PEAT-FORMING ENVIRONMENT OF COAL-BEARING PERMIAN SEDIMENTS IN KACHINAPALLI AREA OF GODAVARI GRABEN, INDIA

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ABSTRACT – This article integrates palaeobotanical and palynological analysis to establish palynostratigraphic succession and depositional environment for the borecore MGK-6 from Kachinapalli area of Lingala-Koyagudem coal belt of Godavari Graben, South India. Palynological analysis in sub-surface sediments of 490.10 m deep borecore have divulged occurrence of three palynoassemblages. Palynoassemblage I at 314.25-346.65 m is marked by dominance of nonstriate disaccates *Scheuringipollenites maximus*, *S. tentulus* along with subdominance of few striate disaccates chiefly *Striatopodocarpites decorus*, *Faunipollenites* (= *Protohaploxylinus*) *varius*, *F. bharadwajii*. Palynoassemblage II at 220.70-298 m is characterized by dominance of striate disaccates viz., *Striatopodocarpites tiwarii*, *Faunipollenites bharadwajii*, *Striatites varius*, *Strotersporites indicus*, *S. communis*, *Lunatisporites diffuses*, *L. ovatus* with subdominance of nonstriate disaccates *Scheuringipollenites maximus*, *S. tentulus* and *Ibisporites jhingurdahiensis*. Palynoassemblage III identified at 46.75-206.70 m shows dominance of striate disaccates viz., *Striasulcites ovatus*, *Striatopodocarpites diffuses*, *S. tiwarii*, *Faunipollenites bharadwajii*, *F. varius*, *F. parvus*, *F. goraensis* and *Crescentipollenites globosus*, *C. brevis* along with a number of stratigraphically significant taxa viz., *Strotersporites indicus*, *Lunatisporites diffusus*, *Corisaccites alutas*, *Guttulapollenites hannonicus*, *Klausipollenites* sp., *Falcisporites zapfei*, *F. nuthallensis*, *Weylandites circularis*, *Striomonosaccites circularis* and *Chordasporites* sp. Palynoassemblage I (Barakar palynoflora) belongs to Artinskian age while, Palynoassemblages II and III (Raniganj palynoflora) belongs to Guadalupian age. The dominance of arborescent vegetation (glossopterids and conifers), low proportion of spores (lycopsids, sphenopsids and filiciopsids) and scarce presence of algal elements suggests that Kachinapalli palaeomire landscape was located in more inland area and the coal was formed in peat swamp forest environment situated in fresh water settings.

Key words: Permian, Artinskian, Guadalupian, Gondwana, Godavari Graben, India.

RESUMO – Este artigo integra análises paleobotânicas e palinológicas para estabelecer sucessão palinostratigráfica e ambiente de sedimentação com base no testemunho de sondagem MGK-6, da área de Kachinapalli, cinturão de carvão de Lingala-Koyagudem, Godavari Graben, sul da Índia. Análise palinológica em sedimentos de poços de sondagem que atingiram até 490,10 m de profundidade, mostraram ocorrências de três palinoassembléias. A Palinoassembléia I entre 314,25-346,65 m, é marcada pelo domínio de dissacados não estriados *Scheuringipollenites maximus*, *S. tentulus* associados ao sub-domínio de alguns dissacados estriados principalmente *Striatopodocarpites decorus*, *Faunipollenites* (= *Protohaploxylinus*) *varius*, *F. bharadwajii*. Palinoassembléia II, entre 220,70-298 m, se caracteriza pelo domínio de dissacados estriados viz., *Striatopodocarpites tiwarii*, *Faunipollenites bharadwajii*, *Striatites varius*, *Strotersporites indicus*, *S. communis*, *Lunatisporites difundes*, *L. ovatus* com subdomínio de dissacados não estriados *Scheuringipollenites maximus*, *S. tentulus* e *Ibisporites jhingurdahiensis*. A Palinoassembléia III, identificada entre 46,75-206,70 m mostra predomínio de dissacados estriados viz., *Striasulcites ovatus*, *Striatopodocarpites diffuses*, *S. tiwarii*, *Faunipollenites bharadwajii*, *F. varius*, *F. parvus*, *F. goraensis* e *Crescentipollenites globosus*, *C. brevis*, junto a vários táxons estratigraficamente significativos viz., *Strotersporites indicus*, *Lunatisporites diffusus*, *Corisaccites alutas*, *Guttulapollenites hannonicus*, *Klausipollenites* sp., *Falcisporites zapfei*, *F. nuthallensis*, *Weylandites circularis*, *Striomonosaccites circularis* e *Chordasporites* sp. A Palinoassembléia I (palinoflora Barakar) é de idade artinskiana enquanto as Palinoassembléias II e III (palinoflora Raniganj) pertencem à idade guadalupiana. O predomínio de vegetação arborescente (glossopterídeas e coníferas), baixa proporção de esporos (licófitas, esfenófitas e filicófitas) e presença esparsa de elementos de algálicos sugerem que a paisagem turfosa de Kachinapalli estava localizada na área intercontinental e o carvão foi formado em pântanos turfosos com florestas, situados em ambientes de água doce.

