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Palynostratigraphy and correlation of the coal bearing Gondwana sediments in the Kothagudem sub basin of the Godavari Graben, South India

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ABSTRACT

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The present investigation deals with the palynology of five sections from the Kothagudem sub–basin of the Godavari Graben, India to unravel the biostratigraphy and palaeovegetation. The palynological analysis in the five sections of Rampur, Hemchandrapuram and Kothagudem areas revealed the presence of Karharbari (Palynozone–I), lower Barakar (Palynozone–II) and Raniganj (Palynozone–III) equivalent palynofloras in lithologically designated Barakar Formation. Palynozone–I is dominated by cordaitalean radial monosaccate pollen grains (*Parasaccites* spp., *Plicatipollenites* spp.) and trilete spores (*Callumispora* spp.) which represent colder climatic conditions. Palynozone–II is chiefly dominated by non–striate bisaccate (*Scheuringipollenites* spp. and *Ibisporites* spp.) and striate bisaccate (*Faunipollenites* spp., *Striatopodocarpites* spp.) grains of conifer and glossopterid origin indicating presence of peat–forming plants and conducive climatic condition for the coal formation. Palynozone–III is mainly dominated by striate bisaccate pollen grains of glossopterid origin along with conifer (*Faunipollenites* spp., *Striatopodocarpites* spp., *Crescentipollenites* spp.) and peltasperm (*Falcisporites* spp., *Chordasporites* spp.) pollen grains representing hot and humid conditions. Palynozone–III is characterized by the dominance of striate bisaccate taxa along with stratigraphically significant palynomorphs (*Corisaccites* sp., *Guttulapollenites* sp., *Lunatisporites* sp., *Chordasporites* sp., *Falcisporites* sp., etc.). On the basis of palynofloral composition Palynozone–I, II and III have been assigned to the Sakmarian (upper Karharbari), Artinskian (lower Barakar) and Lopingian (Late Permian) age respectively.

Key–words—Permian, Lower Gondwana, Kothagudem sub-basin, Sakmarian, Artinskian, Lopingian.

गोदावरी द्रोणिका, दक्षिण भारत के काठागुडेम उप द्रोणी में कोयला दिकमान गोंडवाना अवसादों की परागाणु स्तरिकी एवं सहसंबंध

नेहा अग्रवाल, श्रेया मिश्रा, नीरझा झा एवं पी.वी. शंकर राव

सारांश

जैवस्तरिकी एवं पुरावनस्पति सुलझाने को गोदावरी द्रोणिका, भारत के कोठागुडेम उपद्रोणी से प्राप्त 5 खंडों की परागाणु विज्ञान से यह अन्वेषण सरोकार रखता है। रामपुर, हेमचन्द्र पुरम एवं कोठागुडेम क्षेत्र के 5 खंडों में परागाणविक अन्वेषण ने अश्मविज्ञान संबंधी नामांकित बराकार शैलसमूह में करहरबाड़ी (प्रथम परागाणु मंडल), अधोबराकार (द्वितीय परागाणु मंडल) और रानीगंज (तृतीय परागाणु मंडल) तुल्य परागाणु वनस्पतिजात की विद्यमानता उद्घाटित की। प्रथम परागाणु मंडल कार्डेटेलीन अर्द्ध व्यास एकल सपुट पराग दानों (*पैरासैकाइटिस* जातियां तथा *प्लीकेटीपॉलेनाइटिस* जातियां) एवं त्रिअरीयों से प्रभावित है जो शीत लहर जलवायवी स्थितियां रूपायित करता है। द्वितीय परागाणु मंडल

मुख्यतः गैर रेखीय द्विसपुट (*श्यूरिंगीपॉलेनाइटिस* जातियां और *आईबीस्पोराइटिस* जातियां) एवं शंकुवृक्ष के रेखीय द्विसपुट (*फॉनीपॉलेनाइटिस* जातियां एवं *स्ट्रिएटोपॉलेनाइटिस* जातियां) से प्रभावित है तथा ग्लॉसोप्टेरिड उद्गम कोयला शैलसमूह हेतु गाद–गठन पादप और सहायक जलवायवी स्थिति की विद्यमानता व्यंजित कर रहा है। तृतीय परागाणु समुच्चय शंकुवृक्षों (*फॉनीपॉलेनाइटिस* जातियां, *स्ट्रिएटोपोडोकार्पाइटिस* जातियां एवं *क्रिसेंटीपॉलेनाइटिस* जातियां) के साथ ग्लॉसोप्टेरिड उद्गम के रेखीय द्विसपुटों तथा पेल्टास्पर्म (*फाल्सीस्पोराइटिस* जातियां एवं *कॉर्डास्पोराइट्स* जातियां) पराग दानों से मुख्यतः प्रभावित है, कोष्ण आर्द्र स्थितियां रूपायित कर रहा है। तृतीय परागाणु मंडल स्तिरिक रूप से महत्वपूर्ण परागाणु संरूपों (*कोरीसेकाइट्रिस* जाति, *गुट्टुलापॉलेनाइट्रिस* जाति, *लुनेटीस्पोराइट्रिस* जाति, *कॉर्डास्पोराट्रिस* जाति एवं *फाल्सीस्पोराइट्रिस* जाति) के साथ रेखीय द्विसपुटों की प्रभुत्वता से अभिलक्षणित है। परागाणु पुष्पी संघटन के आधार पर परागाणु मंडल–प्रथम, द्वितीय एवं तृतीय क्रमशः सकमारियन (ऊपरी करहरबाड़ी), अर्टिन्सकियन (अधो बराकार) एवं लोपिनजियन (विलंबित पर्मियन) काल को नियत किए गए हैं।

सूचक शब्द—परमियन, निम्न गोंडवाना, कोठागुडेम उपद्रोणी, सकमारियन, आर्टिन्सकियन, लोपिनजियन।

INTRODUCTION

PALYNOLOGY is the study of the pollen grains and spores of plants. In the wider sense, it also comprises the study of microfossils other than pollen grains and spores, e.g. cysts, cyst–like bodies of algae or unknown origin. Spores and pollen grains represent the sexual stage in the land plant life cycle. Their exinal wall is composed of sporopollenin and can resist degradation in the sediments and gets fossilized (Elsik, 1971; Havinga, 1971). The sporopollenin is one of the most chemically inert biological polymers.

In the industrial sector, India is a developing country for which plenty of energy resources are needed. Fossil fuel like coal is still an important source of energy in India. Coal is mainly confined to the lower (Barakar Formation) and upper (Raniganj Formation) coal bearing horizons of the Permian period. Identification of coal seams on the basis of lithology and other parameters (ash, moisture, grade, thickness) is a bit problematic due to the cyclicity of sediments in the Godavari Graben (Lakshminarayana, 1996).

Palynological analysis can be used as one of the tools in addition to coal parameters for identification, correlation, and vertical and lateral extensions of coal seams (Jha & Aggarwal, 2012; Mishra *et al.,* 2016). Pollen and spores in the rocks of different times are different in their qualitative (morphological) and quantitative (frequency of occurrence of different palynomorphs) attributes. These differences and presence of particular types of pollen and spores characterize a particular horizon (Tiwari & Tripathi, 1992). Correlation of coal and associated sediments is performed by comparing the palynofloras of different areas. In the present investigation, an attempt has been made through palynological studies in three areas (Rampur, Hemchandrapuram and Kothagudem) of the Kothagudem sub–basin of the Godavari Graben, India for biostratigraphic and palaeovegetational investigations.

