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# Palynofloral and sedimentary organic matter analyses of Early Cretaceous sediments exposed along Sher River in Satpura Basin, Madhya Pradesh, India

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## ABSTRACT

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Sediments of Jabalpur Formation, exposed along Sher River near Sehora Village in Satpura Basin, are analyzed to assess diversity in sedimentary organic matter and palynofloral assemblage and their abundance and preservation potential in relation to various strata and lithotypes. The palaeoecology is interpreted on the basis of palynofossils, assigned to various plant groups with their ecological preferences. The depositional environment is inferred on the basis of abundance of sedimentary organic matter encompassed by this sedimentary section. The studied section is categorized into three major units, i.e. lower, middle and upper, in the vertical sequence. The lower unit is characterized by abundance of *Araucariacites australis* with other gymnospermous pollen, pteridophytic spores and moderate frequencies of biodegraded terrestrial and amorphous organic matter. The middle unit exhibits dominance of cycadaceous pollen (*Cycadopites grandis*) followed by *Araucariacites australis* and *Callialasporites* spp. and rich biodegraded terrestrial and amorphous organic matter. Other spore-pollen taxa are comparatively less abundant than those of the lower unit. The upper unit has dominance of *Araucariacites australis* followed by *Cycadopites grandis* and *Callialasporites dampieri* with some recycled Late Permian saccate pollen. The diversity of recycled pollen in this unit exhibits a significant depositional phenomenon and incursion of distant source material eroded from nearby older deposits. The frequencies of biodegraded terrestrial and amorphous organic matter gradually decrease in this unit. The dominance of conifer and cycadaceous pollen in the section suggests that moderately elevated low lying rain forest vegetation flourished in the subtropical regime in this part of Gondwanic continent. Abundance of biodegraded terrestrial and amorphous organic matter indicates moderate aerobic-anaerobic-aerobic burial conditions in these units. The biogeographic distribution of various palynofloras is determined by their comparison with the palynofloras recorded from the other contemporaneous Early Cretaceous (Aptian-Albian) sediments of Australia and Antarctica.

**Key-words:** Palynostratigraphy, sedimentary organic matter, Early Cretaceous, Satpura Basin, Madhya Pradesh, India.

## INTRODUCTION

The Satpura Basin in Central India covers a vast land from western Madhya Pradesh to north-western Maharashtra, in excess of 3500 km$^2$. It contains mostly Gondwanic sediments (Permian-Early Cretaceous) and also non-Gondwanic sediments (Late Cretaceous to Pleistocene). The Early Cretaceous sediments are exposed around Sehora, Chaugan, Achalpur and elsewhere. The section along Sher River near Sehora exposes maximum thickness (30-35 m) and is considered equivalent to the Jabalpur Formation. The palynoflora and sedimentary organic matter (SOM) contents of this section are significant, as they are similar to non-marine strata of other Upper Gondwana deposits of the southern hemisphere.

The section contains alternating argillaceous and arenaceous beds showing dramatic changes in frequency of spores and pollen grains of different plant groups indicating development of vegetation and environmental succession during terminal Gondwana regime. The analysis of palynoflora and sedimentary organic matter and their preservation in various lithotypes provide new palynofacies data which help in evaluating changes in floral diversity, their derivation from woody plants and burial in non-marine depositional system. The presence of recycled pollen of Late Permian age, incorporated in the sediments, is an important local stratigraphic phenomenon and reflects the source of some of the detritus that accumulated here during the Early Cretaceous. Stratigraphic interpretation of various plant groups is presented here on the basis of qualitative and quantitative characteristics of the SOM and palynofloral assemblage. The record of spores and pollen grains also reflects their biogeographic distribution in other neighbouring continents and existence in the late Gondwanic regime.

## MATERIAL AND METHOD

The Jabalpur Formation is exposed near Sehora Village, in a long narrow belt, trending in northeast-southwest direction (Text-figure 1). About 18 m thick vertical section is exposed on both the banks of the Sher River near Sehora, situated at 10 km southeast of Bachai on National Highway no. 26. Part of the basal sandstone bed is submerged in water. Thirty-four clay, sandy shale and carbonaceous shale samples, collected at approximately 10 cm intervals from freshly exposed horizons (Plate 1), have chemically been processed following the standard palynological technique. Most of the samples collected from various lithotypes yielded rich palynoflora and sedimentary organic matter. The sedimentary organic matter and palynoflora in slides of each productive sample were analyzed by counting 400 types (SOM) and about 200 spores and pollen grains under a high power light microscope to delineate changes in palynological contents in the vertical section. Text-figures 2 and 3 show patterns of distribution of spore-pollen and sedimentary organic matter in response to the various depositional factors, vegetation and environmental changes. All palynological slides and material used in this study are housed in the museum of the Birbal Sahni Institute of Palaeobotany, Lucknow.

## PREVIOUS WORK

About fifteen sedimentary sections in Satpura Basin have been studied by earlier workers with a sporadic palynological record and megaflora of Sher River (Feistmantel 1877, Crookshank 1936, Bose 1959, Dev 1961, Dev & Zeba-Bano 1981, Prakash 2008) and from Sher and Hard rivers by Singh (1966). Further, Singh and Kumar (1972), Bharadwaj and Kumar (1972, 1974), Kumar (1973, 1986, 1992a, b, 1994) and Kumar and Kulshreshtha (1979) studied palynological assemblage of exposed sections at Hathidoba, Ranikamar, Hathnapur, Sehora, Parsapani, Kotri, Khatma caves and Kamtara areas of the basin and assigned Early Cretaceous age. Tewari et al. (2009) recorded megaspores assigned to Early Cretaceous from the Sher River Section. The Early Cretaceous beds exposed near village Sehora along the Sher River are richly fossiliferous and yield abundant mega (*Ptilophyllum* flora) and microflora which closely resembles *Araucariacites-Callialasporites-Cycadopites* palynoassemblage zone of Hathnapur, Lameta Ghat and Sehora (Kumar 1994, Singh 1966, Bharadwaj et al. 1972, Singh & Venkatachala 1987).

