen taxa within this 149.34 m are placed in the *Faunipollenites* and *Scheuringipollenites* palynozones. This association correlates with the Barakar Formation

Table 5. *List of the palynomorph taxa identified in present study, arranged under probable plant groups.*

Palynotaxa
Sphenopsida
***Laevigatosporites* Ibrahim (1933)**
Laevigatosporites vulgaris Balme and Hennelly (1956)
Lycopsida
***Indotriradites* Tiwari (1964)**
Indotriradites sparsus Tiwari (1965)
***Gondisporites* Bharadwaj (1962)**
Gondisporites reticulatus Tiwari and Ram-Awtar (1989)
Gondisporites raniganjensis Bharadwaj (1962)
Filicopsida
***Brevitriletes* Bharadwaj and Srivastava (1969)**
Brevitriletes unicus Bharadwaj and Srivastava (1969)
***Cyclogranisporites* Potonié and Kremp (1954)**
Cyclogranisporites gondwanensis Bharadwaj and Salujha (1964)
Cyclogranisporites sbarakarensis Srivastava (1970)
***Didecitriletes* Venkatachala and Kar (1965)**
Didecitriletes horridus Venkatachala and Kar (1965)
***Horriditriletes* Bharadwaj (1962)**
Horriditriletes curvibaculosus Bharadwaj and Salujha (1964)
Horriditriletes sp.
***Microbaculispora indicus* Bharadwaj (1962)**
Microbaculispora gondwanensis Bharadwaj (1962)
Microbaculispora barakarensis Tiwari (1965)
Microbaculispora indica (Tiwari) emend. Tiwari and Singh (1981)
Microbaculispora tentula Tiwari (1965)
***Microfoveolatispora* Bharadwaj (1962)**
Microfoveolatispora bokaroensis Tiwari (1965)
Microfoveolatispora foveolata Tiwari (1965)
Gymnosperms
***Praecolpatites* Bharadwaj and Srivastava (1969)**
Praecolpatites sp.
***Tiwariasporis* Maheshwari and Kar (1967)**
Tiwariasporis flavatus Maheshwari and Kar (1967)
T. gondwanensis (Tiwari) Maheswari and Kar (1967)
***Weylandites* Bharadwaj and Srivastava (1969)**
Weylandites circularis Bharadwaj and Srivastava (1969)
Weylandites indicus Bharadwaj and Srivastava (1969)
Coniferopsida
Monosaccate
***Barakarites* Bharadwaj and Tiwari (1964)**
Barakarites indicus Bharadwaj and Tiwari (1964)
Barakarites indica Tiwari (1965)
***Distriamonosaccites* Bharadwaj (1962)**
Distriamonosaccites ovalis Bharadwaj and Salujha (1964)
***Parasaccites* Bharadwaj and Tiwari (1964)**
Parasaccites bilateralis Tiwari (1965)
Parasaccites korbaensis Bharadwaj and Tiwari (1964)
Parasaccites obscurus Tiwari (1965)
***Plicatipollenites* Lele (1964)**
Plicatipollenites gondwanensis (Balme and Hennely) Lele (1964)
***Striamonosaccites* Bharadwaj (1962)**
Striamonosaccites circularis Bharadwaj and Salujha (1964)
Striomonosaccites ovatus Bharadwaj (1962)