GEOLOGY

The Godavari Graben is an NW–SE trending intra–cratonic basin. It covers an area of about 17000 sq. km and bounded by latitudes 16º38' to 19º32' N and longitudes 79º12' to 81º39' E. The basin is unique in preserving huge coal deposits and almost complete Gondwana sequence ranging from the late Carboniferous? / early Permian to Cretaceous is present. The basin has been developed after the amalgamation of the Dharwar and Bastar cratons during the Palaeoproterozoic. The basin has various faults, comprising discontinuous, intersecting and overlapping faults in lateral, projecting in normal orientation. These extreme faulting patterns resulted in the formation of a series of fault–bounded NNW–SSE grabens and half–grabens (Raiverman *et al.,* 1986; Pande & Tiwari, 1994). Structurally, the basin has been divided into four sub–basin, *viz.* Godavari, Chintalapudi, Kothagudem and Coastal Gondwana Tract of Krishna Godavari Basin (Raja Rao, 1982). Generalized stratigraphy of the Gondwana sediments in the Godavari Graben has been shown in Table 1.

Amongst four sub–basins, Kothagudem sub–basin (Fig. 1) is least explored, hence, the present investigation has been undertaken. This sub–basin is rich in the Lower Gondwana deposits. The Gondwana rocks of the basin unconformably overlie the Dharwar schists and gneiss. The Lower Gondwana rocks (Permian) of the sub–basin include the Talchir, Barakar, Barren Measures and Kamthi formations. Lithologically, overall the Permian succession is represented by sandstone, siltstone and shale, however, the Barakar Formation is distinguished by coal seams alternating with shale bands. The Upper Gondwana deposits are not found in this sub–basin (Lakshminarayana, 1996).

MATERIAL AND METHODS

The present study deals with the analysis of fossil pollen and spores, which were found deposited along the sediments forming sedimentary rocks. The rock samples mainly include palynomorphs rich lithologies, i.e. shale, coal and carbonaceous shale. Recovery of palynomorphs from the rock samples is done by the usual maceration technique proposed by Faegri and Iversen (1975). The extraction of the palynomorphs includes crushing of samples up to 2–5mm size followed by the treatment with various chemicals. Samples were primarily treated with HF (40%) followed by

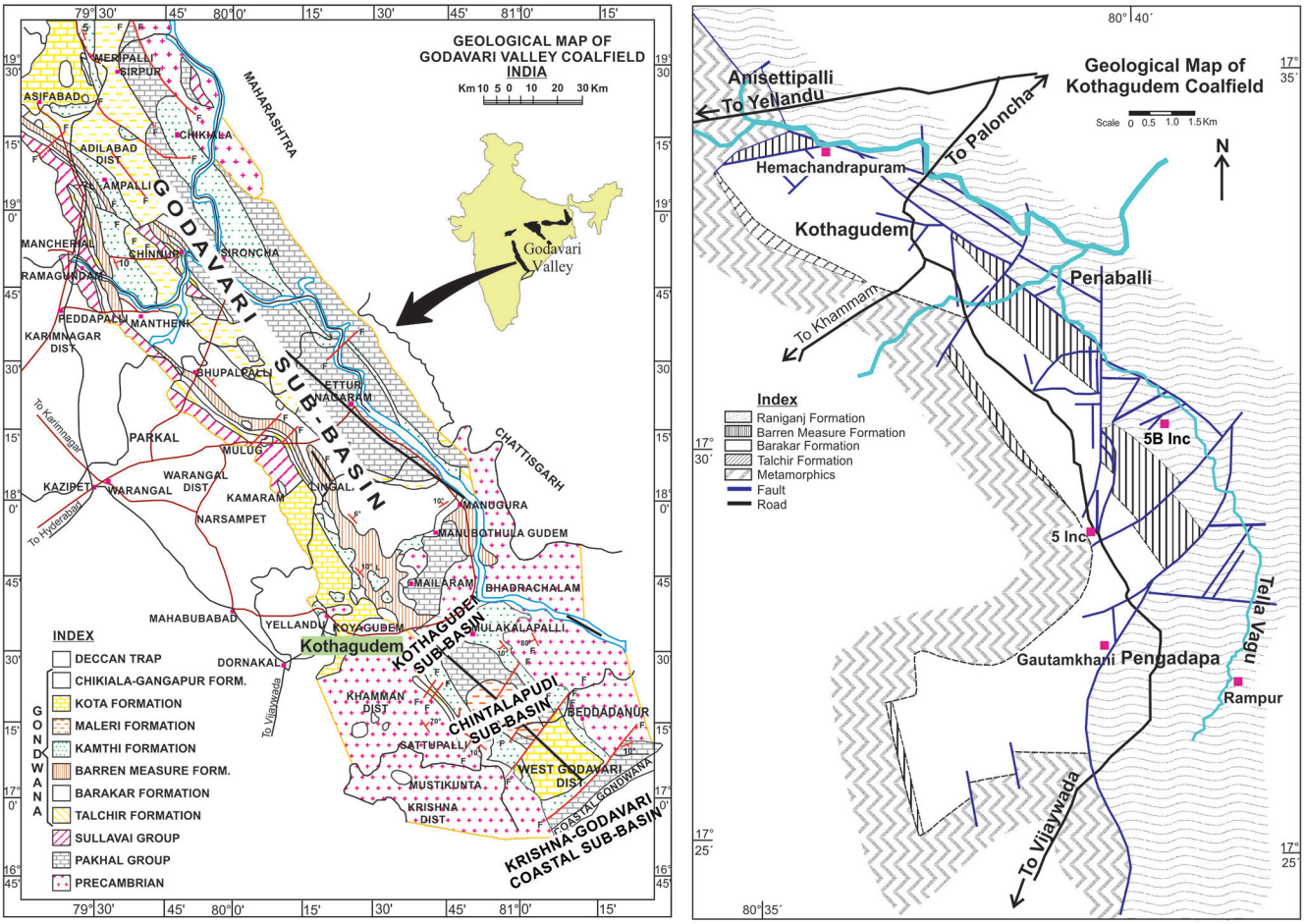

Fig. 1—A. Detailed geological map of the Godavari Graben, showing the location of all the four sub–basins (after SCCL), B. Geological Map of the Kothagudem Coalfield and location of the areas included in the present study (after SCCL).

HNO_3 (63%) for dissolving silicates and humic substances, respectively. The residue after this chemical treatment is retained and further treated by KOH (10%) solution. Washing is done after each chemical treatment using a 400 mesh sieve. Permanent slides were made using polyvinyl alcohol and canada balsam. Olympus BX–61 microscope is used for microscopic studies and DP25 along with CELL–A, software for photography of the palynomorphs. All slides have been deposited in the repository of BSIP (Slide No. 16173–16183).

RESULTS

For the present investigation, the samples collected from different areas (Rampur, Hemchandrapuram and Kothagudem) of the Godavari Graben have been palynologically analyzed. The vertical distribution of various palynomorphs has been represented in Fig. 2 and Table 2. A list of recovered spore–pollen and their affinities have been given in Table 3, and significant photomicrographs have been shown in Pl. 1 and Pl. 2. Palynologically, three distinct palynozones (Fig. 3) have been identified:

Palynozone–I

Palynozone–I has been identified in King Seam of section SR–34 (sample no. 9; Table 2) from Rampur area. This palynozone is characterized by the dominance of monosaccates of cordaitaleans and conifer origin, *viz*. *Parasaccites* (40%: *P. diffuses, P. bilateralis, P. densicorpus, P. obscurus, P. distinctus, P. korbaensis*), *Plicatipollenites* (15%: *P. densus, P. gondwanensis, P. indicus*) and *Divarisaccus lelei* (7%). Very few *Potonieisporites* species are also present in this palynozone. Triletes are represented by fillicopsid spores, *Callumispora* (15%: *C. barakarensis, C. gretensis*) and *Microbaculispora* (7%: *M. tentula, M. villosa, M, gondwanensis*). Very few glossopterid striate bisaccate (*Faunipollenites*–5%: *F. varius, F. perixiguus*; *Striatites*–2%: *S. parvus, S. varius*) and conifer non–striate bisaccate pollen