Palavras-chave: Permiano, Artinskiano, Guadalupiano, Gondwana, Graben Godavari, Índia.

INTRODUCTION

As the Godavari Graben is affected by many small faults and the effect of faults are varying within the sub-basins, the coal seams cannot be fitted into universal pattern of basin evolution, and hence the dating and correlation of coal seams is the basic requirement in this area. Well identified palynomorphs assemblages are efficiently helpful in the palynostratigraphic correlation of coal seams because of their restricted distribution in time and space. Pollen and spores present in various coal bearing horizons are quite different in their morphological as well as their numerical characters, because of that a specific group of spore and pollen (palynoassemblage) acquaint within the particular horizon. By the quantitative and qualitative study of these spores and pollen, coal seams and their associated sediments are recognized which become helpful in dating and correlation. Present communication is based on the quantitative and qualitative palynofloral composition and botanical affinities of palynoflora among distinct palynoassemblages.

GEOLOGY AND LOCATION

The Godavari Graben is a linear NNW-SSE trending coal belt on Precambrian/Vindhyan platform, extending from north of Boregaon, Maharashtra in the north to Eluru in the east coast of Andhra Pradesh, India, covering a surface area of 17,000 km². In this linear belt the Lower Gondwana sediments are exposed along both the eastern and western margins of the basin while the upper Gondwana sediments cover the central/axial portion. Basin comprises four structural sub basins (Godavari, Kothagudem, Chintalapudi and coastal Krishna Godavari) (Raja Rao, 1982). Godavari

Graben holds a unique position not only because it is the only coal producing area in the south India but also because it has more or less a complete succession from Permian to Cretaceous sediments.

Out of 15 identified coal belts in Godavari Graben, Lingala-Koyagudem coal belt has been dealt for the present study. A 50 km long unbroken stretch of Barakar Formation occurring between Lingala in the north west to Koyagudem in the south east on western margin of Godavari Valley coalfield is named as Lingala-Koyagudem coal belt. The coal belt is bounded by North latitude 17°35' to 18°00' and East longitude of 80°03' to 80°30' in the Survey of India Toposheet Nos. 65 B/8 and 65 C/5, C/6 and C/10 spread over an area of 192 km² of Khammam district, South India. This coalbelt is studied between the two active mining centers of Ramagundam in the northwest and Kothagudem in the southwest.

It covers the entire Lower Gondwana succession from Talchir (Asselian) to late Raniganj Formation (Lopingian). These formations are generally trended to NW-SE, with north easterly dips ranging from 10° to 20° with the local variations (Figure 1). The generalized stratigraphic succession in Kachinapalli block, as delimited by Mineral Exploration Corporation Limited (MECL) 2002, is given in Table 1.

MATERIAL AND METHODS

Borecore MGK-6, which provided basic core material (490.10 m deep) for the present study, was drilled by Mineral Exploration Corporation Limited (Figure 1). Total 35 samples of different lithologies viz., clay, carbonaceous shale, coal, grey shale, sandstone etc. has been collected. Extraction of the palynomorphs from the samples was carried out using an established procedure of maceration which includes crushing

Figure 1. Map showing location of borecore MGK-6 in Lingala-Koyagudem coalbelt.

Table 1. Showing generalized stratigraphic succession in Kachinapalli block.

Group	Formation	Lithology
----- Soil Cover -----		
LOWER GONDWANA	Kamthi	Sandstone with subordinate shales and coal seams
	Barren Measures	Grey to greenish grey coarse to pebbly feldspathic sandstone with shale bands
	Barakar	Predominantly medium to coarse grained, grey white sandstone, altered feldspars with subordinate clays/shales and persistent coal seams
	Talchir	Fine to medium grained pale green sandstone with occasional olive green shales
	Pakhhal	Quartzites, phyllites and dolomites

(5-10 gm/sample) followed by 2-4 days hydrofluoric acid treatments. After thorough washing of water post hydrofluoric acid organic residues were oxidized with nitric acid for 2-5 days followed by 10% KOH treatment. Preparation of the slides was done in Canada balsam with the help of Polyvinyl Chloride (PVC). The scanning of slides and the photography of the palynomorphs were done with DP25 Olympus digital camera mounted on a BX62 microscope. The collected samples and prepared palynological slides are housed at the museum of Birbal Sahni Institute of Palaeobotany, Lucknow, India. Botanical affinity of dispersed spores and pollen such as lycopsids, sphenopsids, filicopsids, glossopterids, cordaites, conifers and others were based on anthology of Balme (1995).

