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EARLY PERMIAN (ASSELIAN-SAKMARIAN) PALYNOFLORA FROM CHINTALAPUDI AREA, GODAVARI GRABEN, SOUTH INDIA AND ITS PALAEOENVIRONMENTAL IMPLICATIONS

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ABSTRACT

This article integrates palynological, palaeobotanical and palynofacies analysis to evaluate the stratigraphy, palaeovegetation and palaeoenvironment of the deposited sediments. The palynological investigation has been done in the 100m terrestrially derived sedimentary succession of bore core MCP-9, Chintalapudi area, located on the western margin of Chintalapudi Sub-basin. The quantitative and qualitative analysis indicates a rich palynofloral assemblage dominated by gymnosperm pollens, chiefly radial monosaccates, *viz*. *Parasaccites* and *Plicatipollenites*. *Parasaccites* dominates over *Plicatipollenites*. Based on the recovered palynoflora, *Parasaccites* + *Plicatipollenites* Assemblage zone is framed which corresponds to the upper Talchir palynological assemblage of the Gondwana succession. On the basis of palynocomposition of the assemblage and its correlation with the early Permian palynoflora of India and other Gondwana continents, an early Permian (late Asselian-early Sakmarian) age has been assigned to the studied succession.

The palynofacies studies for the Talchir deposits in the Chintalapudi Sub-basin have also been attempted to interpret the palaeoenvironmental conditions during the deposition of these sediments. The organic matter analysis represent swamp dominated conditions under two different sedimentary environments (Palynofacies-I and II). Palynofacies-I is dominated by degraded organic matter and represents low energy, dysoxic to anoxic environmental conditions. Palynofacies-II is characterized by the dominance of palynomorphs representing low energy, anoxic, water-logged environmental conditions. The recovered palynofacies represent dominance of *Cordaites* monosaccate pollen (*Parasaccites, Plicatipollenites*) along with occasionally growing pteridophytic plant spores indicating colder climatic conditions with intermittent spells of cooler (slightly warmer) and humid environments.

Keywords: Palynology, Gondwana, Talchir, Chintalapudi Sub-basin, Ice age.

INTRODUCTION

The Carboniferous-Permian ice age is the most prevalent and geologically well-embodied ice age of the Phanerozoic, which ended more than 270 million years ago. This late Palaeozoic glaciation of Gondwana comprises of three distinct non-overlapping episodes, amongst which the third glaciation of Pennsylvanian to early Permian age was the most widespread, having a continental ice sheets spread over an area of 17.9 to 22.6 × 10^6 km^2 (Veevers, 1994; Veevers and Tewari, 1995; Crowell, 1995; Wopfner and Cashyap, 1997; Isbell *et al.,* 2003). However, Vijaya (1996) is of the opinion that glaciers on Indian peninsula were in the form of isolated patches not in the continental sheets. The sedimentary rocks of the last ice age of Phanerozoic cover a large area and were deposited during glaciofluvial, glaciolacustrine and glaciomarine environments (Stephenson *et al.,* 2007). In spite of wide distribution of these glacial deposits over the Gondwana continent, their correlation and age demarcation is particularly challenging due to the absence of marker taxa, which are mainly marine and forms the basis of International stages (Archbold and Dickins, 1996; Stephenson, 2008; Jin *et al*., 1997). Thus, palynology serves as the prime tool for the correlation and age assessment of terrestrial strata as palynomorphs (spore-pollen) are abundantly present in almost every kind of sedimentary regime.

The late Carboniferous-Permian Gondwana glaciation is associated with the emergence of *Gangmopteris* flora and peat forming *Glossopteris* flora, the chief component of Permian coal forming palaeovegetation across the Gondwana realm (Chandra and Chandra, 1987). Thus, most of the palynological work on the Carboniferous-Permian deposits in and around Gondwana is mainly restricted to coal (India, Australia and South America) and oil exploration (Arabia and South America). While recently palynology has been also employed in inferring the intensity and duration of the Palaeozoic ice age. The early Permian deposits in peninsular India are mainly terrestrial and lack *Eurydesma connularia* or any other age diagnostic records as those of Australia (endemic marine fauna, Foster and Waterhouse, 1988), South America and Africa (radiometric dating technique, Bangert *et al.,* 1999; Césari, 2007). Owing to this, palynological studies for understanding the age and correlation of coal bearing horizons and the associated sediments from different Gondwana deposits of India has been done by various workers *viz*., Tiwari and Tripathi, 1992; Banerjee and Hait, 2005; Singh *et al.*, 2005; Jha, 2006; Basavaraju and Pundir, 2007; Jha and Aggarwal, 2012; Aggarwal and Jha, 2013, Jha *et al*., 2014. However, the palynological studies on glacial deposits in Chintalapudi sub-basin of Godavari Graben has received limited attention. Thus, the present study aims to present a synthesis of all available palynological data of the early Permian glacial deposits across all the Gondwana continents to deduce age, stratigraphy and palaeoenvironment of the glacial deposits in Chintalapudi sub-basin, Godavari Graben, *i.e*., Talchir Formation.

GEOLOGICAL SETUP

The Gondwana Basins of India occur within the suture zones of Precambrian cratonic blocks of Peninsular India along the linear belts and in the western pericratonic basins. Godavari Graben is one of the biggest Gondwana basins in India (Fig. 1A). It covers an area of 17,000 km^2 and is the largest coal bearing basin of South India. It has been structurally subdivided into four sub-basins-Godavari, Kothagudem, Chintalapudi and Coastal Gondwana tract of Krishna-Godavari sub-basins. The Gondwana rocks of Godavari Graben represents a continuous sedimentary record from the early Permian to early Cretaceous. The Lower Gondwana (Permian) stratum is represented by the Talchir, Barakar and Kamthi (= Raniganj and Panchet) formations, while the Upper Gondwana (Triassic- Cretaceous) is represented by the Maleri, Kota and Chikiala formations (Raja Rao, 1982; Ramanamurthy and Madhusudan, 1996; Jha and Srivastava, 1996).

The Chintalapudi sub-basin represents the south-eastern continuation of Kothagudem sub-basin trending in the NNW-SSE direction and covers an area of 2500 km^2. The basement rocks for Gondwana sequence in Chintalapudi sub-basin are represented by Khondalites and associated granulites. The stratigraphy of the Chintalapudi sub-basin is not well recognized due to the presence of many small faults and the absence or reduction of an intervening strata *i.e.,* Barren Measures, which lies between the two coal bearing horizon (Barakar and Raniganj formations). Earlier, Barakar and Barren Measures were not discovered and the rocks above the Talchir Formation, were referred as Kamthi Sandstone (Blandford, 1872), Kamthi Formation (Raja Rao, 1982) and Chintalapudi Formation (Raiverman *et al*., 1986). Later, Lakshminarayana and Murthy (1990) and Lakshminarayana (1996) revised the stratigraphy of the Chintalapudi sub-basin in which Barakars were overlain by the Kamthi Formation (Table-1).

The early Permian Gondwana succession in the Godavari Graben occurs as a narrow strip along the western margin of the basin from near Mailaram in NW to Lingala in the SE, the continuity is being broken at places owing to effects of faults (Fig. 1B). On the eastern limb, the rocks are exposed along the course to the Godavari near Cherla and Manuguru. Isolated occurrences near Kinnersani and Murreru streams and Mailaram high area have been also recorded. As a result of faulting Talchir beds are exposed in Chinnur-Chandrapalli area. Few outliers are also exposed around Talada and near Yellendu and Kamaram. In the Chintalapudi sub-basin, exposures near the Sattupalli and Chintalapudi areas comprise greenish clays and siltstones belonging to Talchir Formation (Raja Rao, 1982). The present palynological investigation is done on the early Permian deposits in the Chintalapudi area of Chintalapudi sub-basin, Godavari Graben.

The Talchir palynoflora has been identified in bore core MCP-9. Talchir Formation discomformably overlies the basement. It consists of diamictite, rhythmite and the light green sandstone. After a prolonged episode of non-deposition of Carboniferous sequence, 62.36m thick sequence of the present study, predominantly sandstone shale sequence of Talchir

Table 1. Stratigraphic succession of Chintalapudi sub-basin. (after Lakshminarayana, 1996).

Age	Group	Formation	Lithology
Early Cretaceous	UPPER	Gangapur	White sandstone, buff siltstone and claystone
	G		
Jurassic	O	Kota	**UPPER** : Sandstone and conglomeratic sandstone
	N		**MIDDLE** : Limestone and marl
	D		**LOWER** : Conglomeratic sandstone and trough cross stratified sandstone.
	W		
	A		
Md.-Late Triassic	N	Maleri	(?) Red clay and limepellet rock
	A		
------ Unconformity ------			
L.PERMIAN -E.TRIASSIC	LOWER	Kamthi	Conglomerate, conglomeratic sandstone, siltstone and grey shales
	G	------ Unconformity ------	
Early	O	Barakar	**UPPER** : White felspathic sandstone, siltstone, shale, carbonaceous shale and coal seams
P	N		
E	D		**LOWER** : Very coarse grained, pebbly, feldspathic sandstone
R	W		
M	A	Talchir	Diamictite, rhythmite, fine grained light green sandstone and siltstone
I	N		
A	A		
N			
------ Unconformity ------			
Proterozoic Archaean			

EXPLANATION OF PLATE I

1. ***Lacinitriletes badamensis***, B.S.I.P. Slide No. 15179, L25, 2. ***Horriditriletes ramosus***, B.S.I.P. Slide No. 15180, R21. 3. ***Callumispora gretensis,*** B.S.I.P. Slide No. 15162, H40/3, 4. ***Microbaculisporites gondwanensis***, B.S.I.P. Slide No. 15163, L27, 5. ***Brevitriletes unicus***, B.S.I.P. Slide No. 15167, U34/3, 6. ***Leiotriletes virkki***, B.S.I.P. Slide No. 15173, H30/1, 7. ***Jayantisporites conatus***, B.S.I.P. Slide No. 15165, T45/1, 8. ***Quadrisporites horridus***, B.S.I.P. Slide No. 15169, J18/4, 9. ***Balmella*** sp., B.S.I.P. Slide No. 15165, N30/3, 10. Spore tetrad, B.S.I.P. Slide No. 15173, T42/3. 11. ***Verrucosisporites*** tetrad, B.S.I.P. Slide No. 15177, L21/3, 12. ***Verrucosisporites normianus***, B.S.I.P. Slide No. 15166, Q18/4, 13. Fungal spore, B.S.I.P. Slide No. 15166, N42/3, 14. ***Plicatipollenites malabarensis***, B.S.I.P. Slide No. 15170, J43/2, 15. ***Caheniasaccites ovatus***, B.S.I.P. Slide No. 15179, J41, 16. ***Potonieisporites neglectus***, B.S.I.P. Slide No. 15181, M37/1, 17. ***Divarisaccus lelei***, B.S.I.P. Slide No. 15165, P31/2, 18. ***Plicatipollenites gondwanensis***, B.S.I.P. Slide No. 15180, R35,

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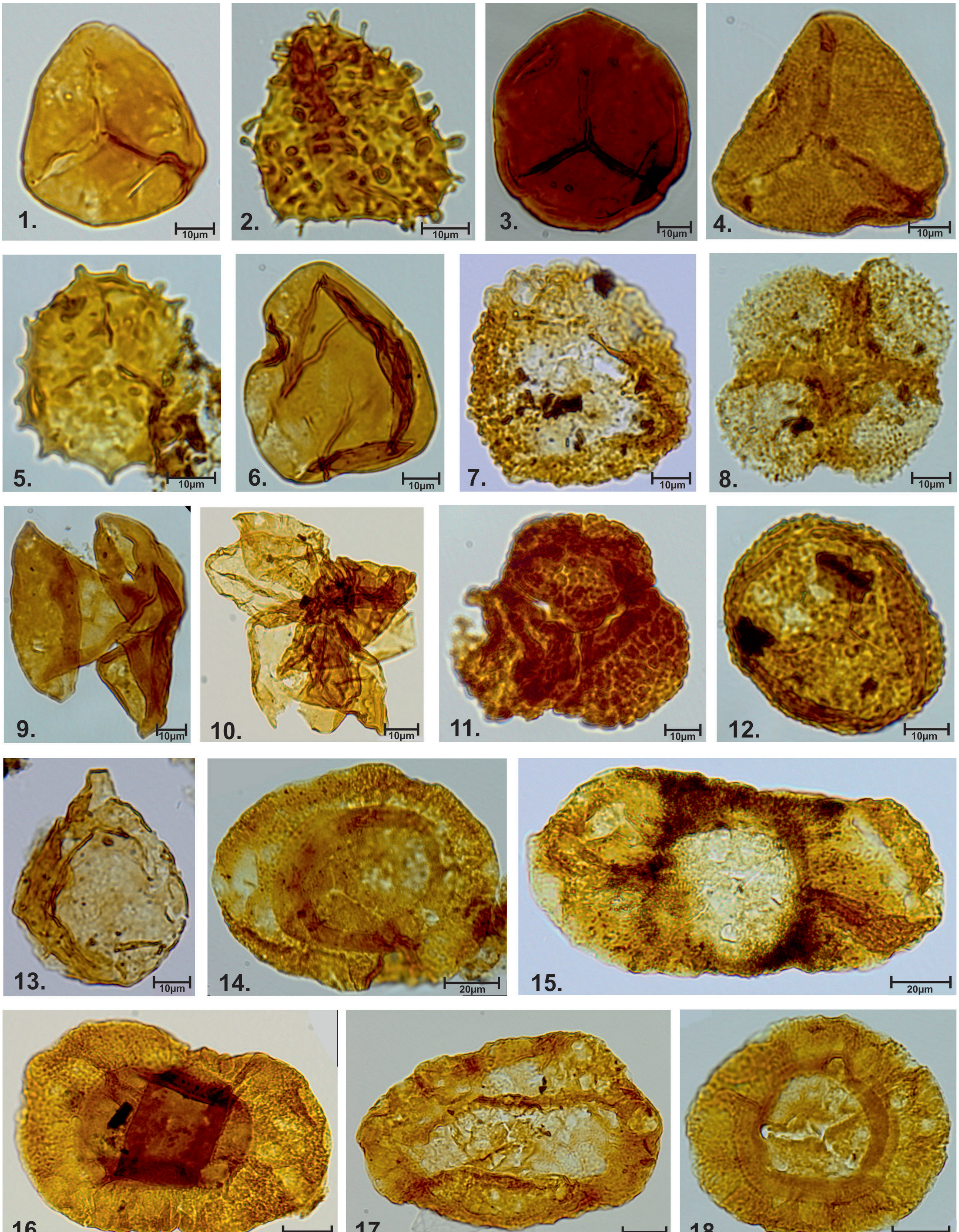
Plate I