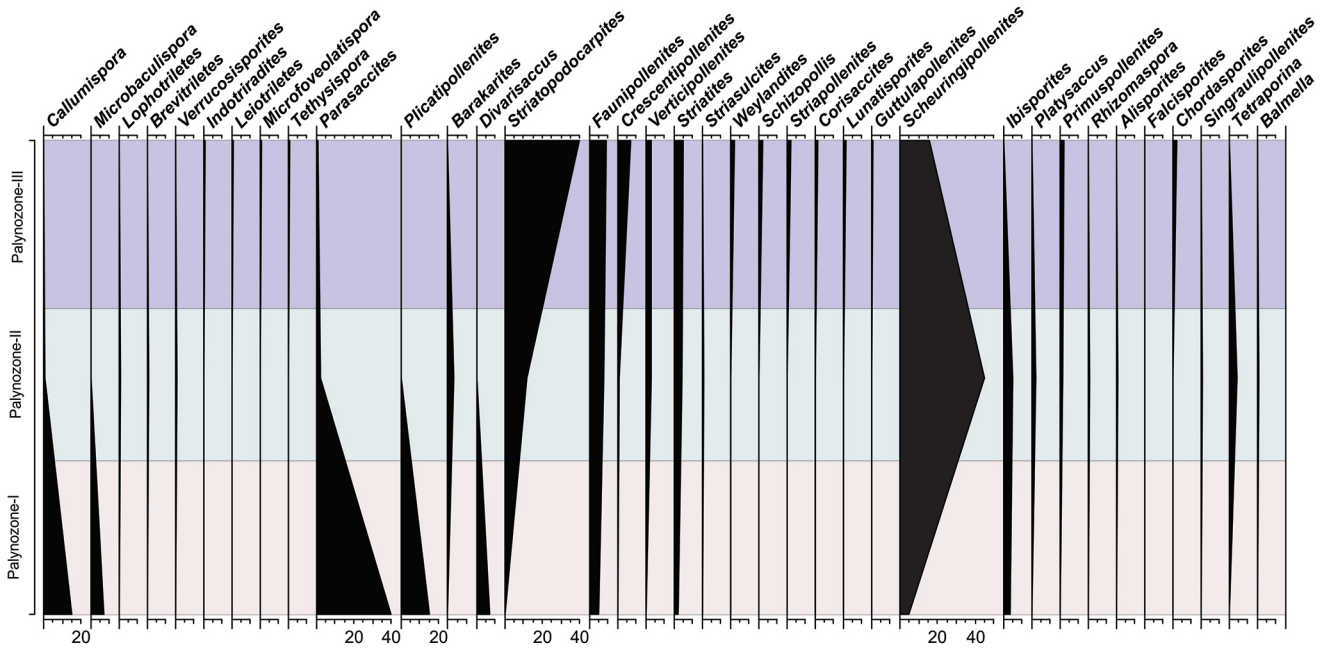

Fig. 2—Frequency distribution of different palynomorphs recovered in the present study.

(*Scheuringipollenites*–5%: *S. maximus, S. barakarensis*); *Ibisporites diplosaccus* (4%) have also been reported.

Age: Sakmarian (Aggarwal & Jha, 2013)

Comparison

Intracorrelation

Palynozone–I compares well with Assemblage–1 of Ramakrishnapuram (Srivastava & Jha, 1989), Palynozone–3 of Ramakrishnapuram (Srivastava & Jha, 1992a), Palynoassemblage–2 of the Manuguru area (Srivastava & Jha, 1992b), upper Karharbari Palynozone of the Chintalapudi sub–basin (Srivastava & Jha, 1993), Palynozone–1 of the Koyagudem area (Srivastava & Jha, 1996), upper Karharbari palynoassemblage of the Wardha Basin (Jha *et al.,* 2011), Palynozone–2 of the Mailaram area (Jha & Aggarwal, 2012) and Palynoassemblage–III of the Chintalapudi sub–basin (Jha *et al.,* 2018).

Intercorrelation

Palynozone–I shows resemblance with Zone–2 of the Korba Coalfield (Bhardwaj & Srivastava, 1973), Zone–2 of the Raniganj Coalfield (Tiwari, 1973), Zone–2 of the Johilla Coalfield (Anand–Prakash & Srivastava, 1984), Zone–2 of the Umaria Coalfield (Srivastava & Anand–Prakash, 1984), Zone–1 of Shobhapur block, Pathakhera Coalfield (Srivastava & Sarate, 1989), Assemblage–I of the Shobhapur and Pathakhera Coal Mine from the Pathakhera Coalfield (Sarate, 1986), Assemblage–A of the Wardha Coalfield (Bhattacharyya, 1997) and palynoassemblage of the Umrer Coalfield (Jha *et al.,* 2007).

PALYNOZONE–II

Palynozone–II has been distinguished in Queen Seam of section SR–34 from Rampur area (sample no. 3–7), Queen Seam of the Hemchandapuram area (4 samples), and top seam of 5 incline of the Kothagudem area (one sample).

PLATE 1

1. *Callumispora barakarensis,* B.S.I.P. Slide No. 16173, N35.
2. *Parasaccites korbaensis,* B.S.I.P. Slide No. 16174, W45/2.
3. *Parasaccites diffuses,* B.S.I.P. Slide No. 16175, P46/1.
4. *Potonieisporites* sp*.,* B.S.I.P. Slide No. 16176, O54/1.
5. *Scheuringipollenites maximus,* B.S.I.P. Slide No. 16177, Q43/1.
6. *Ibisporites diplosaccus,* B.S.I.P. Slide No. 16177, X60/2.
7. *Tiwariasporis simplex,* B.S.I.P. Slide No.16178, V29.
8. *Primuspollenites dicavus,* B.S.I.P. Slide No. 16179, U57.
9. *Vestigisporites rudis*, B.S.I.P. Slide No. 16180, U64.
10. *Scheuringipollenites barakarensis,* B.S.I.P. Slide No. 16173, N63/1.
11. *Faunipollenites varius,* B.S.I.P. Slide No. 16173, M47/4.
12. *Striatopodocarpites globosus,* B.S.I.P. Slide No. 16175, J44/3.