## STRATIGRAPHIC SETTING

The Satpura Basin occupies a vast tract at south of Narmada plains and west central hilly regions of India. The basin comprises wide spectrum of sediments ranging in age from Late Carboniferous to Eocene (Table 1) and has fascinating stratigraphic problems. It caters requirement of coal to thermal energy producing industries of India (Raja Rao 1983).

About eighteen to twenty metres thick cliff section is exposed along the Sher River consisting mainly of clay, siliceous clay/shale, sandy shale and carbonaceous

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**Plate 1**

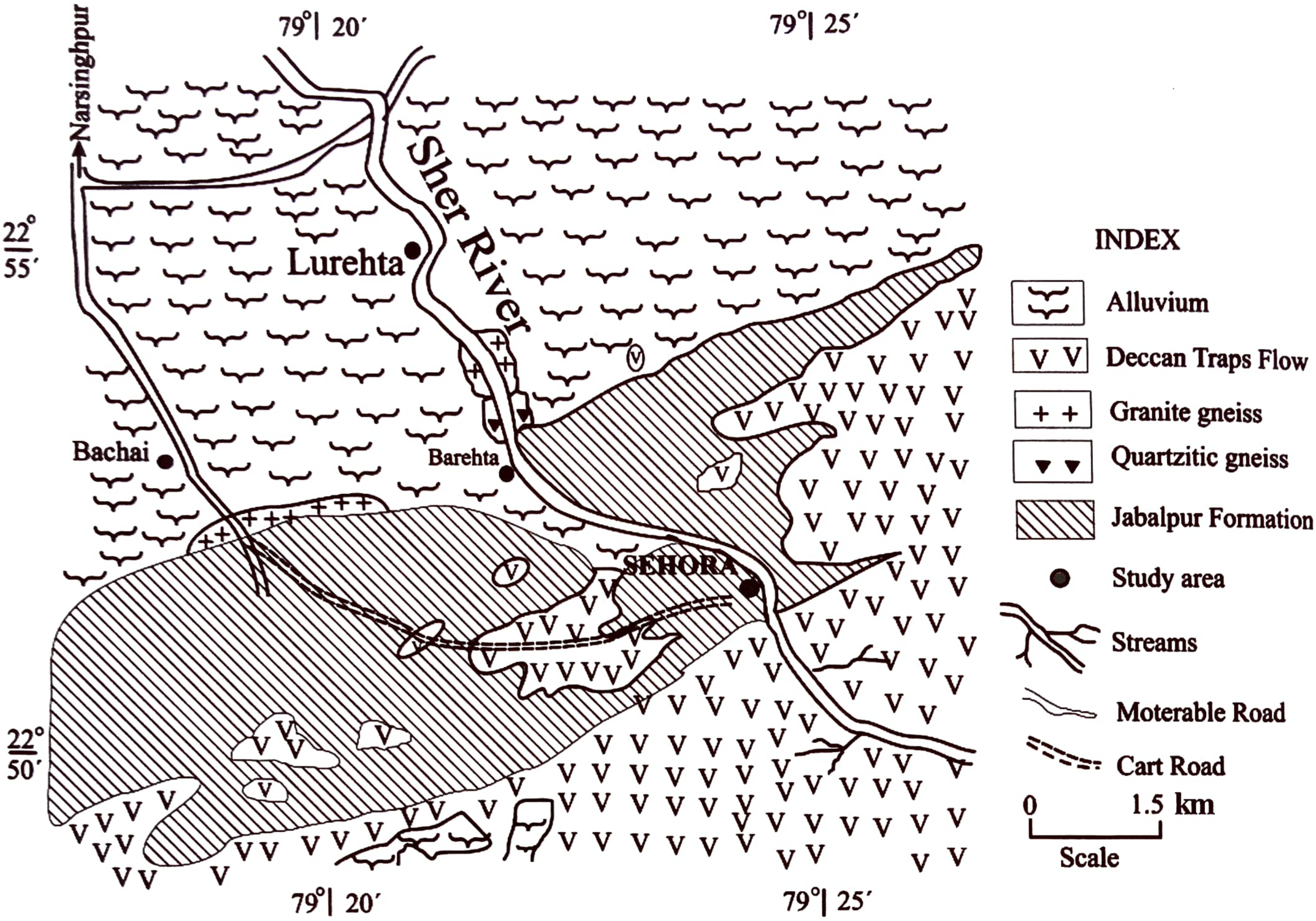
Stratigraphic section exposed along Sher River near Sehora Village, Satpura Basin, Madhya Pradesh.

**Plate 1**

shale interbedded with sandstones of varied thickness. The exposed beds are composed of pale-yellow to dirty white grey and fine to coarse-grained sandstone. The overall bedding type is massive to parallel in nature with thickness of 30 cm - 1.5 m (Plate 1, Text-figure 2). The topmost strata contain carbonaceous shale, grits

**Table 1. Stratigraphic succession in Satpura Basin, Madhya Pradesh**

| Formation | Lithology | Age |
|---|---|---|
| | Laterite, old and recent alluvium caps | Recent |
| Deccan Trap | Lava flows | Late Cretaceous to Eocene |
| Lameta | Coarse calcareous conglomerate, limestone, purple grits/sills, green sandstone | Late Cretaceous |
| | ------------------------------Unconformity-------------------------------- | |
| Jabalpur | Massive sandstone alternating with clays, conglomerate, earthy haematite, coaly lenses, carbonaceous shale, red clay and bed of chert | Jurassic-Early Cretaceous |
| Denwa | Alternating bed of sandstone and variegated clays (red green and buff coloured clays) | Triassic |
| Bagra | Conglomerates, limestone and variegated red clays | |
| | --------------------------------Unconformity------------------------------ | |
| Lower Gondwana | | Permian |
| | Archean Basement | Azoic |