Table 5. *(Continued.)*

Palynotaxa
***Goubinispora* Tiwari and Rana (1981)**
Goubinispora indica Tiwari and Rana (1981)
Goubinispora triassica Vijaya and Tripathi (2008)
Goubinispora sp.
Nonstriate bisaccate
***Krempipollenites* Tiwari and Vijaya (1995)**
Krempipollenites indicus Tiwari and Vijaya (1995)
***Alisporites* Daugherty emend. Jansonius (1971)**
Alisporites opii Daugherty (1971)
Alisporites damudicus Tiwari and Rana (1981)
***Satsangisaccites* Bharadwaj and Srivastava (1969)**
Satsangisaccites nidpurensis Bharadwaj and Srivastava (1969)
***Klausipollenites* Jansoius (1962)**
Klausipollenites schaubergeri Potonie and Klaus emend Jansonius (1962)
***Falcisporites* Leschik emend. Klaus (1963)**
Falcisporites sp.
***Platysaccus* Naumova emend. Potonié and Klaus (1954)**
Platysaccus densus Kar (1968)
***Scheuringipollenites* Tiwari (1973)**
Scheuringipollenites tentulus (Tiwari) Tiwari (1973)
Scheuringipollenites maximus (Hart) Tiwari (1973)
Scheuringipollenites barakarensis (Tiwa) Tiwari (1973)
Scheuringipollenites triassicus (Bharadwaj and Srivastava) Tiwari (1973)
Striate bisaccate
***Crescentipollenites* Bhardwaj, Tiwari and Kar (1974)**
Crescentipollenites fuscus (Baradwaj) Bhardwaj, Tiwari and Kar (1974)
Crescentipollenites. Gondwanensis (Mahesh) Bharadwaj *et al.* (1974)
***Distriatites* Bharadwaj (1962)**
Distriatites bilateris Bharadwaj (1962)
***Faunipollenites* Bharadwaj (1962)**
Faunipollenites varius Bharadwaj (1962)
Faunipollenites singrauliensis Sinhas (1972)
Faunipollenites perexiguus Bharadwaj emend, Tiwari *et al.* (1989)
***Rhizomaspora* Wilson (1962)**
Rhizomaspora indica Tiwari (1965)
***Striasulcites* Venkatachala and Kar (1968)**
Striasulcites tectus Venkatachala and Kar (1968)
Striasulcites ovatus Venkatachala and Kar (1968)
***Striatites* Pant emend. Bharadwaj (1962)**
Satriatites communis Bharadwaj and Salujha (1964)
Satriatites communis Bharadwaj and Salujha (1964)
Striatites tectus Venkatachala and Kar (1968)
***Striatopodocarpites* Soritsch and Sedova emend. Bharadwaj (1962)**
Striatopodocarpites ovatus (Maheshwari) Bharadwaj and Dwivedi (1981)
Striatopodocarpites magnjficus Bharadwaj and Salujha (1964)
***Verticipollenites* Bharadwaj (1962)**
Verticipollenites oblongus Bharadwaj (1962)
Taeniate Bisaccate
***Arcuatipollenites* Tiwari and Vijaya (1995)**
Arcuatipollenites pellucidus (Goubin) Tiwari and Vijaya (1995)
Arcuatipollenites paliensis (Tiwari and Ram-Awatar) Tiwari and Vijaya (1995)
Arcuatipollenites ovatus (Goubin) Tiwari and Vijaya (1995)
Arcuatipollenites sp.
***Guttulapollenites* Goubin (1965)**
Guttulapollenites hannonicus Goubin (1965)
Guttulapollenite punctatus Venkatachala, Goubin and Kar
***Dicappipollenites* Tiwari and Vijaya (1995)**
Dicappipollenites crassus (Sinha) Tiwari and Vijaya (1995)
Dicappipollenites singrauliensis (Sinha) Tiwari and Vijaya (1995)

Table 6. *Distribution of stratigraphically significant and geographically restricted palynotaxa during Late Permian time within the Guttulapollenites showing palaeophytogeograhic province in the central part of Gondwana.*