RESULTS

Lithological attributes

Lithologically, strata from 6-306.20 m in borecore MGK-6 have been designated as Kamthi Formation; while sediments from 306.50-475.30 m have been identified as Barren Measures and the succession from 475.41-490.10 m have been demarcated as Barakar (Figure 2). The borecore was closed at 490.10 m depth. During Permian, cyclic deposition of sandstone, shale and coal seams has been frequently observed. Similar type of the cyclic sedimentation has been examined in the present succession. In the whole succession four complete cycles has been observed. This cyclic sedimentation of the succession shows a clear picture of the fluvial river channel deposit along with some sub-environments like flood plain, lake, lagoon, swamp and wetlands. Sandstone/siltstone symbolize the river channel deposits, the clay mudstone deposited in very low energy environment (flood plain/deep Lake), carbonaceous shale would be represented by low energy regime (swamp/lake/flood plain/leaves) (Gore, 2010). So, lithological characteristics depict the fluvial settings for the borecore MGK-6.

Palynological attributes

Palynology and the palaeobotany of the depositional palynomorphs along with lithology are usually the main tools to be used to define the features of depositional environments. The palynological composition of the succession has been extensively used to distinguish the palaeoenvironment, considering that flora is very susceptible to minor ecological changes, reflected in palaeoflora (Smith, 1962).

Figure 2. Litholog of borecore MGK-6 showing positions of samples and palynoassemblages in different formations.

During palynological studies of the studied borecore, forty three genera and fifty six species were indentified from thirty five samples including stratigraphically significant taxa. A list of all palynomorphs species is given in Table 2 and stratigraphically significant taxa are displayed in plate (Figure 3). The quantitative character of different identified palynoassemblages is shown in histogram (Figures 4, 5). Yielding of the samples was good; in most of the cases at least 200 palynomorphs per sample were counted. After the palynological examination of these 35 samples, on the basis of the distribution pattern and composition of palynoflora, the details of three distinct palynoassemblages are discussed.

Palynoassemblage I

Recorded palynoflora. Palynoassemblage-I has been documented between 314.25-346.65 m (samples 33-34, Figures 2, 7) in having the dominance of *Scheuringipollenites* (49%) and the sub dominance of striate disaccates viz., *Striatopodocarpites* (15-17.5%) and *Faunipollenites* (4-12.5%). Other associated genera in this palynoassemblage are *Brevitriletes* (0.5%), *Lophotriletes* (0.5%), *Microbaculispora* (0.5%), *Caheniasaccites* (0.5%), *Parasaccites* (2.5%), *Densipollenites* (0.5-2.5%), *Plicatipollenites* (2.5-3%), *Ibisporites* (7-7.5%), *Platysaccus* (1.5-2.5%), *Crescentipollenites* (1%), *Strotersporites* (0.5%), *Weylandites* (0.5%), *Hamiapollenites* (2.5-3%) and *Inaperturopollenites* (1-11%).

Botanical affinity. The palynological content of Palynoassemblage-I from borecore MGK-6 analysed, with a dominance of non-striate disaccate pollen grains (>50%) produced by arborescent vegetation with the following species *Scheuringipollenites maximus*, *S. tentulus*, *Ibisporites jhingurdahiensis*, reflects the remarkable presence of glossopterids (Figure 6) in the palaeovegetation (Gould & Delevoryas, 1977). Striate disaccates pollen grains, reflecting the presence of conifers (30%) are represented by mainly *Striatopodocarpites decorus*, *Faunipollenites* (= *Protohaploxylinus*) *varius* and *F. bharadwajii*. Cordaites (Monosaccates grains: 9%) show low species diversity represented by *Caheniasaccites distinctus*, *C. ovatus*, *C. ellipticus*, *Plicatipollenites indicus*, *Densipollenites invisus* and *Parasaccites distinctus*, *P. korbaensis*, *P. obscurus*. So, in the palaeoplant communities' cordaites also represent their significant presence. Rare presences of filicopsids are represented by *Lophotriletes rectus*, *Microbaculispora* sp., *Brevitriletes communis* and *Brevitriletes unicus*. *Inaperturopollenites* (conifer swamp tree: Balme, 1995) nearly 11% also shows the significant presence in this palaeovegetation.

Age. Artinskian age (Aggarwal & Jha, 2013).

Comparison. Palynoassemblage I shows its close resemblance with Palynozone-4 of Ramakrishnapuram (Srivastava & Jha, 1992a), Manuguru area (Srivastava & Jha, 1992b), *Scheuringipollenites barakarensis* (Zone III A) Assemblage Zone (Tiwari & Tripathi, 1992; Damodar Basin), Assemblage-B of Wardha Coalfield (Bhattacharya, 1997), Assemblage-II of Talcher Coalfield (Tripathi,

1997); Sohagpur Coalfield (Ram-Awatar *et al.*, 2003); Palynozone-3 of Mailaram area (Jha & Aggarwal, 2012). This palynoassemblage is also tentatively akin to *Vesicaspora* zone of Ketewaka Coalfield in Tanzania (Manum & Tien, 1973); *Scheuringipollenites*-dominant palynoassemblage of Namwele-Mkomolo and Moze coalfields in Tanzania (Semkiwa *et al.*, 1998).