**Text-figure 1.** Geological map of the area around Sehora Village, Satpura Basin, showing location of the studied area (after Crookshank 1936).

and pebbles covered by 2-3 m thick alluvium. These lithotypes are stretched horizontally in about 1.5 $km^2$ along the bedding plane. All sandstone beds are devoid of fossil contents. A bed, about one metre thick, in middle part of the section contains rich leaf impressions of '*Ptilophyllum* flora' and is very significant to correlate other contemporaneous deposits on the basis of megaflora. At 2 km west, in the vicinity of exposed section, the rocks of Deccan Traps are devoid of fossil contents. The sedimentary sequence recorded in the basin is given in Table 1 (Kumar 1994).

## PALYNOFACIES ANALYSIS

The vertical section, consisting of 14 argillaceous and arenaceous beds, is categorized into three subunits on the basis of frequency abundance of pollen-spores,

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**Plate 2**

1. *Ceratosporites kutchensis* Venkatachala, Slide no. BSIP 13226, L37. 2. *Retitriletes tenuis* Backhouse, Slide no. BSIP 13207, L 49. 3. *Cicatricosisporites* sp., Slide no. BSIP 13220, T22/2. 4. *Cicatricosisporites australiensis* (Cookson) Sah & Jain, Slide no. BSIP 13208, K48. 5, 8. *Contignisporites cooksoniae* (Balme) Dettmann, Slide nos. BSIP 13209, R42; BSIP 13214, U16. 6. *Foraminisporis asymmetricus* Dettmann, Slide no. BSIP 13206, G 29. 7. *Murospora florida* (Balme) Pocock, Slide no. BSIP 13214, H 45. 9. *Laevigatosporites ovatus* Wilson & Webster, Slide no. 13226 U30. 10, 22. *Cyathidites australis* Couper, Slide nos. BSIP 13213, R 24/322; BSIP 13213, Q 44. 11. *Gleicheniidites senonicus* (Ross) Skarby, Slide no. BSIP 13210, R 40/2. 12. *Concavissimisporites* sp., Slide no. BSIP 13212, P 25. 13. *Retitriletes* sp., Slide no. BSIP 13215, Q 27. 14. *Ischyosporites punctatus* Cookson & Dettmann, Slide no. BSIP 13217, R 44. 15. Unidentified spore, Slide no. BSIP 13218, C 27/3. 16-17. *Callialasporites dampieri* Dev, Slide nos. BSIP 13213, N 44/4; BSIP 13207, U 39/4. 18. *Densoisporites velatus* Weyland & Krieger, Slide no. BSIP 13208, J 48. 19. *Dictyophyllidites crenatus* Dettmann, 1963, slide no. BSIP 13222, M 23/3. 20. Reticulate monosulcate pollen, Slide no. BSIP 13219 R 17/1. 21. *Dictyotosporites complex* Cookson & Dettmann, Slide no. BSIP 13207, V27. 23. *Osmundacidites* sp., Slide no. BSIP 13214 V37. 24. *Erlansonisporites mineri* Dev, Slide no. BSIP 13216, O 25 (Bar scale = 20 μm, unless otherwise mentioned. Location of specimen in slide is pointed by England finder).

