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Palynofloral, palaeovegetational and palaeo-environmental investigations in the Lower Kamthi Formation of South India

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ABSTRACT

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These studies were carried out to better understand the palynostratigraphic and palaeoclimatic fluctuations observed in the floral ecosystem. The palynofloral investigation discovered two palynoassemblages (I–II). *Faunipollenites* spp. and *Striatopodocarpites* spp. dominate Palynoassemblage–I (430–232.10 m) with a high incidence of *Striasulcites* spp. Palynoassemblage–II (208.30–83.50 m) is distinguished by striate bisaccates and a high *Densipollenites* spp. frequency. *Alisporites* sp., *Falcisporites nuthaliensis*, *Klausipollenites schaubergeri, Chordasporites australiensis, Guttulapollenites hannonicus* and *Corisaccites alutus* are the younger elements of these palynoassemblages. Guadalupian (Wordian–Capitanian) and Lopingian (Wuchiapingian–Changhsingian) ages have been assigned to the palynoassemblage I and II based on palynofloral evidence. Organic matter in various forms indicates four distinct palynofacies assemblages (PF I–IV). According to their findings, the sequence is dominated by the presence of sub–arborescent/arborescent forest cover that thrived in swampy settings near the depositional site. During deposition, the host sediments exhibit oxic to anoxic conditions as well as variable energy levels of the freshwater regime.

.**Key–words**—Palynology, Palynofacies, Guadalupian, Lopingian, Godavari Valley Coalfield.

INTRODUCTION

THE Godavari Valley Coalfield is a NNW–SSE trending rift basin, located between N 16°38' to N 19°32' and E 79°12' to E 81°39'. The gravity anomalies show a large rift valley where Gondwana sediments were deposited in a block faulted trough that was gradually formed (Qureshy *et al.*, 1968). Later glaciations (post–Barakar Formation deposits) are suggested to have caused the Godavari Coalfield to first emerge as a Sag–type basin before changing it into a rift basin (Biswas, 1999). Based on the tectonics and structure Godavari Coalfield has been divided into four sub–basins, *viz.* (i) Godavari sub–basin, (ii) Kothagudem sub–basin, (iii) Chintalapudi sub–basin and (iv) Krishna–Godavari Coastal Tract. In the current work, the subsurface sedimentary sequence in borehole MJR–13 from the Jangareddygudem region of the Chintalapudi sub–basin is discussed.

Several boreholes in the Chintalapudi sub–basin have been analysed by various authors for palynological studies (Bottapagudem: Jha, 2004; Amavaram: Srivastava & Jha, 1992; Sattupalli: Jha, 2008; Srivastava & Jha, 1994; Ayyanpalli–Gompana: Srivastava & Jha, 1993; Gattugudem: Jha, 2002). Jha *et al*. have recently published a review on the palynostratigraphy of the Chintalapudi sub–basin (2018). Considered to be younger and predominantly developed during the Kamthi Period is the Chintalapudi sub–basin, largely due to the general absence of the Barakar and Barren Measures formations over a significant part of it. Except for Upper Barakar and Barren Measures, a complete palynofloral succession from the Early Permian to Early Triassic sequence has been documented. However, all previous studies focused solely on the palynostratigraphic setup in the basin, whereas the current study includes palynofacies investigation as well as palynostratigraphy, which is useful for establishing the palaeoenvironmental and depositional settings. Very few studies are available from the Chintalapudi sub–basin in context to the palaeoenvironmental setup (Mishra *et al.,* 2018; Mishra & Singh, 2018; Aggarwal *et al.,* 2019).

In this communication, borehole MJR–13 from the Jangareddygudem area, located on the sub–northeastern basin's margin, has been rendered for palynological studies aimed at understanding the stratigraphy, depositional environment, and palynofloral transition. Comparing coeval sequences from intrabasinal and interbasinal correlations in India and other Gondwana continents with contemporaneous deposits has also yielded age estimates. Singareni Collieries Company Limited (SCCL) of South India drilled borehole MJR–13 in the Jangareddygudem area. Fig. 1 shows the location map for borehole MJR–13 in detail. Palynofacies studies are used to better understand the palaeodepositional settings in the study area. Palynofacies analysis reveals information about the depositional environment in the study area as well as the maturation of organic matter. Tyson (1993, 1995) and Batten (1996) classified dispersed organic matter, and the current study follows their classification for palaeoenvironmental studies. The objective of this study is to utilize palynoflora for correlating and dating sediments, alongside investigating palaeodepositional environments within the Chintalapudi sub–basin. A total of 37 samples, sourced from different lithologies within the Kamthi Formation, were collected and subjected to analysis for this purpose.

GEOLOGICAL SETTINGS OF THE AREA

Godavari Coalfield deposits from the Permian, Triassic, and Jurassic periods, as well as the Lower Cretaceous, span the entire Gondwana (Asselian–Albian) Period in the South Indian Peninsula (Mukhopadhyay *et al.,* 2010). Lower Gondwana (Asselian–Changhsingian) sediments are exposed along the basin's eastern and western margins in this linear belt. The Upper Gondwana (Induan–Albian) sediments, on the other hand, cover the central/axial portion of the basin.

The Chintalapudi sub–basin, which extends the Kothagudem sub–basin to the southeast (Fig. 1), is unconformably situated atop the Archaean gneisses and spans an area of 2500 square kilometres. The formations known as the Talchir, Barakar, Kamthi, Maleri, Kota, and Gangapur represent the stratigraphic succession of the Gondwana sediments in this sub–basin (Table 1). The overlaying sequence in this sub–basin encompasses the axial portion of the basin, while the Talchir and Barakar formations are exposed at the eastern and western basin edges. In the past, the Gondwana rocks of this sub–basin have been described as the Chintalapudi Formation, Kamthi Formation, and Kamthi Sandstone (Blanford, 1872; Rao, 1982; Raiverman *et al.*, 1985). The Chintalapudi sub–basin was formerly said to be of a younger generation and to have grown mostly during the deposition of the Kamthi, as evidenced by the widespread lack of the Barakar and Barren Measures formations over a significant portion of the sub–basin (Raiverman *et al.,* 1985). Later, the stratigraphy was corrected by Lakshminarayana and Murti (1990) and Lakshminarayana (1996), who also noticed the existence of the Upper Gondwana sequence and discovered the Talchir and Barakar formations. As a result, the Kamthi Formation likewise sits on top of the Barakar Formation on the southwest edge of the Chintalapudi sub–basin. Still, it is faulted against the foundation rock further south. Barring Barren Measures, the palynological study of the

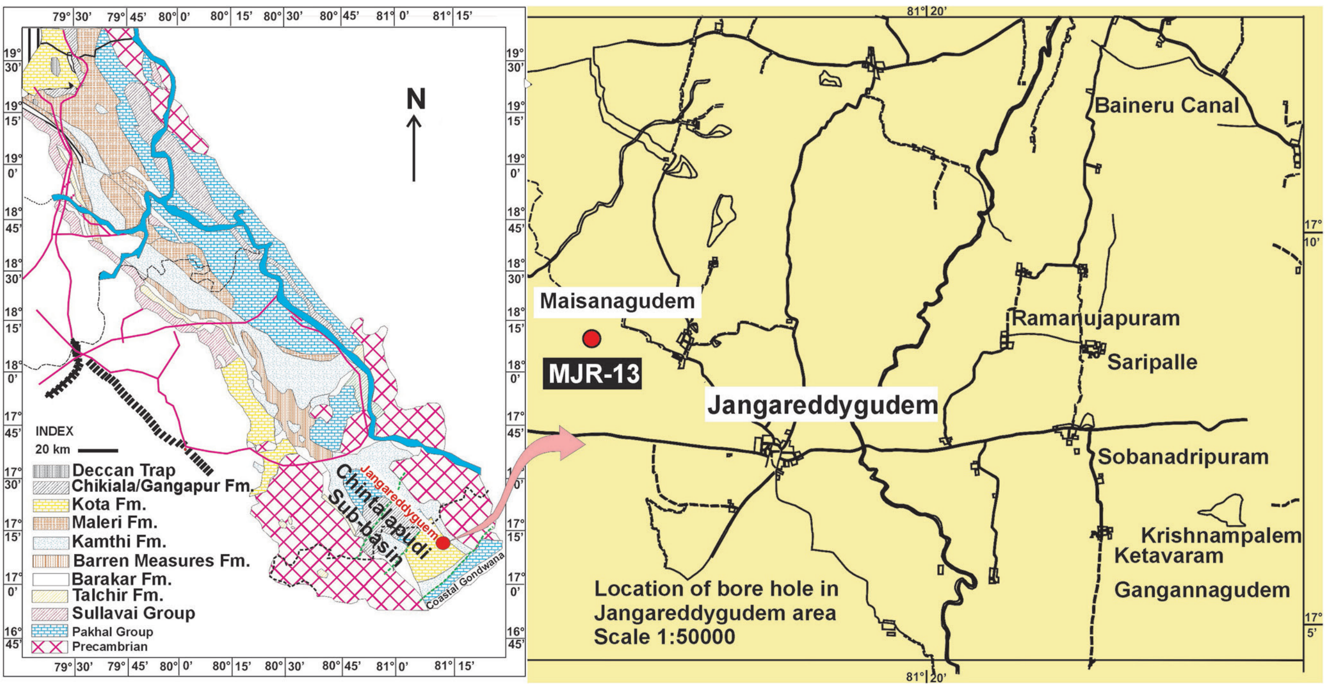

Fig. 1—Study area map of Godavari Graben with location map of the borehole in the Jangareddygudem area.

Table 1—A generalized stratigraphical sequence in Chintalapudi sub–basin (*after* Lakshminarayana, 1996).

Age	Group	Formation	Lithology
EARLY CRETACEOUS	UPPER GONDWANA	Gangapur	White sandstone, buff siltstone and claystone
		Unconformity	
JURASSIC		Kota	UPPER–sandstone and conglomeratic sandstone MIDDLE–limestone and marl LOWER–Conglomeratic sandstone and trough cross stratified sandstone
		Unconformity	
MIDDLE TRIASSIC–LATE TRIASSIC		Maleri	(?) Red clay and lime–pellet rock
EARLY TRIASSIC		Upper Kamthi	Coarse–grained, ferruginous sandstones with clay clasts and pebbles and subordinate violet cherty siltstones and pebble beds
		Middle Kamthi	Alternating sequence of medium–grained white to greenish grey white sandstones and buff to greenish grey clays
Unconformity			
LATE PERMIAN	LOWER GONDWANA	Lower Kamthi/ Raniganj	Medium–to–coarse–grained, greyish–white sandstones with a few coal seams
		Unconformity	
EARLY PERMIAN		Barakar	UPPER–White feldspathic sandstone, siltstone, shale, carbonaceous shale and coal seams LOWER–Very coarse–grained, pebbly, feldspathic sandstone
		Talchir	Diamictite, rhythmite, fine–grained light green sandstone, and siltstone
Unconformity			
PRECAMBRIAN	———	Proterozoic	
		Archaean	

19 boreholes in this sub–basin (Jha *et al.*, 2018) shows that the Early Permian–Early Triassic succession is nearly complete.