Sl. no.	Basin/area	Formation	References
India			
1	Satpura	Bijori	Bharadwaj *et al.* (1978)
2	Godavari	Kamptee (Raniganj)	Jha and Srivastava (1996)
3	South Rewa	Pali Formation (Middle Pali)	Ram-Awatar (1996)
4	Wardha Valley	Kamthi (Late Permian)	Bhattacharya (2004)
Pakistan			
1	Salt Range	Upper Chidru	Balme (1970)
Antarctica			
1	Amery Basin	Upper Chidru	Balme (1970)
2	Bainmedart Coal Measures	Late Permian	Balme and Palyford (1967)
Madagascar			
1	Lr. Sakamena Group	Late Permian/E. Triassic	Goubin (1965)
South Africa			
1	Upper Karoo Sequence	Late Permian	Anderson (1977)
2	Tanzanian	Late Permian	Hankel (1987); Msaky and Srivastava (1997); Wescott *et al.* (1999); Weiss in Wopfner and Kayya (1999)
3	Zimbabwae	Late Permian	Falcon (1975); Osterian and Millstead (1994)
4	Zambia	Late Permian	Utting (1979)

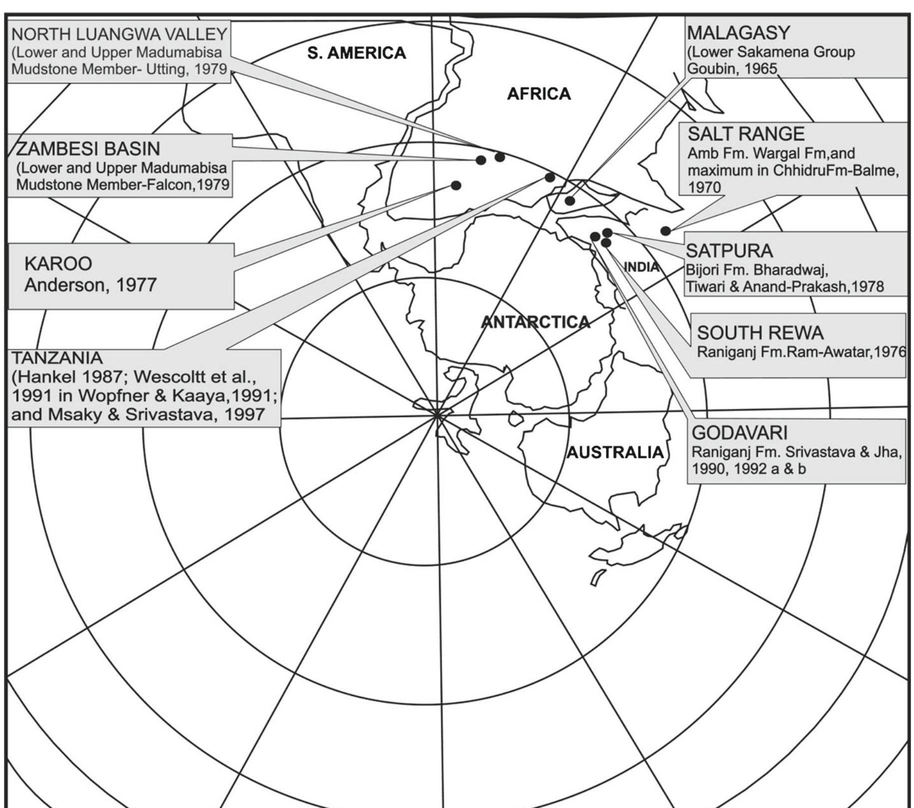

Figure 4. Distribution of stratigraphically significant and geographically restricted palynotaxa during Late Permian time in the *Guttulapollenites* palaeophytogeographic province (after Jha 2006).

of the Damodar Basin, which is late Early Permian in age (Tiwari and Tripathi 1992).

The lower part of the core between 287.15 and 640.00 m yielded predominantly nonstriate bisaccate *Scheuringipollenites* and striate bisaccate *Faunipollenites.* Based on the abundance of these pollen taxa this interval is placed in the *Scheuringipollenites–Faunipollenites* palynozone and is comparable with the Lower Barakar Formation of Damodar Basin of late Early Permian age (Tiwari and Tripathi 1992). In general, the specimens are poorly preserved with an abundance of vegetal matter and dark broken wood debris (table 2).