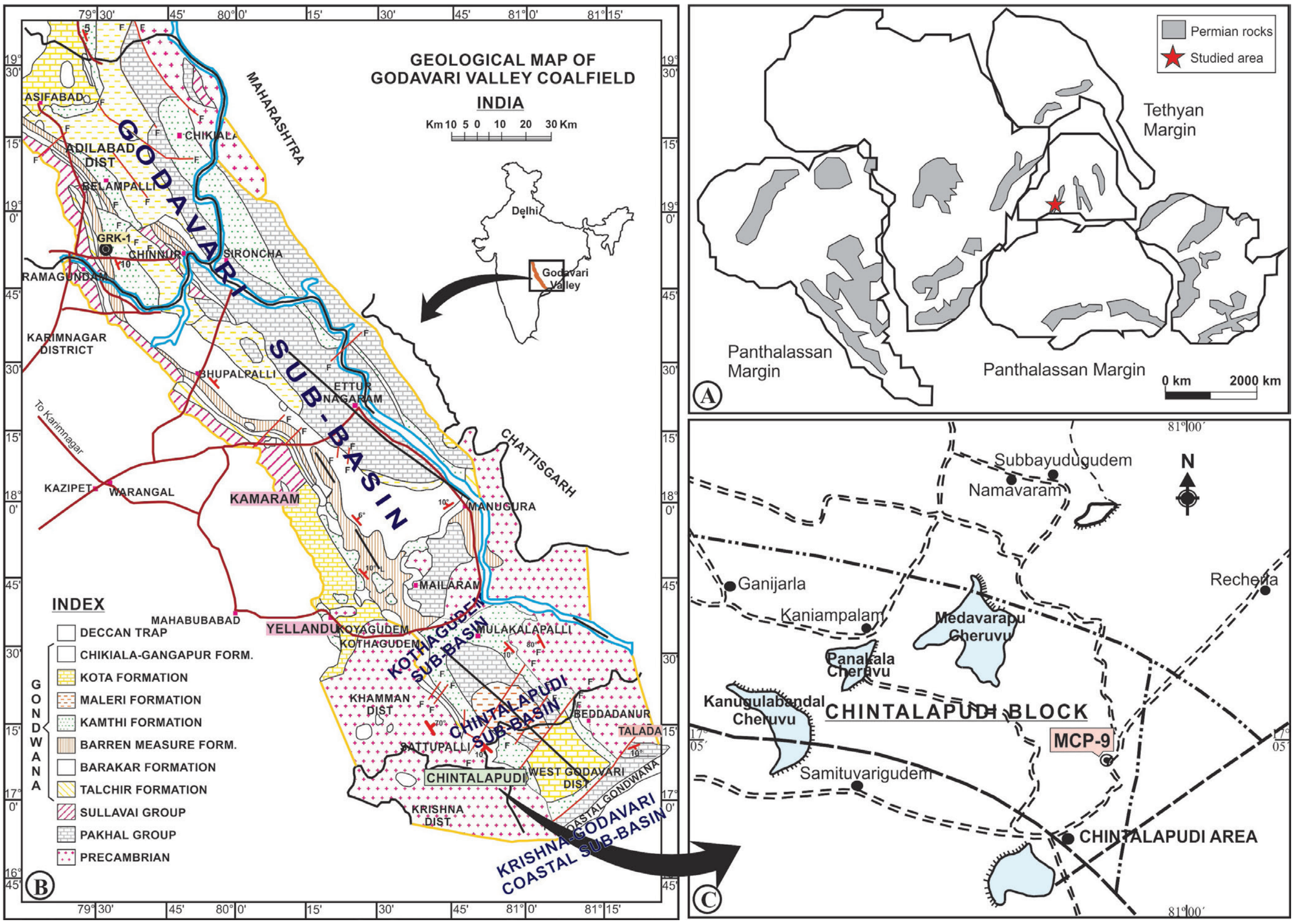


Fig. 1. A, Map of early Permian deposits in the Gondwana continents, B, Map of Godavari Graben showing location of Chintalapudi sub-basin and Chintalapudi area; B, Map of Chintalapudi block showing location of bore core MCP-9 (after SCCL).

Formation records the accumulation of glacial and post glacial deposits in the basin (Lakshminarayana, 1996).

SEDIMENTARY SUCCESSION OF BORE CORE MCP-9

The bore core MCP-9 was drilled by Singareni Collieries Company Ltd. (SCCL) up to 100m depth cutting across the Talchir and Kamthi formations. Lithologically, it has been designated that Kamthi Formation directly overlies the Talchir Formation (Fig. 3). Hence, lithologically a large gap in sedimentation is recorded (Fig. 3). The complete sedimentary sequence mainly consists of greenish sandstone and subordinate greenish shale with the occasional occurrence of siltstone/shale. Sedimentary sequence in bore core MCP-9 consists of 1m thick siltstone/shale deposit at the depth of 64.0m and 87.0m. The bore core from the depth of 44.40m to 57.50 consists mainly of greenish sandstone with subordinate greenish shale and belongs to Talchir Formation. The overlying sediments from 4.0-44.40m consist of sandstone, lithologically designated as Kamthi Formation. The location of bore core is shown in Fig. 1C and its sedimentary succession is shown is Fig. 3.

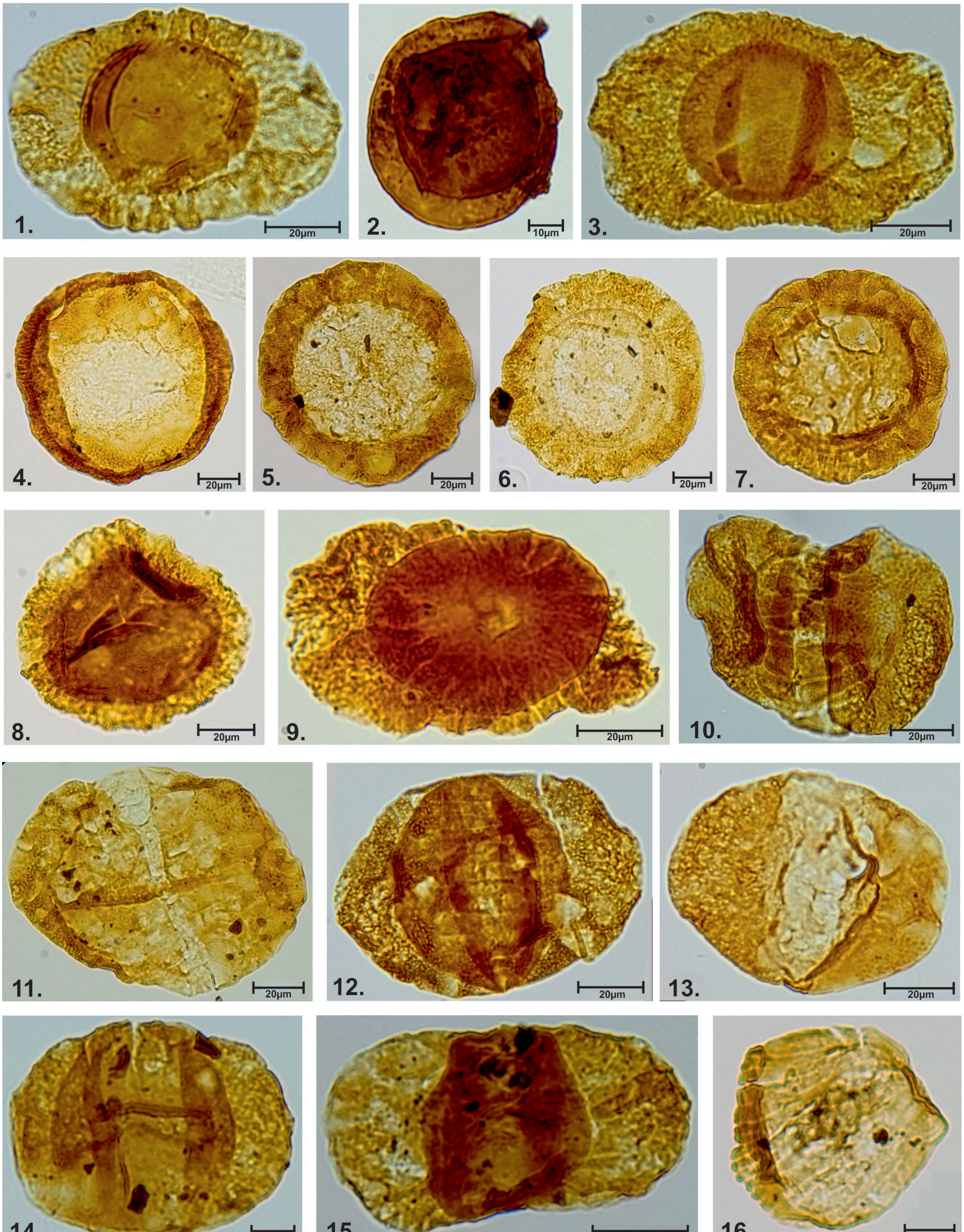
MATERIAL AND METHOD

The five samples of different lithologies were collected in the bore core MCP-9 from Chintalapudi area of the Chinatalapudi sub-basin, Godavari Graben. Recovery of palynomorphs for palynological studies was done using the maceration technique as proposed by Faegri and Iverson (1975). About 15-25gm of the sample was first crushed in mortar and pestle to about 2-3mm size, then treated with 40% Hydrofluoric acid (for dissolving

EXPLANATION OF PLATE II

1. ***Potonieisporites novicus,*** B.S.I.P. Slide No. 15170, F36, 2. Unidentified, B.S.I.P. Slide No. 15169, G23/3, 3. ***Potonieisporites methoris,*** B.S.I.P. Slide No. 15162, V22/1, 4. ***Crucisaccites indicus***, B.S.I.P. Slide No. 15175, R37, 5. ***Parasaccites diffuses***, B.S.I.P. Slide No. 15163, N18/4, 6. ***Plicatipollenites indicus***, B.S.I.P. Slide No. 15168, O19/3, 7. ***Plicatipollenites indicus***, B.S.I.P. Slide No. 15173, J30/1, 8. ***Plicatipollenites indicus***, B.S.I.P. Slide No. 15174, K43, 9. ***Rhizomaspora*** sp., B.S.I.P. Slide No. 15165, 31/1, 10. ***Lunatisporites diffuses***, B.S.I.P. Slide No. 15164, U40/1, 11. ***Strotersporites communis***, B.S.I.P. Slide No. 15162, E20/1, 12. ***Crescentipollenites fusus***, B.S.I.P. Slide No. 15178, N23/3, 13. ***Alisporites tenuicorpus***, B.S.I.P. Slide No. 15177, L17/2, 14. ***Sahnites panchetensis***, B.S.I.P. Slide No. 15173, T41/2, 15. ***Sahnites gondwanensis,*** B.S.I.P. Slide No. 1575, R29/3, 16. ***Vittatina vittifera,*** B.S.I.P. Slide No. 1565, G11/4.

Plate II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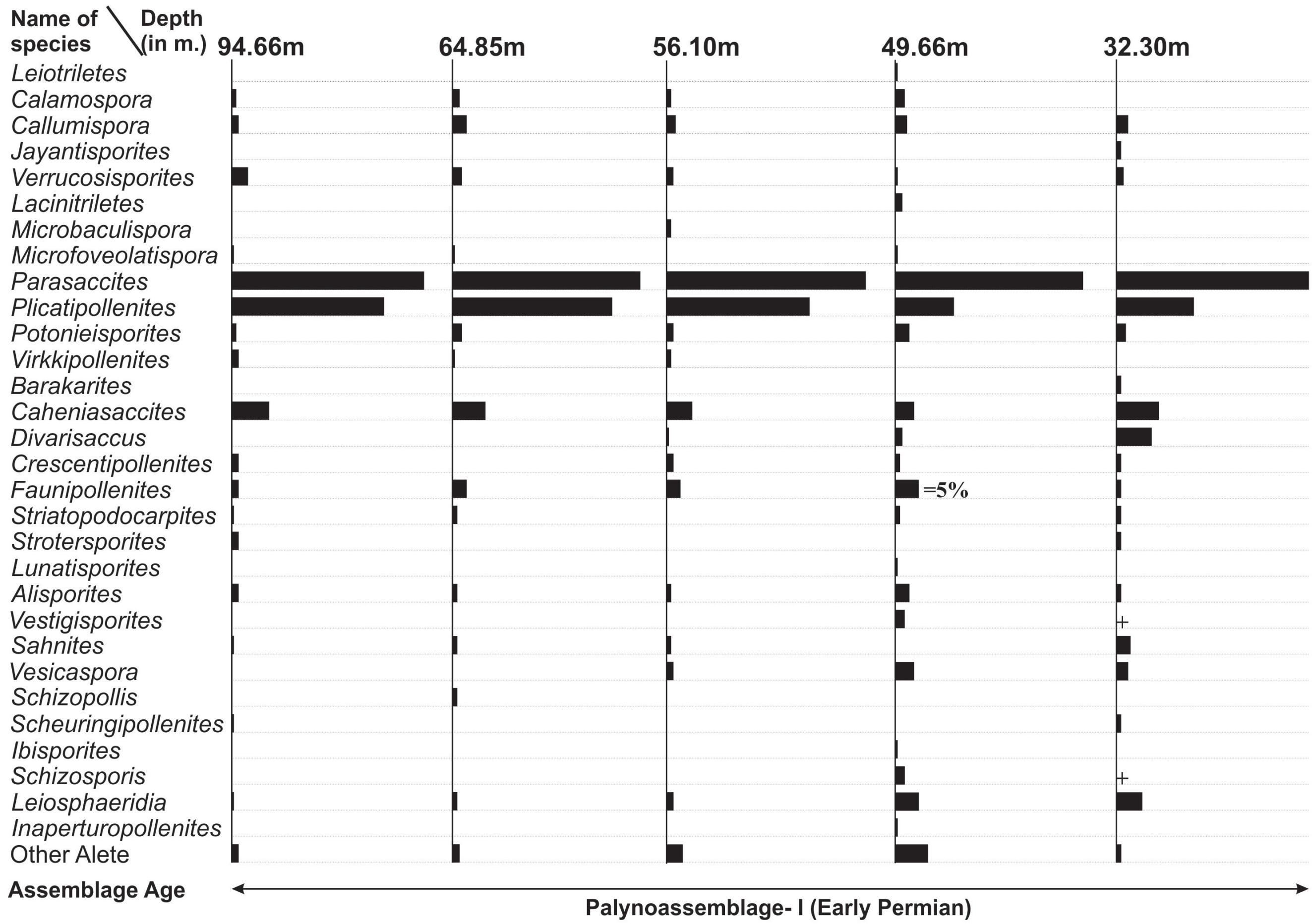

Fig. 2. Histogram showing vertical distribution and percentage frequency of various palynotaxa in bore core MCP-9, Chintalapudi area, Chintalapudi Sub-basin.

silica), followed by the treatment with conc. Nitric acid (for the oxidation of humic matter) and lastly by 10% Potassium hydroxide (for clearing the palynomorphs). Washing with water is done after each treatment by using 400 mesh sized brass sieve. The obtained macerals were then mounted by using poly vinyl alcohol and Canada balsam so as to make them permanent and the slides have been deposited in the repository of the Birbal Sahni Institute of Palaeosciences (BSIP Museum Statement No: 1372). The morphographic studies were done using an Olympus BX-61 microscope and photography is done by DP25 camera.