The stratigraphy of the Kamthi Formation in the Chintalapudi sub–basin remains poorly understood and warrants further investigation (refer to Table 1). This necessitates the execution of dating and correlation efforts in this area, which is the focus of the present study.

MATERIAL AND METHODS

Palynofloral analysis—The thirty–seven rock samples from various lithologies were collected from the drilled borehole MJR–13 (Figs 2 & 3) in the Kamthi Formation. The running borehole was drilled up to 477.50 m, and no workable coal seam has been marked as per lithological information. The thin coal layers identified in the sequence belong to the Kamthi Formation. Samples were processed by standard palynological maceration techniques proposed by Bharadwaj (1962) and Bharadwaj and Salujha (1964).

Palynofacies analysis—A standard non–oxidative procedure (Batten, 1999; Prasad *et al.,* 2013; Aggarwal *et al.,* 2019) proceeded to recover palynofacies matter. The residue was only mounted on slides after treatment with hydrochloric acid (HCL) and hydrofluoric acid (HF).

The chemically treated materials for both analysis were sieved, and slides were prepared using Canada balsam as a mounting medium. For stratigraphic analysis, two hundred (200) palynomorphs and 500 organic matter particles were counted per sample for palynofacies analysis. The optical examination was conducted utilizing an Olympus BX61 microscope paired with a DP–25 camera and Cell A software. All slides are housed at the Museum, Birbal Sahni Institute of Palaeosciences, Lucknow.

PALYNOFLORAL INVESTIGATION

In the complete sequence, two distinct palynological assemblages have been identified, encompassing 49 genera of spores and pollen. Among these, one spore genus belongs to Sphenophyta and five to Pteridophyta. The Gymnosperms are represented by six monosaccate genera, ten striate bisaccate genera, fourteen non–striate bisaccate genera, five taeniate genera, one monosulcate, one praecolpate genus, and two costate genera along with three algal genera and one with unknown botanical affinity. The list of palynomorph taxa with their probable botanical affinity is given in Table 2. The recovered pollen grains range from well–preserved to broken states. Stratigraphically significant taxa have been illustrated in Figs 4, 5, and 6. The stratigraphic range and relative abundance of palynomorphs in borehole MJR–13 are illustrated in Fig. 2.

Palynological assemblage–I (Striate bisaccates–*Striasulcites* spp.)

The distance from 429.50 m to 232.10 m is a part of this palynoassemblage. It is distinguished by a predominance of striate bisaccate pollen grains, primarily species of *Faunipollenites* (=*Protohaploxypinus*) spp. (13–36%) {*F. bharadwajii, F. varius, F. enigmatus, F. singrauliensis*}, *Striatopodocarpites* spp. (1–10%) {*S. brevis, S. multistriatus, S. diffuses, S. magnificus*} and *Striasulcites* spp. (5–50%) {*S. tectus, S. ovatus*}. The other taxa of this assemblage that have been recorded are:

Triletes—*Latosporites colliensis* (1–3%), *Calamospora exile* (1%), *Lophotriletes* sp. (1%), *Horriditriletes* sp. (1%), *Lahirites* sp. (1%), *Leiotriletes* sp. (1%), *Microfoveolatispora foveolata* (1%).

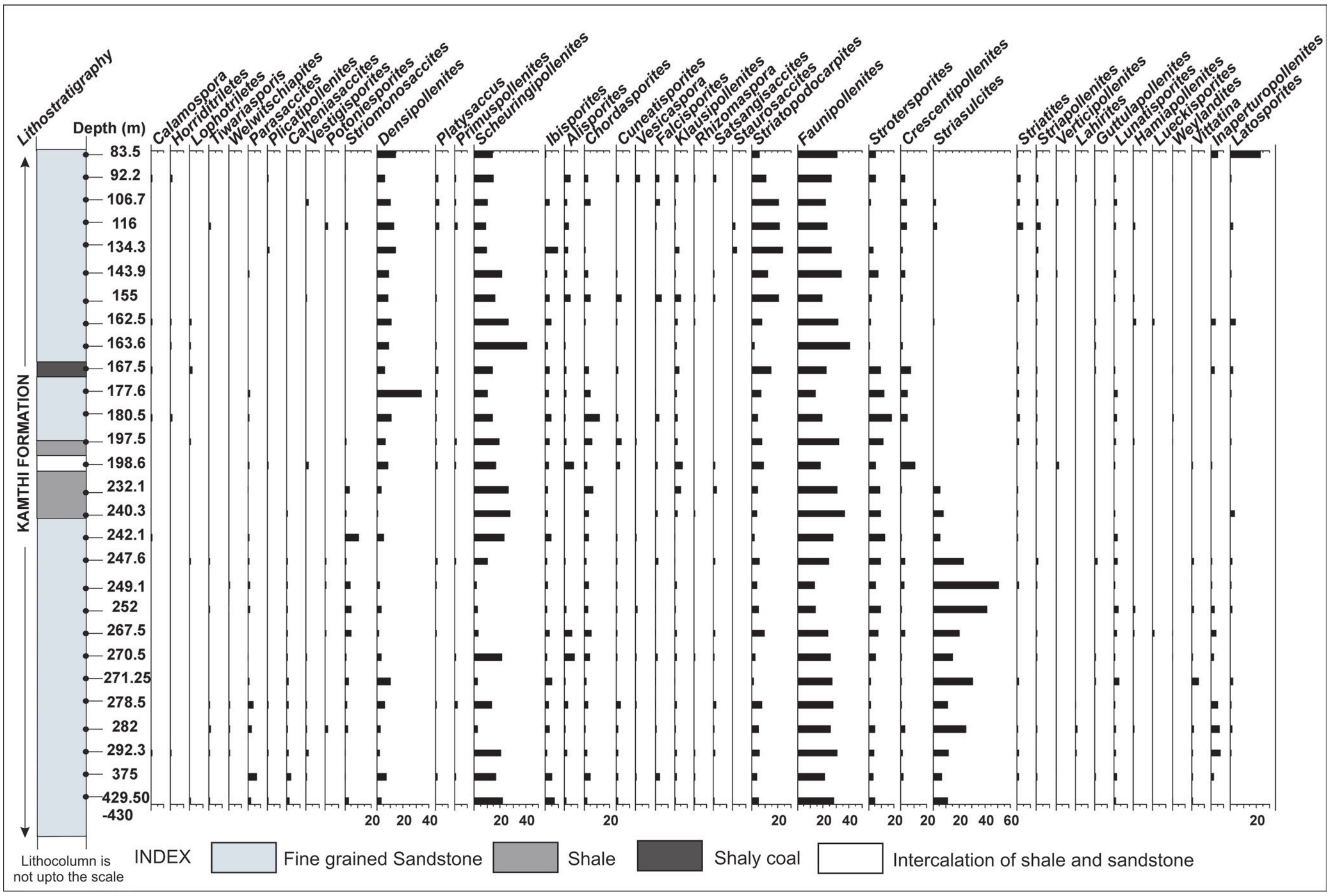

Fig. 2—Lithological column and sample levels, stratigraphic occurrence, and relative abundance of various palynomorphs in borehole MJR–13.

