Palynological correlation of coal-bearing horizons in Gundala area, Godavari Graben, India

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The distributional pattern of various palynotaxa in the coal bearing sediments recovered from six borecores (MLG-23, MLG-24, MLG-28, SGK-2, SGK-3 and SGK-4) in Gundala area of Godavari Graben has suggested occurrence of five distinct palynoassemblages: Palynoassemblage-A marked in borecore MLG-23 shows dominance of monosaccates chiefly *Parasaccites* along with *Plicatipollenites*, *Cahenia-saccites*, *Divarisaccus*, and *Potonieisporites*, represents Talchir palynoflora; Palynoassemblage-B characterized by dominance of radial monosaccates chiefly *Parasaccites* along with trilete taxa *Callumispora* in borecores MLG-23 and MLG-24, corresponds to Lower Karharbari palynoflora; Palynoassemblage-C distinguished in borecores MLG-24, MLG-28, SGK-2, SGK-3 and SGK-4 is marked by dominance of radial monosaccates mainly *Parasaccites* along with nonstriate disaccate *Scheuringipollenites*, represents Upper Karharbari palynoflora; Palynoassemblage-D in borecores MLG-23, MLG-24 and MLG-28 demarcated by dominance of nonstriate disaccates chiefly *Scheuringipollenites*, *Ibisporites* along with sub-dominance of few striate disaccates, *viz.*, *Faunipollenites*, *Striatopodocarpites*, *Crescentipollenites* and *Striatites* signifies Barakar palynoflora; the youngest, Palynoassemblage-E identified in borecores MLG-24 and MLG-28 shows dominance of striate disaccates, *viz.*, *Striatopodocarpites* and *Faunipollenites* in conjunction with *Strotersporites*, *Crescentipollenites*, *Hamiapollenites*, *Corisaccites*, *Weylandites* and *Falcisporites*. This palynoassemblage also shows the appearance of some stratigraphically significant palynomorphs, *viz.*, *Lunatisporites*, *Lundbladispora*, *Playfordiaspora*, *Klausipollenites*, *Kamthisaccites*, *Guttulapollenites* and *Crustaesporites* symbolizing Late Permian Raniganj palynoflora. Almost a complete palynological succession from Talchir to Raniganj has been demarcated in Lower Gondwana succession of Gundala area.

1. Introduction

The Pranhita–Godavari Graben, Andhra Pradesh, India 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. 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.

The complete Lower Gondwana sequence is represented by Talchir, Barakar, Barren Measures and Kamthi (=Raniganj) formations. Talchir Formation, the basalmost and the oldest unit of Lower Gondwana sequence rests unconformably on the Proterozoic basement, and is characterized by boulder beds, greenish sandstones, khaki green shales, varve and rhythmite of glacial origin. The thickness of Talchir Formation as recorded from different borecores is found to be maximum up to 350 m in Godavari Graben. Talchir Formation

Keywords. Palynology; correlation; Godavari Graben; Gundala; Talchir; Karharbari; Barakar; Raniganj; India.

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Table 1. *Stratigraphic succession in Gundala area (after MECL).*

Age	Group	Formation	Lithology
Recent	–	–	Soil cover
Permian	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 persistant coal seams.
		Talchir	Fine to medium grained pale green, sandstone with occasionally olive green shales.
----------		Unconformity	----------
Proterozoic		Pakhal	Quartzites, Phyllites and Dolomites

is succeeded by the coal-bearing Barakar Formation represented by grey white medium to coarse-grained sandstones, shales and coal seams. The succeeding beds consisting of grey to greenish grey coarse to pebbly feldspathic sandstones conformably overly the Barakar Formation with gradational contact. These beds have been considered by the Geological Survey of India (GSI) to represent Barren Measures Formation (noncoal zones). The Kamthi Formation forming hillocks and small mounds, mostly exposed towards the dip side in the south-western part, consists of medium to coarse-grained ferruginous sandstone with few interbedded thin coal seams (after SCCL). The coal-bearing basal member of Kamthi Formation is considered to represent Raniganj Formation in Godavari Graben (Srivastava and Jha 1997).

Near about 15 coal belts have been identified in Godavari Graben. Long unbroken stretch of Lower Gondwana sediments formed between Lingala in the north-west to Koyagudem in the southeast over a length of 50 km on the western margin of Godavari Graben is known as Lingala–Koyagudem coal belt. The entire Lower Gondwana sequence comprising

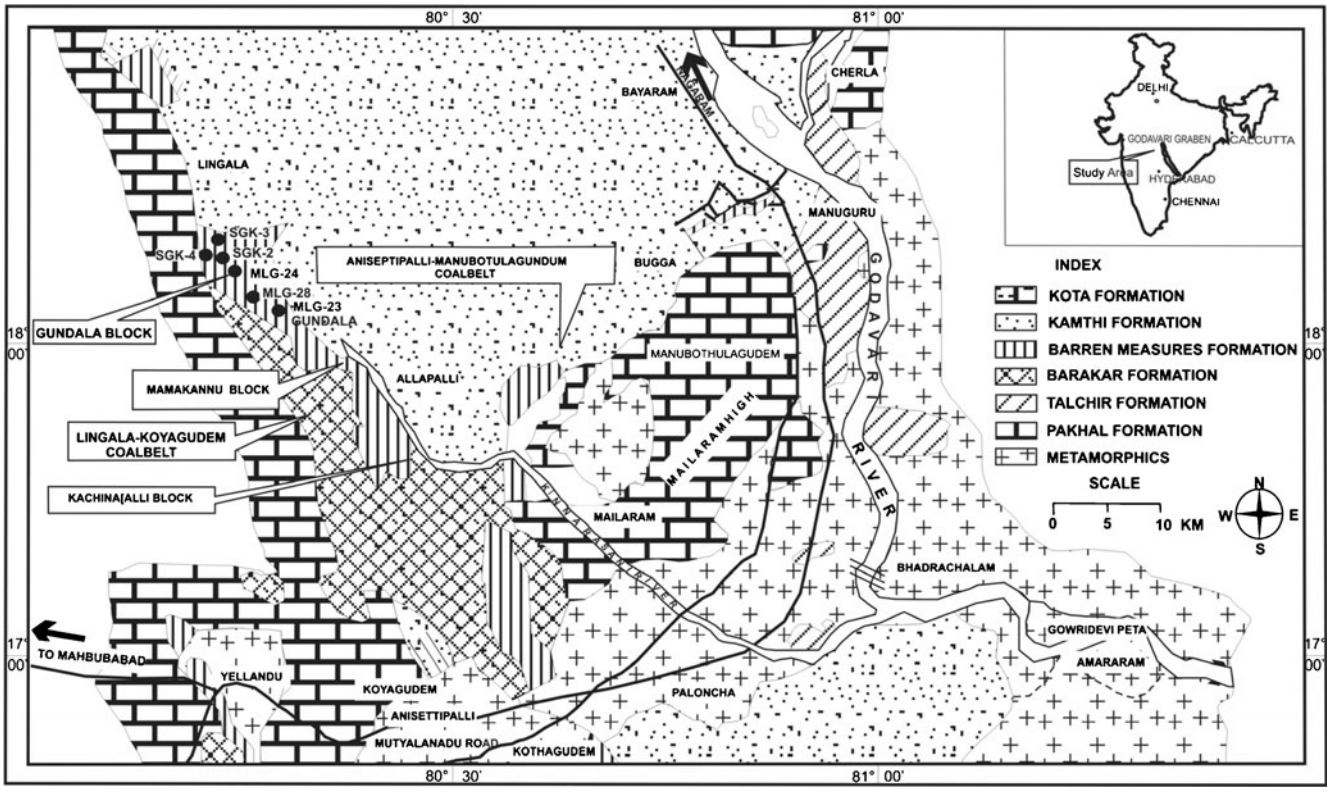


Figure 1. Map of Gundala area showing location of different borecores (after SCCL).