The palynological and organic matter studies include qualitative as well as quantitative analysis. For quantitative study, 300 palynomorphs and organic matter types were counted for each sample to calculate the percentage frequency of each taxon.

PALYNOLOGICAL RESULTS

All the five samples yielded abundant palynomorphs in various states of preservation. The smaller spores are generally well-preserved whereas the larger saccate pollen grains are mostly degraded (biologically or mechanically degraded) or in a fragmentary condition. The palynoflora is dominated by gymnospermous pollen grains, mainly monosaccates palynomorphs (61-84%; Fig. 2) while trilete grains are less common and constitute 9-20% of the microflora. Bisaccate grains are rare forming only 7-19% of the assemblage, except at 49.66m depth, where they constitute almost 20%. The palynomorphs are grouped in different plant categories, *viz*., algae, fillicopsida, lycophyta, equisetopsida, *Cordaites,* glossopterids and conifers (Table 2). A list of recovered palynomorphs and their vertical distribution histogram is given in Table 2 and Fig. 2 respectively. The stratigraphically significant taxa have been illustrated in Plate-I and II.

Palynoassemblage

The Palynoassemblage identified between 32.30m-94.66m is marked by the dominance of diverse forms of monosaccate pollen *viz*., *Parasaccites* (=*Cannanoropollis*) spp. (40-42.5%) {*P. diffuses, P. korbaensis, P. indicus, P. obscurus, P.*

EXPLANATION OF PLATE III

Dispersed Organic Matter (DOM) at different depths in Bore Core MCP-9. 1. Palynofacies showing the fungal hyphae, B.S.I.P. Slide No. 15167, 2. Palynofacies with various types of Dispersed Organic Matter, B.S.I.P. Slide No. 15161, 3. Fungal Hyphae (FE), B.S.I.P. Slide No. 15167, J36/3, 4. Opaque particle (OP), B.S.I.P. Slide No. 15161, N/18/3, 5. Palynomorph (PM), B.S.I.P. Slide No. 15161, Q16/4, 6. Brown phytoclast (BP), B.S.I.P. Slide No. 15172, R15/2, 7. Biodegraded Organic matter (BDOM), B.S.I.P. Slide No. 15161, P18/4, 8. Cuticle (C), B.S.I.P. Slide No. 15161, N14/1, 9. Amorphous organic matter (AOM), B.S.I.P. Slide No. 15166, H36/2.

Plate III

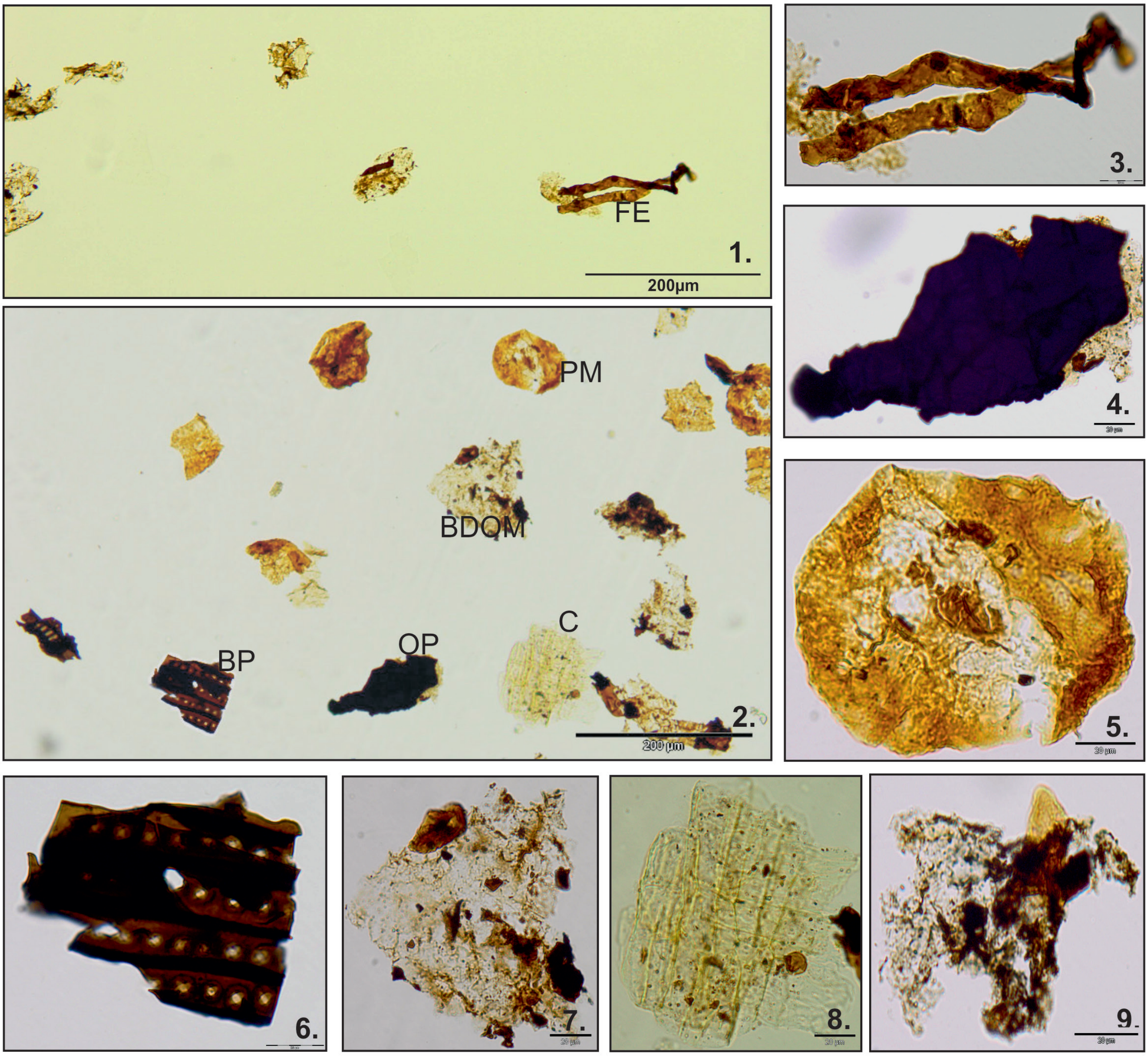

Table 2. List of spore-pollen taxa identified in Bore core MCP-9 and their botanical affinity based on the compilation of various authors (Balme, 1970, 1995; Grauvogel-Stamm, 1978, 1999; Retallack, 1975, 1997; Hochuli *et al*., 2010; Zavada, 1991; Lindström *et al*., 1997; Looy *et al*., 1999; Krassilov and Karasev, 2009; Kustatscher *et al*., 2010; Taylor *et al*., 2009; Gastaldo *et al*., 2005; Lindström and McLoughlin, 2007).

Palynotaxa	Botanical Affinities
Spores	
Lacinitriletes badamensis (Venkatachala and Kar) Tiwari and Singh, 1981	Filicopsids
Microfoveolatispora foveolata Tiwari emend. Tiwari and Singh 1981	
Microbaculispora gondwanensis Bharadwaj, 1962	
Microbaculispora tentula Tiwari, 1965	
Callumispora gretensis (Balme and Henn.) Bharadwaj and Srivastava, 1969	
Callumispora barkarensis Bharadwaj and Srivastava, 1969	
Callumispora fungosa (Bharadwaj and Srivastava) Tiwari and Singh, 1981	
Brevitriletes unicus (Tiwari) Bharadwaj and Srivastava emend. Tiwari and Singh, 1981	
Horriditriletes ramosus (Balme and Hennelly) Bharadwaj and Salujha, 1964	
Horriditriletes bulbosus Tiwari, 1965	
Leiotriletes virkkiae Tiwari, 1965	
Leiotriletes psilatus Kar and Bose, 1967	
Verrucosisporites normianus Balme, 1970	
Verrucosisporites varians Volkheimer, 1972	
Verrucosisporites distinctus Tiwari 1965	
Quadrisporites horridus Potonie and Lele, 1961	
Calamospora aplata Bharadwaj and Salujha, 1964	Eqisetopsida
Calamospora exile Bharadwaj and Salujha, 1964	
Calamospora plicata Tiwari and Navale, 1967	
Jayantisporites pseudozonatus Lele and Makada, 1972	Lycopsids
Jayantisporites indicus Lele and Makada, 1972	
Indospora clara Bharadwaj, 1962	
Leiosphaeridia indica Lele and Chandra, 1972	Algal spores
Leiosphaeridia plicata Bharadwaj, Tiwari and Venkatchala, 1971	
Inaperturopollenites concedipites (Woodhouse, 1933) Krutzsch, 1971	
Inaperturopollenites reidi de Jersey, 1960	
Balmella Balme and Hennelly, 1956	
Pollens	
Parasaccites diffuses Tiwari, 1965	Cordaites
Parasaccites bilateralis Tiwari, 1965	
Parasaccites densicorpus Lele, 1975	
Parasaccites korbaensis Bharadwaj and Tiwari, 1964	
Parasaccites distinctus Tiwari, 1965	
Parasaccites obscurus Tiwari, 1965	
Plicatipollenites indicus Lele, 1964	
Plicatipollenites gondwanensis (Balme and Hennelly) Lele, 1964	
Plicatipollenites densus Srivastava, 1970	
Plicatipollenites malabarensis Foster, 1976	
Vikrkkipollenites Lele, 1964	
Barakarites indicus Bharadwaj and Tiwari, 1964	
Barakarites crassus Bharadwaj and Tiwari, 1964	
Caheniasaccites ovaus Bose and Maheshwari, 1968	Conifers
Caheniasaccites ovatus Bose and Kar, 1966	
Caheniasaccites distinctus Lele and Makada, 1972	
Potonieisporites methoris Hart, Foster, 1975	
Potonieisporites densus Maheshwari, 1967	
Potonieisporites magnus Tiwari, 1965	
Potonieisporites neglectus Potonié and Lele, 1961	
Potonieisporites novicus Bharadwaj, emend. Poort and Veld 1997	
Divarisaccus lelei Venkatchala and Kar, 1966	
Crucisaccites indicus Srivastava, 1970	
Alisporites tenuicorpus Balme, 1970	
Alisporites indicus Bharadwaj and Srivastava, 1969	

Sahnites gondwanensis (Mehta) Pant emend. Tiwari and Singh, 1984	
Sahnites panchetensis Tiwari and Singh, 1984	
Sahnites jayantiensis (Lele and Karim) Tiwari and Singh, 1984	
Vestigisporites rudis Balme and Hennelly, 1954	
Scheuringipollenites maximus (Hart) Tiwari, 1973	
Scheuringipollenites barakarenses (Hart) Tiwari, 1973	
Scheuringipollenites tentulus (Tiwari) Tiwari, 1973	
Ibisporites diplosaccus Tiwari, 1968	
Schizopollis distinctus Sinha, 1972	
Rhizomaspora Wilson, 1962	
Vesicaspora luteus Salujha, 1965	
Lunatisporites diffuses Bharadwaj and Tiwari, 1977	
Striatopodocarpites diffusus Bharadwaj and Salujha 1964	Glossopterids
Striatopodocarpites ovatus (Maheshwari) Tiwari and Rana 1980	
Faunipollenites bharadwaji Maheshwari 1967	
Faunipollenites perixiguus Bharadwaj and Salujha, 1965	
Faunipollenites varius Bharadwaj, 1962	
Crescentipollenites fuscus (Bharadwaj) Bharadwaj, Tiwari and Kar, 1974	
Crescentipollenites amplus (Balme and Hennelly) Tiwari and Rana, 1980	
Strotersporites communis Wilson 1962	
Weylandites obscurus (Tiwari) Bharadwaj and Dwivedi, 1981	
Vittatina vittifera (Luber and Waltz) Samoilovich, 1953	