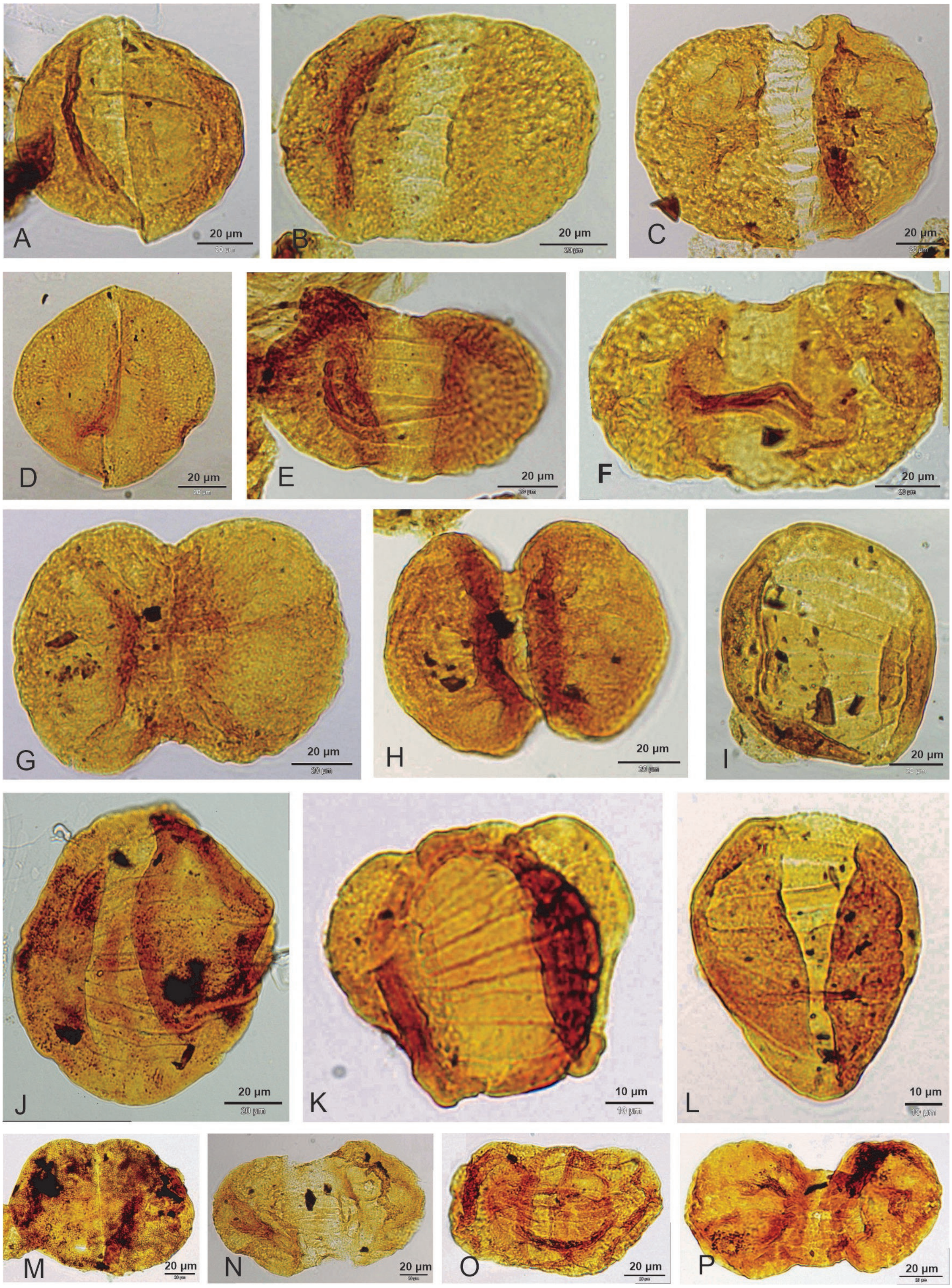

Fig. 3—Stratigraphically significant palynotaxa of palynoassemblage–I (Wordian–Capitanian) of borehole MJR–13. A. *Faunipollenites singrauliensis*, BSIP Slide No. 15328, P57/3, B. *Striatopodocarpites magnificus*, BSIP Slide No. 15329, K48/3, C. *Faunipollenites enigmatus*, BSIP Slide No. 15325, K49, D. *F. singrauliensis*, MJR–13, BSIP Slide No. 15328, U57/4, E. *Strotersporites* sp., BSIP Slide No. 15329, P45/4, F. *Strotersporites crassiletus*, BSIP Slide No.15326, M44/3, G. *Striatites reticuloidus*, BSIP Slide No. 15328, P32/4, H. *Striatopodocarpites* sp., BSIP Slide No. 15329, K55/2, I. *Striasulcites tectus,* BSIP Slide No. 15329, G62/1, J. *S. tectus*, BSIP Slide No. 15332, E62, K. *S. tectus*, BSIP Slide No. 15329, U54/4, L. *S. tectus*, BSIP Slide No. 15328, H38/4, M. *Faunipollenites singrauliensis*, BSIP Slide No. 15326, S33/3, N. *Faunipollenites* sp., BSIP Slide No. 15325, K35/2, O. *Crescentipollenites densus*, BSIP Slide No. 15327, H46, P. *Verticipollenites finimitus,* BSIP Slide No. 15322, H51/4.

Table 2—List of spores and pollen grains with their probable botanical affinities (Balme, 1995; Costamagna *et al*., 2018).

Botanical Affinity (Balme, 1995; Costamagna *et al*., 2018)	**Recovered palynoflora from the studied borehole MJR–13**
	PTERIDOPHYTES
	(i) Sphenophyta
Equisetopsida	*Calamospora* (=*Punctatisporites*) *exile* Bharadwaj & Salujha 1964
Equisetopsida	*Calamospora* (=*Punctatisporites*) sp.
	(ii) Filicophyta
Filicopsid	*Horriditriletes ramosus* (Balme & Hennelly) Bharadwaj & Salujha 1964
Filicopsid	*Horriditriletes* sp.
Filicopsid	*Lacinitriletes* sp.
Filicopsid	*Leiotriletes* sp.
Filicopsid	*Lophotriletes rectus* Bharadwaj & Salujha 1964
Filicopsid	*Lophotriletes* sp.
Filicopsid	*Microfoveolatispora foveolata* Tiwari & Singh 1986
	GYMNOSPERMS
	(i) Monosulcate grains
Cycadales	*Cycadopites* sp.
	(ii) Praecolpate grains
Unknown	*Praecolpatites nidpurensis* Bharadwaj & Srivastava 1969
	(iii) Monosaccate grains
Cordaitales	*Caheniasaccites elongatus* Bose & Kar 1966
Cordaitales	*Caheniasaccites* sp.
Unknown	*Kamthisaccites kamthiensis* Srivastava & Jha 1986
Cordaitales	*Parasaccites* (=*Cannanaropollis*) *densicorpus* Lele 1975
Cordaitales	*Parasaccites diffusus* (Tiwari) Bose & Maheshwari 1968
Cordaitales	*Parasaccites distinctus* Tiwari 1965
Cordaitales	*Parasaccites korbaensis* Bharadwaj & Tiwari 1964
Cordaitales	*Parasaccites obscures* Tiwari 1965
Cordaitales	*Parasaccites* sp.
Cordaitales	*Plicatipollenites indicus* Lele 1963
Cordaitales	*Plicatipollenites ovatus* Kar 1968
Cordaitales	*Plicatipollenites* sp.
Conifers	*Potoniéisporites* sp.
Coniferales	*Striomonosaccites ovatus* Bharadwaj 1962
	(iv) Bisaccate grains
	(a) Nonstriate bisaccates
Conifers	*Alisporites indarraensis* Segroves 1969
Conifers	*Alisporites landianus* Balme 1970
Conifers	*Alisporites* sp.
Unknown	*Brachysaccus* sp.
Peltaspermales	*Chordasporites australiensis* de Jersey 1962
Unknown	*Cuneatisporites* sp.
Conifers	*Falcisporites nuthaliensis* (Clark) Balme 1970

Conifers	*Falcisporites* sp.
Conifers	*Falcisporites zapfei* (Potonié & Klaus) Leschik 1956
Glossopteridales	*Ibisporites diplosaccus* Tiwari 1968
Peltaspermales	*Klausipollenites schaubergeri* (Potonié & Kremp) Klaus 1963
Peltaspermales	*Klausipollenites* sp.
Peltaspermales	*Platysaccus* sp.
Conifers	*Primuspollenites levis* Tiwari 1964
Conifers	*Primuspollenites* sp.
Unknown	*Rhizomaspora indica* Tiwari 1965
Conifers	*Scheuringipollenites barakarensis* (Tiwari) Tiwari 1973
Conifers	*Scheuringipollenites maximus* (Hart) Tiwari 1973
Conifers	*Scheuringipollenites* sp.
Conifers	*Scheuringipollenites tentulus* (Tiwari) Tiwari 1973
Unknown	*Staurosaccites* sp.
Unknown	*Vesicaspora luteus* Salujha 1965
Unknown	*Vestigisporites rudis* Balme & Hennelly 1955
	(b) Striate bisaccates
Glossopterids	*Crescentipollenites barakarensis* Sinha 1972
Glossopterids	*Crescentipollenites densus* Bharadwaj & Srivastava 1969
Glossopterids	*Crescentipollenites globosus* (Maithy) Jha 1996
Glossopterids	*Crescentipollenites* sp.
Glossopteridales	*Faunipollenites bharadwajii* Maheshwari 1967
Glossopteridales	*Faunipollenites enigmatus* Maheshwari 1969
Glossopteridales	*Faunipollenites goraiensis* (Potonié & Lele) Maithy (1965)
Glossopteridales	*Faunipollenites parvus* Tiwari 1965
Glossopteridales	*Faunipollenites singrauliensis* Sinha 1972
Glossopteridales	*Faunipollenites* (=*Protohaploxypinus*) sp.
Glossopteridales	*Faunipollenites varius* (Bharadwaj) Tiwari *et al.* 1989
Coniferales	*Hamiapollenites insolitus* Bharadwaj & Salujha 1964
Unknown	*Lahirites* sp.
Glossopteridales	*Striapollenites saccates* Bharadwaj 1962
Coniferales	*Striasulcites ovatus* Venkatachala & Kar 1968
Coniferales	*Striasulcites* sp.
Coniferales	*Striasulcites tectus* Venkatachala & Kar 1968
Coniferales	*Striatites communis* Bharadwaj & Salujha 1964
Coniferales	*Striatites parvus* Tiwari 1965
Coniferales	*Striatites reticuloidus* Tiwari 1965
Coniferales	*Striatites rhombicus* Bharadwaj & Salujha 1964
Coniferales	*Striatites* sp.
Coniferales	*Striatites tentulus* Tiwari 1965
Glossopteridales	*Striatopodocarpites brevis* Sinha 1972
Glossopteridales	*Striatopodocarpites cancellatus* (Balme & Hennelly 1955) Hart 1963
Glossopteridales	*Striatopodocarpites diffusus* Bharadwaj & Salujha 1964
Glossopteridales	*Striatopodocarpites magnificus* Bharadwaj & Salujha 1964

Glossopteridales	*Striatopodocarpites multistriatus* Jha 1996
Glossopteridales	*Striatopodocarpites* sp.
Glossopteridales	*Striatopodocarpites subcircularis* Sinha 1972
Glossopteridales	*Striatopodocarpites tiwarii* Bharadwaj & Dwivedi 1981
Glossopterids	*Strotersporites communis* (Wilson 1962) Hart 1964
Glossopterids	*Strotersporites* sp.
Glossopterids	*Strotersporites wilsonii* Klaus 1963
Glossopterids	*Strotersporites crassiletus* Jha 1996
Glossopterids	*Strotersporites perfectus* Maheshwari 1966
Glossopterids	*Verticipollenites debilis* Venkatachala & Kar 1968
Glossopterids	*Verticipollenites secretus* Bharadwaj 1962
Glossopterids	*Verticipollenites finimitus* Bharadwaj & Salujha 1964
Glossopterids	*Verticipollenites* sp.
	(c) Taeniate bisaccates
Coniferales	*Corisaccites alutus* Venkatachala & Kar 1968
Unknown	*Crucisaccites* sp.
Coniferales	*Guttulapollenites gondwanensis* Goubin 1965
Coniferales	*Guttulapollenites hannonicus* Goubin 1965
Coniferales	*Guttulapollenites* sp.
Unknown	*Lueckisporites virkkiae* Potonié & Klaus 1954
Coniferales	*Lunatisporites ovatus* (Goubin) Maheshwari & Banerji 1975
Coniferales	*Lunatisporites pellucidus* (Goubin) Helby 1972
Coniferales	*Lunatisporites* sp.
	(d) Costate grains
Coniferales	*Tiwariasporis* sp.
Coniferales	*Weylandites circularis* Bharadwaj & Srivastava 1969
Coniferales	*Weylandites indicus* Bharadwaj & Srivastava 1969
Coniferales	*Weylandites Lucifer* (Bharadwaj & Salujha) Bharadwaj & Dwivedi 1981
	ALGAE
	Inaperturopollenites sp.
	Maculatasporites sp.
	Latosporites colliensis (Balme & Hennelly) Bharadwaj 1962
	Latosporites sp.
	Unknown Botanical Affinity
	Densipollenites densus Bharadwaj & Srivastava 1969
	Densipollenites indicus Bharadwaj 1962
	Densipollenites invisus Bharadwaj & Salujha 1964
	Densipollenites magnicorpus Tiwari & Rana 1981
	Densipollenites magnicorpus var. annulatus Jha 1996
	D. magnicorpus var. distinctus Jha 1996
	Densipollenites marginalis Jha 1996
	Densipollenites sp.