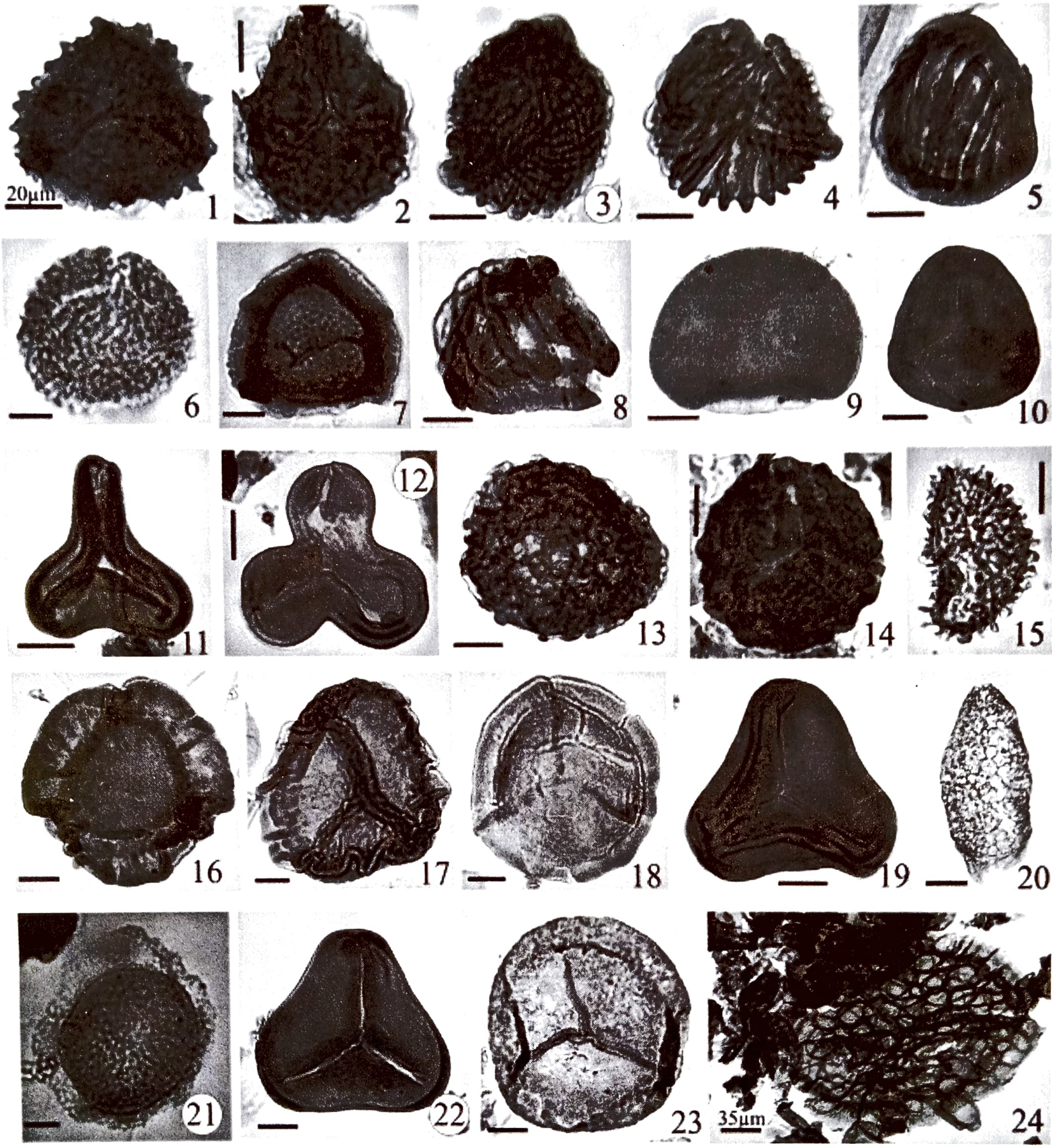
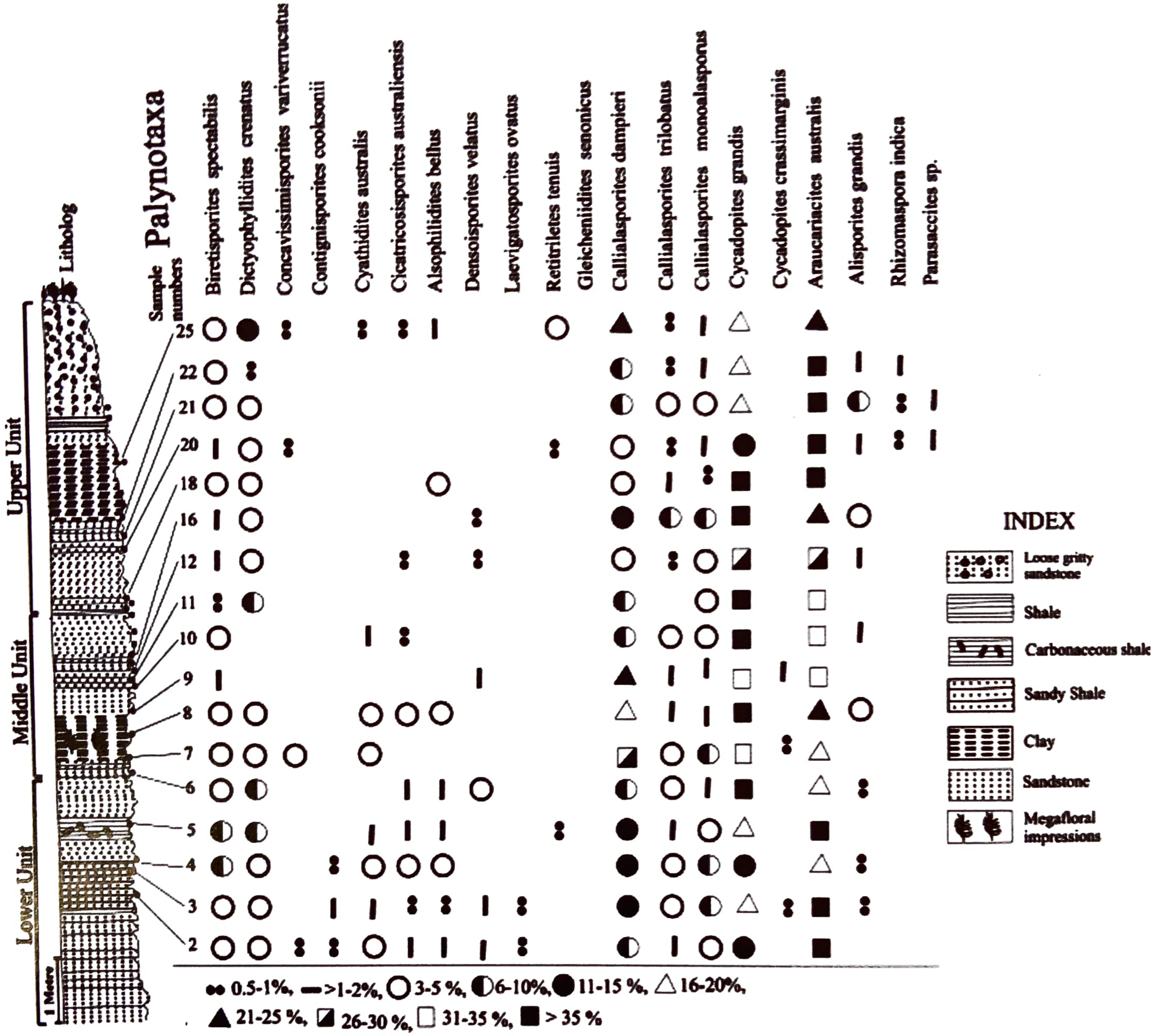



**Plate 2**




**Text-figure 2.** Percentage frequency of selected palynotaxa of the section exposed along Sher River, Satpura Basin, Madhya Pradesh.