Table 2. *The percentage frequency of palynomorphs present in borecore MLG-23.*

Taxa/depth (m)	299	263	244	242.4	263	204	183	163.5	157	140–143	204	183	163.5	157	140–143	130	81.1	70
Verrucosisporites				1.60														
Callumispora	1		0.50	5.80		1			0.90		1			0.90			0.50	
Brevitriletes																		2.50
Jayantisporites				0.80														
Leiotriletes																		
Indotriradites				0.80														
Densipollenites										1					1			
Crucisaccites	2.50		0.50	1.60			0.40		0.90	0.50		0.40		0.90	0.50	0.50	1.50	
Parasaccites	56	81	77.50	62.50	81	6.50	11.79	9	7.54	4.50	6.50	11.79	9	7.54	4.50	3.50	3.50	0.50
Plicatipollenites	2	8	10	4.80	8	1.50					1.50					0.50	0.50	
Caheniasaccites	3.50	4	5	10	4	0.50				0.50	0.50				0.50	2	4	
Potonieisporites	2		3	4.80		11					11					1		
Divarisaccus	2		0.50							0.50					0.50			
Vesicaspora				0.80														
Ibisporites	8					5	18.77	20	7.54	18	5	18.77	20	7.54	18	12.50	12.50	5.50
Platysaccus	3		0.50	0.80		7		3			7		3			3.50	1	3
Scheuringipollenites	5	2	0.50	5.60	2	30	63.75	60	73	40	30	63.75	60	73	40	74	75	65.50
Sahnites	2									0.50					0.50			
Vestigisporites	2		0.50							0.50					0.50			
Strotersporites	0.50	2			2	1				3	1				3			
Crescentipollenites			1			4				1	4				1	0.50		1
Faunipollenites	7	3	1	0.80	3	20.50	1.74	5	5.66	7.50	20.50	1.74	5	5.66	7.50	1	0.50	1.50
Striatopodocarpites	1.50					6			1.80	8	6			1.80	8	1		2
Striatites	1.50					1.50	1.30	3	0.90	13	1.50	1.30	3	0.90	13		0.50	2
Striasulcites									0.90					0.90				
Lunatisporites										1					1			
Inaperturopollenites																		15.50
Tiwariasporis	0.50					4				0.50	4				0.50			
Latosporites																		1

Table 3. *The percentage frequency of palynomorphs present in borecore MLG-24.*

Taxa/depth (m)	326.8	321.7	318.7	307	288	276	231.75	226.5	215	175.4	170.5	163	156	122.4	110.5	82	79.75	36
Callumispora	18.50	2	1	5.50	6		3										3.68	
Lacinitriletes										4.50								
Lophotriletes	0.50									1.50								
Leiotriletes	1																	
Brevitriletes	19.50						4										1.84	
Indotriradites					4		1									2		
Microfoveolatispora													0.80					
Microbaculispora	1						1						1.60					
Playfordiaspora																		Present
Lundbladispora																		Present
Divarisaccus			0.50					2.50		1								0.50
Crucisaccites							1	0.50					0.80	0.50			1.22	
Virkkipollenites										2		2.10		2	0.50			
Potonieisporites	2		2	0.50	4	4.70	1				1		0.80	0.50			1.22	7.50
Parasaccites	25	54.50	62.50	57	58	27.39	14	10	1	1.50	8	2.10	19.20	2.50	1	2	7.90	2
Plicatipollenites	8.50	5.50	7.50	5	18	35.60		1		1	9.50	2.80	6.40			2	1.22	7.50
Caheniasaccites	10.50	21.50	15	16.50	1	2.70	4				0.50	2.10	5.60				3.06	5
Densipollenites																		2
Crustaesporites																		Present
Primuspollenites														0.50			1.22	
Falcisporites																		2
Platysaccus							2		5	5.50	3	7.29	2.40	15			2.44	
Ibisporites						0.68	6		34	6.50	2	24.08	5.60	31	8		6.13	2
Scheuringipollenites	3.50	5.50	1.50	3	5	20.40	37	24.50	60	70	37	46.60	23.20	29	66	38	38.02	4
Klausipollenites																		Present
Sahnites	1		1	2.50	2	6.80	4	1					1.60			2		
Vestigisporites	7	7.50	4	5									0.80				0.61	
Striatopodocarpites		0.50	0.50	1		0.68	3	39		3	11.50	5.10	12.80	8	3	30	7.32	32.50
Faunipollenites	1	2	1	1.50			14	9			1		14.40		17.50	15	14.72	3.50
Strotersporites		0.50	1.50	0.50		0.68		4.50			8.50	0.70	0.80		1	3	0.61	11
Striatites				0.50			3	0.50		2.50	12.50	0.70	1.60	1		2	1.84	2.50
Crescentipollenites	1	0.50	1	0.50	1						3.50	2.10	0.80		1.50	2	1.22	3
Verticipollenites																		
Striasulcites															0.50	2		
Hamiapollenites				0.50				3			0.50							3
Lunatisporites																		5
Kamthisaccites																		Present
Corisaccites								1				1.40						1
Inaperturopollenites											1.50			8				0.50
Weylandites							1	2.50					0.80					5.50
Latosporites						0.68	1			1		1.40						
Maculatasporites					1										0.50			
Tiwariasporis			1	0.50								0.70		2	0.50		5.52	

Talchir, Barakar and Raniganj formations is present in this coal belt. Structurally, this coal belt is traversed by a number of strike and transverse faults as a result of which the successive formations are separated or omitted, hence the dating and correlation of coal seams is the basic requirement in this area.

Pollen and spores present in various coal-bearing horizons are quite different in their morphological characters. The quantitative and qualitative study of these spores and pollen are helpful in dating of coal and associated sediments. On the basis of these palynomorphs the palynostratigraphy of any faulted area can be interpreted where dating and correlation of coal seams is difficult. In the present communication we have presented the palynostratigraphic correlation of Gundala area on the basis of the study of six borecores.

2. Geology of Gundala area

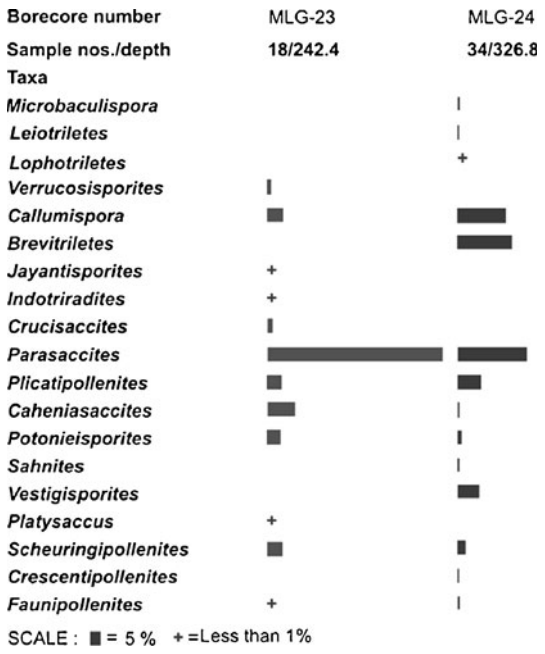
The Gundala area lies in central part of Lingala–Koyagudem coal belt on the southwestern margin of Godavari Graben, with a strike length of 12 km and an average width of 6 km. This block is bounded by latitudes 17°52′33″ to 17°58′56″N and longitudes 80°17′35″ to 80°22′36″E and covers an area about 60 km^2. The stratigraphic succession in this block as computed from the subsurface data obtained from borecores is furnished in table 1. Mainly Barakar and Kamthi (Raniganj) formations are exposed in the central part of Lingala–Koyagudem coal belt while, Talchir Formation is exposed in the north-western part of this block. The sandstone with subordinate shale and coal seams at present designated as Kamthi Formation may represent the Raniganj Formation. Locations

Table 4. *The percentage frequency of palynomorphs present in borecore MLG-28.*

Taxa/depth	377	374	317.5	283	275.5	204	185.5	144	128.6	18
Brevitriletes		2.4	0.8	Barren						
Microfoveolatispora	1.5	1.6								
Microbaculispora	0.5									
Indotriradites	1	0.8								
Callumispora	20.5	1.6								1
Striomonosaccites										0.5
Divarisaccus		1.6								
Parasaccites	6	52	1.6		4.5		1	1	2	1
Kamthisaccites							1			0.5
Plicatipollenites		2.4			1.5					0.5
Potonieisporites			1.6							
Caheniasaccites			0.8		0.5					
Crucisaccites	0.5	0.8								
Sahnites		0.8			1.5				3	5
Vestigisporites			1.6		0.5					
Scheuringipollenites	37.5	12	47.2		47.5	1	21	7	32	15
Ibisporites	6				2.5		1	1.5	2	
Platysaccus	1	0.8	11.2		8.5		1		4	
Falcisporites									1	3.5
Primuspollenites			1.6		2.5					0.5
Crescentipollenites		0.8			2		3	0.5	3	4
Strotersporites		2.4					1	2		5.5
Striatopodocarpites	4	3.2	5.6		15		23	47	38	36.5
Faunipollenites	18.5	10.4	4.8		10.5	1	15	35	13	15.5
Striasulcites								0.5		0.5
Striatites	0.5				0.5		1	3	1	0.5
Lunatisporites								1.5		7
Hamiapollenites							1			1
Guttulapollenites										1.5
Latosporites			1.6							
Tiwarisporis	0.5	5.6	0.8							0.5
Weylandites								1		
Quadrisporites	0.5									
Inaperturopollenites	1.5	0.8			2					