Monosaccates—*Caheniasaccites elongatus* (1–3%), *Densipollenites* spp. (1–10%) {*D. densus, D. magnicorpus, D. invisus, D. marginalis*}, *Parasaccites* (1–7%) {*P. densicorpus, P. distinctus, P. korbaensis, P. diffusus*}, *Crucisaccites* sp. (2%), *Plicatipollenites* sp. (1%), *Potonieisporites* sp. (1%), *Striomonosaccites ovatus* (1–5%).

Non–striate bisaccates—*Klausipollenites* sp. (1–5%), *Alisporites* sp. (1–7%), *Chordasporites australiensis* (1–7%), *Falcisporites nuthaliensis* (1–4%), *Scheuringipollenites* spp. (2–28%) {*S. barakarensis, S. tentulus, S. maximus*}, *Ibisporites diplosaccus* (1–7%), *Brachysaccus* sp. (1%), *Primuspollenites levis* (1%), *Vestigisporites rudis* (1%), *Platysaccus* sp. (1%).

Striate bisaccates—*Crescentipollenites globosus* (1–5%), *Strotersporites communis* (2–13%), *Striasulcites tectus* (2–3%), *Striatites rhombicus* (1%).

Taeniates—*Lunatisporites* spp. (1–4%) {*Lunatisporites* sp., *L. pellucidus*}, *Corisaccites alutus* (2%), *Guttulapollenites hannonicus* (1%), *Hamiapollenites insolitus* (1%), *Kamthisaccites kamthiensis* (1%).

Others—*Inaperturopollenites* sp. (1–7%), *Weylandites indicus*, *W. lucifer* (1%), *Cuneatisporites* sp. (1–3%), *Cycadopites* sp. (1%), *Praecolpatites nidpurensis* (1%).

Comparison—Palynological Assemblage–I compares well with the *Gondisporites raniganjaensis* Zone of the Damodar Basin (Tiwari & Tripathi, 1991). The assemblage also has its resemblance with other records (Palynoassemblage–II: Srivastava & Jha, 1988; Palynozone–F: Tiwari & Ram–Awatar, 1989; Assemblage–IV: Tiwari *et al.,* 1991; Palynozone 2: Srivastava & Bhattacharyya, 1996; Palynozone–5: Jha & Aggarwal, 2012; Palynozone–6: Aggarwal & Jha, 2013; Palynoassemblage–III: Jha & Aggarwal, 2015; Assemblage–I: Mishra *et al.,* 2018; Palynoassemblage–6: Jha *et al.,* 2018; Palynoassemblage–IV: Aggarwal *et al.,* 2019).

Lithostratigraphic distribution—Kamthi Formation.

Age—*Gondisporites raniganjaensis* closely resembles Zone–VII of the Western Australian Gondwana palynological zones (Kemp *et al.,* 1977) in the predominance of the striate bisaccates *Faunipollenites* (=*Protohaploxypinus*) spp., *Striatites* spp. and *Striatopodocarpites* spp. and monosaccate *Densipollenites* spp. Zone–VII of Western Australia has been dated as Wordian–Capitanian (Guadalupian), and Zone–VI has been precisely dated as Roadian based on the recovered ammonites and other invertebrate fossils that lie just below this zone. Wordian–Capitanian (Guadalupian) age has been thus assigned for palynoassemblages–I. Similar records have also been documented in Indian Gondwana (Table 5; Aggarwal & Jha, 2013, Fig. 2; Prasad & Pundir, 2017).

Interregional correlation—By sharing occurrences of *Striatopodocarpites* spp., *Faunipollenites* spp., *Densipollenites* spp., *Scheuringipollenites* spp., *Guttulapollenites hannonicus*, and *Weylandites lucifer*, the current Jangareddygudem palynoflora of India is tentatively correlatable with the Late Permian palynoassemblages (Balme & Playford, 1967; Kemp, 1973; Dibner, 1976; Playford, 1990). It corresponds to the NW Nunatak, Vestfjella, and southern section palynological assemblages from the Late Permian in Dronning Maud Land, Antarctica (Lindström, 1996). *Striatopodocarpites* spp. and *Faunipollenites* spp., which are dominant in both assemblages, are supplemented by a few non–striate bisaccates (*Scheuringipollenites* spp., *Alisporites* spp., etc.). The palynoflora of the Buckley Formation (Mount Archenar, Central Transantarctic Mountains, Farabee *et al.,* 1991) and the top portions of the Mount *Glossopteris* Formation and Queen Maud Formation (Nilsen Plateau, Kyle, 1977; Kyle & Schopf, 1982) from the Late Permian are exhibiting notable parallels. The present palynoflora indicates similarities in having commonly occurring palynocomponents to some extent, with the Upper stage–5 of Australia represented by the dominance of striate bisaccates and a few non–striate bisaccates along with trilete spores (Foster, 1982). The latest Permian palynoassemblages of Australia (Backhouse, 1993) are documented to show *Horriditriletes* spp., *Protohaploxypinus* (=*Faunipollenites* spp.), and *Weylandites lucifer,* which forces for the broad tentative correlation with Indian palynoflora. Present palynoflora has also been correlated with the African palynoflora of Assemblage Zone IV (Falcon, 1975), with the upper part of the Madumabisa Formation palynoassemblage, Zambia (Utting, 1976), and microfloral zone 6 and 7 (Anderson, 1977). Further, the palynoflora of the lower Sakamena Group, Madagascar (Wright & Askin, 1987), and Biozone–E of the north Karoo Basin (MacRae, 1988), including the Palynoassemblage of the Lower Karoo sequence (Semkiwa *et al.,* 2003) and palynoassemblage of the Kalahari Karoo Basin (Modie & Le Hérissé, 2009) are depicting palynofloral similarities. It also indicates little correlation similarity with the *Tornopollenites toreutos* Zone, Andira' Formation of Tapajo's Group, Amazon Basin, northern Brazil (Playford & Dino, 2000, 2005).

Palynological assemblage–II (Striate bisaccates–*Densipollenites* spp.)

The Palynological Assemblage–II (208.30–83.50 m) is distinguished from the previous assemblage by the predominance of striate bisaccates, *Striatopodocarpites* spp. (2–24%) {*S. tiwarii, S. brevis, S. subcircularis, S. multistriatus, S. cancellatus*}, *Faunipollenites* (=*Protohaploxypinus*) spp. (13–40%) {*F. parvus, F. varius, F. goraiensis, F. bharadwajii*} along with a significant percentage of enveloping monosaccate *Densipollenites* spp. (6–33%) {*D. indicus, D. invisus, D. magnicorpus var. distinctus*, *D. magnicorpus var. annulatus*}. The composition of this palynoassemblage is as follows:

Triletes—*Latosporites* (1–23%), *Horriditriletes ramosus* (1%), *Lacinitriletes* sp., *Lophotriletes rectus* (1%), *Leiotriletes* sp. (1%), *Calamospora* sp. (1%).

Monosaccates—*Parasaccites* spp. (2%) {*P. obscures, P. korbaensis*}, *Plicatipollenites* spp. {*P. ovatus, P. indicus*},