recycling of Lower Gondwanic miospores, sedimentary organic matter and their preservation potential. The details of palynological contents in these three subunits are explained below:

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## Plate 3

1. *Parasaccites* sp., Slide no. BSIP 13210, H 21. 2. *Alisporites grandis* (Cookson) Dettmann, Slide no. BSIP 13219, Q22/2. 3. *Microfoveolatisporites* sp., Slide no. BSIP 13223, L 44/2. 4. *Cingutriletes clavatus* Balme, Slide no. BSIP 13223, J 16/3. 5. *Alisporites* sp., Slide no. BSIP 13207, L 51/1. 6. *Rhizomaspora indica* Tiwari, Slide no. BSIP 13221, N 16/2. 7. *Araucariacites australis* Cookson, Slide no. BSIP 13210, S 46/4. 8. *Rhizomaspora* sp., Slide no. BSIP 13228, O41/1. 9. *Ibisporites diplosaccus* Tewari, Slide no. BSIP 13214, U 42/3. 10. *Distriatites bilateralis* Bharadwaj, Slide no. BSIP 13229, K 25/1. 11. *Verticipollenites* sp., Slide no. BSIP 13228, T 17/3. 12. *Lunatisporites* sp., Slide no. BSIP 13226, L 28. 13-15. *Cycadopites grandis* De Jersey & Hamilton, Slide nos. BSIP 13227, R 12/2, BSIP 13207 V 27, BSIP 13220 Q13/3. 16. *Cycadopites couperi* (Dev) Kumar, Slide no. BSIP 13214, T 19. 17. *Schizosporis reticulates* (Cookson & Dettmann) Dettmann, Slide no. BSIP 13210, S 47/4 (Bar scale = 20 μm, unless otherwise mentioned. Location of specimen in slide is pointed by England finder).

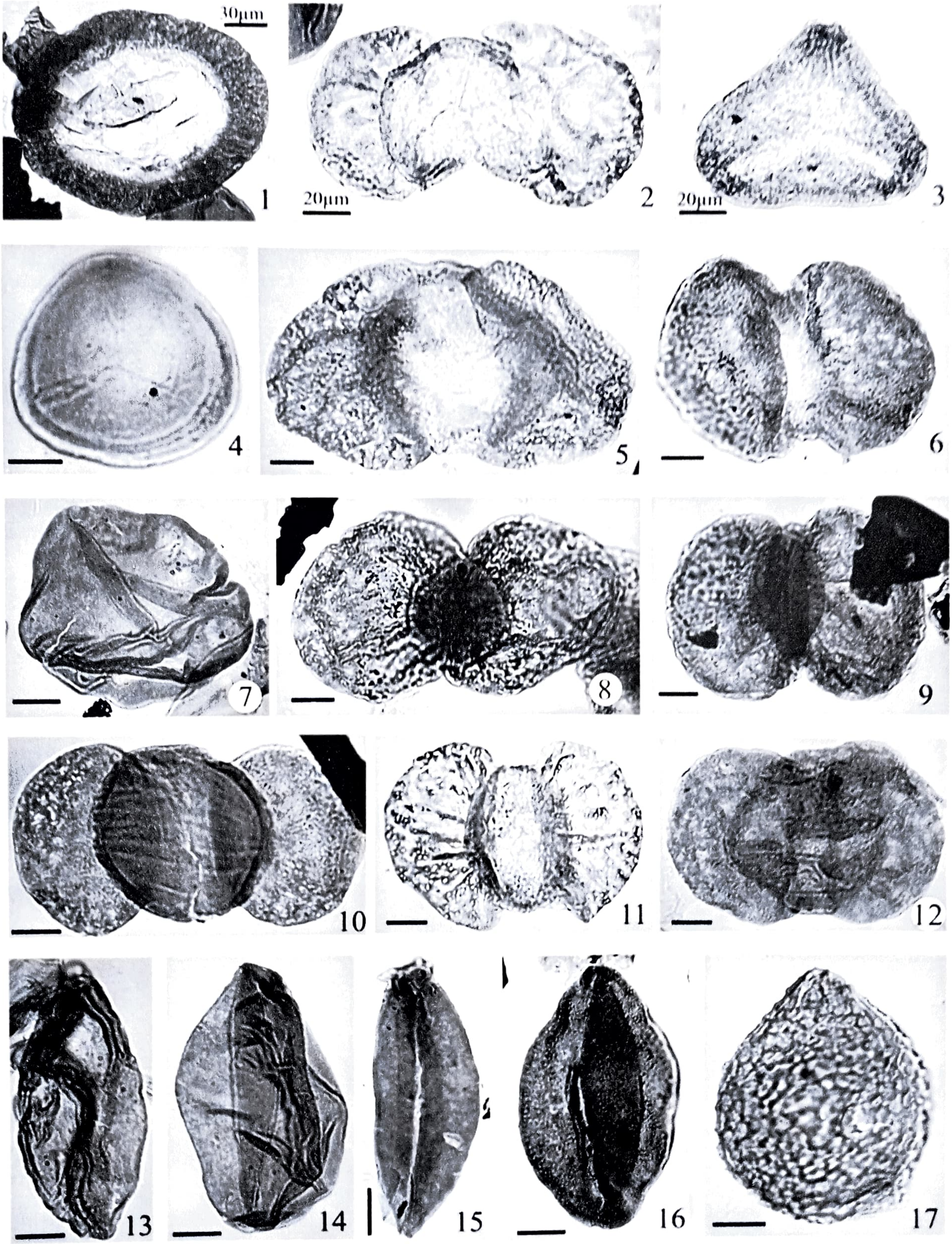



**Plate 3**

**Lower Unit**

**Lithology:** The beds in the lower part of the vertical section show alternation of well sorted medium to coarse grained sandstones and sandy clay of varying thickness. The basal layer is represented by 2-3 m thick sandstone overlain by 90-95 cm thick sandy shale. Further, a 50 cm thick sandstone layer and fossiliferous siliceous brown shale beds are overlain by 70-80 cm thick sandstone bed. These fine to coarse grained sandstone beds are devoid of any fossil contents.