Table 5. *The percentage frequency of palynomorphs present in borecore SGK-2, SGK-3 and SGK-4.*

Borecore number	SGK-2		SGK-3	SGK-4
Sample no.	GD/S_7	GD/S_8	GD/S_{12}	GD/S_{11}
Genera				
Callumispora	0.5	1.7	1.7	0.5
Brevitriletes	2.5	4.3	1.7	1.5
Horriditriletes	0.2	0.4	0.5	1.5
Crucisaccites	12.3	11.3	3.0	5.0
Divarisaccus	2.6	4.0	3.0	3.1
Parasaccites	23.0	30.0	30.8	32.6
Plicatipollenites	1.7	1.7	4.1	7.2
Virkkipollenites	2.7	4.0	4.6	7.2
Potonieisporites	0.8	0.6	1.1	4.1
Platysaccus	0.4	0.4	0.5	0.8
Striatites	3.8	2.5	4.0	1.5
Faunipollenites	8.1	7.0	3.4	5.2
Striatopodocarpites	3.7	3.1	3.0	1.5
Verticipollenites	1.7	2.1	4.6	1.5
Scheuringipollenites	22.5	17.3	22.8	19.5
Ibisporites	3.8	3.0	2.8	3.6
Tiwariasporis	7.6	5.2	6.2	1.5
Aletes	2.0	2.2	3.1	2.5

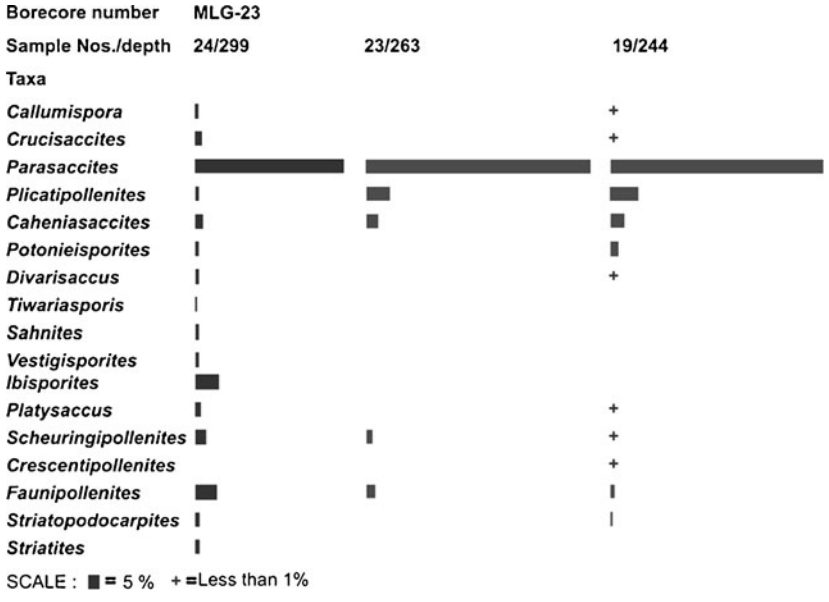


Histogram II. Vertical distribution of different palynotaxa in Palynoassemblage-B.

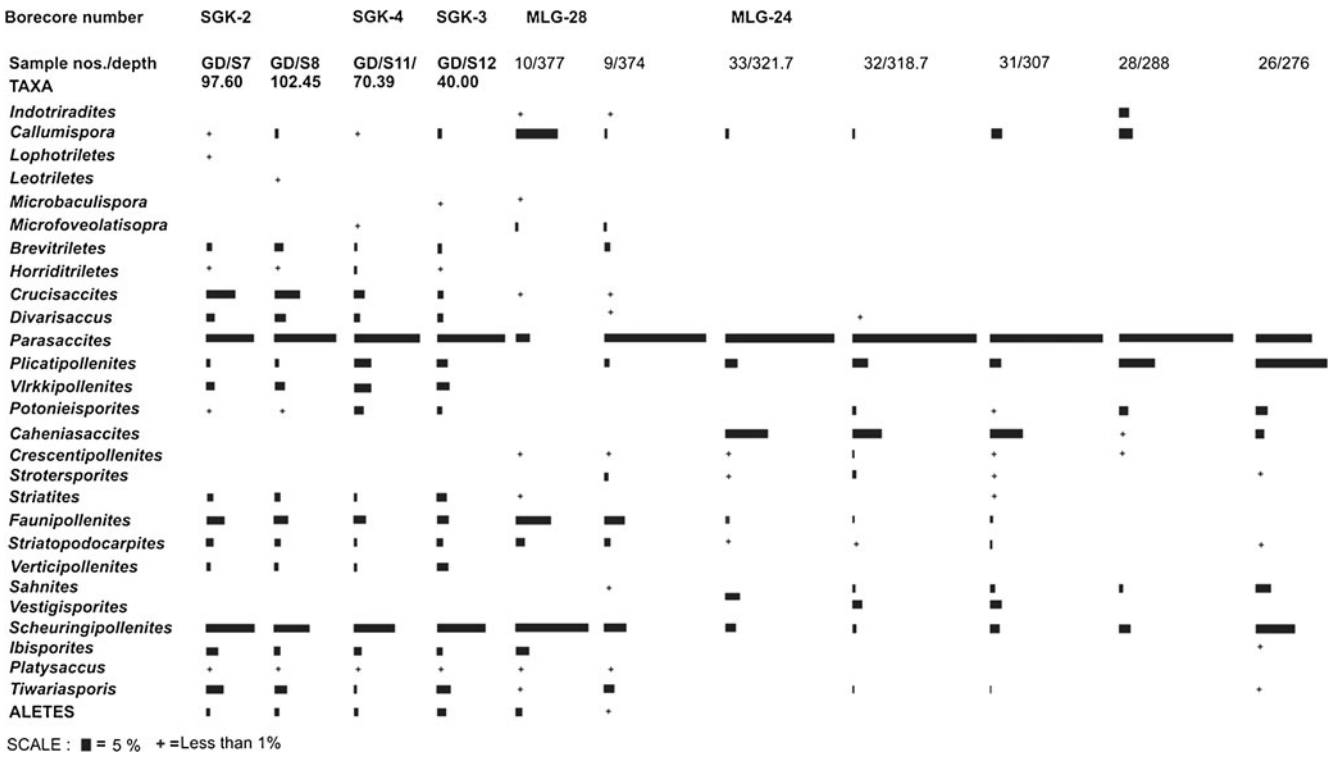
of all studied borecores have been shown in figure 1 (after SCCL) and palynological investigations were carried out on the samples of MLG-23, MLG-24, MLG-28, SGK-2, SGK-3 and SGK-4 from the Gundala block.

3. Materials and methods

In all 86 samples of different lithologies, *viz.,* coal, carbonaceous shale, grey shale, sandstone, carbonaceous streaks in sandstones and clay was collected from the six borecores. Samples were subjected to simple maceration technique. For maceration, 5–10 g of material was crushed to 2–4 mm size and subjected to acid treatment. They were initially treated with hydroflouric acid (HF) for 2–3 days in order to dissolve out the silica component. After thorough washing, the samples were treated with commercial nitric acid (HNO_3) for 3–4 days to make the palynomorphs free from humic material. Later they were treated with 10%



Histogram I. Vertical distribution of different palynotaxa in Palynoassemblage-A.



Histogram III. Vertical distribution of different palynotaxa in Palynoassemblage-C.

KOH to bleach the palynomorphs. The macerates were then mounted in Canada balsam with the help of polyvinyl chloride and slides were prepared. Palynomorphs were counted from each sample for palynofloral analysis and different species were identified. Out of all the 86 macerated samples only 43 samples have the countable number of palynomorphs. 200 palynomorphs per sample were counted for the quantitative estimation of the different palynoassemblages. Vertical distribution of palynomorphs in each borecore has been shown in tables 2–5 and different palynoassemblages have been shown in Histograms I–V. Photomicrographs of nicely preserved stratigraphically significant taxa have been shown in plates 1–4.

4. Palynology

All the six borecore samples were macerated from Gundala area. The *sporae dispersae* in this area has been assigned to forms of trilete spores, monosaccate, disaccate pollen and alete spores (table 6) among which the following are quantitatively and qualitatively important ones, individually or by forming distinguished groups in association with the other palynospores genera in different palynoassemblages.