The cyclic sequence of siltstones, mudstones, shales, coaly shales, and coal facies of the Barakar Formation (41.95–640.00 m) is not consistently productive palynologically. Previously, this litho-succession was considered to be Early Permian in age (GSI, table 1 and figure 2).

The infrequent occurrence of *Scheuringipollenites, Faunipollenites, Striatopodocarpites* and radial monosaccates, along with abundance of plant remains and amorphous matter between 358.55 and 640.00 m is indicative of the Barakar Formation.

6. Phytogeographic provincialism

It is well documented that the palynotaxa *Guttulapollenites* is known from most, if not all, of the Gondwana continents (India, Australia, Madagascar, Africa, Antarctica and Salt Range). In the Assemblage Zone-I (*Gondisporites raniganjensis*), a large number of striate bisaccate and taeniate pollen were recorded in association with *Guttulapollenites*. This genus was first reported by Goubin (1965), and later emended by Venkatachala *et al.* (1967). To date, only two species are known; *Guttulapollenites hannonicus* and *G. gondwanensis* were recorded by Goubin (1965). In addition, *Guttulapollenites* is known from all the Gondwanan continents (table 6, figure 4).

Outside former Gondwanaland, *Guttulapollenites* has also been recorded from the Triassic sediments in the Netherlands by Visscher (1966). The occurrence of *Guttulapollenites* in the Netherlands may be due to migration along the southern Tethys coast into Europe (Bharadwaj 1976).

It is generally believed that two phytogeographic provinces: an Africa/West Gondwanaland and an Australia/East Gondwanaland existed (Truswell 1980). Within the accepted model of the supercontinent Gondwanaland, it is opined that it contained two segments; the west Gondwanaland province that includes Africa and South America and the east Gondwanaland province consisting Antractica, Australia and India. Recently, Jha (2006) suggested based on palynology that there were three palaeophytogeographical provinces during Late Permian period. They are the East Gondwana Floral Province (Australia and part of Antractica, N–E part of India, viz., Arunachal Pradesh); West Gondwana Floral Province (South America and western half of Africa); and Central Gondwana Floral Province (Antarctica, southern part of Africa, Madagascar, India and Pakistan (figure 4)).

During the Late Permian time, India and south-eastern Africa (Kenya, Tanzania, Zimbabwe and South Africa) were located in the same latitudinal position, approximately 40°–60° south of the equator (Bharadwaj 1976). It is possible that during Permian time both continents (India and Africa) were connected, which has been suggested by an earlier study (Medlicot and Blanford 1879). On the Gondwana supercontinent *Guttulapollenites* is the only taxon that has been recorded from India, Pakistan (Salt Range), Malagasy, Africa and Antarctica constituting a distinct phytogeographic province. The occurrence of abundant *Guttulapollenites* from the Mand–Raigarh Coalfield indicates that same phytogeographic province existed in India and South Africa.

7. Conclusions

- Three palynoassemblages have been identified from borecore MBKW-3 in the Mand–Raigarh Coalfield and are indicative of Early to Late Permian age.
- The Raniganj Formation was intersected between 41.95 and 98.35 m depth. The Lower Barakar and Upper Barakar Formation were identified between 135.55–284.89 and 287.15–640 m, respectively.
- The occurrence of abundant *Guttulapollenites* in the assemblages, attests to the existence of phytogeographic provincialism in the Gondwana supercontinent.

Acknowledgements

Authors are thankful to Prof. Sunil Bajpai, Director, BSIP, Lucknow for kind permission to publish this work. They extend their sincere thanks to the Dy. DG and officers of the Coal Wing Division, Geological Survey of India, Kolkata, for providing borecore samples for the present study. They also extend sincere thanks to reviewer Dr Cortland Eble, Kentucky Geological Survey, University of Kentucky for encouragement, suggestions and comments, which have greatly improved the earlier version of the manuscript. One of the authors (Saurabh Gautam) expresses his gratitude to the UGC, New Delhi for granting the RGNF Fellowship to carry out Ph.D. work at BSIP, Lucknow.