**Sedimentary organic matter contents:** The unit exhibits dominance of biodegraded terrestrial (20-40%) followed by amorphous, black debris and spore - pollen. The palynoassemblage shows their abundance between 2-25%. The resins and gelified matter are encountered here with 10-13%. The structured terrestrial, pieces of leaf cuticles and woody matters are represented by 2-7% of the total abundance.

**Pollen-spores:** The palynological assemblage in this unit shows dominance of *Araucariacites australis* followed by *Cycadopites grandis, Callialasporites dampieri, C. monoalasporus, Biretisporites spectabilis, Dictyophyllidites crenatus, Cyathidites australis, Cicatricosisporites australiensis, Ischyosporites punctatus, Klukisporites verigatus, Alsophilidites bellus, Contignisporites cooksoniae, Laevigatosporites ovatus, Alisporites* sp., etc. (Plates 2, 3).

**Preservation potential:** Samples from basal layer of the unit contain rich black debris and woody fragments, which gradually decrease in upper lithotypes and are replaced by rich spore-pollen, biodegraded terrestrial and amorphous organic matter. The high frequency of spore-pollen in the unit exhibits that the deposition of the bed took place under rapid setting of siliceous sandy clay that created inter-granular spaces in the sedimentary matrix. The clastic sediments are rounded in nature and other associated silica particles are coarsely granular in texture and well sorted, which are dominantly inter-bedded in shale and clayey lithotypes indicating deposition under high energy with flooding condition that enormously accumulated large sized fragmented vegetal matter of arboreal plants to the depositional site (Text-figures 2, 3). These vegetal matter entrapped between sedimentary matrix become partially oxidized by available oxygen in pore matrices by creating least favourable condition for microbial decay. As a result, the frequency of biodegraded and amorphous organic matter are found to be less in abundance. The resin particles and gelified matter encountered here exhibit incursion of highly lignified plant material mainly produced by arboreal gymnosperms. The fern genera encountered in this unit indicate that these plant groups were successfully colonizing around swampy lake margins.