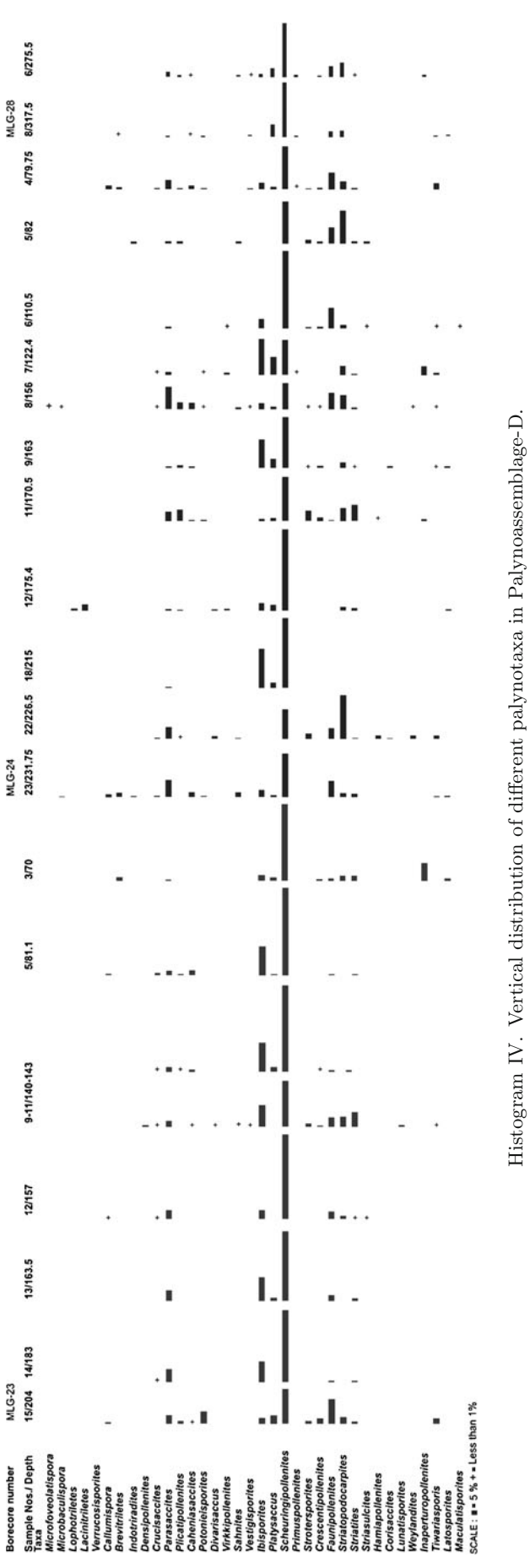
Brevitriletes, Callumispora, Indotriradites, Jayantisporites, Playfordiaspora, Lundbladispora, Falcisporites, Klausipollenites, Platysaccus, Scheuringipollenites, Ibisporites, Vestigisporites, Sahnites, Kamthisaccites, Parasaccites, Plicatipollenites, Potonieisporites, Crucisaccites, Caheniasaccites, Striomonosaccites, Crustaesporites, Striasulcites, Striatites, Faunipollenites, Striatopodocarpites, Strotersporites, Crescentipollenites, Lunatisporites, Hamiapollenites Corisaccites, Guttulapollenites, Weylandites, Tiwariasporis, Inaperturopollenites.

In addition to above genera, the following genera are rather inconsistently present but in very low percentages. The behaviour of some genera is not consistent throughout the palynofloral spectrum although they are present in significant amount in some samples. However, their presence among the palynoassemblages have been ignored as their affinity, occurrence and significance in the stratigraphy are not precisely known.

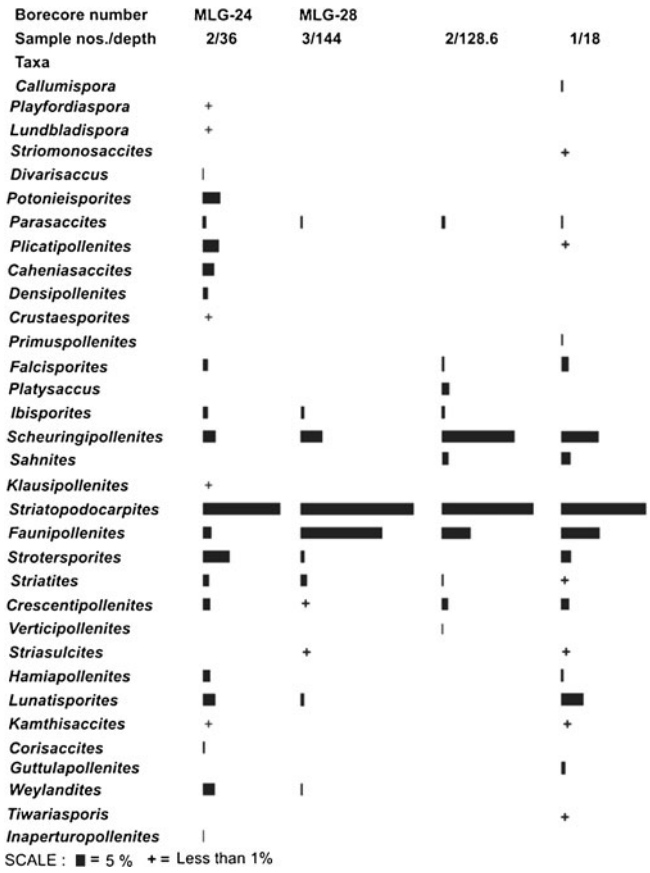
Horriditriletes, Microbaculispora, Microfoveolatispora, Verrucosisporites, Lacinitriletes, Leiotriletes, Lophotriletes, Densipollenites, Divarisaccus, Maculatasporites, Primuspollenites, Verticipollenites, Virkkipollenites, Latosporites, Quadrisporites, Cycadopites.

5. Sporological comparison

The present investigation reveals five distinct palynoassemblages, which are distributed in



Histogram IV. Vertical distribution of different palynotaxa in Palynoassemblage-D.

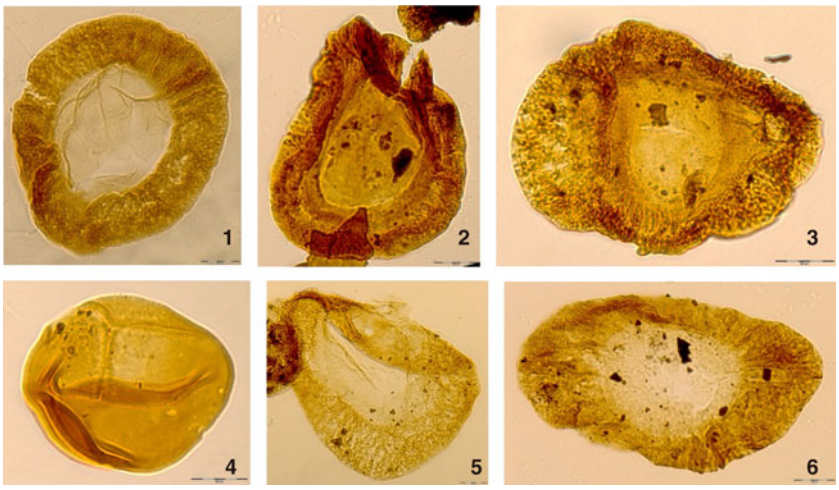


Histogram V. Vertical distribution of different palynotaxa in Palynoassemblage-E.

various samples. The quantitative association of palynospores as well as their qualitative representation in different palynoassemblages has been discussed separately as each of them is situated wide apart.