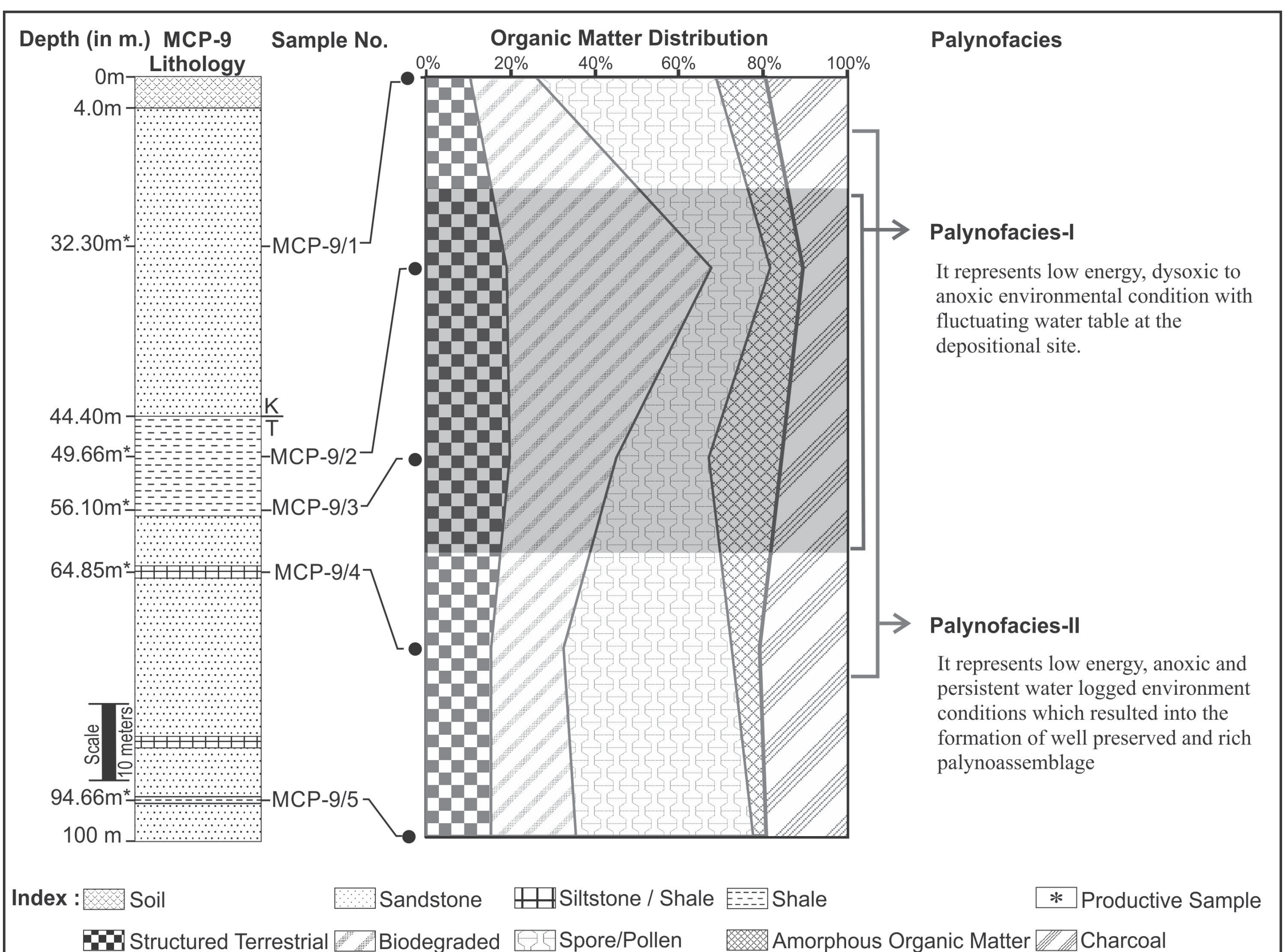

Fig. 3. Palynofacies identified in Bore core MCP-9. Lithostratigraphy: **K-**Kamthi Formation, **T-**Talchir Formation.

bilateralis, P. densicorpus, P. distinctus}, *Plicatipollenites* spp. (12.5-34%) {*P. indicus, P. gondwanensis, P. densus, P. malabarensis*}, *Caheniasaccites* spp. (4-9%) {*C. ellipticus, C. ovatus, C. distinctus*}, *Potonieisporites* spp. (1-3%) {*P. densus, P. magnus, P. neglectus, P. novicus, P. methoris*}, *Barakarites* spp. (0-1%) {*B. indicus, B. crassus*}, *Divarisaccus lelei* (0-7.5%) and presence of stratigraphically significant lycopsid spores *i.e*., *Jayantisporites pseudozonatus, Jayantisporites indicus, Indospora clara.* Palynotaxa found associated with these are non-striate bissacates; *Alisporites* spp. (1-3%) {*A. tenuicorpus*, *A. indicus*}, *Sahnites* (0-3%) {*S. gondwanensis, S. jayantiensis*}, *Scheuringipollenites* spp. (0-1%) {*S. maximus, S. barakarenses, S, tentulus*}, *Schizopollis distinctus* (0-1%), *Ibisporites diplosaccus* (0-0.5%), striate bisaccates *viz*., *Faunipollenites* (=*Protohaploxypinus*) spp. (1-5%) {*F. bharadwaji, F. perixiguus, F. varius*}, *Crescentipollenites* spp. (0-1.5%) {*C. fuscus, C. amplus*}, *Strotersporites communis* (0-1.5%), *Striatopodocarpites* spp. (0-1%) {*S. diffusus, S. ovatus*}, taeniate grains: *Lunatisporites diffuses* (0-0.5%); trilete spores: *Calamospora* spp. (0-2%) {*C. aplata, C. exila, C. plicata*}, *Callumispora* (=*Punctatisporites*) spp. (1.5-2.5%) {*C. gretensis, C. barkarensis, C. fungosa*}, *Verrucosisporites* spp. (0.5-3.5%) {*V. normianus, V. varians, V. distinctus*}, *Lacinitriletes badamensis* (0-1.5%), *Microbaculispora* sp. (0-1%) {*M. gondwanensis, M. tentula*}, *Microfoveolatispora foveolata* (0-0.5%), *Leiotriletes* sp. (0-0.5%) {*L. virkki, L. psilatus*}, *Horriditriletes* spp. (0-0.5%) {*H. ramosus, H. bulbosus*}. Algal spores *viz*., *Inaperturopollenites* sp. (0-0.5%) {*I. concedipites, I. reidi*} and *Leiosphaeridia* spp. (5.5%) {*L. indica, L. plicata*} have also been observed in the upper part of the bore core at 32.30 and 49.66m respectively.

COMPARISON

The Gondwanan sedimentation started with the glacial deposits in all the Gondwana basins of India *i.e*., Talchir Formation (Raja Rao, 1982). The formation is found to be dominated by radial monosaccates along with the presence of lycopsid spores and shows gross similarity in the palynoflora all over the Indian and Gondwanan continents (Jha, 2006; Barbolini and Bamford, 2014). The intra- and inter-basinal correlation has been done with the early Permian deposits in India and across other Gondwana continents to deduce its age.

A. Intra-Basinal (Godavari Graben)

The recovered palynoflora represents the Talchir Formation as it compares well with the Palynozone-I of Ramakrishnapuram area (Srivastava and Jha, 1992), Palynozone-I (Srivastava and Jha, 1994) and Palynoassemblage-A of Sattupalli area (Bilwa *et al*., 2012) along with Palynozone-I of Budharam area (Srivastava and Jha, 1995) from Chintalapudi sub-basin. Palynoflora of Talchir Formation is also comparable to Assemblage-E of Yellendu area (Srivastava, 1987), Palynozone-I of Mailaram area (Jha and Aggarwal, 2012), and Palynozone-I of Gundala area (Aggarwal and Jha, 2013). Similarly, presence of similar Talchir palynoflora in sediments has also been recorded in the bore hole GCH-4 from Chintalapudi area at 163m and bore core GAG-1 (at 534.40m) from Ayyanapalli-Gompana area of Chintalapudi sub-basin, where well preserved *Gangmopteris* leaf impressions have been observed in grey black splintery shales (Srivastava and Jha, 1993), which are lithologically comparable to black needle shales of the Talchir Formation from Manendragarh (Lele and Chandra, 1972) containing index fossil of early Permian age *i.e*, *Eurydesma,* a marine invertebrate.

B. Inter-Basinal (Other Gondwana basins of India)

The Talchir palynoflora of the present study is very much similar with the other parts of Indian subcontinent like, Palynozone-III (*Parasaccites korbaensis* Assemblage zone) of Tiwari and Tripathi (1992) in having palynotaxa like, *Parasaccites korbaenisis, Parasaccites* spp., *Callumispora gretensis, Jayantisporites indicus, Divarisaccus lelei, Plicatipollenites* spp. Therefore, the present palynoflora represents upper Talchir palynozone and is early Permian (late Asselian-early Sakmarian) in age. The present assemblage is comparable to the early Permian assemblage of youngest horizon of Talchir Formation from West Bokaro Coalfield (Lele, 1975) in having dominance of radial monosaccates *viz*., *Parasaccites* spp., *Plicatipollenites* spp., *Virkkipollenites* spp. and *Potonieisporites* spp. with triletes and Leiosphaerids. Palynoassemblage is also comparable to the many other known assemblages of Talchir Formation recovered from Damodar Basin (Bharadwaj, 1975; Lele and Makada, 1972; Srivastava, 1973; Vijaya, 1998; Banerjee and Hait, 2005).

The similar assemblages are also recorded from Cauveri basin (Basavaraju and Govindan, 1997), Mahanadi Basin (Tripathi, 1993; Chakraborty, 2003; Vijaya *et al*. 2012; Goswami and Singh, 2013), Satpura Basin (Kar, 2012; Murthy *et al.,* 2013), Wardha Valley (Kumar and Jha, 2000; Mahesh *et al*., 2011) and South Rewa Basin (Ram-Awatar, 1996).

The early Permian deposits having dominance of radial monosaccates have also been recorded from the extra-peninsular part of India *viz*., Assam Arakan Basin (Basavaraju and Pundir, 2003, 2007), *Plicatipollenites stigmatus* zone of Rilu Member from Rangit Formation in Arunachal Pradesh (Srivastava and Bhattacharya, 1996). The Chongtash Formation of Shyok Valley and Karakoram (Upadhyay *et al*., 1999; Sinha *et al*., 2004) from Himalayan range had also yielded early Permian (Asselian-Sakmarian) flora having dominance of radial monosaccates.

Singh *et al*. (2005) compared the mega as well as microflora of the Indian Gondwana flora of Talchir Formation. They found that Indian megaflora of Talchir Formation consists of *Gangamopteris* sp., *Noeggerathiopsis* sp. and *Glossopteris* sp. While, microflora dominated by *Plicatipollenites, Parasaccites, Virkkipollenites, Callumispora* and *Quadrisporites.* They suggested early Permian (late Asselian-early Sakmarian) age on palaeontological, palaeobotanical and palynological grounds. Tiwari and Kumar (2002) assigned Asselian-Sakmarian age for the *Parasaccites-Plicatipollenites* rich assemblage of Talchir Formation on the basis of *Eurydesma* fauna (Kunnanian age: Waterhouse, 1976) of Manendragarh marine bed of the Talchir Formation in Madhya Pradesh. Thus, the present assemblage is early Permian (late Asselian-early Sakmarian) in age due to its close similarity with these palynoflora.

C. Global Comparison

The initiation of Gondwana sedimentation in all the basins is marked by glacial deposits and in India it is named as Talchir Formation, which represents the basal stratigraphic unit of the Lower Gondwana sequence of India lying unconformably over the Precambrian platform. In other Gondwana continents *viz.,* Africa, the lower most unit is Dwyka tillite , in Australia: Baccus Marsk Tillite and in S. America 'Itararé Group (Lower), while in Antarctica it has different names in different area *viz.,* Darwin Tillite, Mackellar Formation, Buckley Formation, etc.

The palynoflora of Dwyka Tillite and Baccus Marsh Tillite and Lower Itararé Group have carboniferous taxa along with dominance of monosaccate taxa chiefly *Parasaccites* and *Plicatipollenites.* Whereas, in India no Carboniferous taxa has been recorded in Talchir Formation.

Antarctica

The oldest early Permian assemblage was encountered in the Darwin Tillite, South Victoria land by Kyle (1977) and the rocks equivalent to this were found at the Ohio and Wisconsin Ranges and the Nilsen Plateau in the Transantarctic Mountains (Kyle and Schopf, 1982) along with Victoria Group of Trans Antarctic Mountains (Truswell, 1980). The present palynoflora of Talchir Formation is closely correlatable with the *Parasaccites* zone of Victoria Group of Trans-Antarctica which shows an acme of *Parasaccites* and *Potonieisporites* along with rarity of bisaccates (Kyle, 1977; Barrett and Kyle, 1975). The assemblage is equated with ammonoid fauna and is late Sakmarian in age (Glenister and Furnish, 1961). Buckley Formation of Wisconsin and Ohio Range (Kemp, 1975), Mackellar Formation (Masood *et al*., 1994), Beacon Supergroup at Milorgfjella, Dronning Maud Land (Larsson *et al*., 1990) are similar to present assemblage in having abundance of monosaccates chiefly *Parasaccites* and rarity of bisaccate pollen.

Lindström (1995) described a palynoassemblage from Heimefrontfjella, Dronning Maud Land. The palynoassemblage from Locality A contains various radial monosaccate forms and many other palynomorphs like, *Jayantisporites conatus, Microbaculisporites tentula, Sahnites* sp. and algal spores like, *Leiosphaeridia.* Due to similarity in the palynomorph forms the assemblage is comparable to present palynoassemblage. They equated the *Parasaccites korbaensis* assemblage Zone III of Talchir Formation of Damodar Basin (Tiwari and Tripathi, 1992) to late Asselian-Tastubian in age. The present palynoassemblage has close affinity with *Parasaccites korbaensis* assemblage Zone III (Tiwari and Tripathi, 1992) thus also comparable to the palynoassemblage of Locality A and is late Asselian-Tastubian in age.

Africa

Falcon (1975) had presented a comprehensive scheme of Palynozonation for the Mid-Zambezi Basin, Zimbabwe. The present palynoassemblage is younger to the Assemblage Zone-I (*Virkkipollenites-Plicatipollenites* Assemblage) due to having Permian palynotaxa like, *Virkkipollenites, Plicatipollenites, Potonieisporites, Microbaculispora, Calamospora* and *Lophotriletes* and lacking typical Carboniferous taxa *Granulatisporites, Cycadopites, Punctatisporites, Zinjispora, Apiculatisporis, Acanthotriletes, Retusotriletes* palynotaxa. Thus, the present palynoassemblage represent early Permian flora not Carboniferous. Falcon (1988, 1989) reported a distinctive low diverse monosaccate rich miofloral containing *Virkkipollenites*, *Barakarites*, *Caheniasaccites*, *Plicatipollenites*, and *Potonieisporites* from the No. 2 seam, Witbank coalfield, Vryheild Formation, Karoo Basin. The assemblage is assignable to early Permian age, deposited during the post-glacial regime and is comparable to the present palynoassemblage. Zone-1 in Dwyka Tillite North Maui basin (Anderson, 1977); Zone I A of Zimbabwe (Falcon, 1978), *Plicatipollenites indicus-Cannanoropollis obscurses* Zone of Zambia, Mid Zambesi basin (Utting, 1978), Biozone-B (*Potonieisporites novicus-Cannanoropollis densus*) from Ellisras and Tshipise Basins (MacRae, 1988) also corroborates with the present palynoassemblage in having dominance of monosaccates. The present early Permian palynoflora also correlates with the monosaccate rich palynoassemblage of the Tshabong area (Key *et al*., 1998) from Botswana. Nyambe and Utting (1997) palynologically dated the *Plicatipollenites indicus-Cannanoropollis obscurus,* a monosaccate rich palynoassemblage from Siankondobo Formation, Zambia. This assemblage can be correlated with the present palynoassemblage due to the presence of *Plicatipollenites indicus*, *Cannanoropollis* (*=Parasaccites*) *obscurus, Brevitriletes* sp. and *Microbaculispora* sp. Biozone-I (*Potonieisporites novicus-Cannanoropollis densus* Zone; Aitken, 1998) of Vryheid Formation, Ecca Group can be correlated with the present palynoassemblage. *Cordaitina* Zone of Tanzania, Ketewake (Manum and Tien, 1973) also shows dominance of monosaccates.