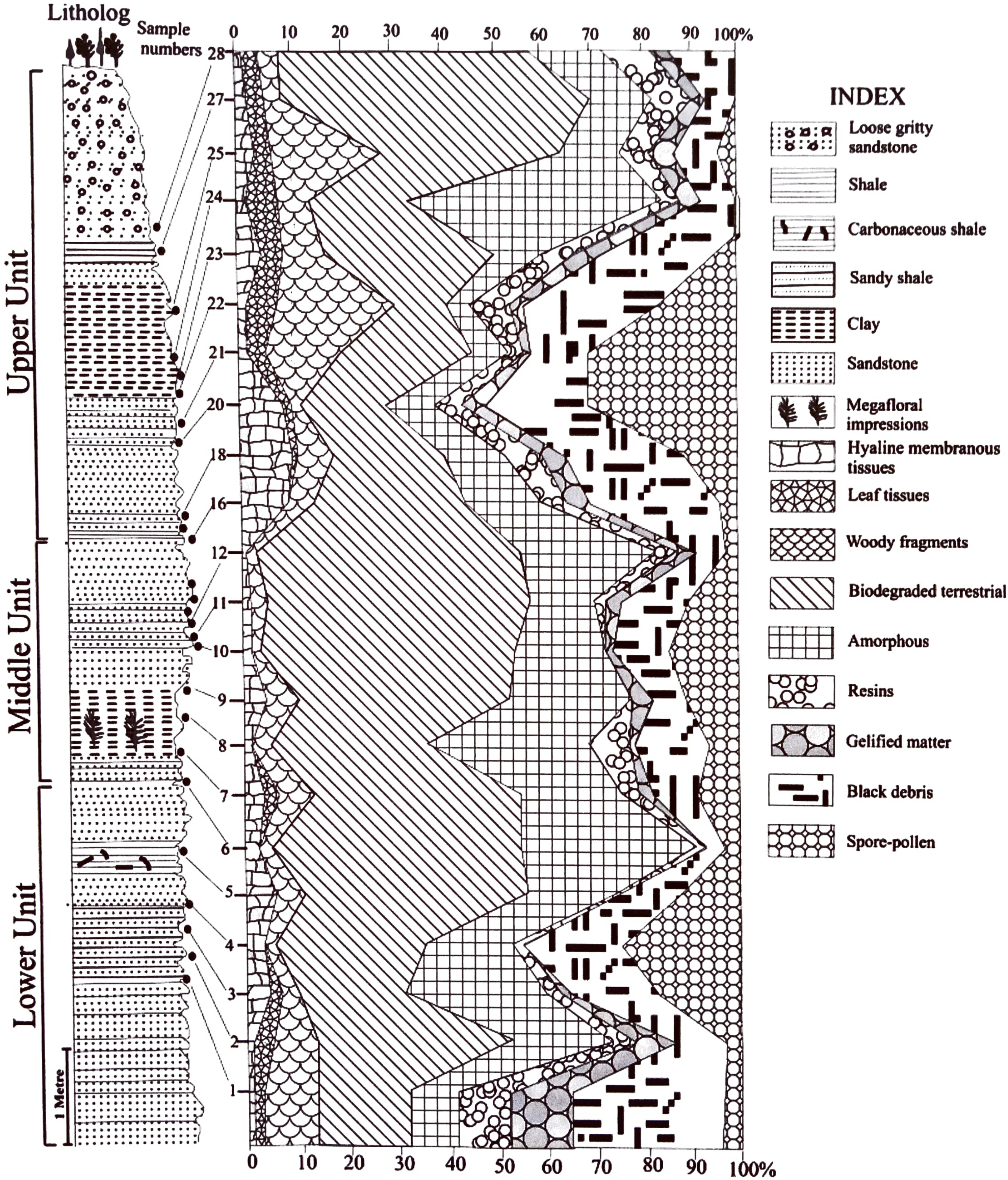
**Middle Unit**

**Lithology:** This unit is 3.47 m thick and is composed of fine grained sandstone (thickness about 80 cm) showing alternation of clay and 1.0 m thick sandy/siliceous gray shale; overlain by about 60 cm thick carbonaceous to gray shale bed. The distinguishing feature of this unit is sandwiching of 90 cm thick fine grained clay bed containing rich *Ptilophyllum* leaf compressions.

**Sedimentary organic matter contents:** Rich biodegraded terrestrial (30-35 %) along with amorphous and black debris occur in this unit. The gelified matter is represented by 1-2 %, while resin globules occur (7%) only in megafloral bed. The frequency of spore-pollen is 3-15% in this unit.

**Pollen-spores:** The palynoassemblage shows rich *Cycadopites grandis* followed by *Araucariacites australis, Callialasporites trilobatus, C. monoalasporus, Ischyosporites punctatus. Klukisporites verigatus, Cycadopites crassimarginus, Biretisporites spectabilis, Dictyophyllidites crenatus, Cyathidites australis, Cicatricosisporites australiensis, Microfoveolatisporites* sp., *Densoisporites velatus*, etc. (Plates 2, 3).

**Preservation potential:** In this unit the argillaceous stratotypes contain fine clay, shale and sandy shale beds containing well preserved phytoclasts in fine lithologies, which were best suited for enhanced microbial activities on plant fragments. The microbial activities over plant fragments are evidenced by occurrences of high frequency of biodegraded terrestrial and amorphous organic matter. Occurrence of high




**Text-figure 3.** Percentage frequency and trend of occurrence of sedimentary organic matter in the Sher River Section, Satpura Basin, Madhya Pradesh.

frequency of biodegraded organic matter indicates anaerobic condition and activity of microbes resulting into deployment of available oxygen between the pore spaces in the bed. This phenomenon also helped in preservation and compression of leaves in well laminated fine clay/shale beds. Well preserved megafloras in well laminated fine clay/shale interbedded with sandstone indicate minimum transport of plant material in low energy setting of the sediment. Occurrence of rich Bennettitales, such as '*Ptilophyllum* flora' and pollen of *Cycadopites grandis, Araucariacites australis, Callialasporites trilobatus* shows colonization of cycadalean and conifer trees around the depositional site.

**Upper Unit**

**Lithology:** This 4.63 m thick unit contains 20 and 60 cm thick sandy shale, 1.60 m thick clay and siliciclastic clay alternating with compact sandstone beds. The topmost gritty/pebbled (size 0.5-1.5 cm in diameter) sandstone beds are covered by alluvium of variable thickness (>1.50 m). Coarse-grained sandstones are interbedded with silicified clay-shale layers. The sandy shale beds show granules of coals (1-3 mm in diameter). The 2.5 m thick gritty-pebble bed showing well rounded grits embodied in coarse sandy matrix are devoid of any plant fossil contents.

**Sedimentary organic matter contents:** This unit also shows rich biodegraded terrestrial (15-60%) followed by black debris, woody fragments and amorphous types. Pollen and spores are found to be rich only in basal part of the unit. The structured terrestrial (hyaline tissues and pieces of leaf cuticles), resin globules and gelified matter do not show any marked deviation as it is observed in the case of biodegraded and amorphous organic matters.

**Pollen-spores:** Pollen of *Araucariacites australis* show maximum abundance in the assemblage followed by occurrence of *Cycadopites grandis, Callialasporites dampieri, C. trilobatus, C. monoalasporus, Biretisporites spectabilis, Dictyophyllidites crenatus, Concavissimisporites variverrucosus, Cicatricosisporites australiensis, Alsophilidites bellus, Alisporites* sp. and *Retitriletes* sp. The recycled Permian saccate pollen, e.g. *Parasaccites* sp., *Rhizomaspora indica, Ibisporites diplosaccus, Distriatites bilateralis, Verticipollenites* sp., *Microfoveolatisporites* sp., *Lunatisporites* sp. and *Trabeculisporites* sp., are also encountered in the assemblage (Plates 2, 3). The recycled Permian saccate pollen encountered in the sequence of the unit are most characteristic to exhibit transportation of eroded older deposits from nearby area to the depositional site. Occurrence of these recycled taxa in upper bed of the section is also considered as indirect evidence that points specific stratigraphic unit where allochthonous detritus were incorporated.

**Preservation potential:** The rich frequency of spore-pollen and large sized structured organic matter indicates deposition under maximum flooding stage and rapid settling of suspension which leave inter-granular spaces in sedimentary matrix. The oxygen available in sediments oxidizes plant fragments. The plant tissues entrapped within thin clay beds are progressively well preserved due to its occurrences in fine lithology. The topmost loose sandstone bed containing pebbles exhibits activity of rapid flow of the river channels towards elevated topography that did not accumulate any plant fragments. The facies association of silty clay and fine coal fragments found to be scattered in this bed occur due to deposition under flooded stream channels where recycled material from preexisting older sequences was transported here from other places of Satpura Basin.