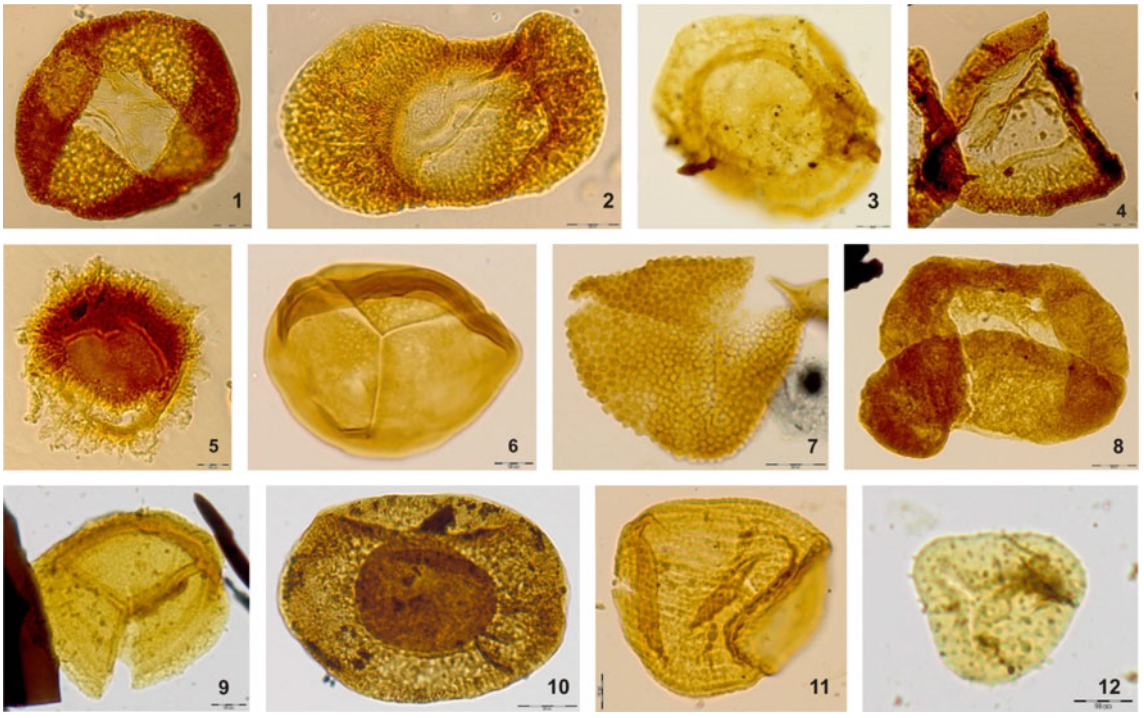
5.1 *Palynoassemblage-A*

Sediments between 244 and 299 m (sample no. 19–24) in borecore MLG-23 show dominance of radial monosaccates chiefly *Parasaccites*. The other monosaccates present in the palynoassemblage includes *Caheniasaccites, Plicatipollenites, Crucisaccites, Potonieisporites,* and *Divarisaccus.* Nonstriate disaccates present in sub-dominance are *Ibisporites, Platysaccus*, *Sahnites*, *Vestigisporites* and *Scheuringipollenites.* Few striate disaccates present in the palynoassemblage are *Faunipollenites, Striatopodocarpites* and *Striatites. Callumispora* and *Tiwariasporis* are also recorded in small amounts. Except in borecore MLG-23, this palynoassemblage has not been traced in any other studied borecores. A look at the frequencies of different genera given in Histogram I reveals a close resemblance in all the samples having the dominance of *Parasaccites* along with few other monosaccates.



1. *Parasaccites*, B.S.I.P. slide no. 13977, S41-2, 2. *Plicatipollenites*, B.S.I.P. slide no. 13807, H69-2, 3. *Vestigisporites*, B.S.I.P. slide no. 13978, H49, 4. *Callumispora*, B.S.I.P. slide no. 13818, J36-1, 5. *Divarisaccus*, B.S.I.P. slide no. 13979, R54-2, 6. *Caheniasaccites*, B.S.I.P. slide no. 13977, K34-2.

Plate 1. Talchir palynoflora.

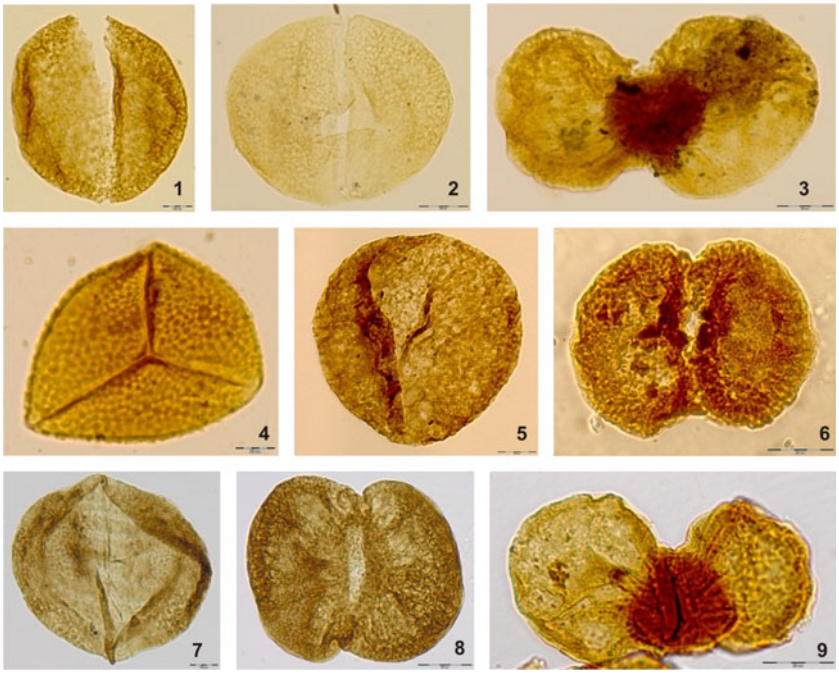


1.*Crucisaccites*, B.S.I.P. Slide no. 13816, K40-2, 2. *Caheniasaccites*, B.S.I.P. Slide no. 13816, V47-4, 3. *Plicatipollenites*, B.S.I.P. Slide no. 13813, P52-3, 4. *Parasaccites*, B.S.I.P. Slide no. 13815, R53/3, 5. *Jayantisporites*, B.S.I.P. Slide no. 13807, H64-4, 6. *Callumispora*, B.S.I.P. Slide no. 13940, V48-1, 7. *Microbaculispora*, B.S.I.P. Slide no. 13941, M46-4, 8. *Crucisaccites*, B.S.I.P. slide no. 13940, 9. *Indotriradites*, B.S.I.P. Slide no. 13947, D57-3, 10. *Platysaccus*, B.S.I.P. Slide no. 13888, G28, 11. *Tiwariasporis*, B.S.I.P. Slide no. 13946, U65-4, 12. *Lophotriletes*, B.S.I.P. slide no. 13947, H49-2.

Plate 2. Karharbari palynoflora.

5.2 *Palynoassemblage-B*

The Palynoassemblage-B is identified at 242.4 m (sample no. 18) in MLG-23 and at 326.80 m (sample no. 34) in borecore MLG-24. It shows the abundance of monosaccate chiefly *Parasaccites* with trilete taxa *Brevitriletes* and *Callumispora*. The other recorded taxa in this palynoassemblage are triletes, *viz., Verrucosisporites*, *Indotriradites*, *Lophotriletes*, *Leiotriletes* and *Microbaculispora*; monosaccates, *viz., Crucisaccites*, *Plicatipollenites*, *Caheniasaccites*, *Potonieisporites*; nonstriate



1. *Scheuringipollenites,* B.S.I.P. slide no. 13950, F63-1, 2. *Scheuringipollenites,* B.S.I.P. slide no. 13943, F46-2, 3. *Striatites,* B.S.I.P. slide no. 13945, J64-1, 4. *Microbaculispora,* B.S.I.P. slide no. 13980, M57, 5. *Scheuringipollenites,* B.S.I.P. slide no. 13981, T39, 6. *Ibisporites,* B.S.I.P. slide no. 13982, M61-4, 7. *Faunipollenites,* B.S.I.P. slide no. 13893, P52-4, 8. *Ibisporites,* B.S.I.P. Slide no. 13891, J36-1, 9. *Verticipollenites,* B.S.I.P. Slide no. 13810, D58.

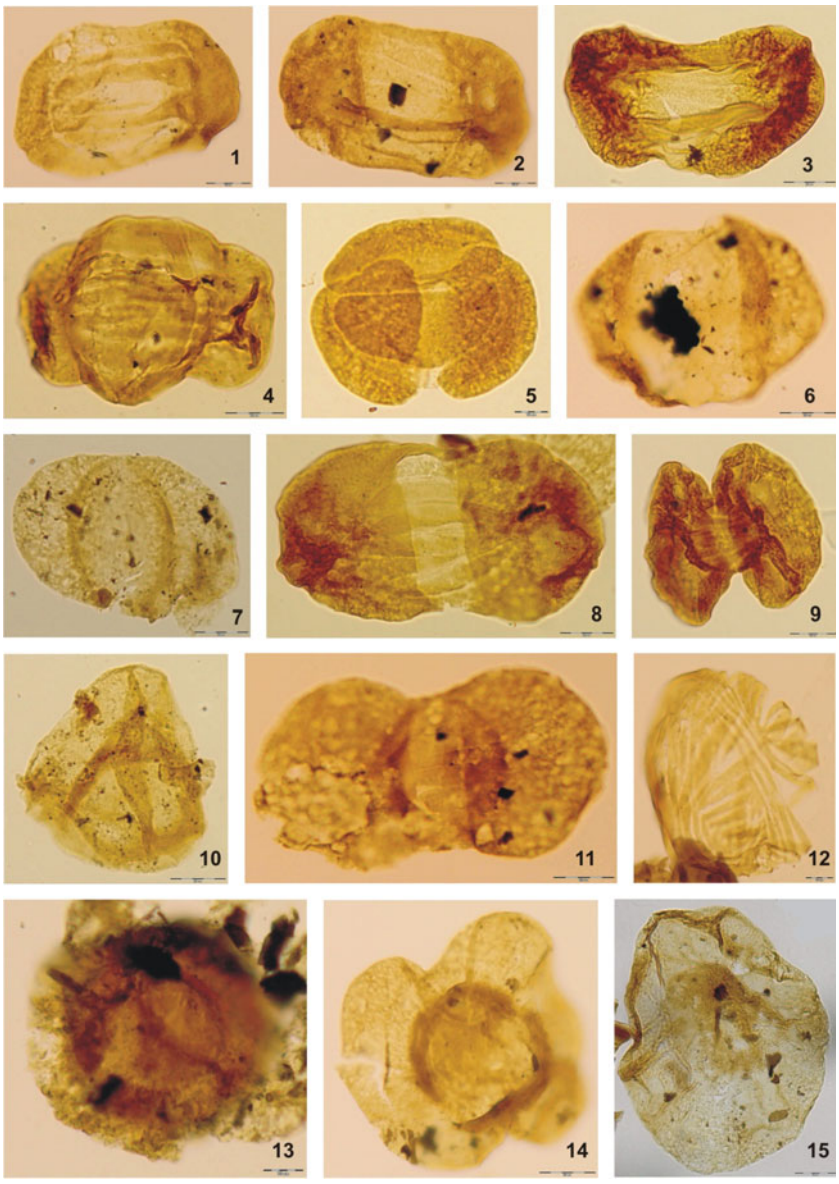
Plate 3. Barakar palynoflora.