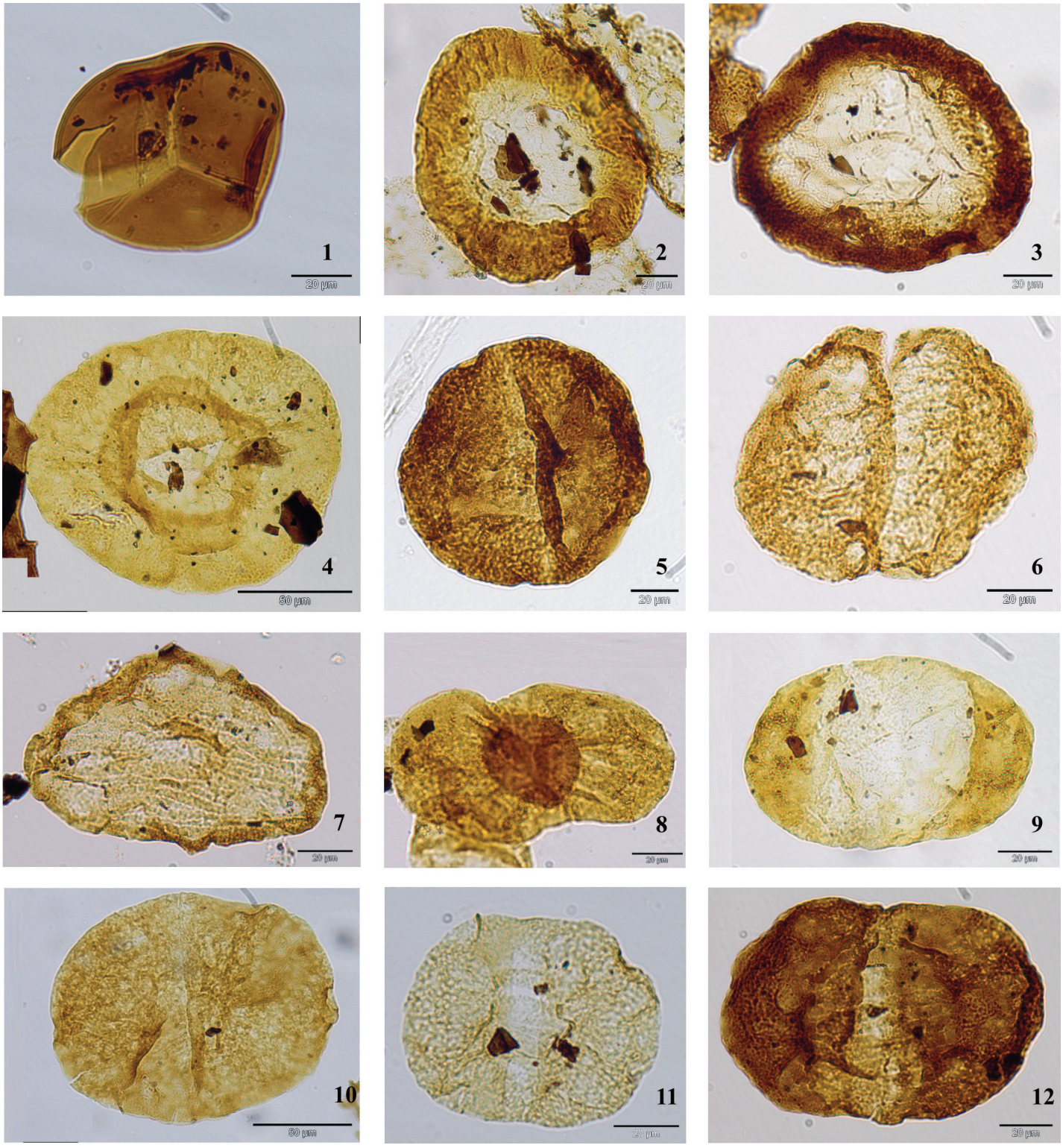
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PLATE 1

This Palynozone is represented by the increased incidence of pollen, *viz*. *Scheuringipollenites* (43–59%: *S. barakarensis, S. maximus, S. tentulus, S. minutes*), *Ibisporites diplosaccus* (5%), *Platysaccus* (2–3%; *P. levis, P. dicavus*), *Primuspollenites levis* (1–2%), *Rhizomaspora* (1%), *Alisporites indicus* (1%) and few *Vestigisporites rudis*. Striate bisaccates of glossopterid origin are represented by *Striatopodocarpites* (9–18%: *S. diffuses, S. ovatus*), *Faunipollenites* (7–14%: *F. bharadwajii, F. parvus, F. varius*), *Striatites* (4–6%: *S. solitus, S. parvus, S. communis*), *Verticipollenites* (3%: *V. secretus, V. subcircularis*), *Striasulcites tectus* (1%) and *Crescentipollenites fuscus* (1%). Cordaitalean monosaccate pollen have declined and represented by only two palynotaxa, *Parasaccites* (3–4%: *P. korbaensis, P. diffuses*) and *Barakarites* (3%: *B. indicus, B. crassus*). The understory flora is dominated by fillicopsid spores like *Lophotriletes rectus* (1%), *Brevitriletes unicus* (1%), *Callumispora barakarensis* (1%) and equisetalean spores (*Verrucosisporites distinctus*–1%). Algal spores are also present in this palynozone and represented by *Singraulipollenites* sp. (1%), *Tetraporina* sp. (4%) and *Balmella* sp. (1%).

Age: Artinskian (Aggarwal & Jha, 2013)

Comparison

Intracorrelation

Palynozone–II compares well with Palynozone–4 of the Ramakrishnapuram (Srivastava & Jha, 1992a), Manuguru area (Srivastava & Jha, 1992b), Budharam area (Srivastava & Jha, 1995), Palynozone–2 of the Koyagudem area (Srivastava & Jha, 1996) in showing the dominance of *Scheuringipollenites* in conjunction with striate disaccate taxa, *viz*. *Faunipollenites, Striatopodocarpites*, Palynozone–3 of the Mailaram area (Jha & Aggarwal, 2012), Palynoassemblage–I of the Kachinapalli area (Jha & Aggarwal, 2015) and Palynoassemblage–IV of the Chintalapudi sub–basin (Jha *et al.,* 2018).

Intercorrelation

Palynozone–II is correspondent to the Barakar stage of the Jharia Coalfield (Tripathi & Tiwari, 1982), Zone–3 of the Johilla Coalfield (Anand–Prakash & Srivastava, 1984), Assemblage–II of the Pathakhera Coalfield (Sarate, 1986), Zone–2 of the Umaria Coalfield (Srivastava & Anand–Prakash, 1984), *Scheuringipollenites barakarensis* (Zone IIIA) Assemblage Zone (Tiwari & Tripathi, 1992; Damodar Basin), Assemblage–II of the Talcher Coalfield (Tripathi, 1997), Assemblage–B of the Wardha Coalfield (Bhattacharyya, 1997), Palynozone–2 of Ib River Coalfield (Meena, 2000), Zone II of the Tatapani–Ramkola Coalfield (Kar & Srivastava, 2003), Palynoassemblage–I of the Pali sediments of the Sohagpur Coalfield (Ram–Awatar *et al.,* 2004), Palynoassemblage of Bandar Coalfield (Sabina *et al.,* 2007), Assemblage–II of the Raniganj Coalfield (Murthy *et al.,* 2010), Lower Barakar palynoassemblage of Wardha Basin (Jha *et al.,* 2011), *Scheuringipollenites barakarensis* zone of Tatapani–Ramkola Coalfield (Tripathi *et al.,* 2012),