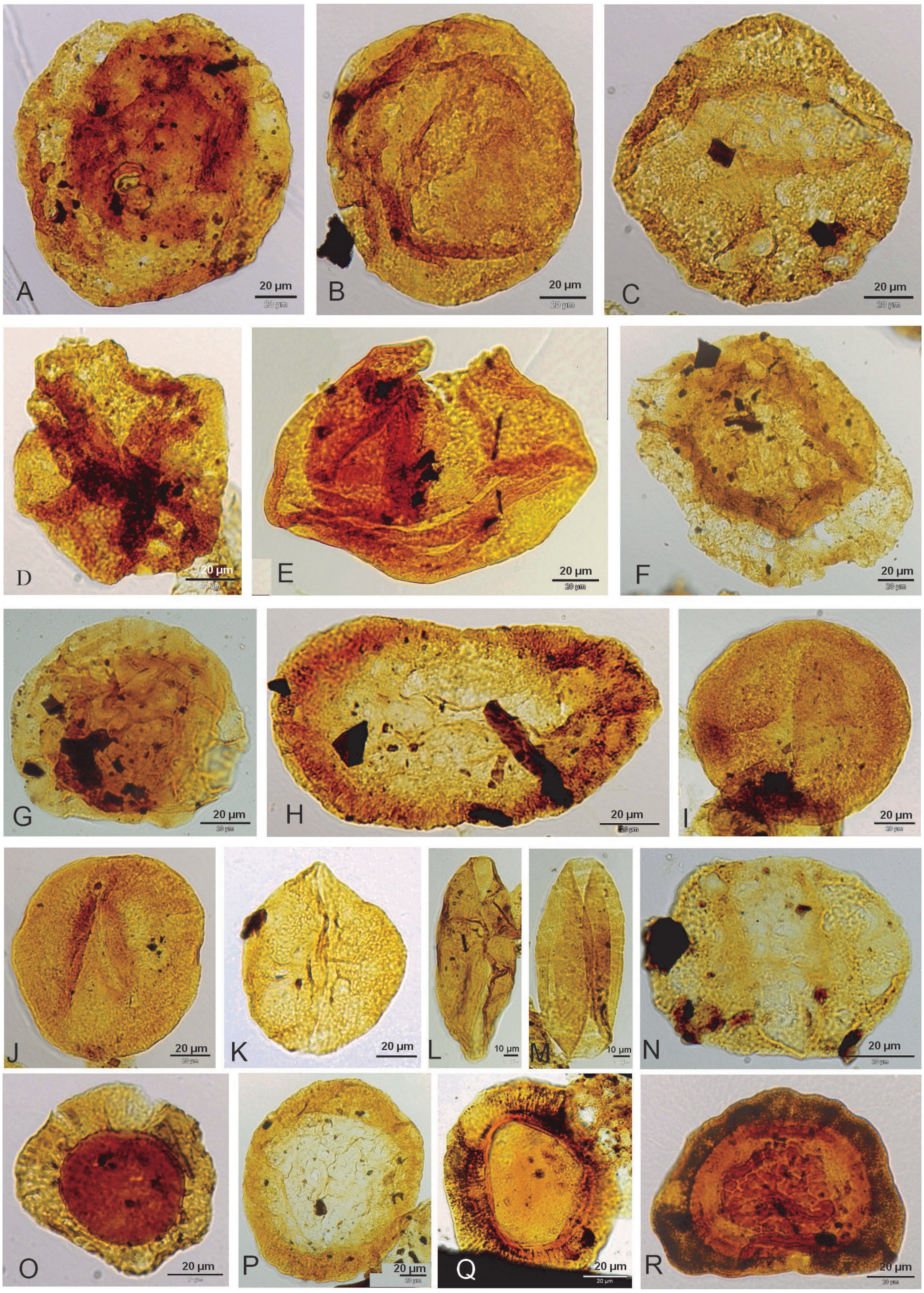

Fig. 4—Stratigraphically significant palynotaxa of palynoassemblage–II (Wuchiapingian–Changhsingian) of borehole MJR–13. A. *Densipollenites magnicorpus*, BSIP Slide No. 15321, W57/4, B. *D. invisus*, BSIP Slide No. 15325, J52, C. *D. invisus*, BSIP Slide No. 15325, J52/4, D. *D. invisus*, BSIP Slide No. 15325, K37/3, E. *D. indicus*, BSIP Slide No. 15320, E61/1, F. *D. marginalis*, BSIP Slide No. 15332, P53/4, G. *D. magnicorpus*, BSIP Slide No. 15331, O69/1, H. *Caheniasaccites elongatus*, BSIP Slide No. 15330, E63/1, I. *Scheuringipollenites maximus*, BSIP Slide No. 15329, Q46/2, J. *S. maximus*, BSIP Slide No. 15328, K67/4, K. *S. maximus*, BSIP Slide No. 15325, K51, L. *Cycadopites* sp., BSIP Slide No. 15329, F52/4, M. *Striasulcites* sp., BSIP Slide No. 15329, F52/4, N. *Falcisporites zapfei*, BSIP Slide No. 15332, W59/2, O. *Parasaccites densicorpus*, BSIP Slide No. 15324, M61/4, P. *P. diffusus*, BSIP Slide No. 15321, E50/2, Q. *Plicatipollenites ovatus*, BSIP Slide No. 15332, W55/3, R. *P. indicus*, BSIP Slide No. 15334, P64/4.

Potonieisporites sp. (1%), *Striomonosaccites ovatus* (1%), *Crucisaccites* sp. (1%).

Non–striate bisaccates—*Scheuringipollenite*s spp. (8–40%) {*S. barakarensis, S. tentulus, S. maximus*}, *Klausipollenites schaubergeri* (1–6%), *Alisporites* spp. (1–4%) {A. *landianus, A. indarraensis*}, *Chordasporites australiensis* (1–11%), *Falcisporites zapfei* (1–3%), *Ibisporites diplosaccus* (1–10%), *Platysaccus* sp. (1–3%), *Primuspollenites* sp. (1%), *Vestigisporites* sp. (1%), *Vesicaspora luteus* (1%).

Striate bisaccates—*Striapollenites saccates* (1–3%), *Striatites* spp. (1–5%) {*S. tentulus, S. parvus*, *S. communis, S. reticuloidus*}, *Striasulcites* spp. (1–4%) {*S. ovatus, S. tectus*}, *Crescentipollenites* spp. (3–11%) {*C. globosus, C. barakarensis. C. densus*}, *Strotersporites* spp. (1–19%) {*S. wilsonii, S. communis, S. crassiletus, S. perfectus*}, *Lahirites* sp. (1%), *Verticipollenites* spp. (2%) {*V. debilis, V. secretus, V. finimitus*}.

Taeniates—*Corisaccites alutus* (1%), *Hamiapollenites insolitus* (1%), *Lunatisporites ovatus* (1%), *Guttulapollenites* spp. (1%) {*G. hannonicus, G. gondwanensis*}, *Lueckisporites virkkiae* (1%).

Others—*Inaperturopollenites* sp. (1–5%), *Cuneatisporites* sp. (1–4%), *Weylandites circularis* (1%), *Rhizomaspora indica* (1%), *Staurosaccites* sp. (2–3%), *Tiwariasporis* sp. (1%), *Latosporites colliensis* (1%), *Maculatasporites* sp. (1%).

Lithostratigraphic distribution—Kamthi Formation.

Comparison—Palynoassemblage–II is akin to the *Densipollenites magnicorpus* Assemblage zone of Damodar Basin (Tiwari & Tripathi, 1991) in predominance of striate bisaccates along with acme of the monosaccate genus *Densipollenites* spp. It also closely resembles the *Guttulapollenites gondwanensis–Striatopodocarpites tiwarii* zone of Krishna Godavari Basin (Prasad *et al.,* 1995; Prasad & Pundir, 2017). Similar palynoflora has also been recorded from other places (Palynozone–6: Jha & Aggarwal, 2012; Palynozone–8: Srivastava & Jha, 1995; Palynoassemblage–II: Jha, 2004; Palynoassemblage–I: Jha *et al.,* 2014; Assemblage–II Mishra *et al.,* 2018; Palynoassemblage–VII: Jha *et al.,* 2018). Besides, this *Densipollenites* Assemblage zone is well–known from the other Indian Gondwana basins such as South Rewa Basin (Ram–Awatar *et al.,* 2005); Damodar Basin (Srivastava *et al.,* 1997; Vijaya, 2011; Murthy, 2010; Murthy *et al.,* 2010, 2015); Satpura Basin (Bharadwaj *et al.,* 1978; Murthy *et al.,* 2013); Mahanadi Basin (Tiwari *et al.,* 1991; Tripathi, 1997; Chakraborty, 2003; Vijaya *et al.,* 2012; Sahoo *et al.,* 2020); Rajmahal Basin (Vijaya, 2006, 2009; Tripathi *et al.,* 2010); Talcher Basin (Patel *et al*., 2022); Son Valley (Tiwari & Ram–Awatar, 1989).

Age—However, the *G. gondwanensis–S. tiwarii* zone documented from the latest Permian (uppermost part of Lower Gondwana succession) in India, including Godavari Coalfield, is also closely comparable with the Late Permian palynofloras of Chhidru Formation (Salt Range, Pakistan: Balme, 1970) and Gungri Shale (Spiti Valley, Tethyan Himalaya: Singh *et al.,* 1995) in having the dominant occurrence of the species of *Striatopodocarpites, Densipollenites, Crecentipollenites,* and *Guttulapollenites*. The associated sediments have been dated as Lopingian (Wuchiapingian–Changhsingian) based on the occurrence of the *Productus*, *Spiriferella,* and *Cyclolobus walkeri* (Prasad & Pundir, 2017). The occurrence of *Densipollenites magnicorpus* zone just below the *Lunatisporites pellucidus–Klausipollenites schaubergeri* Zone of Griesbachian (Early Triassic) age in India (=*Lunatisporites pellucidus* Zone; Helby *et al.,* 1987) confirms its Wuchiapingian–Changhsingian (Lopingian) age. So, the Lopingian age has been assigned to the palynoassemblage II of this study (Table 5: Aggarwal & Jha, 2013, Fig. 2; Prasad & Pundir, 2017).

International correlation—Present palynoassemblage is tentatively correlated with the Late Permian palynoflora of the Prince Charles Mountain (Lindström & McLoughlin, 2007) as well as with the Buckley Formation, Central Transantarctic Mountain (Farabee *et al.,* 1991; Ram–Awatar *et al.,* 2014). It shows similarity with the palynoassemblage reported by Collinson *et al.* (2006) from the base of Buckley Formation at Graphite Peak. The palynocomponents in the present assemblage allow its tentative correlation with the palynoflora of the African Maji Ya Chumvi Formation (Hankel, 1992), upper Stage 5 of Foster (1982) in Eastern Australia, and with the lower part of the Sabina Sandstone (Backhouse, 1993), with Unit–VIII of the Grant Formation, with the Amb Formation (Balme, 1970), Canning Basin (Kyle, 1977), and with the Sardhai Formation (Jan *et al.,* 2009) along with the Chhidru Formation (Hermann *et al.,* 2011, 2012, 2015) of the Salt Range. Correlation of the present palynoflora can be seen with the *Klausipollenites schaubergeri* Zone of Steiner *et al.* (2003) of Carlton Heights. It can be correlated with the assemblage described by Prevec *et al.* (2010) in New and Old Wapadsberg Pass, Eastern Cape Province, South Africa. It shows similar features compared with the Lower Sakamena Group palynoassemblage of Madagascar (Wright & Askin, 1987). However, Late Permian palynozones of South America have significant disparities with the Indian palynoflora. However, the present Late Permian Jangareddygudem palynoassemblage shows some similarities with the *Tornopollenites toreutos* Zone, northern Brazil (middle and upper part of the Andirá Formation, Playford & Dino, 2005), and the La Veteada Formation, Argentina (Gutiérrez *et al.,* 2011) in having a common occurrence of diverse association of striate bisaccates and a few spores. It can broadly be correlated with the palynoassemblage of the La Veteada Formation, Sierra De Narváez Catamarca Province, Argentina (Zavattieri *et al.,* 2008).