disaccates, *viz., Scheuringipollenites*, *Platysaccus, Sahnites, Vestigisporites* and rarely present striate disaccates, *viz., Faunipollenites* and *Crescentipollenites*. Sample no. 18 in MLG-23 shows the presence of *Jayantisporites.* These two samples compare well particularly in the dominance of *Parasaccites* and sub-dominance of *Callumispora.* However, a glance at Histogram II suggests some differences in these two samples like in sample 34/326.8 m (MLG-24). *Brevitriletes* is very prominent while it is not at all recorded in 18/242.4 m (MLG-23) so also the genus *Vestigisporites*, but similarity in the incidences of the other well-represented genera such as *Parasaccites, Callumispora, Plicatipollenites*, *Potonieisporites* and *Scheuringipollenites* is so great that their close sporological relationship becomes quite evident.

5.3 *Palynoassemblage-C*

The Palynoassemblage-C has been marked at the depth of 97.60–102.45 m in borecore SGK-2 (sample no. GD/S7, GD/S8), at 70.39 m in borecore SGK-4 (sample no. GD/S11), at 40.00 m in borecore SGK-3 (sample no. GD/S12), at 377–374 m in borecore MLG-28 (sample nos. 10 and 9) and at 321.7–276 m in borecore MLG-24 (sample nos. 33–26).

The most dominating genera in this palynoassemblage are monosaccate *Parasaccites*, which is ranging from 6–62.5% and nonstriate disaccate *Scheuringipollenites,* ranging from 1.5–37.5%. The genus *Crucisaccites* with good amount has been recorded in all the samples of borecore SGK-2, SGK-3 and SGK-4 and MLG-24 while on the other hand, *Callumispora* (1.6–20.5%) has been marked in good percentage at 377 m in borecore MLG-28 (sample no. 10). The other recorded taxa in this palynoassemblage are triletes, *viz.*, *Horriditriletes*, *Callumispora*, *Microbaculispora*, *Leiotriletes*, *Brevitriletes*, *Lophotriletes Microfoveolatispora, Indotriradites*; monosaccates, *viz.*, *Virkkipollenites*, *Plicatipollenites*, *Caheniasaccites*, *Potonieisporites*, *Crucisaccites* and *Divarisaccus*; nonstriate disaccates, *viz.*, *Platysaccus*, *Vestigisporites*, *Sahnites*; striate disaccates chiefly, *viz.*, *Faunipollenites*, *Striatopodocarpites*, *Strotersporites*, *Striatites*, *Crescentipollenites*, and *Verticipollenites*. Beside these, alete spores *Tiwariasporis*, *Inaperturopollenites*, *Quadrisporites*, *Maculatasporites* and monolete spore *Latosporites* have also been recorded in this palynoassemblage. However, a glance at Histogram III shows the dominance of monosaccates along with nonstriate disaccate *Scheuringipollenites* and few striate disaccates distinguishes this palynoassemblage from the others.



1. *Lunatisporites*, B.S.I.P. Slide no. 13894, J47/4, 2. *Stroterspores*, B.S.I.P. Slide no. 13895, G41/2, 3. *Striatopodocarpites*, B.S.I.P. slide no. 13953, L67-4, 4. *Hamiapollenites*, B.S.I.P. slide no. 13952, Q38-1, 5. *Guttulapollenites*, B.S.I.P. slide no. 13954, O45-1, 6. *Klausipollenites*, B.S.I.P. Slide no. 13898, R63/4, 7. *Falcisporites*, B.S.I.P. slide no. 13952, P58-2, 8. *Striatopodocarpites*, B.S.I.P. slide no. 13954, J35-1, 9. *Striatites*, B.S.I.P. slide no. 13954, J45-4, 10. Densoisporites, B.S.I.P. slide no. 13955, F43-1, 11. *Crescentipollenites*, B.S.I.P. Slide no. 13894, S47/3, 12. *Weylandites*, B.S.I.P. Slide no. 13894, T46, 13. *Lundbladispora*, B.S.I.P. Slide no. 13896, W37/1, 14. Crustaesporites, B.S.I.P. Slide no. 13895, M52/2, 15. *Playfordiaspora*, B.S.I.P. Slide no. 13894, N46/1.

Plate 4. Raniganj palynoflora.

5.4 *Palynoassemblage-D*

Palynoassemblage-D has been demarcated in borecore MLG-23 (depth 204–70 m and sample no. 15-3), MLG-24 (depth 231.5–79.75 m and sample no. 23-4) and MLG-28 (depth 317.5–275.5 m and sample no. 8-6). Palynoassemblage-D is characterized by dominance of nonstriate disaccate *Scheuringipollenites* along with nonstriate disaccates, *viz., Ibisporites, Platysaccus* and striate disaccates, *viz., Striatopodocarpites*, *Faunipollenites*, *Striatites*, *Striasulcites, Strotersporites* and *Crescentipollenites*. Other associated taxa present in this palynoassemblage are triletes *Lacinitriletes*, *Verrucosisporites, Brevitriletes*, *Callumispora*, *Indotriradites*, *Lophotriletes*, *Microbaculispora*, and *Microfoveolatispora*; monosaccates, *viz., Parasaccites, Potonieisporites*, *Divarisaccus, Virkkipollenites, Densipollenites, Crucisaccites, Plicatipollenites,* and *Caheniasaccites*; aletes *Inaperturopollenites, Maculatasporites,* and *Tiwariasporis;* nonstriate

Table 6. *List of spores and pollen species recorded from Gundala area.*

Recorded taxa	Early Permian	Late Permian
Brevitriletes communis Bharadwaj and Srivastava emend Tiwari and Singh (1981)	+	
Brevitriletes unicus (Tiwari) Bharadwaj and Srivastava emend Tiwari and Singh (1981)	+	
Callumispora barakarensis (Bharadwaj and Srivastava) Tiwari, Srivastava, Tripathi and Vijaya (1989)	+	
Callumispora tenuis Bharadwaj and Srivastava (1969)	+	
Horriditriletes rampurensis Tiwari (1968)	+	
Horriditriletes ramosus (Balme and Hennelly) Bharadwaj and Salujha (1964)	+	
Verrucosisporites surangei Maheshwari and Banerjee (1975)	+	
Indotriradites sparsus Tiwari (1965)	+	
Leiotriletes rectus Bharadwaj and Salujha (1964)	+	
Lophotriletes rectus Bharadwaj and Salujha (1964)	+	
Microfoveolatispora foveolata (Tiwari) Tiwari and Singh (1981)	+	
Lacinitriletes sp.	+	
Microbaculispora sp.	+	
Jayantisporites pseudozonatus Lele and Makada (1972)	+	
Caheniasaccites distinctus Lele and Makada (1972)	+	
Caheniasaccites ovatus Bose and Kar (1966)	+	
Caheniasaccites ellipticus Bose and Maheshwari (1968)	+	
Caheniasaccites elongates Bose and Kar (1966)	+	
Crucisaccites indicus Srivastava (1970)	+	
Crucisaccites monoletes Maithy (1965)	+	
Densipollenites invisus Bharadwaj and Salujha (1964)	+	
Divarisaccus lelei Venkatachala and Kar (1966)	+	
Plicatipollenites indicus Lele (1964)	+	
Potonieisporites neglectus Potonič and Lele (1961)	+	
Potonieisporites barrelis Tiwari (1965)	+	
Potonieisporites lelei Maheshwari (1967)	+	
Potonieisporites distinctus Lele and Makada (1972)	+	
Virkkipollenites orientalis Tiwari (1965)	+	
Vestigisporites sp.	+	
Platysaccus plicatus Bharadwaj and Dwivedi (1981)	+	
Platysaccus leschiki Hart (1960)	+	
Striatopodocarpites decorus Bharadwaj and Salujha (1964)	+	
Strotersporites sp.	+	
Crescentipollenites gondwanensis (Maheshwari) Bharadwaj, Tiwari and Kar (1974)	+	
Lunatisporites pellucidus Goubin (1965 emend. Maheshwari and Banerjee (1975))	+	
Tiwariasporis gondwanensis (Tiwari) Maheshwari and Kar (1967)	+	
Tiwariasporis simplex (Tiwari) Maheshwari and Kar (1967)	+	
Latosporites sp.	+	
Maculatasporites sp.	+	
Callumispora sp.	+	+
Parasaccites distinctus Tiwari (1965)	+	+
Parasaccites korbaensis Bharadwaj and Tiwari (1964)	+	+
Parasaccites obscurus Tiwari (1965)	+	+
Scheuringipollenites maximus (Hart) Tiwari (1973)	+	+
Scheuringipollenites barakarensis (Tiwari) Tiwari (1973)	+	+
Scheuringipollenites tentulus (Tiwari) Tiwari (1973)	+	+
Ibisporites jhingurdahiensis Sinha (1972)	+	+
Ibisporites diplosaccus Tiwari (1968)	+	+
Sahnites sp.	+	+
Primuspollenites levis Tiwari (1964)	+	+
Faunipollenites varius Bharadwaj (1962)	+	+
Faunipollenites bharadwajii Maheswari (1967)	+	+
Striatites communis Bharadwaj and Salujha (1964)	+	+
Striatopodocarpites tiwarii Bharadwaj and Dwivedi (1981)	+	+