Modie (2007) and Modie and Hérissé (2009) compared its biozones S1-1 and S1-2 of the Dwyka and the lowermost Ecca Group and in STRAT 1 with that of the Talchir flora of Damodar-Rajmahal Basin of India (Tiwari and Tripathi, 1992). Stephenson (2009) reported a diverse palynoassemblage from the Aranos Basin which is correlatable with the *Converrucosisporites confluens* Oppel Zone in the Canning Basin and present palynoassemblage due to the presence of *Caheniasaccites ovatus*, *Parasaccites* (=*Cannanoropollis* spp.), *Horriditriletes* sp., *Plicatipollenites* spp., *Alisporites* sp., *Horriditriletes* sp., *Microbaculispora* sp. and the palynoassemblage is early Permian in age. The Assemblage Zone-I of Mmamantswe, Botswana can be also compared with present assemblage due to the dominance of monosaccates over bisaccates (Barbolini and Bamford, 2014). However, the spore percentage of the assemblage exceeds the pollen percentage. But due to the presence of palynotaxa like, *Horriditriletes ramosus, Cannanoropollis densus, Horriditriletes* sp., *Inaperturopollenites* sp., *Laevigatosporites* sp. *Brevitriletes* sp. and very low percentage of bisaccates, a tentative correlation can be done.

South America

The correlation of the Indian and Argentinian biozones is difficult; nevertheless we propose that present palynoassemblage is tentatively comparable to *Cristatisporites* Assemblage Zone of Chacoparanense Basin (Archangelsky and Vergel, 1996) dominated by *Vittatina* and triletes, *Fusacolpites fusus* - *Vittatina subsaccata* Assemblage zone from Paganzo basin (Césari and Gutierrez, 2000), *Potonieisporites-Lundbladispora* Zone of the Chacoparana Basin (Playford and Dino, 2002) and *Pakhapites fusus-Vittatina subsaccata* Biozone (FS Biozone) of Césari *et al*. (2011). These zones are assignable to early Permian in age.

The palynostratigraphy of Paraná Basin was revised in detail by Souza and Marques-Toigo (2003, 2005) and Souza (2006), incorporating the later studies done by Daemon and Quadros (1970). The *Protohaploxypinus goraiensis* Subzone of the *Vittatina costabilis* Interval Zone (VcZ; Souza and Marques-Toigo 2003, 2005; Souza 2006) resembles the present palynoassemblage in having dominance of monosaccates and occurrence of striate bisaccates and is early Permian in age.

Gutiérrez *et al*., (2010) described the palynology of Paraná Basin, Uruguay based on the previous records. On the basis of abundance of triletes and monosaccates, assemblages 221-I and 221-II are assignable to early Permian (Asselian-Sakmarian) age. The dominance of monosaccates deduce a close similarity with present palynoassemblage. Beri *et al*. (2010) synthesized palynological data from the Lower Permian Cerro Pelado Formation from Paraná Basin, Uruguay. The present palynoassemblage can be tentatively correlated from later in having *Callumispora* (=*Punctatisporites*), *Caheniasaccites*, *Potonieisporites*, *Faunipollenites* (=*Protohaploxypinus*) and *Plicatipollenites.*

Beri *et al.* (2011) recorded early Cisuralian palynozone in Uruguay, Paraná Basin *i.e*., *Cristatisporites inconstans-Vittatina saccata* Assemblage Zone. The Lower IS Zone in Uruguay can be correlated with the *Cristatisporites* Zone defined by the advent of *Hamiapollenites fusiformis* and *Protohaploxypinus limpidus* and by the predominance of monosaccate pollen grains as well as apiculate and zonate trilete spores, specifically with diversification of the genus *Cristatisporites.* This zone has been correlated with *Vittatina costabilis* Zone (VC) of Parana Basin and an early Cisuralian age has been assigned. IS Zone identified in the San Gregorio and Tres Islas Formation and in the basal part of Melo Formation in Uruguay is characterized by acme of trilete spores (56-96%) and monosaccate pollen grains (1.3-36.7%). The bisaccate, taeniate and plicate pollen grains are rare. The percentage of monosaccates is low in Uruguay assemblage whereas in Talchir palynoflora of Chintalapudi area, percentage of trilete spores is low. Monte Mor Palynoflora from Parana basin, Brazil (Beri et al., 2010) have dominance of monosaccates but presence of typical Carboniferous taxa *viz*., *Vallatisporites, Cristatisporites* & *Reticulatisporites, Spelaeotriletes* etc. distinguishes it from present palynoassemblage.

Souza *et al*. (2015) studied biostratigraphy and palaeoecology of the sediments from Aquidauana Formation of Paraná Basin. The palynoflora is exceptionally dominated by monosaccate pollen grains *viz*., *Parasaccites* (=*Cannanoropollis*-30.41%), *Potonieisporites* (28.14%) and *Plicatipollenites* (19.52%) and many other forms like *Divarisaccus, Calamospora, Caheniasaccites and Scheuringipollenites* and compares very well with the present palynoassemblage. The Aquidauana palynoflora is assignable to late Pennsylvanian to early Permian age. But, due to the absence of significant Carboniferous taxa in present palynoassemblage it is early Permian in age.

The present palynoassemblage is tentatively correlatable with the lower assemblage (MP-P6029) of Copacabana Formation of Apillapamapa, Cochabamba, Bolivia (Di Pasquo and Grader, 2012) on the basis of dominance of *Cordaites* pollens. However, the palynoflora deviate from the later in having *Marsupipollenites striatus, Pakhapites ovatus,* and *Vittatina costabilis.*

Australia

The abundance of monosaccate grains suggests that the studied assemblage can be compared with the Stage-2 (Lower Permian) of Eastern Australia (Kemp *et al*., 1977) due to the presence of radial monosaccates, but the studied assemblage differ in having monocolpate forms, which were present in the later. The palynoflora can be compared with the Lower Permian of the Perth Basin, Western Australia (Segroves, 1970) due to the presence of *Microbaculispora* and *Parasaccites* sp. Thus, Stage 2 encompasses the Corboniferous-Permian transition in older level while the oldest assemblage zone in Talchir Formation does not have Carboniferous taxa and is late Asselian in Age.

Backhouse (1991, 1993) did Permian palynostratigraphy of the Collie Basin, Western Australia. The present palynoassemblage is comparable to *Pseudoreticulatispora confluens* Zone of the glacigene deposits from top of the Stockton Formation (Collie basin) and Southern Perth Basin in having dominance of radial monosaccates and presence of palynotaxa like *Horriditriletes, Brevitriletes* and *Jayantisporites pseudozonatus*. The existing palynoassemblage is also comparable to *Pseudoreticulatispora confluens* zone from Western Australia (Evans, 1969; Foster, 1979).

Mory and Backhouse (1997) gave the Permian palynostratigraphy of the Carnarvon Basin, Western Australia. They considered Stage 2 as the oldest zone of the Carnarvon basin (late Carboniferous to Asselian), which is overlain by *Pseudoreticulatispora confluens* Zone. Both the zones have a marked presence of stratigraphically significant taxa *Jayantisporites pseudozonatus,* which is also present in the present palynoassemblage. So, it is evident that it lies between these two zones of Australia, indicating an Asselian-Tastubian (early Sakmarian) age as those of glacial deposit of Lyons Group.

Eyles *et al*. (2002, 2003) resolved the Carboniferous-Permian palynostratigraphy of west Australian basins on the basis of FADs of palynomorphs. The Grant group having sandstone with minor conglomerate, diamictite and mudstone lithology as fluviodeltaic-glacial facies of Canning basin, appears to lie entirely within the *Pseudoreticulatispora confluen*s and is possibly mid-Asselian to early Sakmarian in age (equivalent to Stage 2, and the *Pseudoreticulatispora confluens* Zones; Archbold, 1995; Mory, 2010). Its assemblage shows a rapid increase in spore-pollen assemblages from the Asselian to early Sakmarian. This palynoassemblage is comparable to the present palynoassemblage in having dominance of monosaccates.

Salt Range, Pakistan

Jan (2014) did palynology and correlation of the Nilawahan Group of the Salt Range, Pakistan. The Tobra Formation yielded a diverse palynoflora containing *Brevitriletes, Horriditriletes, Microbaculispora, Plicatipollenites, Potonieisporites, Cannanoropollis, Protohaploxypinus, Striaopodocarpites* and *Limitisporites.* This palynological assemblage is assignable to early Permian Asselian age (Stephenson *et al*., 2013) and is younger to the present palynoassemblage on the basis of its correlation with *Parasaccites korbaensis* Zone of Tiwari and Tripathi (1992).

PALYNOFACIES ANALYSIS

The organic matter studies have been utilized to define the depositional conditions of various sediments including coal/lignite by various workers (Singh and Singh., 1991; Singh *et al*., 1992; Tyson, 1995; Batten, 1996; Cazzulo *et al*. 2009). In the present paper, palynological investigation/analysis along with the palynofacies studies have been attempted for interpreting the palaeoenvironmental conditions during the deposition of the sediments following the classification of Tyson (1995) and Batten (1996). The recovered palynological matter has been divided under following five categories on the basis of which two palynofacies assemblage (Fig. 3) has been made:

1. Palynomorphs - Spores and pollen grains
2. Structured Organic Matter
    a. Structure Terrestrial – Leaf, stem and root remains (non-woody and woody)
    b. Degraded – Degraded structured terrestrial
    c. Charcoal – Oxidized phytoclast

3. Unstructured Organic Matter - Amorphous Organic Matter.

The different organic matter types and their relative frequencies at their respective sampling depths are illustrated in the Plate III and Fig. 3.

Palynofacies assemblage

Palynofacies-I: This palynofacies is dominated by degraded organic matter and is represented at 49.66m and 56.10m depth *i.e.,* sample no. 2 and 3. The main component of the facies is degraded organic matter which corresponds to 37 % of the total dispersed organic matter (Plate-III, Fig. 3). The other elements of this palynofacies consists of structured organic matter (19%), palynomorphs (17.5%), opaque phytoclast (13%) and amorphous organic matter (12.5%).

Palaeoenvironmental interpretation: The decomposition of organic matter in terrestrial environments is regulated by a complex interplay between physical and biological mechanisms. The main factors controlling the degradation of organic matter are its chemical composition, temperature, physical accessibility, microbial community structure, and nutrient availability (Kujawinski, 2011; Dungait *et al*., 2012). The sedimentation rate and energy level of a water body are also responsible for the rate of organic matter degradation (Mendonça Filho *et al.,* 2011). In subaerial environments, organic matter is easily destroyed by chemical or microbial oxidation. Thus, the preservation of high number of degraded organic matter resulted due to low energy environments *viz*., stagnant water/ water logged conditions in a dysoxic to anoxic sedimentary facies (Mendonça Filho *et al*., 2011). The dominance of degraded organic matter and fair occurrence of fragmented and degraded palynomorphs infers a low preservation rate at the depositional site under low energy and dysoxic environments (Tyson, 1993). The high microbial activity in this facies can be evidenced by the occurrence of fungal elements (Plate I, 13; Plate III, 3) which resulted into the decrease of palynomorphs (Fig. 3). The dominance of translucent organic matter (degraded and structured organic matter) can be related with the deposition in the proximal environments (Carvalho *et al*., 2013). The presence of charred gymnospermous wood in the facies bearing secondary xylem with uni- to multiseriate pitting infers the presence of woody gymnosperms (*Cordaites*?) in the hinterland which have been transported to the depositional site from surrounding well drained environments (Pfefferkorn, 1980; Plate-III, Fig. F). The presence of charcoal also suggests oxic to sub-oxic environments (Tyson, 1995). The fair representation of terrestrial amorphous organic matter (12.5%) at this depth is also indicative of high microbial activity, as it is the derived product of microbial degradation of woods, cuticles, etc (Pacton *et al*., 2011). Thus, this palynofacies has been deposited under swamp dominated, low energy and dysoxic to anoxic environments.

Palynofacies-II: This palynofacies is represented in three samples (1, 4, 5) and palynodebris is dominated by palynomorphs (41 %). The other sub-dominant components of dispersed organic matter include opaque phytoclast (20 %), degraded organic matter (17.5 %) and structure organic matter (14.5 %). AOM is the least abundant component of the palynodebris (7%).

Palaeoenvironmental interpretation: This palynofacies is characterized by the dominance of palynomorphs and sub-dominance of translucent organic matter (degraded and structured organic matter) suggesting low energy environments under dysoxic to anoxic conditions like, marsh and swamps (Batten and Stead, 2002). The palynomorphs of the facies mainly belong to gymnosperms, preceded by spores of pteridophytic and bryophytic affinity. Pollen are produced in more enormous number than the spores and they have wider distribution due to wind and water transportation (Traverse, 1988). Amongst gymnosperms the *Cordaites* (*Plicatipollenites, Parasaccites*), and glossopterids (*Faunipollenites, Striatopodocarpites*) are dominant groups which grow in varied environmental conditions ranging from mesophyllous to xerophyllous palaeoenvironments, flourishing in lowland areas forming coal *i.e*., swamp (Knoll and Nicklas, 1987). The dominance of monosaccate pollens of *Cordaites* is suggestive of drier and colder areas from the seasonal continental interior, post-glaical floras (DiMichele *et al*., 2001; Falcon-Lang, 2003; Goldberg, 2004; Stephenson *et al*., 2007). The conifers (*Potonieisporites, Caheniasaccites, Scheuringipollenites, Sahnites*) are the minor component of the palynoflora and probably restricted to xerophytic upland areas, more distant from mires (Cazzulo-Klepzig *et al*., 2007). *Leiotriletes, Calamospora, Verrucosisporites, Horriditriletes* are related to herbaceous plants *i.e*., filicopsids. These group of spores flourish in hygrophilous to mesophylous environments and infer fresh water input at the depositional site (Parry *et al*., 1981). *Jayantisporites* and *Indospora* spores have lycopsid origin and can tolerate colder and drier environments of the glacial early Permian Period (Rothwell, 1988; DiMichele and Phillips, 1985, 1994). *Calamospora* represent ancient plant communities which colonise swamp margins (Pyror, 1996). Abundance of acritarch *viz*., *Leiosphaeridia* sp., witness extreme climatic conditions (cold climates) during early Permian sedimentation in India (Talchir Formation; Basavaraju and Pundeer, 2003; Goswami, 2008).