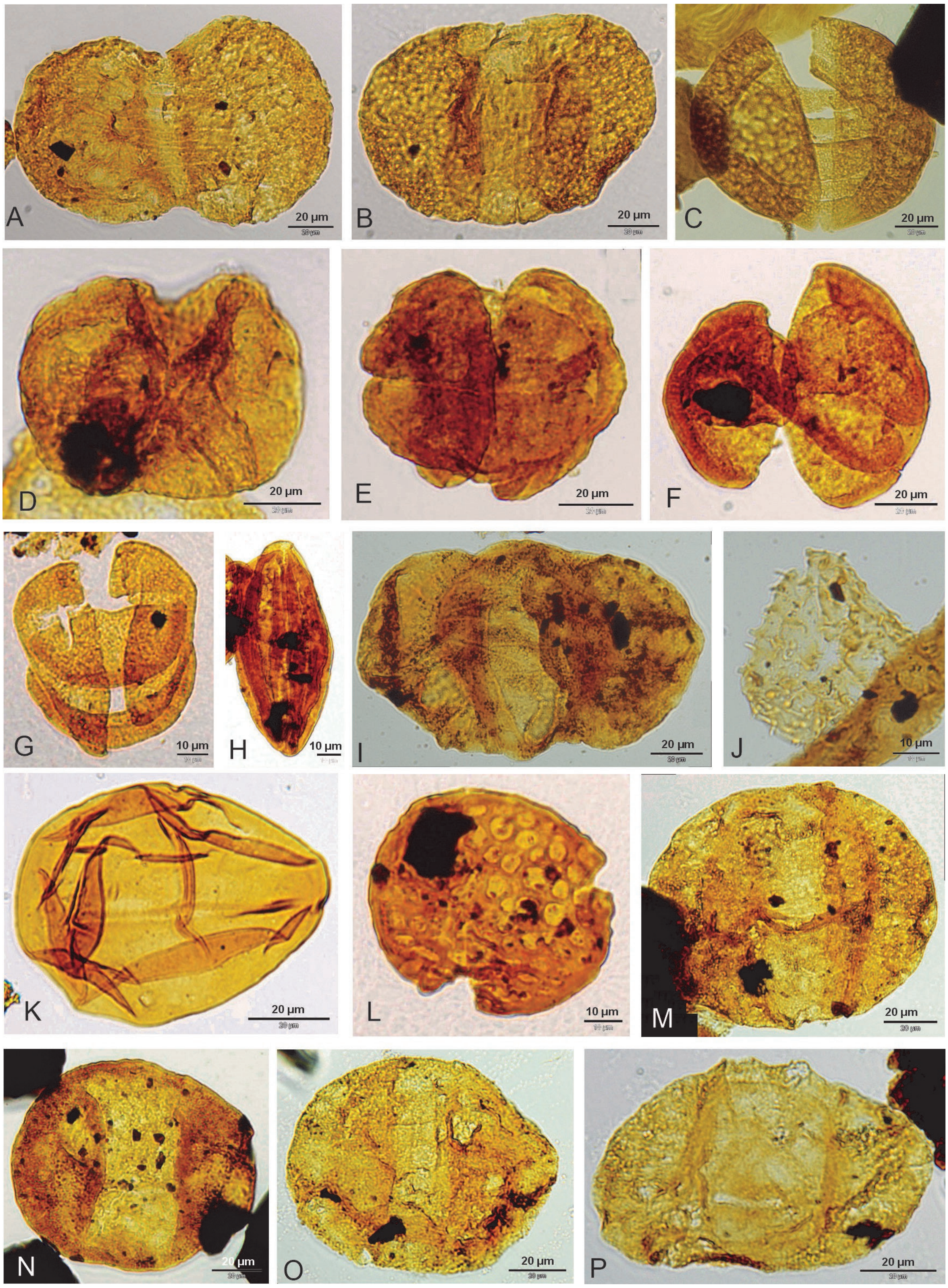

Fig. 5—Stratigraphically significant palynotaxa of Wordian–Changhsingian. A. *Striatopodocarpites multistriatus*, BSIP Slide No. 15325, G49/1, B. *S. multistriatus*, BSIP Slide No. 15325, M39/1, C. *Lunatisporites pellucidus*, BSIP Slide No. 15319, S61/2, D. *Striatites rhombicus*, BSIP Slide No. 15325, C37/4, E. *Guttulapollenites hannonicus*, BSIP Slide No. 15325, O63/4, F. *Corisaccites alutus*, BSIP Slide No. 15325, O36/4, G. *C. alutus*, BSIP Slide No. 15334, R60/2, H. *Praecolpatites nidpurensis*, BSIP Slide No. 15321, O68/4, I. *Lunatisporites* sp., BSIP Slide No. 15331, N69/4, J. *Horriditriletes ramosus*, BSIP Slide No. 15331, H49/3, K. *Latosporites colliensis*, BSIP Slide No. 15319, V52/4, L. *Maculatasporites* sp., BSIP Slide No. 15335, J61/1, M. *Strotersporites perfectus*, BSIP Slide No. 15326, H41/2, N. Unidentified bisaccate–monolete, BSIP Slide No. 15333, G53/1, O. *Faunipollenites singrauliensis*, BSIP Slide No. 15326, F43/3, P. *Vestigipollenites rudis*, BSIP Slide No.15326, Q36/2.

PALYNOFACIES ANALYSIS

In the present study, the palynofacies are exclusive of continental origin as the organic matter is entirely devoid of any type of marine element (dinoflagellate cysts, foraminiferal linings, marine algae, etc.). The palynofacies components are represented by the pollen–spore (SP), which includes spores, pollen grains, fungal spores; structured phytoclasts (ST)/translucent phytoclasts (wood particle, tracheids, cuticles, and planar organic matter); opaque black phytoclasts (charcoal) comprised of oxidized black to brownish–black coloured woody tissues, including tracheids; degraded organic matter (DOM) includes pale yellow to yellow/brown disintegrated organic matter produced after degradation of the algal/fungal activity, whose cellular structure is not clear; amorphous organic matter (AOM) includes all microscopic structureless organic components including bacterially derived AOM, resins and amorphous products of the diagenesis of macrophytic tissues.

Samples have been processed for the palynofacies analysis, out of which 35 samples were found rich in organic matter, and two samples (6 & 17) were low in organic matter. The configuration of various organic components is plotted in a ternary diagram proposed by Hacquebard and Donaldson (1969) and modified by Singh and Singh (1996) and Aggarwal *et al.* (2019) to link the current outcomes to the depositional setting. The frequency distribution of organic matter in borehole MJR–13 has been given in Fig. 6. The different types of palynofacies components recovered from the studied sequence of the Jangareddygudem area of Godavari Coalfield are shown in Fig. 7. Based on the recovery of the different types of organic matter, four distinct (Fig. 8) palynofacies assemblages (PF I to PF IV) have been identified, which are described as follows.

Palynofacies I (PF I)

Palynofacies I is the most occurred (18 samples; Fig. 8) palynofacies assemblage in the whole succession, which is mainly predominated by the occurrence of the ST (3.78–79.07%; av. 33.84%), followed by the occurrence of the SP (0–49.79%; av. 26.37%). Other constituents of this assemblage are DOM (0–46.66%; av. 27.17%), opaque phytoclasts (0–37.80%; av. 10.67%) and AOM (0–4.6%; av. 1.89%). Along with these elements, a meagre percentage (0–0.87%; av. 0.71%) of fungal remains has also been documented. PF I corresponds to the carbonaceous shales, shaly coals, and very fine to fine–grained sandstone.

Palynofacies II (PF II)

PF II is featured by the predominance of the degraded matter, including DOM (1.7–69.56%; av. 41.32%) and AOM (0.3–53.81%; av. 12.32%) and sub–dominated by the occurrence of the SP (7.8–34.72%; av. 17.19%) and ST (av. 15.63%). Opaque phytoclasts of PF II are in fewer

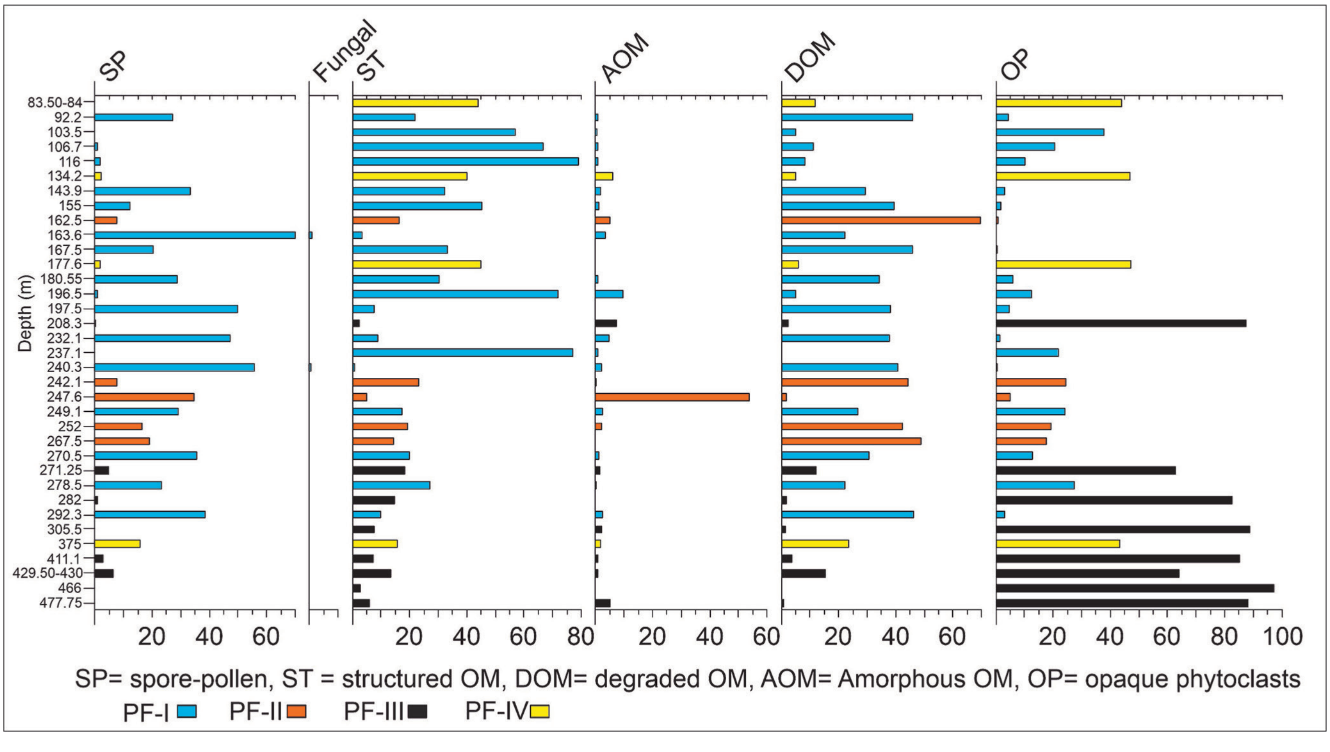

Fig. 6—Frequency distribution of organic matter and palynofacies identified in borehole MJR–13.