Table 6. *(Continued).*

Recorded taxa	Early Permian	Late Permian
Striatopodocarpites diffusus Bharadwaj and Salujha (1964)	+	+
Crescentipollenites fuscus (Bharadwaj) Bharadwaj, Tiwari and Kar (1974)	+	+
Crescentipollenites globosus (Maithy) Jha (1996)	+	+
Verticipollenites debiles Venkatachala and Kar (1968)	+	+
Striasulcites sp.	+	+
Hamiapollenites insolitus Bharadwaj and Salujha (1964)	+	+
Corisaccites alutas Venkatachala and Kar (1966)	+	+
Weylandites circularis Bharadwaj and Srivastava (1969)	+	+
Tiwariasporis sp.	+	+
Inaperturopollenites sp.	+	+
Lundbladispora raniganjensis Tiwari and Rana (1981)		+
Playfordiaspora cancellosus (Playford and Dettman) Maheshwari and Banerji (1966)		+
Plicatipollenites ganjraensis Saxena (1971)		+
Divarisaccus sp.		+
Potonieisporites sp.		+
Caheniasaccites sp.		+
Densipollenites indicus Bharadwaj (1969)		+
Striomonosaccites ovatus Bharadwaj (1972)		+
Platysaccus sp.		+
Falcisporites nuthaliensis Clarke, Balme (1970)		+
Klausipollenites sp.		+
Verticipollenites secretus Bharadwaj (1962)		+
Striatopodocarpites multistriatus Jha (1996)		+
Strotersporites communis Wilson (1962)		+
Strotersporites wilsonii Klaus (1963)		+
Lunatisporites diffusus Bharadwaj and Tiwari (1977)		+
Kamthisaccites kamthiensis Srivastava and Jha (1986)		+
Lunatisporites ovatus (Goubin) Maheshwari and Banerji (1966)		+
Hamiapollenites minimus Jha (1996)		+
Guttulapollenites hannonicus Goubin (1965)		+
Guttulapollenites gondwanensis Goubin (1965)		+
Crustaesporites sp.		+

disaccates, *Vestigisporites*, *Sahnites* and *Primuspollenites.* Beside these *Weylandites*, *Hamiapollenites*, *Corisaccites* and *Latosporites* have also been recorded in this palynoassemblage. In this palynoassemblage sample no. 3 of borecore MLG-23 shows the high percentage of *Inaperturopollenites.* However a glance at the Histogram IV characterize this palynoassemblage by the dominance of nonstriate disaccates with few striate disaccates.

5.5 *Palynoassemblage-E*

Palynoassemblage-E marked at the depth of 144–18 m (sample no. 3-1) in borecore MLG-28 and at the depth of 36 m (sample no. 2) in borecore MLG-24 registers a change in composition, with remarkable dominance of striate disaccates, *viz., Striatopodocarpites* along with *Faunipollenites*, *Crescentipollenites, Strotersporites.* Monosaccates present in this palynoassemblage are *Striomonosaccites, Caheniasaccites, Potonieisporites*, *Densipollenites, Divarisaccus, Parasaccites*, and *Plicatipollenites.* Other nonstriate disaccates, *viz., Scheuringipollenites*, *Ibisporites*, *Platysaccus*, *Klausipollenites, Sahnites, Falcisporites*, *Primuspollenites*; and striate disaccates, *viz., Crescentipollenites*, *Striatites*, *Verticipollenites*, *Striasulcites* are also present in this palynoassemblage. On the other hand, taeniate grains, *viz., Lunatisporites, Weylandites*, *Guttulapollenites*, *Kamthisaccites, Corisaccites* and *Hamiapollenites*; trilete *Callumispora*; aletes *Inaperturopollenites* and *Tiwariasporis* have also been recorded inconsistently. Presence of the stratigraphically significant taxa, *viz., Lundbladispora, Playfordiaspora*, *Crustaesporites, Striomonosaccties, Guttulapollenites*, *Kamthisaccites, Klausipollenites* and *Falcisporites* make this palynoassemblage different from others (Histogram V).

6. Discussion

The foregoing account of palynology of the Lower Gondwana sequence in Gundala area of Godavari Graben suggests that rich and diversified vegetation existed in the region during the formation of these sediments. The *sporae dispersae* of six borecores samples from Gundala area studied is represented by five distinct palynoassemblages. The quantitative estimation of various taxa at generic level shows marked change in palynoflora from Talchir to Raniganj. The Lower Gondwana sedimentation in Gundala area commenced with the deposition of Talchir Formation. The oldest palynoassemblage, Palynoassemblage-A has been recorded in borecore MLG-23 between 244 and 299 m with the maximum percentage of radial monosaccates chiefly *Parasaccites* along with other monosaccates. This Palynoassemblage-A compares well with the Talchir palynoassemblage of different areas of Godavari Graben as well as other basins, *viz.,* Palynozone-1 of Ramakrishnapuram (Srivastava and Jha 1992b), Assemblage-E of Yellandu area (Srivastava 1987), Talchir assemblage and zone-1 of Korba Coalfield (Bharadwaj and Srivastava 1973; Srivastava 1973b), Assemblage-1 of Katol area (Kumar and Jha 2000), *Parasaccites korbaensis* zone of Talcher Coalfield (Tripathi 1991).

The next younger Lower Karharbari palynoflora in Gundala area has been demarcated as Palynoassemblage-B in borecores MLG-23 and MLG-24 at 242.4 m and 326.80 m, respectively. This palynoassemblage is akin to Palynozone-2 of Ramakrishnapuram (Srivastava and Jha 1992b), Palynoassemblage-1 of Manuguru area (Srivastava and Jha 1992a), Lower Karharbari Palynozone of Chintalapudi sub basin (Srivastava and Jha 1993), Lower Karharbari palynoassemblage of Girdih Coalfield (Srivastava 1973a), zone-1 of Raniganj Coalfield (Tiwari 1973).