The abundance of organic matter types in the facies *viz*. spore pollen, translucent organic matter represents the presence of thick forest cover in the hinterland. Abundance of structured terrestrial matter indicates high sedimentation rate under anoxic environments. Hence, the presence of thick forest cover in the hinterland and low energy, peat forming anoxic palaeoenvironmental conditions has been inferred for this depositional facies.

DISCUSSION

The palynological and palynofacies studies have been carried out in the bore core MCP-9 of Chintalapudi area, located on the western margin of Chintalapudi Sub-basin of Godavari Graben. The complete 100m deep sedimentary sequence represents only one palynoassemblage dominated by radial monosaccates *viz*., *Parasaccites, Plicatipollenites, Potonieisporites.* Palynoassemblage is correlatable with the other palynoassemblages of Talchir Formation of Godavari Graben *viz.,* Palynozone of Budharam, Mailaram and Gundala area (Srivastava and Jha, 1995; Jha and Aggarwal, 2012; Aggarwal and Jha, 2013). The palynoassemblage is comparable to the youngest palynozone-III of Talchir Formation i.e., *Parasaccites korbaensis* Assemblage zone of Talchir Formation (Tiwari and Tripathi, 1992). Palynoassemblage is also correlatable with the well palynologically dated radial monosaccate dominated assemblages from peninsular and extra-peninsular parts of India (Singh *et al*., 2005; Upadhyay *et al*., 1999; Sinha *et al*., 2004). On the basis of this the present palynoassemblage belongs to Talchir Formation in India and is early Permian (Asselian-Sakmarian), not Permo-Carboniferous in age as no characteristic Carboniferous palynotaxa *viz*., *Vallatisporites arcuatus, V. ciliaris, V. spinosus, Cristatisporites indignabundus, C. crassilabratus, C. inordinatus, C. menendezii, Spelaeotriletes ybertii*, *Raistrickia, Crassispora, Microreticulatisporites, Cirratriradites, Crassispora, Vestispora* has been encountered either in the present palynoassemblage or other palynoassemblages in Talchir sediments of India.

Present palynoassemblage is comparable to the *Pseudoreticulatus confluens* zone of Stockton Formation of Collie Basin in having coexistence of *Jayantisporites pseudozonatus* (Evans, 1969; Foster, 1979; Backhouse, 1991, 1993). The palynoassemblage lies between the younger part of the Stage 2 and *Pseudoreticulatus confluens* zone of Carnovoron Basin and is equitable to the glacial deposits of the Lyons Group in having *Jayantisporites pseudozonatus,* indicating an Asselaian-Tastubian (early Sakmarian) age. Along with this similar palynoflora (having dominance of monosaccates) has been recorded from the Grant Group of the Canning Basin, which lies within the Stage 2 and *Pseudoreticulatus confluens* zone and is mid Asselian to early Sakmarian in age (Eyles *et al.,* 2002, 2003).

Talchir flora of India is more correlatable with that of African palynoflora as compared to Australia. The No. 2 seam of Witbank Coalfield, Vryheid Formation of Main Karoo Basin (MacRae, 1988, Falcon, 1988, 1989) and Assemblage Zone-I of Mmamantswe, Botswana (Barbolini and Bamford, 2014) are correlatable with the present palynoassemblage. Apart from Karoo Basin, the *Plicatipollenites indicus-Cannanoropollis obscurses* Zone of Mid Zambesi Basin and Siankondobo Formation, Zambia (Utting, 1978; Nyambe and Utting, 1997) is also similar to the recovered palynoaasemblage. Palynoassemblage is also correlatable with the *Parasaccites* Zone (Kyle, 1977 of Central Transantarctic Mountains, palynoassemblage from Locality A from Dronning Maud Land (Lindström, 1995), Mackellar Formation (Masood *et al*., 1994), Beacon Supergroup at Milorgfjella, Dronning Maud Land (Larsson *et al*., 1990) of Antarctica. Similar palynoflora has been recovered from the Aquidana Formation sediments of Paraná Basin, South Africa (Souza *et al*., 2015) and from the Tobra Formation, Nilawahan Group of the Salt Range (Jan, 2014). On the basis of global correlation an early Permian (Asselian-Sakmarian) age has been assigned to the investigated palynoassemblage.

Megafloristically, Talchir Formation reveals more or less similar type of flora in all the Gondwana basins of India. It has been noted that typical Carboniferous taxa like *Rhacopteris, Lepidodendron, Botrychiopsis* and *Triphyllopteris* have never been recorded in India from Talchir sediments. Hence, Talchir Formation in India is early Permian, not Permo-Carboniferous in age.

The palynofacies data presented here shows gross similarity in the palynological and organic matter distribution composition. However, slight differences do occur in the organic matter constitution and on the basis of which two palynofacies have been made. Palynofacies-I differs from the Palynofacies-II in the dominance of degraded organic matter over palynomorphs. Palynofacies-I represents low swamp dominated low energy, dysoxic to anoxic environmental condition. Whereas, palynomorph dominated Palynofacies-II represents swampy low energy, anoxic and persistent water-logged environment conditions resulting into the formation of rich and well-preserved palynoassemblage.

The rich and diverse palynological results suggest that these deposits were formed during interglacial or post glacial phase which is also in agreement with the proposal that Gondwana glaciation were characterised by discrete glacial phases alternating with warmer climatic episodes, providing favourable conditions for vegetational growth. Based on the dominance of cold tolerant plant *i.e*, cordaitalean pollen grains, it seems quite possible that seasonally dry and cold tolerant vegetation dominated the basinal lowlands for longer period than the hygrophytic vegetation during early Permian (Asselian-Sakmarian) times. This monosaccate dominant (*Cordaites* dominated) palynoflora, representing post-glacial flora is also seen in other parts of Gondwana (Backhouse, 1991; Iannuzzi *et al*., 2007, 2010; Stephenson *et al*., 2005). The palynological content found in these strata represents a diverse palaeoflora of *Cordaites*, glossopterids, conifers, filicopsids, equisetopsids, lycopsids, algal and few acritarch that persisted in wider land area under ameliorating colder environments. Hence, it is suggested that glaciers did not occur as the continental sheets on Indian peninsula. Instead, they were in the form of ice lobes originating from the ice-caps existing on the highlands (Vijaya, 1996).

CONCLUSION

- The Talchir palynoflora of early Permian (Asselian-Sakmarian) age have been identified in bore core MCP-9 from Chintalapudi area which is comparable with the known early Permian palynoflora of Godavari Graben and other Gondwana basins of S. America, S. Africa, Antarctica and Australia. Hence, the age of glacial deposits in India *i.e.,* Talchir Formation is early Permian.
- The dominance of glossopterids and *Cordaites* plant derived palynomorphs and absence of marine palynofacies (acritarchs or marine algal spores etc.) represent a “forest swamp” that prevailed in reducing environment and fresh water conditions.
- The result from palynofacies and palynological analysis suggests that these sediments were deposited during ameliorating interglacial or postglacial warmer climate phase.
- The palynological studies reveals that the vegetation was not as impoverished during early Talchir as it has been interpreted earlier (Chandra and Chandra, 1987). The dominance of *Cordaites* pollens infers colder, glaciated climates during Talchir (Vijaya, 1996; Falcon-Lang and Scott, 2002; Falcon-Lang, 2000). However, the climate started ameliorating and continental sheets melted and became restricted to isolated patches to provide space for the growth of the dense vegetation.

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REFERENCES

Aggarwal, N. and Jha, N. 2013. Permian palynostratigraphy and palaeoclimate of Lingala-Koyagudem Coalbelt, Godavari Graben, Andhra Pradesh, India. *Journal of Asian Earth Sciences,* **64**: 38-57.

Aitken, G. A. 1998. A palynological and palaeoenvironmental analysis of Permian and early Triassic sediments of the Ecca and the Beaufort groups, Northern Karoo Basin, South Africa. *Unpublished Ph.D. Thesis, University of the Witwatersrand Johannesburg.*

Anderson, J. M. 1977. The Biostratigraphy of the Permian and Triassic-Part-3. A Review of Gondwana Permian Palynology with Particular Reference to the Northern Karoo Basin, South Africa. *Memoir of Botanical Survey of South Africa,* **41**:1-67.

Archangelsky. S. and Vergel, M. M. 1996. Capítulo 2. Cuenca Chacoparanense. Paleontología, Bioestratigrafía Y Paleoecología. Uruguay. p. 40-44. In: *El Sistema Pérmico en la Republica Argentina y en la República Oriental del*. (Ed. Archangelsky S.), Academia Nacional de Ciencias, Córdoba, Argentina.

Archbold, N. W. 1995. Studies on Western Australian Permian brachiopods 12. Additions to the late Asselian-Tastubian faunas. *Proceedings of Royal Society of Victoria,* **107**: 95-112.

Archbold, N. W. and Dickins, J. M. 1996. Permian (chart 6), p. 127-135. In: *An Australian Phanerozoic Timescale.* (Eds. Young, G.C. and Laurie, J.R.), Melbourne: Oxford University Press, Australia.

Backhouse, J. 1991. Permian palynostratigraphy of the Collie Basin, Western Australia. *Review of Palaeobotany and Palynology*, **67**: 237-314.

Backhouse, J. 1993. Palynology and correlation of Permian sediments in the Perth, Collie, and Officer basins, Western Australia. *Geological Survey of Western Australia Report,* **34**: 111-128.

Balme, B. E. 1970. Palynology of Permian and Triassic Strata in the Salt Range and Surghar Range, Western Pakistan, p. 305-455. In: *Stratigraphic boundary problems: Permian and Triassic of West Pakistan.* (Eds. Kummel, B. and Teichert, C.), Geology department, University of Kansas.

Balme, B. E. 1995. Fossil *in situ* Spores and Pollen Grains: An Annotated Catalogue. *Review of Palaeobotany and Palynology,* **87**: 81-323.

Banerjee, M. and Hait. A. K. 2005. Palynostratigraphic zonations with emphasis on eco-climatic analysis to resolve major-minor environmental changes in the Early Permian sediments of Saharjuri Basin, Jharkhand. *Journal of Geological Society of India,* **65**: 411-427.

Bangert, B., Armstrong, R., Stollhofen, H. and Lorenz, V. 1999. The geochronology and significance of ash-fall tuffs in the glaciogene Carboniferous-Permian Group of Namibia and South Africa. *Journal of African Earth Sciences,* **29:** 33-49.

Barbolini, N. and Bamford, M. K. 2014. Palynology of an Early Permian coal seam from the Karoo Supergroup of Botswana. *Journal of African Earth Sciences,* **100**: 136-144.

Barrett, P. J. and Kyle R. A. 1975. The Early Permian Glacial Beds of South Victoria Land and Darwin Mountains, Antarctica, p. 333-346. In: *Gondwana Geology.* (Ed. Campbell K.S.W.), Australian National University, Canberra, Australia.

Basavaraju, M. H. and Govindan, A. 1997. First record of Permian palynofossils in subsurface sediments of Cauvery Basin, India. *Journal of the Geological Society of India*, **50**: 571-576.

Basavaraju, M. H. and Pundeer, B. S. 2003. Occurence of early Permian palynofossils in the subsurface sediments of Dhansiri valley, Assam Arakan basin, India. *Journal of the Geological Society of India*, **62**: 627-633.

Basavaraju, M. H. and Pundeer, B. S. 2007. Palynostratigraphy and Source Rock Potential of Subsurface Gondwana Sediments in Dhansiri Valley, Upper Assam. *Journal of Geological Society of India,* **70**(1): 158-168.

Batten, D. J. 1996. Palynofacies and palaeoenvironmental interpretation, p. 1011-1064. In: Palynology: principles and applictaions. (Eds. Jansonius J. and McGregor D.C.), *American Association of Stratigraphic Palunologists,* **3**.

Batten, D. J. and Stead, D. T. 2005. Palynofacies analysis and its stratigraphic application. In: *Applied Stratigraphy.* (Ed. Koutsoukos, E.A.M.),. Springer, Dordrecht, Netherland, pp. 203-226.

Beri, Á., Martínez-Blanco, X. and Mourelle, D. 2010. A synthesis of palynological data from the Lower Permian Cerro Pelado Formation (Paraná Basin, Uruguay): A record of warmer climate stages during Gondwana glaciations. *Geologica Acta*, **8**(4): 419-429.

Beri, A., Gutiérrez, P. and Balarino, L. 2011. Palynostratigraphy of the Late Palaeozoic of Uruguay, Paraná Basin. *Review of Palaeobotany and Palynology,* **167**: 16-29.

Bharadwaj, D. C. 1975. Palynology in Biostratigraphy and Palaeoecology of Indian Lower Gondwana Formations. *Palaeobotanist,* **22**:150-157.

Bilwa, L. M., Nagamadhu, C. J. and Prameela, M. 2012. Palynodating of Talchir palynoflora from Lower Gondwana sediments of Godavari Valley Coalfield, South India. *International Journal of Geology and Earth Environmental Sciences*, **2**(2): 294-299.

Blanford, W. T. 1872. On the description of geology of Nagpur and its neighbourhood. *Memoir of Geological Survey of India,* **9:** 295-358.

Carvalho, M. de A., Ramos, R. R. C., Crud, M. B., Witovisk, L., Kellner, A. W. A., Silva , Helder de P., Grillo, O. N., Riff , D. and Romano P. S. R. 2013. Palynofacies as indicators of paleoenvironmental changes in a Cretaceous succession from the Larsen Basin, James Ross Island, Antarctica. *Sedimentary Geology,* **295**: 53–66.

Cazzulo-Klepzig, M., Guerra-Sommer, M., Menegat, R., Simas, M. W. and Mendonça Filho, J. G. 2007. Peat-forming environment of Permian coal seams from the Faxinal coalfield (Paraná Basin) in Southern Brazil, based on palynology and palaeobotany. *Revista Brasileira de Paleontologia,* **10**(2): 117-127.

Cazzulo–Klepzig, M., Mendonca Filho, J. G., Guerra-Sommer, M., Menezes, T. R., Simas, M. W., Mendonca, J. O. and Degani–Schmidt, I. 2009. Effect of volcanic ash fall on a Permian peat forming environment, on the basis of Palynology, palynofacies and paleobotany (Faxinal Coalfield; Brazil). *Revista Brasileira de Paleontologia,* **12**: 179-194.