Palynoassemblage II

Recorded palynoflora. At the depth of 220.70-298 m (samples 20-31, Figures 2, 7) Palynoassemblage II has been identified by the dominance of striate disaccates viz., *Faunipollenites* (11.5-53%), *Striatopodocarpites* (20.5-47.5%) and sub-dominance of *Scheuringipollenites* (8.5-41.5%). Other identified genera in Palynoassemblage II are *Lacinitriletes* (0.5%), *Callumispota* (0.5%), *Leiotriletes* (0.5%), *Verrucosisporites* (0.5%), *Horriditriletes* (0.5%), *Brevitriletes* (0.5-1%), *Plicatipollenites* (0.5-1%), *Densipollenites* (1.5%), *Caheniasaccites* (1-2%), *Parasaccites* (0.5-2%), *Platysaccus* (0.5-1.5%), *Ibisporites* (1-10.5%), *Crescentipollenites* (1-2%), *Striasulcites* (2%), *Striatites* (1-12%), *Latosporites* (0.5-8.5%), *Vestigisporites* (0.5%) and *Inaperturopollenites* (0.5%). Beside these some stratigraphically significant taxa viz., *Chordasporites* (0.5-3%), *Falcisporites* (0.5-1%), *Strotersporites* (0.5-2.5%), *Hamiapollenites* (1-3%), *Weylandites* (1.5%) and *Lunatisporites* (0.5-9%) have also been marked in the palynoassemblage.

Botanical affinity. The palynofloral content of Palynoassemblage II is represented by the dominance of conifers (>50%) mainly represented by *Faunipollenites bharadwajii*, *F.* (= *Protohaploxylinus*) *varius*, *Striatopodocarpites tiwarii*, *Lunatisporites diffusus*, *L. ovatus*, *L. pellucidus*. Glossopterids are subdominant mainly represented by *Scheuringipollenites maximus*, *S. tentulus*, *Ibisporites jhingurdahiensis*. Cordaites are very less (Figure 6) which are represented by *Parasaccites distinctus*, *P. korbaensis*, *P. obscurus*, *Densipollenites indicus*, *D. magnicarpus*, *Plicatipollenites ganjraensis*, *Caheniasaccites* sp. Spores (11.5%) are represented by Filicopsids (*Horriditriletes rampurensis*, *Brevitriletes communis*, *B. unicus*, *Verrucosisporites gondwanensis*), lycopsids (*Callumispota* sp.) and sphenopsids (*Latosporites colliensis*).

Age. Guadalupian age (Aggarwal & Jha, 2013).

Comparison. Palynoassemblage II compares well with *Striatopodocarpites* + *Faunipollenites* Assemblage zone (zone V-A; lies under *Gondisporites raniganjensis*) of Tiwari & Tripathi (1992). It also compares well with Assemblage-I of Chelpur area (Srivastava & Jha, 1986); Assemblage-I of Mantheni Area (Bharadwaj *et al.*, 1987); Pali Formation of South Rewa Basin (Tiwari & Ram-Awatar, 1989); Palynozone-5 of Sattupalli area (Srivastava & Jha, 1994); Kamthi Formation of Kamptee Coalfield (Srivastava & Bhattacharya, 1996); Assemblage-III of Sohagpur Coalfield (Ram Awatar, 1996); Palynoassemblage I of Bottapagudem area of Chintalapudi sub basin (Jha, 2004); Palynozone-4 of Mailaram area (Jha & Aggarwal, 2012).

Table 2. List of taxa recorded in borecore MGK-6, Kachinapalli area, Godavari Graben.