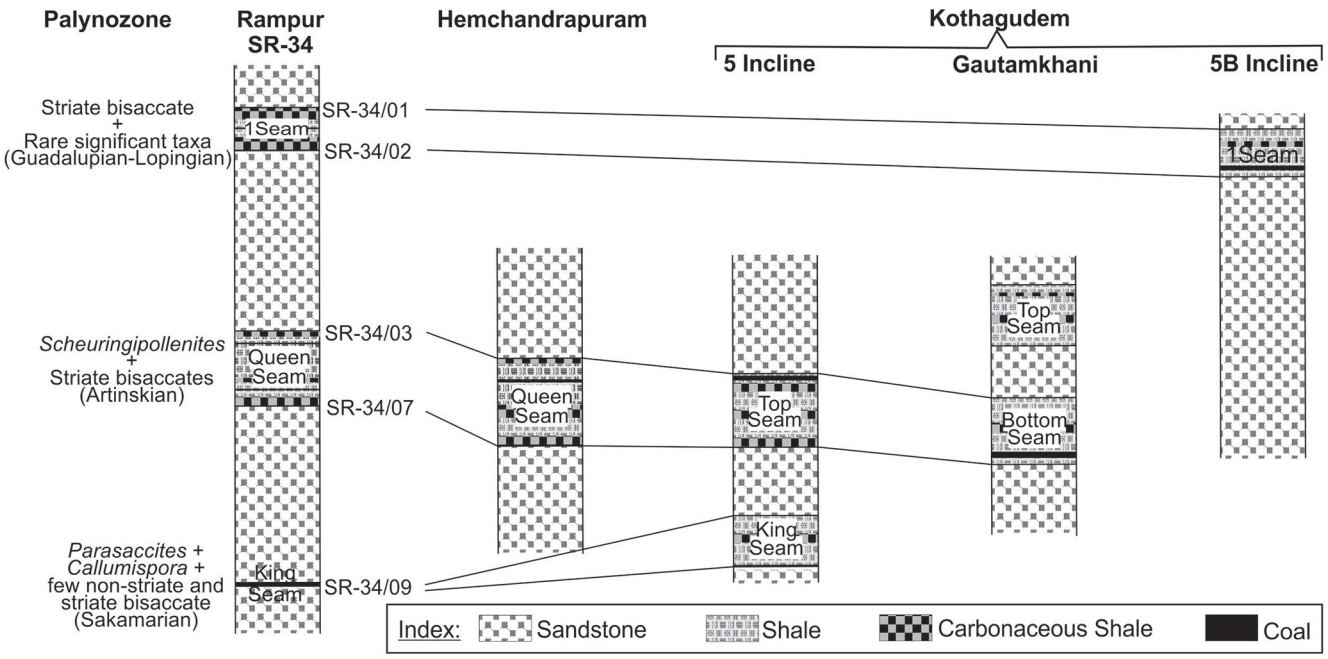

Fig. 3—Palynological correlation of different sections.

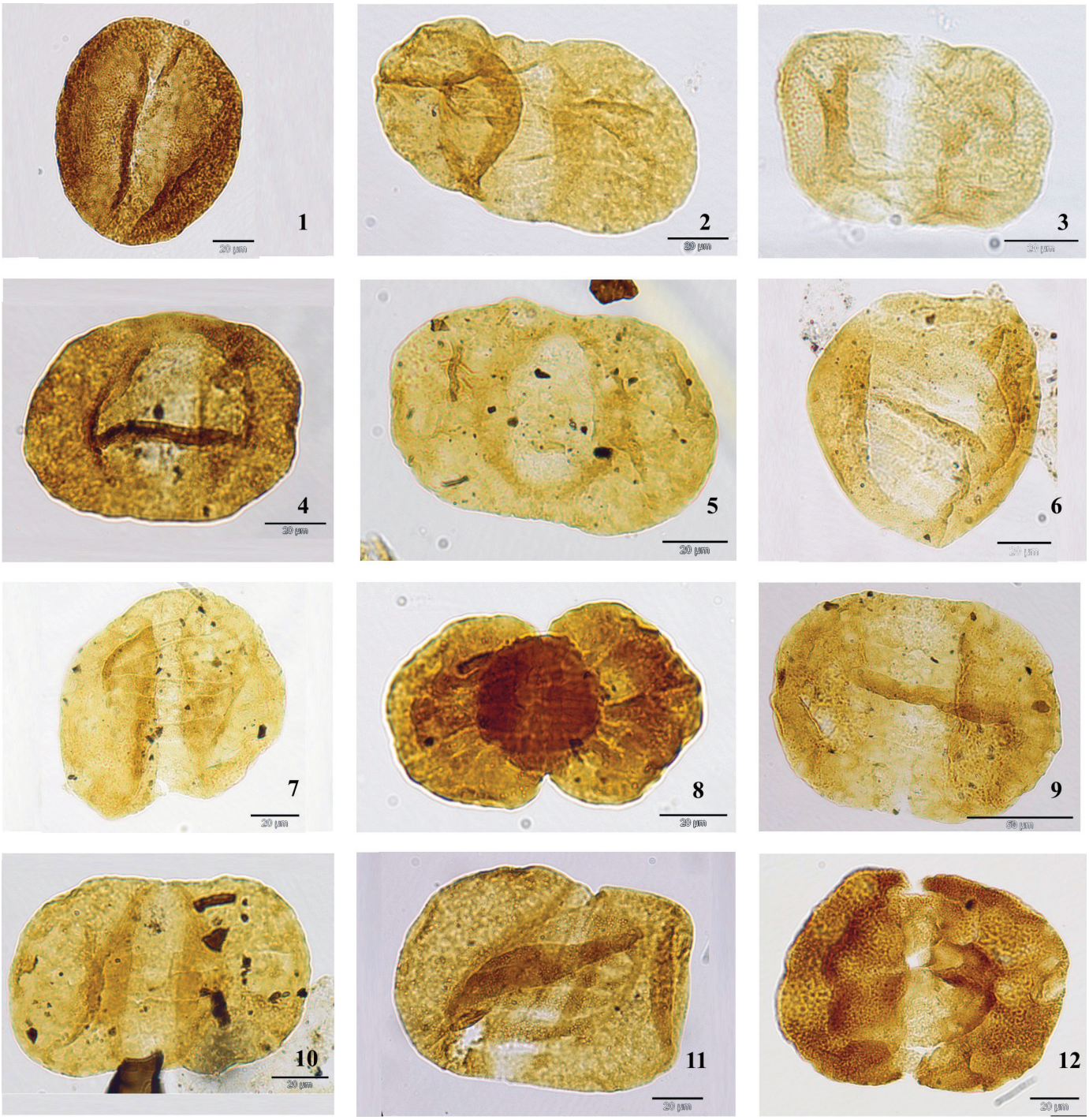

PLATE 2

1. *Scheuringipollenites maximus,* B.S.I.P. Slide No. 16181, F38/3.
2. *Striatopodocarpites magnificus,* B.S.I.P. Slide No. 16182, H51.
3. *Faunipollenites* sp. B.S.I.P. Slide No. 16173, P35/4.
4. *Chordasporites australiensis,* B.S.I.P. Slide No. 16180, J29/1.
5. *Striomonosaccites ovatus,* B.S.I.P. Slide No. 16183, M48/4.
6. *Striasulcites tectus,* B.S.I.P. Slide No. 16180, E36/2.
7. *Striatopodocarpites brevis,* B.S.I.P. Slide No. 16180, H34.
8. *Striatites varius,* B.S.I.P. Slide No. 16180, R32.
9. *Strotersporites indicus,* B.S.I.P. Slide No. 16180, R34/2.
10. *Crescentipollenites globosus,* B.S.I.P. Slide No. 16183, H38/2.
11. *Lunatisporites pellucidus,* B.S.I.P. Slide No. 16182, V61/1.
12. *Corisaccites alutus,* B.S.I.P. Slide No. 16175, D36.

Table 1—Generalized stratigraphy of the Kothagudem Sub–basin, Godavari Graben, South India (after SCCL).

Group	Age	Formation	Lithology
Lower Gondwana	Upper Permian	Raniganj	Conglomerate, sandstone, siltstone, grey shale
	Upper Permian	Barren Measures/Kulti	Sandstone, siltstone, and carbonaceous clays
	Upper part of Lower Permian	Barakar	Upper: White feldspathic sandstone, siltstone, shale, carbonaceous shale, and coal seam
			Lower: very coarse–grained pebbly sandstone, feldspathic
	Lower Permian	Talchir	Diamitite, rhythmite and light green sandstone
————Unconformity————			
Archaean			

Palynoassemblage of New Majri Opencast Mine, Wardha Basin (Mahesh *et al.,* 2014), Palynoassemblage–III of Mand–Raigarh Coalfield (Murthy *et al.,* 2014).