Césari, S. N. 2007. Palynological biozones and radiometric data at the Carboniferous-Permian boundary in western Gondwana. *Gondwana Research*, **11**: 529-536.

Césari, S. N. and Gutiérrez, P. R. 2000. Palynostratigraphy of Upper Paleozoic Sequences in Central–Western Argentina. *Palynology,* **24**:113-46.

Césari, S. N., Limarino, C. O. and Gulbranson, E. L. 2011. An Upper Paleozoic biochronostratigraphic scheme for the western margin of Gondwana. *Earth-Science Reviews,* **106**(1-2):149-160.

Chakraborty, S. 2003. Miofloral assemblage of the subsurface Lower Gondwana rocks of Permian in parts of Mahanadi Basin, India. *Acta Palaeontologica Sinica,* **42**(1): 13-21.

Chandra, S. and Chandra, A. 1987. Vegetational changes and thier climatic implications in coalbearing Gondwana. *Palaeobotanist*, **36**: 74-86.

Crowell, J. C. 1995. The ending of the Late Paleozoic ice age during the Permian, p. 62-74. In: *The Permian of Northern Pangea, Palaeogeography, Palaeoclimates, Stratigraphy,* (Eds. Scholle, P.A., Peryt, T.M. and Ulmer-Scholle, D.S.), Springer Verlag, 1.

Daemon, R. F. and Quadros, L. P. 1970. Bioestratigrafia do Neopaleozóico da Bacia do Paraná, p.359-412. In: Congresso Brasileiro de Geologia, XXIV, Brasília, 1970. *Anais* Sociedade Brasileira de Geologia, Brasília.

Di Pasquo, M. and Grader, G. W. 2012. The palynology of the Lower Permian (Asselian–? Artinskian) Copacabana Formation of Apillapampa, Cochabamba, Bolivia. *Palynology*, **36**(2):1-13.

DiMichele, W. A. and Phillips, T. L. 1985. Arborescent lycopod reproduction and palaeoecology in a coal-swamp environment of late Middle Pennysylvanian age (Herrin Coal, Illinios, USA). *Review of Palaeobotany and Palynology,* **44**: 1-26.

DiMichele, W. A. and Phillips, T. L. 1994. Palaeobotanical and palaeoecological coonstraints on models of peat formation in the Late Carboniferous. *Palaeogeography, Palaeoclimatology, Palaeoecology,* **106**: 39-90.

DiMichele, W. A., Stein, W. E. and Bateman, R. M. 2001. Ecological sorting of vascular plant classes during the Palaeozoic evolutionary radiation, p. 285-335. In: *The ecological context of macroevolution change,* (Eds. Allman, W.D. and Battjer, D.J.), Columbia University Press, New York.

Dungait, J. A. J., Hopkins, D. W., Gregory, A. S. and Whitmore, A. P. 2012. Soil organic matter turnover is governed by accessibility not recalcitrance. *Global Change Biology*, **18**: 1781–1796.

Evans, P. R. 1969. Upper Carboniferous and Permian palynological stage and their distribution in eastern Australia, pp. 41-54. In: Gondwana Stratigraphy (Ed. Amos, A.J.) , UNESCO, Paris.

Eyles, N., Mory, A. J. and Backhouse, J. 2002. Carboniferous-Permian palynostratigraphy of west Australian rift basins: resolving tectonic and eustatic controls during Gondwanan glaciations. *Palaeogeography, Palaeoclimatology, Palaeoecology,* **184**: 305-319.

Eyles, C. H., Mory, A. J. and Eyles, N. 2003. Carboniferous-Permian facies and tectono-stratigraphic successions of the glacially influenced and rifted Carnarvon Basin, Western Australia. *Sedimentary Geology,* **155**(1), 63-86.

Faegri, K. and Iversen, J. 1975. Textbook of Pollen Analysis. Munksgaard, Copenhagen, Denmark, p. 295.

Falcon, R. M. S. 1975. Application of Palynology in Sub-dividing the Coal-bearing Formations of the Karoo Sequence in Southern Africa. *South Journal of Science,* **71**:336-344.

Falcon, R. M. S. 1978. New Permian Miospores from Rhodesia. *Arnoldia Rhodesia,* **8**(24):1-32.

Falcon, R. M. S. 1988. Collaborative investigation of the Witbank No. 2 Seam – Petrographic and Palynological aspects. National Geoscience Programme. Final Report for sub-programme COAL. *CSIR Internal Report*, pp. 40.

Falcon, R. M. S. 1989. Macro- and micro-factors affecting coal-seam quality and distribution in southern Africa with particular reference to the No. 2 seam, 357 Witbank coalfield, South Africa. *International Journal of Coal Geology,* **12**: 681-731.

Falcon-Lang, H. J. 2003. Late Carboniferous Tropical Dryland Vegetation in an Alluvial-plain Setting, Joggins, Nova Scotia, Canada. *Palaios,* **18**: 197–211.

Falcon-Lang H. J. and Scott, A. C. 2000. Upland ecology of some Late Carboniferous cordaitalean trees from Nova Scotia and England. *Palaeogeography Palaeoclimatology Palaeoecology,* **156:** 225–242.

Foster, C. B., 1979. Permian plant microfossils or the Blair Alhol Coal Measures. Baralaba Coal Measures and Basal Rewan Formation of Queensland**.** Geological Survey of Queensland Publications 372, *Palaeontological Paper*, 45, 1-244.

Foster, C. B. and Waterhouse, J. 1988. The *Granulatisporites confluens* Oppel Zone and Early Permian marine faunas from the Grant Formation on the Barbwire Terrace, Canning Basin, Australia. *Australian Journal of Earth Science*, **35**: 135-157.

Gastaldo, R. A., Adendorff, R., Bamford, M., Lavandería, C. C., Neveling, J. and Sims, H. 2005. Taohonomic trends of macroflora assemblages across the Permian–Triassic Boundary, Karoo Basin, South Africa. *Palaios,* **20**: 479–497.

Glenister, B. F. and Furnish, W. M. 1961. The Permian ammonoids of Australia. *Journal of Palaeontology*, **35**(4): 673-736.

Goldberg, K. 2004. Floral diversity in the assessment of paleoclimate in the Paraná Basin, southern Brazil. *Journal of Geology*, **112**: 719–727.

Goswami, S. 2008. Marine influence and incursion in the Gondwana basins of Orissa, India: A review. *Palaeoworld*, **17**(1): 21-32.

Goswami, S. and Singh, K. J. 2013. Floral biodiversity and geology of the Talcher Basin, Orissa, India during the Permian-Triassic Interval. *Geological Journal*, **48**: 39-56.

Grauvogel-Stamm L. 1978. La flore du Grès-a-Voltzia (Buntsandstein Supérieur) des Vosges du Nord (France). Morphologie, anatomie, interprétations phylogénique et paléogéographique. Sciences et Géologie. *Sciences Géologiques: Mémoire,* **50**: 1-225.

Grauvogel-Stamm L. 1999. Pleuromeia sternbergii (Mu¨nster) Corda, ein characteristische Pflanze des deutschen Buntsandsteins, p. 271–281. In: *Trias—Eine ganz andere Welt. Europa im fru¨hen Erdmittelalter,* (Ed. Hauschke, N. and Verlag, V. W.), Friedrich Pfeil, Munchen.

Gutiérrez, P., Balarino, M. L. and Beri, A. 2010. Palynology of tha Lower Permian of Paraná Basin, Uruguay. *Journal of Systematic Palaeontology*, **8**: 459–502.

Hochuli, P. A., Hermann, E., Vigran, J. O., Bucher, H. and Weissert, H. 2010. Rapid demise and recovery of plant ecosystem across the end-Permian extinction event. *Global and Planetary Change,* **74**: 144-155.

Iannuzzi, R., Souza, P. A. and Holz, M. 2007. Lower Permian post-glacial succession in the southernmost Brazilian Paraná Basin: stratigraphy and floral (macro and micro) record. In: *4th European Meeting on the Palaeontology and Stratigraphy of Latin America*. (Eds. Díaz-Martinez, E. and Rábano, I.), Cuadernos del Museo Geominero, **8**, pp. 207–212.

Iannuzzi, R., Souza, P. A., and Holz, M. 2010. Stratigraphic and paleofloristic record of the Lower Permian postglacial succession in the southern Brazilian Paraná Basin. *GSA Special Paper*, **468**: 113–132.

Isbell, J. L., Miller, M. F., Wolfe, K.L. and Lenaker, P. A. 2003. Timing of late Palaeozoic glaciation in Gondwana: Was glaciation responsible for development of Northern Hemisphere Cyclotherms? p. 5-24 In: *Extreme Depositional environments: Mega End Members in Geologic Time,* (Eds. Chan, M.A. and Archer, A.W.), *Geological Society of America, Special Paper*, **370**.

Jan, I. U. 2014. Progress in the Gondwanan Carboniferous–Permian palynology and correlation of the Nilawahan Group of the Salt Range, Pakistan: A brief review. *Journal of Earth System Science*, **123**(1), 21–32.

Jha, N. 2006. Permian palynology from India and Africa: A phytogeographical paradigm. *Journal of Palaeontological Society of India*, **51**(1), 43-55.

Jha, N. and Aggarwal, N. 2012. Permian- Triassic Palynostratigraphy in Mailaram Area, Godavari Graben, Andhra Pradesh, India. *Journal of Earth System Science,* **121**:1257-1285.

Jha, N. and Srivastava, S. C. 1996. Kamthi Formation palynofloral diversity, p.355-368. In: *Ninth International Gondwana Symposium, Hyderabad,* (Ed. Guha, P.K.S., Sengupta, S. Ayyasami K. and Ghosh R. N.), Geological Survey of India.

Jha, N., Pauline Sabina K., Aggarwal, N. and Mahesh, S. 2014. Late Permian Palynology and depositional environment of Chintalapudi sub basin, Pranhita–Godavari basin, Andhra Pradesh, India. *Journal of Asian Earth Sciences,* **79**: 382–399.

Jin, Y. G., Wardlaw, B. R., Glenister, B. F. and Kotlyar, G. V. 1997, Permian chronostratigraphic subdivisions. *Episodes*, **20**: 10–15.

Kar, R. 2012. A basal Gondwana palynoflora from the glacigene sediments of Tatapani-Ramkola Coalfield, India. *Palaeobotanist,* **61**: 131-138.

Kemp, E. M. 1975. The palynology of Late Palaeozoic glacial deposits of Gondwanaland, p.397-422. In: *Gondwana Geology,* Australian National University Press, Camberra.

Kemp, E. M., Blame, B. E., Helby, R. A., Playford, G., and Price, P. L. 1977. Carboniferous and Permian Palynostratigraphy in Australia and Antarctica: A Review . *BMR Journal of. Australian Geology and Geophysics,* **2**:177-208.

Key, R. M., Tidi, J., McGeorge, I., Aitken, G., Cadman, A. and Anscombe, J. 1998. The Lower Karoo Supergroup geology of the southeastern part of the Gemsbok Sub-basin of the Kalahari Basin, Botswana. *South African Journal of Geology,* **101**(3): 225-236.

Knoll, J. and Nicklas, E. 1987. Adaptation, plant evolution, and the fossil record. *Review of Palaeobotany and Palynology,* **72**: 886- 887.

Krassilov, V. and Karasev, E. 2009. Paleofloristic evidence of climate change near and beyond the Permian-Triassic boundary. *Palaeogeography, Palaeoclimatology, Palaeoecology,* **284**: 326–336.

Kumar, P. and Jha, N. 2000. Subsurface palynological succession from Katol area, Nagpur, Maharashtra. *Geophytology*, **29**: 65-68.

Kustatscher, E., Wachtler, M. and Konijnenburg-van Cittert 2010. Lycophytes from the Middle Triassic (Anisian) Locality Kühwiesenkopf (Monte Prà Della Vacca) in the Dolomites. *Palaeontology,* **53**(3): 595-626

Kyle, R. A. 1977. Palynostratigraphy of the Victoria Group, South Victoria Land, Antarctica. *Newzealand Journal of Geolagy and Geophysics.,* **20**:1081-1102.

Kyle, R. A. and Schopf, J. M. 1982. Permian and Triassic Palynostratigraphy of the Victoria Group, Trans Antarctic Mountains, p.649-659. In: *Antarctic Geoscience*, (Ed. Craddock), University Winconsin Press, Madison.

Lakshminarayana, G. 1996. Stratigraphy and Structural Framework of the Gondwana Sediments in the Pranhita-Godavari Valley, Andhra Pradesh, p.311-330. In: *Ninth International Gondwana symposium,* (Ed. Guha, P.K.S., Sengupta, S., Ayyasami K. and Ghosh, R.N.), Hyderabad, Geological Survey of India. Oxford and IBH Publishing Co., New Delhi- Calcutta.

Lakshminarayana, G. and Murthy, K. S. 1990. Stratigraphy of the Gondwana Formations in the Chintalapudi Sub-Basin, Godavari Valley, Andhra Pradesh. *Journal of Geological Society of India,* **36**:13-35.

Larsson, K., Lindström, S. and Guy-Ohlson, D. 1990. An Early Permian palynoflora from Milorgfjella, Dronning Maud Land, Antarctica. *Antarctic Science,* **2**(4):331-344.

Lele, K. M. 1975. Studies in Talchir Flora of India-10. Early and Late Talchir Microflora from the West Bokaro Coalfield, Bihar. *Palaeobotanist,* **22**:219-235.

Lele, K. M. and Chandra, A. 1972. Palynology of Marine Intercalations in Lower Gondwana of Madhya Pradesh. *Palaeobotanist,* **19**:253-262.

Lele, K. M. and Makada, R. 1972. Studies in the Talchir Flora of India-7. Palynology of the Talchir Formation in the Jayanti Coalfield, Bihar. *Geophytology,* **2**(1):41-73.

Lindström, S. 1995. Early Permian palynostratigraphy of the northern Heimefrontfjella mountain range, Dronning Maud land, Antarctica. *Review of Palaeobotany and Palynology*, 89: 359–415.

Lindström, S. and McLoughlin S. 2007. Synchronous palynofloristic extinction and recovery after the end-Permian event in the Prince Charles Mountains, Antarctica: implications for palynofloristic turnover across Gondwana. *Review of Palaeobotany and Palynology*, **145**: 89–122

Lindström, S., McLoughlin, S. and Drinnan, A. N. 1997. Intraspecific Variation of Taeniate Bisaccate Pollen within Permian Glossopterid Sporangia, from the Prince Charles Mountains, Antarctica. *International Journal of Plant Sciences,* **158**(5): 673-684.