References

Bharadwaj D C 1976 Palaeogeograhy of India during Gondwana time and its bearing on the climate; *Geophytology* **6** 153–161.

Chakraborti B 2001 New palaeobotanical evidence for Early Triassic to Middle Triassic age for the lower most red bed of Kampthi Formation, Raigarh Gondwana Basin, M.P; In: Proc. Natl. Sem. on Recent Advances in Coal and Lignite Basins of India, Calcutta 1997 (eds) Dutta *et al.*, *Geol. Surv. India Spec. Publ.* **54** 113–122.

Chakraborti B and Chakraborty S 2001 Triassic floral assemblage from Baronakunda, Raigarh Gondwana basin, Madhya Pradesh; In: Proc. Natl. Sem. on Recent Advances in Geology of Coal and Lignite Basins of India; *Geol. Surv. India. Spec. Publ.* **54** 103–112.

Chakraborti B and Ram-Awatar 2006 Inter-relationship of the palynofloral assemblages from Mand Coalfield, Chhattisgarh and its significance; *Indian Minerals* **60(3&4)** 153–170.

Chakraborti B, Roy D K, Rajaram K N and Mukhopadhyay G C 2002 Final report on regional exploration for coal in Ongana–Potiya area, Mand Coalfield, Raigarh District, Chhattisgarh; *Unpubl. Rep. Geol. Surv. India, Coal Wing.*

Goubin N 1965 Description et repartition des principaux pollenites permicns, triassiques et jurassiques des sondages du basin de Morondava (Madagascar); *Revue Institut Francais du Petrole* **20** 1415–1461.

Jana B N, Bhattachryya A P and Chakraborti B 2002 Permian palynological succession from Mand–Raigarh Coalfield, Chhattisgarh; *J. Geol. Soc. India* **59** 537–546.

Jha Neerja 2006 Permian palynology from India and Africa – A phytogeographical paradigm; *J. Palaeontol. Soc. India* **51(1)** 43–55.

Medlicot H B and Blanford W T 1879 A manual of geology of India; *Geol. Surv. India* **1** 1–144.

Raja Rao C S 1983 Coal resources of Madhya Pradesh, Jammu and Kashmir Coalfields of India, Mand–Raigarh Coalfield, Madhya Pradesh; *Bull. Geol. Surv. India* **45(3)** 12–20.

Ram-Awatar 2007 Palynostratigraphy and depositional environment of Lower Gondwana sediments in Raigarh Basin, Chhattisgarh, India; In: *Micropalaeontology: Application in Stratigraphy and Palaeoceanography* (ed.) Devesh K Sinha, pp. 71–79.

Tiwari R S and Tripathi A 1988 Palynological zones and their climatic inference in the coal bearing Gondwana of peninsular India; *Palaeobotanist* **36** 87–101.

Tiwari 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.

Truswell E M 1980 Permo-Carboniferous palynology of Gondwanaland: Progress and problem in the decade to 1980; *BMR J. Geol. Geophys.* **5** 95–111.

Venkatachala B S, Goubin N and Kar R K 1967 Morphological study of *Guttulapollenites* Goubin; *Pollen Spores* **9(2)** 357–362.

Vijaya and Tiwari R S 1987 Role of spore pollen species in identification of Permo-Triassic boundary in Raniganj Coalfield, West Bengal; *Palaeobotanist* **35** 242–248.

Visscher H 1966 Palaeobotony of the mesophytic. III. Plant micofossils from the upper Bunter of Hengeol, The Netherlands; *Acta Botanica Neerlandica* **15** 316–375.

MS received 6 January 2014; revised 13 June 2014; accepted 14 June 2014