PALYNOZONE–III

This is the youngest palynozone of the studied samples. Palynozone–III has been identified in seam–I of section SR–34 from the Rampur area (sample no. 1–2), and seam–I of 5B incline from Kothagudem area. Palynozone–III is characterized by the dominance of striate bisaccate taxa chiefly *Striatopodocarpites* (36–44%: *S. decorus, S. magnificus, S. diffuses, S. multistriatus, S. subcircularis, S. brevis, S. globosus*), *Faunipollenites* (8–10%: *F. goraiensis, F. parvus, F. varius, F. singrauliensis*) along with *Crescentipollenites* (7–8%: *C. barakarensis, C. gondwanensis, C. globosus, C. fuscus*). The other striate bisaccate genera present in the palynozone comprise *Striatites* (5%: *S. parvus, S. tentulus*), *Verticipollenites* (2–4%: *V. secretus, V. finimitus*), *Weylandites* (2%: *W. lucifer, W. obscurus*), *Schizopollis disaccoids* (2%)*, Striapollenites obliquus* (2%) and a few *Strotersporites indicus*. Other recorded taxa of this palynozone are *Scheuringipollenites* (16%: *S. barakarensis, S. maximus, S. minutus, S. ovatus, S. tentulus*), *Primuspollenites levis* (2–3%), *Corisaccites alutus* (1–2%), *Lunatisporites pellucidus* (1–2%), *Guttulapollenites hannonicus* (1%) and *Striomonosaccites ovatus*. Cordaitalean (*Parasaccites* sp.–1%) and Peltasperm pollen (*Falcisporites zapfei*–1–2%; *Chordasporites australiensis*–1–3%) are rare elements of the palynoflora. Spores are the infrequent component of the palaeoflora comprising few lycopsids (*Indotriradites sparsus*–1%) and fillicopsids like *Leiotriletes* sp. (1%)*, Microbaculispora villosa* (1%), *Microfoveolatispora* sp. (1%) and *Tethysispora unica* (1%) along with *Tiwariasporis simplex.*

Age: Lopingian (Aggarwal & Jha, 2013)

Comparison

Intracorrelation

This palynozone is akin with Assemblage–II of the Ramagundam (Mantheni area) and Manuguru (Srivastava & Jha, 1987) areas, Assemblage–III of the Mailaram area (Srivastava & Jha, 1990), Palynozone–9 of the Budharam area (Srivastava & Jha, 1995), Palynoassemblage III of the Bottapagudem area of the Chintalapudi sub–basin (Jha, 2004) corresponds with this palynozone in comprising *Striatopodocarpites, Faunipollenites*, *Scheuringipollenites, Chordasporites* and *Falcisporites,* Palynozone–7 of the Mailaram area (Jha & Aggarwal, 2012), Palynoassemblage–II of the Chintalapudi area (Jha *et al*., 2012) and Palynoassemblage–VIII of the Chintalapudi sub–basin (Jha *et al.,* 2018).

Intracorrelation

Palynozone–III shows resemblance with Assemblage–RB–I of the Damodar Basin (Tiwari & Singh, 1986), Assemblage–IV of the Mahanadi Basin (Tiwari *et al.,* 1991), Palynozone–2 of the Kamptee Coalfield (Srivastava & Bhattacharyya, 1996), *Striatopodocarpites–Crescentipollenites* Zone (Table–4; Zone V–D) or the *Densipollenites magnicorpus* assemblage Zone (VD) of the Damodar Basin (Tiwari &Tripathi, 1992), Palynozone–2 of the South Rewa Basin (Ram–Awatar, 2001) and

Palynoassemblage–II of Sohagpur Coalfield (Ram–Awatar *et al.,* 2004). This palynozone resembles with the Raniganj palynoflora of the Damodar Valley Coalfields (Bharadwaj *et al*., 1979; Bharadwaj & Tiwari, 1977) in having an abundance of striate bisaccates. However, *Indospora* and *Spinosporites* present in the Raniganj sediments are absent in the Godavari assemblages.

DISCUSSION

Comparison of palynozones with different assemblages of the Godavari Graben

A lot of palynological work has been done in different basins of India and a standard palynological succession from the Talchir to Raniganj formations has been established in all the basins particularly in the Damodar (Tiwari & Tripathi, 1992), Mahanadi, South Rewa and Godavari basins (Jha *et al*., 2012). The first effort to synthesize all the information on the quantitative and qualitative occurrence of sporae dispersae in the Lower Gondwana rocks was done by Bharadwaj (1966). As further information piled up, a revised synthesis led to the recognition of many miofloristic zones in the Lower Gondwana sequence of India. Thus, according to Bharadwaj (1975), Talchir palynoflora is recognized by the dominance of radial monosaccates and few *Callumispora*. In the present investigation, this assemblage has not been recognized. The Karharbari palynoflora, which overlies the Talchir palynoflora, is palynologically divisible into two parts, the Lower part (dominance of *Parasaccites* and sub dominance of *Callumispora*) and the upper part (dominance of *Parasaccites* and sub dominance of *Scheuringipollenites*). In the present investigation, upper Karharbari (Sakmarian) palynoflora has been reported in sample no. 9 of section SR–34 (Table 2; Fig. 2).

The Karharbari palynoflora is succeeded by the Barakar palynoflora of the Lower Gondwana succession. Palynologically, the Barakar palynoflora is divisible in two parts (Bharadwaj, 1975): older (acme of *Scheuringipollenites* along with sub dominance of striate bisaccates) and younger (co–dominance of striate bisaccates and non–striate bisaccates). In the present study, *Scheuringipollenites* dominant assemblage (Lower Barakar=Artinskian age) has been demarcated in Rampur, Hemchandapuram, five incline (King seam) and Gautamkhani (Bottom Seam) area (Table 2; Fig. 2). So far, in the Godavari Graben, upper Barakar palynoflora has not been reported.

The Barren Measures palynoflora is characterized by striate bisaccates along with the significant occurrence of enveloping monosaccate, *Densipollenites* has not been recognized in the present study. In the Raniganj palynoflora, striate bisaccate pollens continue to dominate along with stratigraphically significant taxa like *Chordasporites, Lunatisporites, Corisaccites, Weylandites, Crescentipollenites, Falcisporites, Guttulapollenites, Tethysispora, Verticipollenites, Lundbladispora, Densoisporites, Gondisporites, Vitreisporites, Hamiapollenites,* etc. Palynozone–III, of the present study (Kothagudem and Rampur area), is characterized by the dominance of striate bisaccates along with some stratigraphically significant taxa (Table 2; Fig. 2). Lopingian age (Late Permian) age has been assigned to Palynozone–III.

Comparisons with other Gondwanan palynozones

Exact comparison of the Indian palynozones with other Gondwanan continents is little bit complex as diverse stratigraphic and taxonomic methods have been adopted to analyze the palynological data like: in eastern Australia palynostratigraphic framework (Kemp *et al*., 1977), in South Africa concurrent range zone (MacRae, 1988) and in India assemblage zones have been utilized (Jha & Aggarwal, 2012). In the present investigation, the palynozones have been made on the basis of the dominance and the sub–dominance of the palynoflora. Phytogeographic provincialism and different taxonomic techniques render the relationship rather tentative, between the different Gondwanic continental palynofloras as attempted by numerous workers (Balme, 1980; Césari & Gutiérrez, 2001; Jha, 2006; Stephenson, 2008; Tiwari, 1999). The Karharbari palynoflora has been found tentatively correlatable with Stage 3 in the eastern province of Australia (Kemp *et al*., 1977; Price, 1976) and palynofloras of the Beacon Super Group of the Dronning Maud Land, Antarctica (Lindstrom, 1995, 1996) in having the dominance of triletes and the presence of *Jayantisporites pseudozonatus.* On the other hand, the Barakar palynoflora has been found to be tentatively akin to the *Vesicaspora* zone of Ketewaka Coalfield, Tanzania (Manum & Tien, 1973); *Scheuringipollenites*–dominant palynoassemblage of the Moze and Namwele–Mkomolo coalfields of Tanzania (Semkiwa *et al*., 1998); lower part of *Lueckisporites virkkiae* zone, Paraná Basin, Brazil (Souza & Toigo, 2005); *Lueckisporites–Weylandites* (LW) Assemblage Biozone of Argentina in having dominance of bisaccates (Césari & Gutiérrez, 2001); OSPZ3 (Oman and Saudi Arabia palynological zones) of Arabia (Stephenson *et al*., 2003). Late Permian palynofloras are also tentatively akin with Amery Group of East Antarctica, Buckley Formation (Balme & Playford, 1967; Lindstrom, 1995, 1996; Playford, 1990; Truswell, 1980) and *Striatites* Assemblage zone of Argentina (Archangelsky & Vergel, 1996; Beri *et al*., 2011; Césari & Gutiérrez, 2001).