Palynotaxa	Early Permian	Late Permian	Botanical Affinity (Balme, 1995)
<i>Lophotriletes rectus</i> Bharadwaj & Salujha, 1964	+		Filicopsids
<i>Microbaculispora</i> sp.	+		
<i>Caheniasaccites distinctus</i> Lele & Makada, 1972	+		
<i>Caheniasaccites ovatus</i> Bose & Kar, 1966	+		Cordaitea
<i>Caheniasaccites ellipticus</i> Bose & Maheshwari, 1968	+		
<i>Plicatipollenites indicus</i> Lele, 1964	+		
<i>Ibisporites diplosaccus</i> Tiwari, 1968	+		Glossopterid
<i>Striatopodocarpites decorus</i> Bharadwaj & Salujha, 1964	+		Conifers
<i>Strotersporites</i> sp.	+		
<i>Hamiapollenites</i> sp.	+		
<i>Densipollenites invisus</i> Bharadwaj & Salujha, 1964	+		Cordaitea
<i>Brevitriletes communis</i> Bharadwaj & Srivastava emend Tiwari & Singh, 1981	+	+	Filicopsids
<i>Brevitriletes unicus</i> (Tiwari) Bharadwaj & Srivastava emend Tiwari & Singh, 1981	+	+	
<i>Parasaccites distinctus</i> Tiwari, 1965	+	+	
<i>Parasaccites korbaensis</i> Bharadwaj & Tiwari, 1964	+	+	Cordaitea
<i>Parasaccites obscurus</i> Tiwari, 1965	+	+	
<i>Scheuringipollenites maximus</i> (Hart) Tiwari, 1973	+	+	
<i>Scheuringipollenites tentulus</i> (Tiwari) Tiwari, 1973	+	+	Glossopterids
<i>Ibisporites jhingurdahiensis</i> Sinha, 1972	+	+	
<i>Platysaccus plicatus</i> Bharadwaj & Dwivedi, 1981	+	+	
<i>Striatopodocarpites tiwarii</i> Bharadwaj & Dwivedi, 1981	+	+	Conifers
<i>Faunipollenites varius</i> Bharadwaj, 1962	+	+	
<i>Faunipollenites bharadwajii</i> Maheshwari, 1967	+	+	
<i>Crescentipollenites fuscus</i> (Bharadwaj) Bharadwaj, Tiwari & Kar, 1974	+	+	Others
<i>Weylandites circularis</i> Bharadwaj & Srivastava, 1969	+	+	
<i>Inaperturopollenites</i> sp.	+	+	
<i>Callumispora</i> sp.		+	Lycopsid
<i>Leiotriletes</i> sp.		+	Filicopsids
<i>Horriditriletes rampurensis</i> Tiwari, 1968		+	
<i>Lacinitriletes</i> sp.		+	
<i>Indotriletes</i> sp.		+	Lycopsid
<i>Verrucosiporites gondwanensis</i> Srivastava, 1970		+	Filicopsids
<i>Microfoveolatispora</i> sp.		+	
<i>Caheniasaccites</i> sp.		+	
<i>Densipollenites indicus</i> Bharadwaj, 1962		+	Cordaitea
<i>Densipollenites magnicarpus</i> Tiwari & Rana, 1981		+	
<i>Divarisaccus</i> sp.		+	
<i>Potonieisporites</i> sp.		+	Glossopterids
<i>Plicatipollenites ganjraensis</i> Saxena, 1971		+	
<i>Klausipollenites</i> sp.		+	
<i>Chordasporites</i> sp.		+	Conifers
<i>Falcisporites nuthallensis</i> (Clarke) Balme, 1970		+	
<i>Falcisporites zapfei</i> Leschik, 1956		+	
<i>Striatopodocarpites diffusus</i> Bharadwaj & Salujha, 1964		+	Conifers
<i>Faunipollenites parvus</i> Tiwari, 1965		+	
<i>Faunipollenites goraensis</i> (Potonié & Lele) Maithy, 1965		+	
<i>Crescentipollenites globosus</i> (Maithy) Jha, 1996		+	Conifers
<i>Crescentipollenites brevis</i> (Bose & Kar) Bhardwaj, Tiwari & Kar, 1974		+	
<i>Crescentipollenites gondwanensis</i> (Maheshwari) Bharadwaj, Tiwari & Kar, 1974		+	

Continues

Table 2. Continuation.

Palynotaxa	Early Permian	Late Permian	Botanical Affinity (Balme, 1995)
<i>Sahnites</i> sp.		+	
<i>Vestigisporites</i> sp.		+	Glossopterids
<i>Primuspollenites levis</i> Tiwari, 1964		+	
<i>Striapollenites obliquus</i> Bharadwaj & Salujha, 1964		+	
<i>Striatites communis</i> Bharadwaj & Salujha, 1964		+	
<i>Striatites varius</i> Kar, 1968		+	
<i>Striatites solitus</i> Bharadwaj & Salujha, 1964		+	
<i>Strotersporites communis</i> Wilson, 1962		+	
<i>Strotersporites indicus</i> Tiwari, 1965		+	
<i>Strotersporites wilsonii</i> Klaus, 1963		+	
<i>Striasulcites ovatus</i> Venkatachala & Kar, 1968		+	
<i>Corisaccites alutas</i> Venkatachala & Kar, 1966		+	Conifers
<i>Lunatisporites diffusus</i> Bharadwaj & Tiwari, 1977		+	
<i>Lunatisporites ovatus</i> (Goubin, 1965) Maheshwari & Banerji, 1966		+	
<i>Lunatisporites pellucidus</i> (Goubin, 1965) Maheshwari & Banerji, 1975		+	
<i>Guttulapollenites gondwanensis</i> Goubin, 1965		+	
<i>Guttulapollenites hannonicus</i> Goubin, 1965		+	
<i>Hamiapollenites minimus</i> Jha, 1996		+	
<i>Hamiapollenites insolitus</i> Bharadwaj & Salujha, 1964		+	
<i>Striomonosaccites circularis</i> Bharadwaj & Salujha, 1964		+	Cordaite
<i>Maculatasporites</i> sp.		+	Others
<i>Latosporites colliensis</i> (Balme & Hennelly, 1956) Venkatachala & Kar, 1968		+	Sphenopsid
<i>Polypodioidites</i> sp.		+	
<i>Tiwariasporis</i> sp.		+	Others