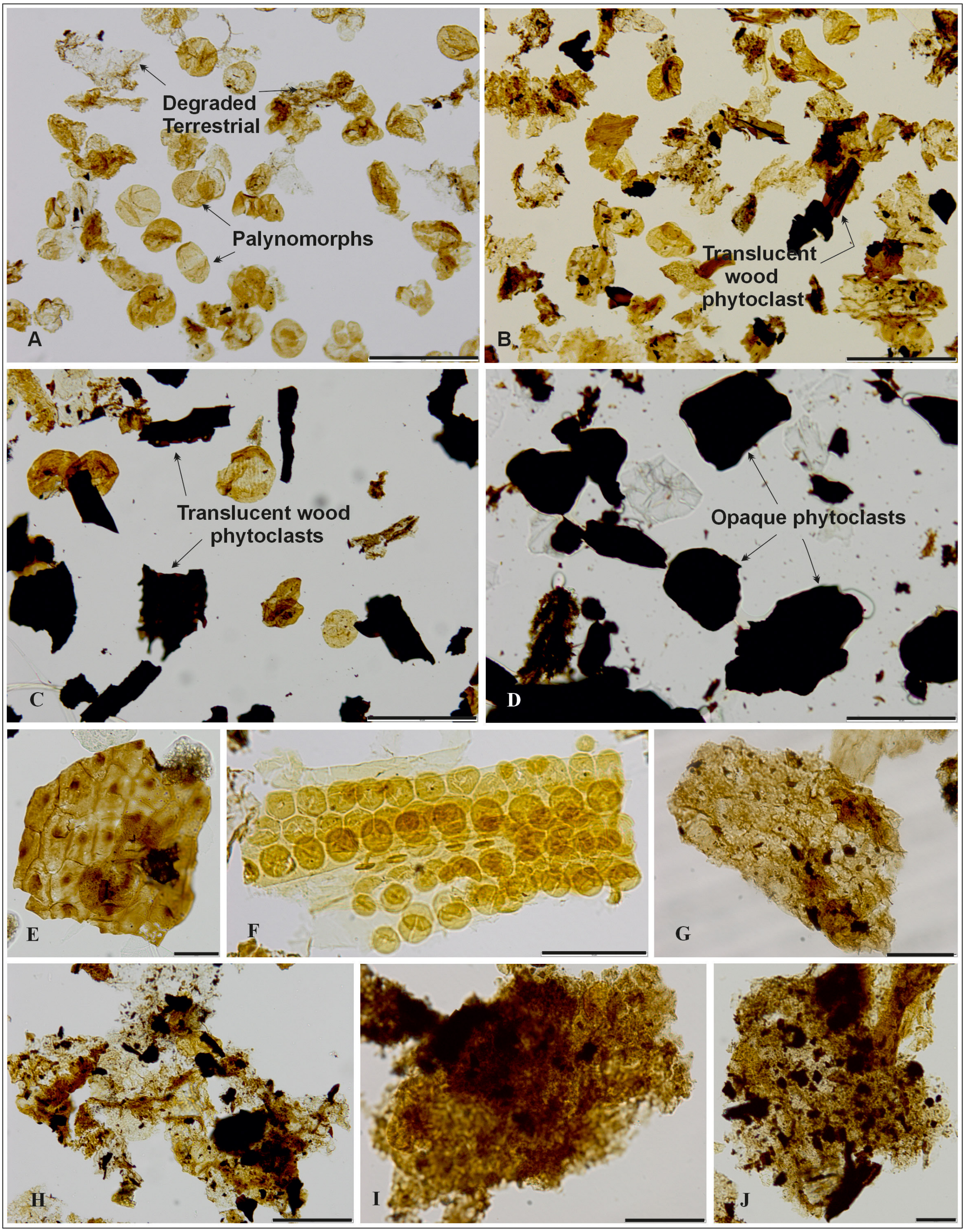

Fig. 7—Representative photomicrographs of palynofacies components (all bars 50 µm). A. Palynofacies showing palynomorphs and degraded terrestrial phytoclasts, BSIP Slide No. 15327, Q55/1, B. translucent wood, BSIP Slide No. 15329, K45/3, C. translucent wood, BSIP Slide No. 15328, L43/2, D. opaque wood phytoclasts, BSIP Slide No. 15329, J60/4, E. structured organic matter (leaf cuticle), BSIP Slide No. 15335, P63/2, F. Structured organic matter, BSIP Slide No. 15321, W49/1, G. degraded terrestrial matter, BSIP Slide No. 15333, M60/2, H. degraded terrestrial organic matter, BSIP Slide No. 15331, D45/2, I. Amorphous organic matter (AOM), BSIP Slide No. 15325, S41/1, J. Amorphous organic matter (AOM), BSIP Slide No. 15321, S45/1.

amounts (0.8–24.62%; av. 13.50%). This type of association is represented by the shale, very fine to medium–grained sandstone. PF–II is represented by the five samples (Fig. 8).

Palynofacies III (PF III)

PF III is shown by the abundant occurrence of opaque phytoclasts (62.70–97.34%; av. 82.02%). Other constituents of this palynofacies association are ST (2.53–14.73%; av. 9.10%), DOM (0.8–12.29%; av. 4.74%), AOM (0–7.25%; av. 2.19%) and SP (0–4.9%; av. 1.93%). PF III is mainly represented by coarse–grained sediments like coarse–grained sandstone, and sandstone with carbonaceous matter except in one or two places (shale and thin coal band). A total of eight samples of this succession are represented by PF III (Fig. 8).

Palynofacies IV (PF IV)

PF IV is the least occurred palynofacies in borehole MJR–13. This palynofacies association is represented by the predominance of the opaque phytoclasts (43.23–47.06%; av. 45.28%) sub–dominated by ST (15.72–45.09%; av. 36.20%). Other constituents of PF–IV are SP (0–15.72%; av. 4.98%), DOM (5.88–23.58%; av. 11.60%), and AOM (0–5.91%; av. 1.91%). This type of association is represented by various lithologies like claystone, shale, and fine to medium–grained sandstone (Fig. 8).

PALAEOENVIRONMENTAL INTERPRETATION

The palynofloral analysis demonstrates the predominance of the glossopterid pollen grains and the abridged proportion of pteridophytic spores. The gymnospermous pollen grains are represented mainly by monosaccates, monosulcate, striate bisaccates, non–striate bisaccates, taeniates, praecolpate and costate grains. The abundant occurrence of the arborescent vegetation suggests the hygrophilous to the mesophilous environment (Cazzulo–Klepzig *et al.,* 2005; Ruckwied *et al.,* 2014) in the recovered palynofloral assemblages (Figs 2, 3). Predominant occurrence of the gymnospermous pollen grains and the scarce presence of the algal (*Inaperturopollenites* sp., *Maculatasporites* sp. and *Latosporites colliensis*) and peridophytic (*Calamospora, Horriditriletes, Lacinitriletes, Leiotriletes, Lophotriletes, Microfoveolatispora*) forms also suggests the hygrophilous to mesophilous environmental (Rothwell, 1988; Di Michele & Philips, 1994) conditions for both of the palynoassemblages (Figs 9, 10; Table 2).

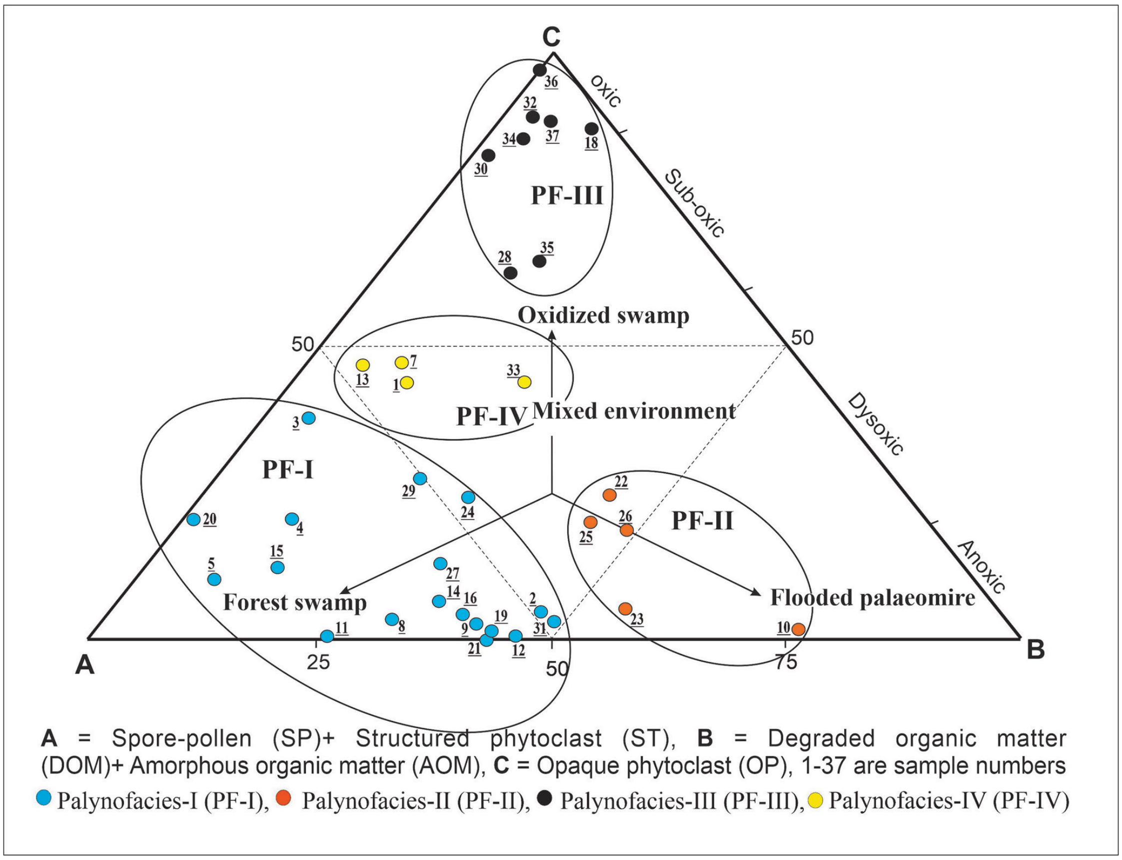

Fig. 8—Ternary diagram showing the distribution of various palynofacies (after Aggarwal *et al*., 2019).

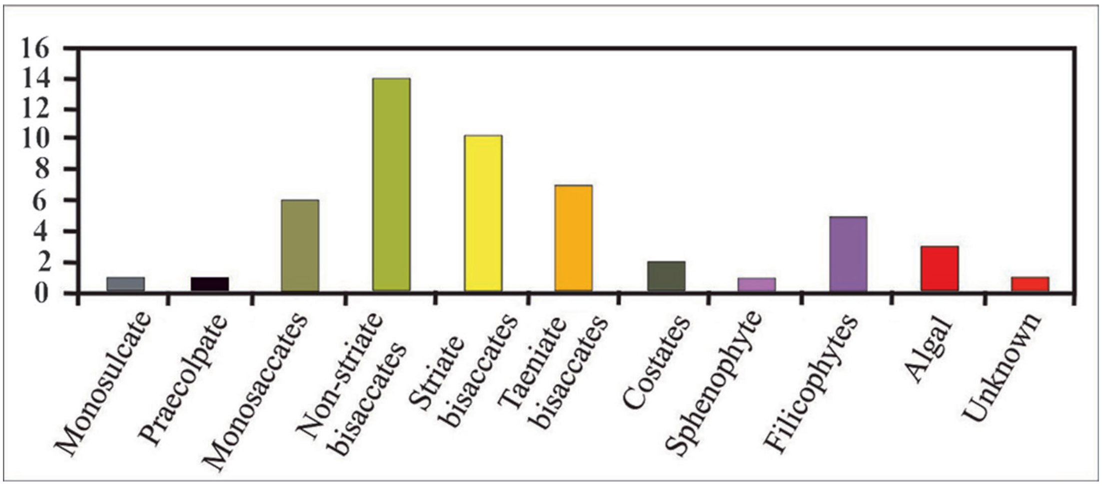

Fig. 9—The number of palynotaxa recovered in borehole MJR–13 belongs to different plant groups.