Palaeoclimatic interpretations

Morphographic and quantitative variations of pollen grains and spores play a significant role in understanding their palaeoclimatic sensitivity (Banerjee & Basu, 1987; Tiwari & Tripathi, 1987). The dominance

Table 2—Recovered spores and pollen grains from the collected core from Rampur, Kothagudem and Hemchandrapuram area.

		RAMPUR AREA	Age
Section SR-33			
Seam-I (309.90-310.5 m) :		Low spore-pollen *Scheuringipollenites, Ibisporites, Striatopodocarpites, Parasaccites*	----
Seam-II (493.75-494.70 m):		Barren, No spore-pollen	
Section SR-34			
1	**Seam-I**	Dominance of striate bisaccates chiefly *Striatopodocarpites* (36%), *Faunipollenites* (10%), *Crescentipollenites* (7%), *Striatites* (5%), *Verticipollenites* (2%). Non-Striate bisaccates chiefly *Scheuringipollenites* (17%), *Primuspollenites* (3%) and *Schizopollis* is 2%. Taeniates are represented by *Corisaccites*, *Lunatisporites* and *Guttulapollenites*. Triletes are low in percentage represented by *Leiotriletes, Indotriradites* and *Tethysispora*. Monosaccates are very rare *Parasaccites* (1%).	Raniganj (Lopingian)
2		The abundance of tracheids and wood fragments. Pollen and spores are also present. The assemblage is dominated by striate bisaccates, *Striatopodocarpites* (44%), *Faunipollenites* (8%) *Crescentipollenites* (8%). Other bisaccates include *Verticipollenites* (4%), *Schizopollis* (2%), *Striapollenites* (2%). Presence of *Falcisporites*, *Chordasporites* and *Weylandites* is significant.	
3	**Queen Seam**	Poor in spore and pollen. Few palynomorphs present and include *Scheuringipollenites, Striatopodocarpites* and *Striatites*.	Barakar (Artinskian)
4		Dominated by *Scheuringipollenites* (54%), *Ibisporites* (5%) and *Alisporites* (1%). Striate bisaccates are represented by *Striatopodocarpites* (18%), *Faunipollenites* (7%), *Verticipollenites* (3%). Other taxa are *Rhizomaspora* (1%) *Platysaccus* (2%), *Parasaccites* (4%), *Lophotriletes* (1%) and *Brevitriletes* (1%).	
5		Dominated by non-striate bisaccates chiefly *Scheuringipollenites* (43%), *Ibisporites* (5%) and *Alisporites* (1%). Striate bisaccates are represented by *Striatopodocarpites* (15%), *Faunipollenites* (14%), *Striatites* (4%) and *Striasulcites* (1%). Other taxa are represented by *Rhizomaspora* (1%), *Parasaccites* (3%), *Singraulipollenites* (1%), *Tetraporina* (5%) and *Balmella* (1%).	
6		The abundance of wood fragments and tracheids, low pollen and spores. *Scheuringipollenites*, *Ibisporites* and *Striatopodocarpites* are present.	
7		Dominated by non-striate bisaccates chiefly *Scheuringipollenites* (59%) *Ibisporites* (5%) along with few striate bisaccates, *viz. Faunipollenites* (11%), *Striatites* (6%), *Striatopodocarpites* (9%), *Primuspollenites* (1%) and *Crescentipollenites* (1%). Other taxa are *Rhizomaspora* (1%), *Parasaccites* (2%) and *Barakarites* (3%).	
8		Devoid of spore-pollen.	-----

9	**King Seam**	Dominated by monosaccates, *viz. Parasaccites, Plicatipollenites, Potonieisporites* and *Divarisaccus.* Triletes are represented by *Callumispora* and *Microbaculispora*. Very few striate and non-striate bisaccates represented by *Faunipollenites*, *Striatites* and *Scheuringipollenites*.	Karharbari (Sakmarian)

KOTHAGUDEM AREA

5B Incline			
Seam-I		Besides the abundance of tracheids and wood fragments few spores and pollen grains are present in low frequency. Striate bisaccates (*Striatopodocarpites, Faunipollenites, Crescentipollenites, Striatites, Primuspollenites*) show maximum representation. The occurrence of *Chordasporites, Corisaccites, Lunatisporites, Weylandites* has also been observed. Triletes are represented by *Leiotriletes*, *Microbaculispora* and *Microfoveolatispora*.	Raniganj (Permian)
5 Incline			
1	**Top Seam**	The abundance of wood fragments and tracheids, very low spore-pollen. In this sample dominance of non-striate bisaccate *Scheuringipollenites*, *Ibisporites* has been marked, along with *Striatites*, *Striatopodocarpites*. *Faunipollenites*, *Divarisaccus* and *Rhyzomospora*.	Barakar (Artinskian)
2-8		No spore-pollen	-----
1-2	**King Seam**	The abundance of wood fragments and tracheids, no spore-pollen	-----
3-4		The abundance of wood fragments and tracheids, very low spore-pollen	

HEMCHANDRAPURAM AREA

1-4		In this sample abundance of wood fragments and tracheids has been observed. Spores and pollen grains are presented in low amounts with non-striate bisaccate *Scheuringipollenites*, *Ibisporites*, *Alisporites*, *Platysaccus*. Other taxa are represented by *Faunipollenites, Primuspollenites*, *Callumispora, Verrucosisporites* and *Parasaccites*.	Barakar (Artinskian)

Table 3—List of palynomorphs recovered in the present study along with their allied plant affinity (Balme, 1995; Taylor *et al.,* 2009; Lindström & McLoughlin, 2007).

Palynomorphs affinity	Palynotaxa	Palynozones		
		I	II	III
Spores				
Algal	*Singraulipollenites* sp.		*	
	Tetraporina sp.		*	
	Balmella Balme & Hennelly, 1956		*	
Fillicopsida	*Callumispora barakarensis* (Bharadwaj & Srivastava) Tiwari *et al.,* 1989	*	*	
	Callumispora gretensis (Balme & Hennelly) Bharadwaj & Srivastava, 1969	*		
	Leiotriletes rectus Bharadwaj & Salujha, 1964			*
	Lophotriletes rectus Bharadwaj & Salujha, 1964		*	
	Brevitriletes unicus (Bharadwaj & Srivastava) Tiwari & Singh, 1981		*	
	Microbaculispora tentula Tiwari, 1965	*		*
	Microbaculispora villosa (Balme & Hennelly 1955) Bharadwaj, 1962	*		*
	Microbaculispora gondwanensis Bharadwaj, 1962	*		
	Microfoveolatispora sp.			*
	Tiwariasporis simplex (Tiwari) Maheshwari & Kar, 1967			*
Equisetopsids	*Verrucosisporites distinctus* Tiwari, 1965		*	
Lycopsida	*Indospora sparsus*			*
	Tethysispora unica Vijaya & Tiwari, 1988			*
Pollen				
Cordaitales	*Parasaccites* (=*Cannanaropollis*) *densicorpus* Lele, 1975	*		
	Parasaccites (=*Cannanaropollis*) *distinctus* Tiwari, 1965	*		
	Parasaccites (=*Cannanaropollis*) *obscurus* Tiwari, 1965	*		
	Parasaccites (=*Cannanaropollis*) *diffuses* Tiwari, 1965	*	*	
	Parasaccites (=*Cannanaropollis*) *bilateralis* Tiwari, 1965	*		
	Parasaccites (=*Cannanaropollis*) *korbaensis* Bharadwaj & Tiwari, 1964	*	*	*
	Plicatipollenites indicus Lele, 1964	*		
	Plicatipollenites densus Srivastava, 1970	*		
	Plicatipollenites gondwanensis (Balme & Hennelly) Lele, 1964	*		
	Potonieisporites sp.	*		
	Barakarites indicus Bharadwaj & Tiwari, 1964		*	
	Barakarites crassus Bharadwaj & Tiwari, 1964		*	
Coniferales	*Divarisaccus lelei* Venkatachala & Kar, 1966a	*	*	
	Striomonosaccites ovatus Bharadwaj, 1964			*
	Lunatisporites pellucidus (Goubin) Maheshwari & Banerji, 1975			*
	Guttulapollenites hannonicus Goubin, 1965			*
	Corisaccites alutus Venkatachala & Kar, 1966			*
	Ibisporites diplosaccus Tiwari, 1968	*	*	
	Vestigisporites rudis Balme & Hennelly, 1954		*	
	Rhizomaspora sp.		*	
	Chordasporites australiensis de Jersey, 1962			*