Lower Karharbari palynoflora (Palynoassemblage-B) is succeeded by Palynoassemblage-C which is present in SGK-2 (97.60–102.45 m), SGK-4 (70.39 m), SGK-3 (40.00 m), MLG-28 (377–374 m) and MLG-24 (321.7–276 m). This is the only palynoassemblage which has been traced in all the borecores except MLG-23. The sediments between 242.4 and 204 m in borecore MLG-23 has not been sampled, hence the absence may be due to nonavailability of samples. Palynoassemblage-C resembles Upper Karharbari palynoflora of Godavari and other Gondwana basins in India (Bharadwaj 1975; Jha 2006) in having the dominance of *Parasaccites* with nonstriate disaccate *Scheuringipollenites*. This palynoassemblage compares well with zone-2 of Korba Coalfield (Bharadwaj and Srivastava 1973), zone-1 of Shobhapur block, Pathakhera Coalfield (Srivastava and Sarate 1989), Palynozone-3 of Ramakrishnapuram (Srivastava and Jha 1992b), Upper Karharbari palynozone of Chintalapudi subbasin (Srivastava and Jha 1993), Assemblage-A of Wardha Coalfield (Bhattacharyya 1997) and palynoflora of Umrer Coalfield (Jha *et al* 2007). Unlike other basins, Godavari Graben is deprived of well established

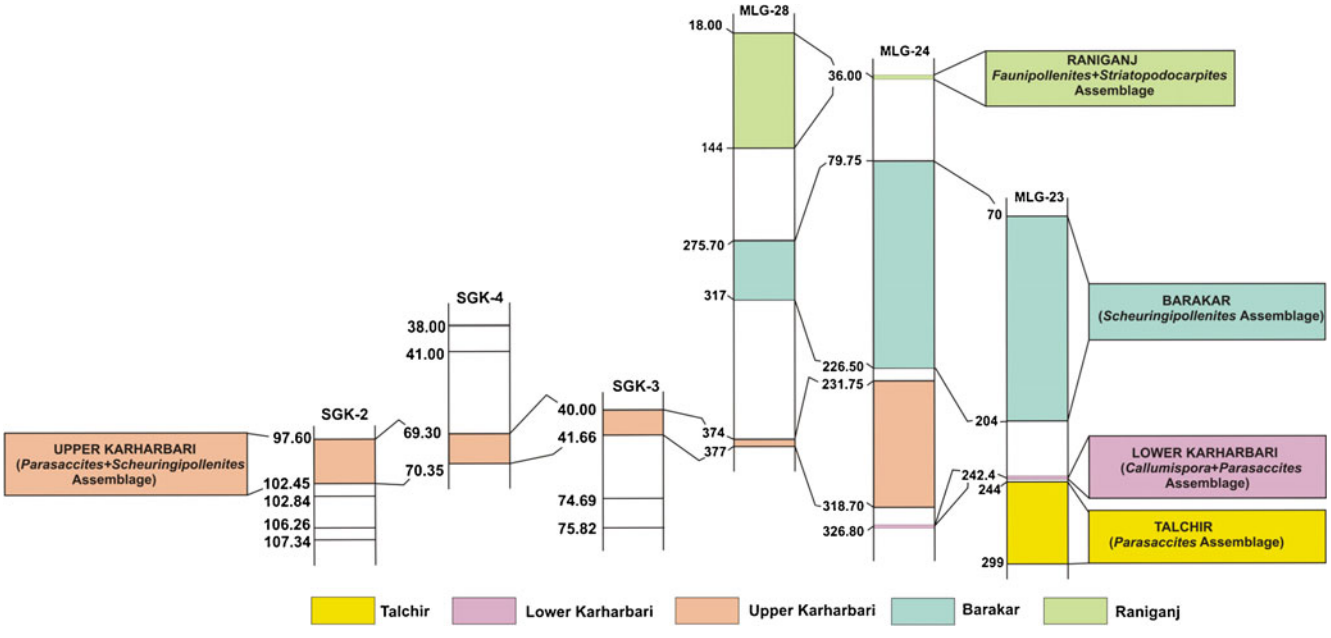


Figure 2. Diagrammatic representation of palynological correlation of different palynoassemblages in Gundala area.

Table 7. *An overview of the identified palynoassemblages in different borecores of the Gundala area.*

Palynoassemblage/borecore	MLG-23 Depth/sample no.	MLG-24 Depth/sample no.	SGK-2 Depth/sample no.	MLG-28 Depth/sample no.	SGK-3 Depth/sample no.	SGK-4 Depth/sample no.
Palynoassemblage-E (Raniganj)	–	36 m (2)	–	144–18 m (3-1)	–	–
Palynoassemblage-D (Barakar)	204–70 m (15-3)	204–70 m (23-4)	–	317.5–275.5 m (8-6)	–	–
Palynoassemblage-C (Upper Karharbari)	–	321.7–276 m (33-26)	97.60–102.45 m (GD/S7, GD/S8)	377–374 m (10-9)	40.00 m (GD/S12)	70.39 m (GD/S11)
Palynoassemblage-B (Lower Karharbari)	242.4 m (18)	326.80 m (34)	–	–	–	–
Palynoassemblage-A (Talchir)	244–299 m (24-19)	–	–	–	–	–

lithostratigraphic zones distinguishing Karharbari and Barakar sequences. It is also noteworthy that lithological characters did not help their categorization. This necessitates a thorough search of plant fossil evidences in order to understand the Karharbari floristics.

In the present study, the Palynoassemblage-D has been observed in borecores MLG-23, MLG-24 and MLG-28 in having the dominance of nonstriate disaccates mainly *Scheuringipollenites* and *Ibisporites* along with presence of few striate disaccates, *viz., Striatopodocarpites, Faunipollenites* and *Striatites*. Occurrence of Barakar palynoflora above the Karharbari palynoflora in these borecores confirms the order of palynological as well as the lithological succession. Dominance of *Scheuringipollenites* has been recorded in Lower Barakar Formation of all the Lower Gondwana coalfields of India, *viz.,* Godavari Coalfield (Srivastava and Jha 1989, 1992b, 1995, 1996; Jha and Aggarwal 2010), Girdih Coalfield (Srivastava 1973a), Raniganj Coalfield (Tiwari 1973), Jharia Coalfield (Tripathi and Tiwari 1982), Johilla Coalfield (Anand Prakash and Srivastava 1984), Wardha Coalfield (Bhattacharyya 1997), IB river Coalfield (Meena 2000), Sohagpur Coalfield (Ram-Awatar *et al* 2004). In Damodar Basins, Barakar palynoflora is divisible in to older – *Scheuringipollenites* dominated palynoflora and the younger – dominated by striates (Bharadwaj 1975). The Upper Barakar palynoflora has not been recorded in Godavari Graben. A hiatus at this level has been interpreted by palynofacies studies also (Mitra 2001).

The youngest Palynoassemblage-E demarcated in borecores MLG-24 (36 m) and MLG-28 (144–18 m) represents the Late Raniganj palynoflora because of the dominance of striate disaccates along with some qualitatively important taxas, *viz., Kamthisaccites, Klausipollenites, Lunatisporites, Falcisporites, Hamiapollenites*, *Playfordiaspora, Lundbladispora, Crustaesporites, Guttulapollenites* and *Weylandites*. Palynoassemblage-E is akin to the Assemblage-I of Chelpur area (Srivastava and Jha 1986), Assemblage-I of Ramagundam area (Bharadwaj *et al* 1987), Palynozone-6 of Ramakrishnapuram area (Srivastava and Jha 1992b), Palynoassemblage-V of Manuguru area (Srivastava and Jha 1992a), Palynoassemblage-I of Bottapagudem area of Chintalapudi sub-basin (Jha 2004), Palynoassemblage-II of Sohagpur Coalfield (Ram Awatar *et al* 2004) and is accommodated well within the *Striatopodocarpites–Faunipollenites* assemblage-zone of Tiwari and Tripathi (1992).

Diagrammatic representation of palynological correlation of these palynoassemblages from Gundala area is shown in figure 2 and an overview of the identified palynoassemblages in

different borecores of the Gundala area is given in table 7.

7. Conclusion

The palynological investigation of the Lower Gondwana sediments in subsurface sediments of Gundala area in Godavari Graben suggests the following points:

- Existence of almost complete Lower Gondwana succession from Talchir to Raniganj Formation has been established. Gundala area records five distinct palynoassemblages (Palynoassemblage A–E). Palynoassemblage-A has been demarcated in borecore MLG-23, Palynoassemblage-B has been identified in MLG-23 and MLG-24 while Palynoassemblage-C has been demarcated in borecores MLG-24, MLG-28, SGK-2, SGK-3 and SGK-4. Palynoassemblage-D has been marked in MLG-23, MLG-24 and MLG-28 while the youngest Palynoassemblage-E has been distinguished in MLG-24 and MLG-28.
- Karharbari palynoflora has been recorded in lower part of lithologically designated Barakar Formation.
- In different northern areas of Godavari Graben, Barren Measures palynoflora has been marked by different workers, *viz.,* in borecore GRK-1 at 109.45–493.57 m and GRK-24 at 363.70–515.75 m of Ramakrishnapuram by Srivastava and Jha (1992b), in GBR-5 at 118.50–253.00 m of Budharam by Srivastava and Jha (1995), in GM-3 at 295–308 m of Manuguru by Srivastava and Jha (1992a). However, in Gundala area situated in Lingala–Koyagudem coalbelt (the southern side of Godavari Graben) Barren Measures palynoflora has not been observed in any borecore of the present investigation may be due to non-availability of samples or there may be thinning of the Barren Measures beds from northern to southern part of the graben.
- Existence of two coal horizons one belonging to Early Permian (Lower coal Measures – Karharbari and Barakar) and other belonging to Late Permian (Upper coal Measures – Raniganj) has been established. Obviously this parameter would definitely be helpful in delineating coal horizons in other areas of Gundala area.

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