Palynoassemblage III

Recorded palynoflora. The youngest Palynoassemblage III has been demarcated between 46.75–206.70 m (samples 2–19, Figures 2, 7) by the dominance of *Striasulcites* (4–30%) and sub-dominance of *Faunipollenites* (4.9–20%), *Striatopodocarpites* (3–34%) and *Scheuringipollenites* (4–45%). Other associated genera of this palynoassemblage are triletes: *Callumispora* (0.5–1.5%), *Leiotriletes* (1–11%), *Brevitriletes* (0.5–1.5%), *Lacinitriletes* (1–4%), *Verrucosisporites* (1%), *Indotriletes* (0.5–10.5%), *Microbaculispora* (0.5–8%), *Microfoveolatispora* (0.5–5%), *Horriditriletes* (0.5%); monosaccates: *Densipollenites* (0.5–3.5%), *Plicatipollenites* (0.5–3.5%), *Caheniasaccites* (0.5–5%), *Parasaccites* (0.5–6%), *Potonieisporites* (0.5–5%), *Divarisaccus* (0.5–2.5%); non-striate disaccates: *Ibisporites* (1–11.2%), *Sahnites* (0.5–1%), *Platysaccus* (0.5–2.8%), *Primuspollenites* (1–2.5%); striate disaccates: *Crescentipollenites* (1–20%), *Striatites* (0.7–7.5%), *Polypodioidites* (1%); aletes: *Inaperturopollenites* (0.5–1.4%), *Latosporites* (0.5–2%), *Maculatasporites* (0.5–2.5%), *Tiwariasporis* (1%). Beside, these some marked stratigraphically significant taxa are *Falcisporites* (0.5–7.5%), *Klausipollenites* (0.5–2.5%), *Chordasporites* (1–5%), *Striomonosaccites* (0.5–2%), *Lunatisporites* (1.5–11.9%), *Strotersporites* (1–15.5%), *Corisaccites* (0.5–1.4%), *Hamiapollenites* (0.5–2%), *Guttulapollenites* (1–3%), *Weylandites* (0.5–10%). *Striapollenites* has also been recorded in this palynoassemblage.

Botanical affinity. Palaeovegetation of Palynoassemblage III has also been represented by the dominance of conifers (>50%) *Faunipollenites bharadwajii*, *F. (=Protohaploxylinus) varius*, *F. parvus*, *F. goraensis*, *Striatopodocarpites diffusus*, *S. tiwarii*, *Lunatisporites diffusus*, *L. ovatus*, *L. pellucidus*, *Primuspollenites levis*. Sub-dominant glossopterids of this palaeovegetation are mainly represented by *Scheuringipollenites maximus*, *S. tentulus*, *Ibisporites jhingurdahiensis*, *Falcisporites nuthallensis*, *F. zapfei*, *Weylandites circularis* while, the cordaites (25%) are distinguished by the presence of *Parasaccites distinctus*, *P. korbaensis*, *P. obscures*, *Densipollenites indicus*, *D. magnicarpus*, *Plicatipollenites ganjraensis*, *Caheniasaccites* sp., *Primuspollenites levis*, *Potonieisporites* sp., and *Divarisaccus* sp. Spores are represented by the small association of filicopsids (*Polypodioidites* sp., *Horriditriletes rampurensis*, *Brevitriletes communis*, *B. unicus*, *Verrucosisporites gondwanensis*, *Microfoveolatispora* sp., *Microbaculispora* sp., *Leiotriletes* sp.), lycopsids (*Callumispora* sp., *Indotriletes* sp.) and sphenopsids (*Latosporites colliensis*).

Age. Guadalupian age (Aggarwal & Jha, 2013).

Comparison. Palynoassemblage III correlates with Palynozone-F of Johilla Coalfield of Son Valley (Tiwari & Ram Awatar, 1989) in having the presence of *Striatopodocarpites*, *Crescentipollenites*, *Faunipollenites*, *Callumispora*, *Klausipollenites*; Assemblage-II of Mantheni Area of Godavari Graben (Bharadwaj *et al.*, 1987); Palynoassemblage II from Ramagundam, Khammampalli and Manuguru areas (Srivastava & Jha, 1988); Assemblage-IV of

Figure 3. Plate showing Permian palynotaxa in borecore MGK-6 Kachinapalli area, Godavari Graben. **A**, *Densipollenites magnicorpus*, B.S.I.P. Slide No. 14019a, N42-2. **B**, *Striomonosaccites circularis*, B.S.I.P. Slide No. 14020, M53-4. **C**, *Falcisporites zapfei*, B.S.I.P. Slide No. 13980, O57-2. **D**, *Striapollenites obliquus*, B.S.I.P. Slide No. 14021, K41-2. **E**, *Strotersporites* sp., B.S.I.P. Slide No. 14022, D55. **F**, *Striatites varius*, B.S.I.P. Slide No. 14022, F33-4. **G**, *Striasulcites ovatus*, B.S.I.P. Slide No. 14023a, R55-2. **H**, *Strotersporites indicus*, B.S.I.P. Slide No. 13574, S49-2. **I**, *Hamiapollenites insolitus*, B.S.I.P. Slide No. 14024, E52-2. **J**, *Lunatisporites* sp., B.S.I.P. Slide No. 14020a, F55-3. **K**, *Lunatisporites pellucidus*, B.S.I.P. Slide No. 14025, J60-3. **L**, *Guttulapollenites hannonicus*, B.S.I.P. Slide No. 13577, M51-1. Scales bars = 20 µm.