Looy, C. V., Brugman, W. A., Dilcher, D. L. and Visscher, H. 1999. The delayed resurgence of equatorial forests after the Permian–Triassic ecologic crisis. *Proceedings of the National Academy of Sciences,* **96**:13857–13862.

MacRae, C. S. 1988. Palynostratigraphic correlation between the Lower Karoo sequence of the Waterberg and Pafuri coal-bearing basins and the Hammanskraal plant macrofossil locality, Republic of South Africa. *Memoirs of the Geological Survey of South Africa,* **75**:1–217.

Mahesh, S., Pauline Sabina, K. and Bilwa, M. L., 2011. Palynodating and correlation of subsurface sediments from bore-hole CMWY-95 of Wardha Valley Coalfield, Maharashtra, Central India. *Palaeobotanist,* **60**(2): 299-307.

Manum, S. B. and Tien, N. D. 1973. Palynostratigraphy of the Letewaka Coalfield (Lower Permian). *Review of Palaeobotany and Palynology,* **16**:213-227.

Masood, K. R. Taylor, T. N. Horner, T. and Taylor, E. L. 1994. Palynology of the Mackellar Formation (Beacon Supergroup) of East Antarctica. *Review of Palaeobotany and Palynology,* **83**:329-337.

Mendonça Filho, J. G., Menezes, T. R. and Mendonça, J. O. 2011. Organic Composition (Palynofacies Analysis), pp. 33-81. Chapter 5. In: *ICCP Training Course on Dispersed Organic Matter*, Porto.

Modie, B. N. 2007. The Palaeozoic palynostratigraphy of the Karoo Supergroup and Palynofacies insight into palaeoenvironmental interpretations, Kalahari Karoo Basin, Botswana. *Ph.D. thesis, Université de Bretagne Occidentale, Brest*.

Modie, B. N. and Le Hérissé, A. 2009. Late Palaeozoic palynomorph assemblages from the Karoo Supergroup and their potential for biostratigraphic correlation, Kalahari Karoo Basin, Botswana. *Bulletin of Geosciences*, **84**(2): 337–358.

Mory, A. J. 2010. A review of mid-Carboniferous to Triassic stratigraphy, Canning Basin, Western Australia. *Geological Survey of Western Australian Report,* **107**: 1–130.

Mory, A. J. and Backhouse, J. 1997. Permian stratigraphy and palynology of the Carnarvon Basin, Western Australia. *Geological Survey of Western Australian Report,* **46**:1–101.

Murthy, S., Vijaya and Vethanayagam, S. M. 2013. Palynostratigraphy of Permian succession in the Pench Valley Coalfield, Satpura basin, Madhya Pradesh, India. *Journal of Palaeontological Society of India*, **58**(2), 241-250.

Nyambe, I. A. and Utting, J. 1997. Stratigraphy and palynostratigraphy, Karoo Supergroup (Permian and Triassic), mid-Zambezi Valley, southern Zambia. *Journal of African Earth Sciences,* **24**(4): 563 -583.

Pacton, M., Gorin, G. E. and Vasconcelos, C. 2011. Amorphous organic matter-experimental data on formation and the role of microbes. *Review of Palaeobotany and Palynology*, **166**: 253–267.

Parry, C. C., Whitley, P. K. J. and Simpson, R. D. H. 1981. Integration of palynological and sedimentological methods in facies analysis of the Brent Formation. In: *Petroleum geology of the continental shelf of North-West Europe.* (Eds. Illing, L.N. and Hobson, G.D.), Institute of Petroleum, London, pp. 205-215.

Pfefferkorn, H. W. 1980. A note on the term "upland flora". *Review of Palaeobotany and Palynology,* **30**: 157-158.

Playford, G. and Dino, R. 2000. Palynostratigraphy of upper Palaeozoic strata (Trapajós Group), Amazonas Basin, Brazil: Parts One and Two. *Palaeontographica Abteilung* B **255**: 1–46, 87-145

Pryor, J. S. 1996. The Upper Pennsylvanian Duquesne coal of Ohio (USA): evidence for a dynamic peat accumulation swamp community. *International Journal of Coal Geology,* **29**:119-146.

Raiverman, V., Rao, M. R. and Pal, D. 1986. Stratigraphy and Structure of the Pranhita-Godavari Graben. *Petroleum Asia Journal,* **8**:174-189.

Raja Rao, C. S. 1982. Coalfield of India-2. Coal resources of Tamil Nadu, Andhra Pradesh, Orissa and Maharashtra. *Bull. geol. Surv India,* **45**(A):9-40.

Ramanamurty, B. V. and Madhusudan, R. C. 1996. A New Stratigraphic Classification of Permian (Lower Gondwana) Succession of Pranhita-Godavari Basin with Special Reference to Ramagundem Coalbelt, Andhra Pradesh, India, p. 67-78. In: *Gondwana Nine* (Eds. Guha, P.K.S., Sengupta, S., Ayyasami K. and Ghosh, R.K.), Oxford and IBH Publishing Co. Pvt. Ltd., New Delhi, India, **1**.

Ram-Awatar 1996. Palynological succession through Gondwana sediments in South Rewa Basin, Madhya Pradesh, India. *Geophytology,* **26**(1): 33-38.

Retallack, G. J. 1975. The life and times of a Triassic Lycopod. *Alcheringa,* **1:** 3-29.

Retallack, G. J. 1997. *A Colour Guide to Paleosols,* John Wiley and Sons, Chichester, UK.

Rothwell G. W. 1988. Cordaitales**,** p. 273–297. In: *Origin and Evolution of Gymnosperms*, (Ed. Beck C.B.), Columbia University Press, New York.

Sergroves, K. L. 1970. Permian Spores and Pollen Grains from the Perth Basin, Western Australia. *Grana Palynologica,* **10**(1):43-73.

Singh, A. and Singh, B. D. 1991. Particulate organic matter in relation to depositional aspect of the main lignite seam in Neyveli lignite field, Cauvery Basin, India. *Indian Journal of Geology,* **63**:17-39.

Singh, A., Mishra, B. K., Singh, B. D. and Navale, G. K. B. 1992. The Neyveli lignite deposits (Cauvery Basin), India: Organic composition, age, depositional pattern. *International Journal of Coal Geology,* **2**:45-97.

Singh, K. J., Chandra, A. and Chandra, S. 2005. Evaluation of earliest Permian flora of India and its equivalents in other Gondwana continents. *Palaeobotanist,* **54**: 107-113.

Sinha, A. K., Jha, N. and Upadhyay, R. 2004. Additional information on palynological dating of Chhongtash Formation in Eastern Karakoram and its palaeogeographical significance. *Current Science*, **86**(5): 719-723.

Souza, P. A. 2006. Late Carboniferous palynostratigraphy of the Itararé Subgroup, northeastern Paraná Basin, Brazil. *Review of Palaeobotany and Palynology,* **138**:9-29.

Souza, P. A. and Marques-Toigo, M. 2003. An Overview on the Palynostratigraphy of the Upper Paleozoic Strata of the Brazilian Parana Basin. *Revista del Museo Argentino de Ciencias Naturales,* **77**:353-365.

Souza, P. A. and Marques-Toigo, M. 2005. Progress on the Palynostratigraphy of the Permian Strata in Rio Grande Do Sul State, Parana Basin, Brazil. *Annals of the Brazilian Academy of Sciences,* **77**(2):353-365.

Souza, P. A., Perinotto, J. A. J., Félix, C. M. and Araújo, B. C. 2015. Biostratigraphy and paleoecology of an unusual palynological record from the Aquidauana Formation, Late Pennsylvanian of Paraná Basin. *Anais da Academia Brasileira de Ciências*, **87**(2): 611-622.

Srivastava, S. C. 1973. Talchir Mioflora from Korba Coalfield, Madhya Pradesh. *Geophytology,* **3**:102-105.

Srivastava, S. C. 1987. Palynological Correlation of Coal Seams in Godavari Graben, Andhra Pradesh, India. *Palaeobotanist,* **35**:281-296.

Srivastava, S. C. and Bhattacharyya, A. P. 1996. Palynofloral Assemblages from Permian Sediments, West Siang District, Arunachal Pradesh, India pp. 261-268. In: Ninth International Gondwana Symposium (Eds. Guha, P.K.S., Sengupta, S., Ayyasami, K., Ghosh, R.N.), Hyderabad. Geological Survey of India. Oxford and IBH Publishing Co., New Delhi-Calcutta.

Srivastava, S. C. and Jha, N. 1992. Permain palynostratigraphy in Ramakrishnanpuram area, Godavari Graben, Andhra Pradesh, India. *Geophytology*, 20(2): 83-95.

Srivastava, S. C. and Jha, N. 1993. Palynostarigraphy of Lower Gondwana Sediments in Cintalapudi Sub-Basin, Godavari Graben, Andhra Pradesh. *Geophytology,* **23**(1):93-98.

Srivastava, S. C. and Jha, N. 1994. Palynological Dating of Lower Gondwana Sediments in Sattupalli Area, Cintalapudi Sub-Basin, Andhra Pradesh, India. *Palaeobotanist,* **42**(2):169-173.

Srivastava, S. C. and Jha, N. 1995. Palynostratigraphy and correlations of Permian-Triassic sediments in Budharam Area, Godavari Graben. *Journal of Geological Society of India,* **46**: 647-653.

Stephenson, M. H. 2008. Spores and pollen from the Middle and Upper Gharif members (Permian) of Oman. *Palynology,* **32**:157-182.

Stephenson, M. H. 2009. The age of the Carboniferous–Permian *Converrucosisporites confluens* Oppel Biozone: new data from the Ganigobis Shale Member (Dwyka Group) of Namibia. *Palynology*, **33**: 167-177.

Stephenson, M. H., Leng, M. J., Vane, C. H., Osterloff, P. L. and Arrowsmith, C. 2005. Investigating the record of Permian climate change from argillaceous sediments, Oman. *Journal of the Geological Society London*, **162**: 641–651.

Stephenson, M. H., Angiolini, L. and Leng, M. J. 2007. The Early Permian fossil record of Gondwana and its relationship to deglaciation: A review, p. 169-189. In: *Deep time perspectives on climate change: Marrying the signal from computer models and biological proxies*, (Eds. Williams, M., Heywood, A.M., Gregory, F.J. and Schimdt, D.N.), London, Publication of the Micropalaeontological Society and the Geological Society, London.

Stephenson M. H., Jan I. U., Zeki S. A. and Al-Mashaikie K. 2013. Palynology and correlation of Carboniferous-Permian glacigene rocks of Oman, Yemen and Pakistan. *Gondwana Research*, **24**: 203-211.

Taylor, T. N., Taylor, E. L. and Krings, M. 2009. *Paleobotany: the Biology and Evolution of Fossil Plants,* Second Edition, Elsevier.

Tiwari, R. S. and Kumar, R. 2002. Indian Gondwana Palynochronology: relationship and chronocalibration. *Palaeobotanist,* **51**:13-30.

Tiwari, R. S. and Tripathi, A. 1992. Marker Assemblage Zones of Spore and Pollen Species through Gondwana Palaeozoic-Mesozoic Sequence in India. *Palaeobotanist,* **40**:194-236.

Traverse, A. 1988. Plant evolution dances to a different beat; plant and animal evolutionary mechanisms compared. *Historical Biol*, **1**: 277-301.

Tripathi, A. 1993. Palynosequence in Subsurface Permian Sediments in Talcher Coalfield, Orissa, India. *Geophytology,* **23**:99-106.

Truswell, E. M. 1980. Permo-Carboniferous Palynology of Gondwanaland: Progress and Problem in the Decade to 1980. *BMR Journal of Australian Geology and Geophysics,* **5**:95-111.

Tyson, R. V. 1993. Palynofacies analysis, p.153-191. In: D.J. Jenkins (ed.), Applied Micropalaeontology, Kluwer Acadmic Publishers.

Tyson, R. V. 1995. Sedimentary Organic Matter: Organic Facies and Palynofacies. Kluwer Academic, Dordrecht, Holland, pp. 615.

Upadhyay, R., Chandra, R., Sinha, A. K., Kar, R. K., Chandra, S., Jha, N. and Rai, H. 1999. Discovery of Gondwana plant fossils and palynomorphs lo Late Asselian (Early Permian) age in the Karakoram block. *Terra nova,* **11**: 278-283.

Utting, J. 1978. Lower Karoo Pollen and Spore Assemblages from the Coal Measures and Underlying Sediments of the Siankondobo Coalfield, Mid-Zambesi Valley, Zambia. *Palynology,* **2**:53-68.

Veevers, J. J. and Tewari, R. C. 1995. Gondwana master basin of peninsular Indiabetween Tethys and the interior of the Gondwanaland province of Pangea. *Memoir of Geological Society of America*, **187**: 1-73.

Veevers J. J. 1994. Case for the Gamburtsev subglacial Mountains of East Antarctica originated by mid-Carboniferous shortening of an intra cratonic basin. *Geology,* **22**:593-596.

Vijaya 1996. Advent of Gondwana deposition on Indian peninsula: A palynological reflection and relationship. In: *Ninth International Gondwana Symposium*, (Eds. Guha, P.K.S., Sengupta, S., Ayyasami, K. and Ghosh, R.N.), Hyderabad, Geological Survey of India, Oxford and IBH Publishing Co., New Delhi–Calcutta, pp. 283–298.

Vijaya 1998. Early Permian palynoassemblage from Ajay River Section, Damodar Basin, India. *Geophytology*, **26**(2): 57-63.

Vijaya, Tripathi, A., Roy, A. and Mitra S. 2012. palynostratigraphy and age correlation of subsurface strata within the sub-basins in Singrauli Gondwana Basin, India. *Journal Earth System Science*, **121**(4): 1071-1092

Waterhouse, J. B. 1976. World correlations for Permian marine faunas. *Paper of Department of Geology*, University Old, **7**(2).

Wopfner, H. and Cashyap, S. M. 1997. Transition from freezing to sub-tropical climates in the Permo-Carboniferous of Afro-Arabia and India, p. 192-212. In: *Late glacial and post-glacial environmental changes: Quaternary, Carboniferous-Permian and Proterozoic,* (Ed. Martini, I.P.), Oxford, UK, Oxford University Press.

Zavada, M. S. 1991. The ultrastructure of pollen found in the dispersed sporangia of *Arberiella* (Glossopteridaceae). *Botanical Gazette,* **152**:248-255.

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