Interpretation of the depositional environment based on palynofacies analysis:

Palynofacies assemblage I is characterized by the dominant occurrence of ST and SP. By taxonomic characterization, palynomorphs can usually be identified and assigned their botanical affinities, while structured phytoclast particles with internal structures can only be related to a type of plant. The dominance of gymnospermous palynomorphs and structured organic matter (dominated by the wood particles and tracheids, Fig. 8) having an affinity with sub–arborescent/arborescent vegetation suggests proliferated forest development with its closeness to the terrestrial landmass (due to the absence of any marine element) in the temperate climatic conditions (Götz & Ruckwied, 2014).

The dominance of structured organic matter derived from higher plant debris implies a fairly dense vegetation cover near the deposition site. Land plant–derived phytoclasts are represented by structured and opaque phytoclasts, which may be equidimensional or elongated lath–shaped and translucent fragments of thin, tubular, elongated wood tracheids. Hydrodynamic equivalence of translucent wood phytoclasts controls their distribution in sediments since woody phytoclasts are composed of relatively larger and denser particles, and their abundances have commonly been reported to correlate with coarse silts and very fine–grain sand (Habib, 1983; Firth, 1993; Tyson, 1993). Their high relative and absolute abundances indicate a substantial influx with proximal depositional settings (Muller, 1959; Pocklington & Leonard, 1979). The concurrence of sediments comprising carbonaceous shale, shale, fine–grained sandstone, and organic matter components has led to assuming low–energy environmental settings through the deposition of PF I. Thus, overall, the swampy environments have been deduced for PF I.

PF II is represented by the dominance of degraded organic matter, including DOM and AOM, followed by SP and ST. Degraded plant debris and amorphous organic matter derived from the microbiological activity, indicating the existence of dysoxic–anoxic conditions during the deposition of sediments. AOM is characterized by a lack of cellular structures and indistinct and unrecognizable outlines. Structureless organic matter cannot be inferred from its probable botanical affinity and has also been documented in terrestrial settings (Tyson, 1995). High relative or absolute abundances of DOM and AOM are usually associated with deposits below the upwelling water column and dysoxic conditions in the bottom (Davey & Rogers, 1975; Tissot & Pelet, 1981; Summerhayes, 1983). AOM has been reported to decrease in shallow shelf sediments, whereas it tends to increase in a deeper basinward direction under dysoxic–anoxic conditions (Dow & Pearson, 1975; Bujak *et al.,* 1977). According to Batten and Stead (2002), in freshwater and brackish environments, oxidizing and high or low energy conditions may be associated with periodically exposed areas of floodplains, riverbeds, and lakes or lagoon margins (Zhang *et al.,* 2010). The concurrence of the sedimentological data and organic matter components in high to low energy conditions in the flooded palaeomires have been inferred for PF II.

PF III is dominated by opaque phytoclasts. The hydrodynamic equivalence of opaque woody phytoclasts has been indicated to control by particle size rather than its shape (Tyson, 1995). Larger particles have been reported to be collected in proximal and relatively high–energy environments, i.e. sand and silt (Van der Zwan, 1990; Baird, 1992). Opaque wood phytoclast concentrations have been found to reflect deposition polarity, sediment transport distance, and oxygenation level in host sediments (Carvalho *et al.,* 2013). According to numerous studies, (including those by Marsan & Pocock, 1981; Pocock *et al.,* 1987; Closas *et al.,* 2005; Piekowski & Waksmundzka, 2009), opaque phytoclasts are frequently found in oxic swamps, prodelta, delta fronts, and river deposits. Black wood particles are very common in

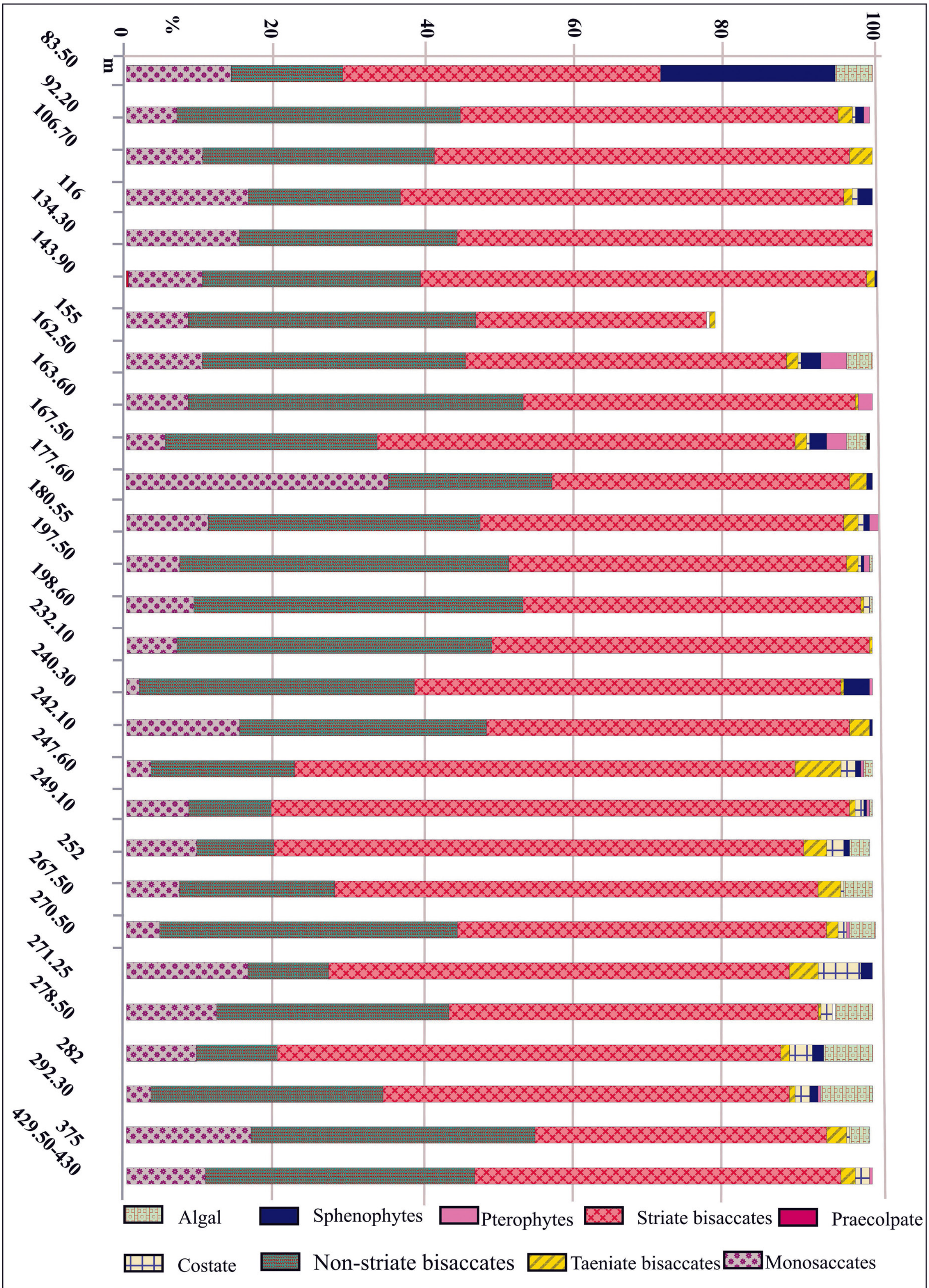

Fig. 10—Differential distribution of palynotaxa belonging to different plant groups at individual depth levels.

high–energy, proximal, coarse–grained sediments of fluvial to delta–top systems (Fisher, 1980; Nagy *et al.,* 1984; Smyth *et al.,* 1992; Williams, 1992). Except one or two locations (Fig. 2), PF III was largely dominated by coarser sediments, which may have been caused by the abundance of terrigenous clastic deposits due to increased fluvial input from precipitation. The considerable representation of opaque phytoclasts and the low occurrence of other organic matter types in PF III suggest that exposed sections of deposited beds experienced extremely oxidizing conditions. Most of the lath–shaped opaque phytoclasts over the equidimensional ones have been noticed in the present studies, reflecting deposition in proximal settings (Batten & Stead, 2002). Oxidized swamp settings have been thus inferred for this palynofacies assemblage (Fig. 8).

The sub–dominance of the ST and the dominance of the OP are characteristics of PF IV. The predominance of OP in PF IV demonstrates its deposition in oxidizing environments, while the sub–dominance of ST depicts the deposition of this form of palynofacies association close to the source of the vegetation. As a result, it was concluded that PF–IV was deposited under less oxidizing conditions than PF III. The concurrence of the lithological data and organic matter elements for PF IV demonstrates the mixed environmental setup, which mainly prevailed by the oxic swamps with low to medium energy levels.

Palynofacies study results demonstrate that the succession of MJR–13 is dominated by the presence of PF I (Fig. 8), which clearly demonstrates swampy settings in a dysoxic to anoxic environment for the succession and corroborates earlier research conducted by investigators during this time (Aggarwal *et al.,* 2019).

CONCLUSIONS

1. Based on the palynofloral evidence, two distinct palynoassemblages (I–II) have been identified within the Kamthi Formation located in the Chintalapudi sub–basin of the Godavari Coalfield. Palynoassemblage I (Striates+*Striasulcites* spp.), and Palynoassemblage II (striates+*Densipollenites*), which have been dated as Guadalupian and Lopingian, respectively.
2. Based on the recovered different types of organic matter, four distinct palynofacies (I–IV) have been identified. These palynofacies are characterized by the dominance of structured phytoclasts along with sporomorphs; degraded OM along with amorphous OM; opaque phytoclasts and opaque phytoclasts along with structured phytoclasts, respectively.
3. The presence of freshwater algal spores and the complete absence of marine components in the palynological samples attested to the deposition in the freshwater regime.
4. Palynofacies I indicates dense vegetation cover close to the site of deposition with its closeness to the terrestrial landmass in swampy settings; PF II suggests the existence of dysoxic–anoxic conditions in the flooded palaeomires; PF III indicates oxidized swamp settings, and PF IV represents the mixed environmental setup which is mainly prevailed by the oxic swamps with low to medium energy levels.
5. Succession is mainly predominated by the abundant occurrence of the glossopterids and conifers co–occurring along with filicophytes and sphenophytes is indicative of hypoautochthonous sedimentation in the proximal settings and low–energy environments. It denotes that the landmass was located in more inland areas, and peat formation occurred in forest swamps in the terrestrial regime.

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