Talcher Coalfield, Orissa (Tiwari *et al.*, 1991); Palynozone-2 of Bazargaon, Nagpur (Srivastava & Bhattacharya, 1996); Palynozone-5 of Mailaram area (Jha & Aggarwal, 2012).

In the present study the palynoassemblages have been identified on the basis of the dominance and subdominance of the datum while, if we observe the data of other Gondwana continents then the authors have made the palynozones/palynoassemblages on the basis of concurrent range zone (South Africa; MacRae, 1988), by the first occurrence of

index taxa (Australia; Kemp *et al.*, 1977), etc. In such cases only tentative correlation is possible in place of exact correlation. Late Permian palynoassemblages have also been found tentatively akin to Assemblage Zone-IV of Dwyka of Mid Zambesi basin (Falcon, 1975); Amery Group of East Antarctica, Buckley Formation from Mount Archernar and *Fossilryggen Vestfjella* Dronning Maund Land, Antarctica (Truswell, 1980; Playford, 1990); Lower Sakamena Group of Madagascar, Karoo Zone 4 and 5 of South Africa and

Figure 4. Histogram showing vertical distribution of different palynotaxa in Palynoassemblages I and II of borecore MGK-6, Kachinapalli area, Godavari Graben.

Figure 5. Histogram showing vertical distribution of different palynotaxa in Palynoassemblage III of borecore MGK-6, Kachinapalli area, Godavari Graben.

Figure 6. Frequency distribution of different plant types in borecore MGK-6, Kachinapalli area, Godavari Graben.

palynomorph zone of Maduma Basin Mudstone Formation from Mid-Zambia Basin (Nyambe & Utting, 1997), Upper part of *Lueckisporites-Weylandites* (LW) and *Striatites* Assemblage Biozone of Argentina (Césari & Gutiérrez, 2001; Beri *et al.*, 2011).

DISCUSSION

Age demarcation on the basis of palynofloral diversity

In Lower Gondwana palynofloral succession striate disaccates show fairly good representation in Lower Barakar, attain dominance in Upper Barakar and remain dominant component of palynoflora up to the Raniganj Formation (Late Permian). Thus, the striate disaccates lose the stratigraphic significance and the associated taxa become important while identifying the assemblages in Late Permian. The quantitative estimation of various taxa at generic level shows marked changes in microfossils from Early Permian to Late Permian. In Godavari Graben, total 12 palynoassemblages have been defined in Lower Gondwana succession on the basis of dominance and sub-dominance of striate and non-striate disaccates. Palynocomposition of Permian (Lower Gondwana) palynoassemblages in Godavari Graben has been described by Jha (2006) in detail. On the basis of palynological studies we have found only three out of twelve palynoassemblages in the presently studied borecore.

The dominance of non-striate disaccates *viz.*, *Scheuringipollenites*, *Ibisporites* and sub-dominance of striate disaccates *viz.*, *Striatopodocarpites*, *Faunipollenites*,

Crescentipollenites in Palynoassemblage I (314.25-346.65 m) suggests the Barakar palynoflora (Early Permian), dominance of striate disaccates *viz.*, *Faunipollenites*, *Striatopodocarpites*, *Striasulcites* and sub-dominance of nonstriate disaccate *Scheuringipollenites* alongwith some stratigraphically significant taxa *viz.*, *Lunatisporites*, *Falcisporites*, *Klausipollenites*, *Striomonosaccites*, *Chordasporites*, *Weylandites*, *Corisaccites*, *Guttulapollenites*, *Stroterisporites*, *Hamiapollenites* in Palynoassemblage-II (220.70-298 m) and Palynoassemblage III (46.75-206.70 m) suggests the Raniganj palynoflora (Late Permian). Hence, it is inferred that Palynoassemblage I was preserved during Artinskian age and the rest two; Palynoassemblage II and Palynoassemblage III were preserved during Guadalupian age.

Floristic changes and paleoecological variability

The present Kachinapalli palynoflora confirmed the dominance of gymnosperm pollen grains mainly assignable to glossopterids (*Scheuringipollenites maximus*, *S. tentulus*, *Ibisporites jhingurdahiensis*) and conifers (*Faunipollenites bharadwajii*, *F. (=Protohaploxypinus) varius*, *F. parvus*, *F. goraensis*, *Striatopodocarpites tiwarii*, *S. diffusus*, *Lunatisporites diffusus*, *L. ovatus*, *L. pellucidus*, *Primuspollenites levis*). Glossopterids grow in mesophyllous to xerophyllous palaeoenvironment, flourished in lowland peats while conifers were carried out from more distant areas to the mires (Knoll & Nicklas, 1987).