Glossopterids	*Scheuringipollenites barakarensis* (Tiwari) Tiwari, 1973	*	*	*
	Scheuringipollenites maximus (Hart) Tiwari, 1973	*	*	*
	Scheuringipollenites miuntus (Sinha) Bharadwaj & Dwivedi, 1981		*	*
	Scheuringipollenites tentulus (Tiwari) Tiwari, 1973		*	*
	Scheuringipollenites ovatus (Balme & Hennelly) Foster, 1979			*
	Striatopodocarpites brevis Sinha, 1972			*
	Striatopodocarpites decorus Bharadwaj & Salujha, 1964			*
	Striatopodocarpites diffuses Bharadwaj & Salujha, 1964		*	*
	Striatopodocarpites multistriatatus Jha, 1996			*
	Striatopodocarpites subcircularis Sinha, 1972			*
	Striatopodocarpites ovatus Bharadwaj & Dwivedi, 1981		*	
	Striatopodocarpites globosus Maheshwari, 1967			*
	Striatopodocarpites magnificus Bharadwaj & Salujha, 1964			*
	Faunipollenites (=*Protohaploxypinus*) *bharadwajii* Maheshwari, 1967		*	
	Faunipollenites (=*Protohaploxypinus*) *goraiensis* (Potonié & Lele) Maithy, 1965			*
	Faunipollenites (=*Protohaploxypinus*) *parvus* Tiwari, 1965		*	*
	Faunipollenites (=*Protohaploxypinus*) *perixigus* Tiwari, 1965	*		
	Faunipollenites (=*Protohaploxypinus*) *singrauliensis* Sinha, 1972			*
	Faunipollenites (=*Protohaploxypinus*) *varius* Bharadwaj, 1962	*	*	*
	Crescentipollenites fuscus (Bharadwaj) Bharadwaj *et al.*, 1974		*	*
	Crescentipollenites barakarensis (Bharadwaj & Srivastava) Tiwari *et al.,* 1989			*
	Crescentipollenites gondwanensis (Maheshwari) Bharadwaj *et al.*, 1974			*
	Crescentipollenites globosus (Maithy) Jha, 1996			*
	Strotersporites indicus Tiwari, 1965			*
	Verticipollenites finitimus Bharadwaj & Salujha, 1964			*
	Verticipollenites secretus Bharadwaj, 1962		*	*
	Verticipollenites subcircularis Bharadwaj & Salujha, 1964		*	
	Striapollenites obliquus Bharadwaj & Salujha, 1964			*
	Striasulcites tectus Venkatachala & Kar, 1968		*	
	Striatites communis Bharadwaj & Salujha, 1964		*	
	Striatites parvus Tiwari, 1965	*	*	*
	Striatites solitus Bharadwaj & Salujha, 1964		*	
	Striatites tentulus Tiwari, 1965			*
	Striatites varius Kar, 1968	*		
	Schizopollis disaccoids Venkatachala & Kar, 1964			*
	Weylandites lucifer (Bharadwaj & Salujha) Foster, 1975			*
	Weylandites obscurus (Tiwari) Bharadwaj & Dwivedi, 1981			*
Peltaspermales	*Alisporites indicus* Bharadwaj & Srivastava, 1969		*	
	Falcisporites zapfei (Potonié & Klaus) Leschik, 1956			*
	Platysaccus papliοnsis Potoníe & Klaus, 1954		*	
	Primuspollenites dicavus Tiwari, 1964		*	
	Primuspollenites levis Tiwari, 1964		*	*

of *Cordaites* derived radial monosaccate palynomorphs (*Parasaccites* and *Plicatipollenites*) along with pteridophytic spores (*Callumispora*), and non–striate bisaccates (*Scheuringipollenites*) suggests the cooler but humid climate during Palynozone–1 (Sakmarian), which favoured the formation of very thin coal bands. In Palynozone–II (Artinskian) of the present study, the dominance of the non–striate bisaccate (*Scheuringipollenites* and *Ibisporites* >50%) and striate bisaccates (*Striatites* and *Faunipollenites)* signifies the presence of conifers and glossopterids in the palaeovegetation (Gould & Delevoryas, 1977). Presence of these peat forming gymnosperm plants along with pteridophytes resulted in the formation of thick coal seams during the sedimentation of the Barakar Formation. Palynozone–II shows the decrease in monosaccate pollen grains as compared to Palynozone–I and an increase in bisaccate pollen grains, indicating a transition from a cooler to a fluctuating cool–temperate climate (Wheeler & Götz, 2016). Warming of the climate during the Artinskian has also been supported through oxygen isotopic studies (Korte *et al*., 2005, 2008) of brachiopods and bivalves in Australia and Salt Range. This phase promoted the formation of the thick coal beds during the Artinskian. Palynozone–III (Lopingian) of the present study, is also dominated by the bisaccate pollen of glossopterids and conifers which suggests the warm climate with very high humidity (Tiwari &Tripathi, 1987). A warmer climate is also suggested through oxygen isotopic studies of conodonts at the Guadalupian–Lopingian boundary in China (Chen *et al*., 2011).

CONCLUSIONS

The following conclusions can be derived from the palynological analysis of the Lower Gondwana sediments of the Rampur, Hemchandrapuram and Kothagudem areas of the Godavari Graben

Palynologically three distinct Palynozones (I–III) have been identified belonging to the Sakmarian (Karharbari), Artinskian (Barakar) and Lopingian (Raniganj) ages, respectively, in the lithologically designated Barakar Formation.

The existence of the two coal–bearing horizons has been confirmed by the palynofloral diversity, one belonging to the early Permian (Karharbari and Barakar) and the other one belonging to the late Permian (Raniganj).

Present study divulges cool to warm palaeoclimate with variable humidity during the Permian succession of the palynozones. Palynozone–I represents mildly cooler climate while Palynozone–II and III represent cool–temperate to warm–humid climate (temperate), respectively.

The Barakar and Raniganj palynofloras confirm the presence of thick arborescent vegetation by the dominance of gymnosperm pollen grains assigned to glossopterids and conifers (*Scheuringipollenites* spp., *Ibisporites* spp., *Faunipollenites* spp., *Striatopodocarpites* spp., *Lunatisporites* spp., *Primuspollenites* spp.). Glossopterids are the peat–forming vegetation, having various distributions from xerophilous to mesophyllous palaeoenvironment and lowland peats while, on the other hand, conifers are more adaptable to upland areas having drier climates (Jha & Aggarwal, 2015).

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