Conifers are considered to be extrabasinal or hinterland elements which typically show several adaptations for

Figure 7. Diagrammatic representation of identified palynofloras at the different depths of borecore-MGK-6.

survival in drier habitats. Likely less frequent cordaites (*Caheniasaccites distinctus*, *C. ovatus*, *C. ellipticus*, *Plicatipollenites indicus*, *P. ganjraensis*, *Densipollenites invisus*, *D. indicus*, *D. magnicarpus*, *Parasaccites distinctus*, *P. korbaensis*, *P. obscurus*, *Caheniasaccites* sp., *Primuspollenites levis*, *Potonieisporites* sp., *Divarisaccus* sp.), also grow from the more distant areas from the palaeomire, where they are scarcely preserved (Cazzulo-Klepzig *et al.*, 2005). Cordaitophytic pollen grains also love the mesophilous palaeoenvironment near the mire and palaeoecologically they inhabited in well drained, clastic low land substrates (Taylor & Taylor, 1993). Fragmentary presence of cordaites recommends the incursion of remnants of a parautochthonous seasonal dryland flora in the depositional environment (Jasper *et al.*, 2006).

Low percentage of pteridophytic spores belonging to Filicopsids (*Lophotriletes rectus*, *Microbaculispora* sp., *Horriditriletes rampurensis*, *Brevitriletes communis*, *B. unicus*, *Verrucosiporites gondwanensis* *Polypodioidites* sp., *Verrucosiporites gondwanensis*, *Microfoveolatispora* sp., *Microbaculispora* sp., *Leiotriletes* sp.), lycopsids (*Callumispora* sp., *Indotriradites* sp.) and sphenopsids (*Latosporites colliensis*) flourish in hygrophilous to mesophylous palaeoenvironment. Some authors *viz.*, Rothwell (1988), DiMichele & Phillips (1985, 1994) suggested that these spores might have a capacity to tolerate the flooded environment because of their reproductive strategies and specialized growth.

On the basis of botanical affinity the dominance of glossopterids (*Scheuringipollenites maximus*, *S. tentulus*,

Ibisporites jhingurdahiensis) and conifers (*Striatopodocarpites decorus*, *Faunipollenites* (= *Protohaploxypinus*) *varius*, *F. bharadwajii*, *F. goraensis*, *Striasulcites ovatus*, *Crescentipollenites globosus*) in the palynofloras represents a peat-forming community. Contributory cordaites, triletes pteridophytic spores belonging to lycopsids, sphenopsids and filicopsids are less and variable in percentage. Algae like elements (*Maculatasporites*) are very few or rarely present. Such type of palynofloral composition is very common in Indian coal palynoflora. Dominance of woody seed plants, variable-low percentage of pteridophytic plants along with scant percentage of algal form suggests the peat swamp forming vegetation (Guerra-Sommer *et al.*, 1983) in telmatic environment (forest moor) in a habitat with periods of standing water (Teichmüller, 1962). Similar type of palaeoenvironment has also been interpreted in Brazil (Guerra-Sommer *et al.*, 1983; Cazzulo-Klepzig *et al.*, 2007). The dominance of arborescent vegetation, low proportion of spores (lycopsids, sphenopsids and filicopsids) and diminutive presence of algal elements suggests that Kachinapalli palaeomire landscape was located in more inland area and the coal was formed in wet forest environment situated in fresh water setting. In the whole succession at some places a very good percentage of spores represent the flooding environment signatures in the palaeomire.

CONCLUSIONS

Lithologically Barren Measures and Kamthi formations have been demarcated between 306.50-475.30 m and 6-306.20 m, respectively, while on the basis of palynological studies in borecore MGK-6 falls under two groups: Palynoassemblage I, belonging to Artinskian age, and the rest two (Palynoassemblage II & III) belonging to Guadalupian age. The palynoflora present at the depth of 314.25-346.55 m shows continuation of Artinskian palynoflora, while the sediments between 220.70-298 m and 46.75-206.70 m have its equivalence with the Guadalupian palynoflora.

The presence of Barren Measures Formation in this sequence appear debatable (Figure 7). It is reasonable to assume that Barakar sedimentation has continued up to 306.50 m and the sedimentation through Barren Measures time is not preserved. However, no break in sedimentation is documented.

The complete succession of the present study represents a clear picture of the fluvial river channel deposit along with some sub-environments like flood plain, lake, lagoon, swamp and wetlands. On the basis of palynofloral components the present succession represents a peat-forming community mainly composed of glossopterids, cordaites and conifers. Contributory trilete pteridophytic spores belonging to lycopsids, sphenopsids and filicopsids are less and variable in percentage. Algae like elements (*Maculatasporites*) are very few or rarely present. Dominance of woody seed plants, variable-low percentage of pteridophytic plants along with scarce percentage of algal forms, suggests the peat swamp forming vegetation in telmatic environment (forest moor) in a habitat with periods of standing water.

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