## COMPOSITION OF PALYNOFLORAL ASSEMBLAGE

Clay, silty clay, shale and carbonaceous sandy shale in the argillaceous beds of all three subunits yielded well-preserved sedimentary organic matter and diverse spore-pollen and recycled Permian saccate pollen. Among these, the palynofossils representing Early Cretaceous age are: *Araucariacites australis* and *Cycadopites grandis* in dominance along with other taxa, e.g. *Callialasporites dampieri, C. trilobatus Klukisporites verigatus, Cycadopites crassimarginus, Biretisporites spectabilis, Dictyophyllidites crenatus, Cyathidites australis, Cicatricosisporites australiensis, Osmundacidites* sp. and *Densoisporites velatus*, etc. *Cycadopites* *grandis* is a dominant element among the cycadales. This grain shows higher frequency in middle unit only but frequencies of pteridophytic spores are very low here (Text-figure 2). The details of percentage frequency of taxa and their assigned botanical families which are found under dominance of *Araucariacites australis* in lower and middle units and sub-dominance in upper unit are enumerated below:

a. The conifer taxa, represented by 34.38% in the total assemblage, are: **Araucariaceae:** *Araucariacites australis, Callialasporites dampieri, C. trilobatus, C. monoalasporus*; **Corystospermaceae:** *Alisporites grandis*.

b. Ferns mostly represented in basal unit but sporadically represented in upper sequences are: **Cyatheaceae:** *Cyathidites australis* (2.2%); **Dipteridaceae:** *Dictyophyllidites crenatus* (5.65 % in basal unit but its aggregate abundance in all three units is 4.48 %); **Dicksoniaceae:** *Concavissimisporites variverrucosus* (<1%); **Pteridaceae:** *Contignisporites cooksoniae* and *Ceratosporites kutchensis* showing 1% abundance; **Osmundaceae:** *Osmundacidites* sp. < 1%; **Gleicheniaceae:** *Gleicheniidites senonicus* (< 1%); **Schizaeaceae:** *Klukisporites verigatus* (< 1%); **Ceratopteridaceae:** *Cicatricosisporites australiensis* (1%); **Pterophyta:** *Biretisporites spectabilis* (5.08% in Lower unit but aggregate in all three units is 2.90%), *Laevigatosporites ovatus* (<0.5%) and *Densoisporites velatus* (0.5%); **Hepaticae:** *Aequitriradites verrucosus* (1%).

## RECYCLING OF LATE PERMIAN PALYNOTAXA

Recycling of various palynotaxa in Early Cretaceous sediments was result of erosion of nearby Permian deposits of the southern Gondwana, a common phenomenon occurring in a majority of depositional system of younger ages (Kemp 1972, Hathway & Riding 2001, Sajjadi & Playford 2002a, b), which is also observed in the upper beds of the Sher River Section. Occurrence of reworked taxa in the palynoassemblage indicates inclusion of some of the detritus from Permian strata possibly from Mohpani coalfield which is near to the Sher River Section. The Early Permian coal seams in Satpura Basin show a characteristic development of a thick sequence of Barakar strata belonging to the Lower Gondwana among which the Bijori Formation (Late Permian) also shows coal seams of variable thickness at south of Pachmarhi in Satpura Basin (Raja Rao 1983). The succeeding upper pebble layer interfingering in sandstone also prove transportation of detritus materials. The exines of reworked saccate pollen are partially corroded and show distinct effect of abrasion during their transport through fluvial channels from the source. The localities of such older deposits are much difficult to pinpoint as they enormously occur in the basin. The absence of recycled palynoflora in basal sequences indicates that no deposition of eroded material took place here. It might be possible that the local depositional materials could not be accommodated in the depositional site but such materials might be accumulated at other distant place in the same horizon. The phenomenon of recycling indicates that the site was a part of Narmada Graben and subsidence of preexisting rocks made a platform of filling of material which brought eroded detritus from distant older deposits and transported here by stream channels due to better slope and accumulated under high flooding stage. Although, recognition of reworked sedimentary organic matter is difficult to distinguish from in-situ material when the preservational status of both in-situ and reworked palynoflora are same, but finer observation of pollen morphology, their sculptural and structural organization and comparative frequency counts help to distinguish them.

## SOURCE OF THE SEDIMENTS AND PRESERVATION OF ORGANIC MATTER

Fine grained sandy/siliciclastic clay, carbonaceous clay and shale lithotypes embody rich palynological assemblage. These fine grained sediments show greater potentialities for preservation of plant derived organic matter. Behaviour of such organic matter in the section exhibits minor deviation in their frequency, but occurrence of rich biodegraded or non-degraded organic matter derived from higher plants are incorporated in various lithotypes exhibiting several phases, such as non-biodegradation to severely biodegradation are the result of diagenetic factors that prevailed during their burial condition. Permeable sediments, viz. sandstone, coarse grained or highly siliciclastic deposits are devoid of palynomorphs or sedimentary organic matter as they have less potentiality to preserve them by allowing dissemination of oxygen in sedimentary water column along with presence of other corrosive minerals. The analysis of spore-pollen assemblage and sedimentary organic matter recovered from various lithotypes reveals:

a. The deposition during first phase at basal unit in the vertical section exposed along Sher River indicates in-situ detritus admixed with high frequency of plant fragments. The inundation of pollen taxa derived from higher gymnosperm plants of Araucariaceae and Cycadaceae suggests thriving of arboreal trees prior to the deposition of the sediments in this unit. The high frequency of spore-pollen, woody fragments and moderate biodegraded tissues with resins and black debris indicates that the deposition took place under high flooding condition.

b. Facies architecture of the middle unit characterized by well laminated clay contain rich '*Ptilophyllum* flora' with araucarian and cycadalean pollen. This indicates moderate deep to plain topography around depositional site. The comparatively low frequency of spore-pollen other than this unit suggests that deposition took place under low flooding condition. The waning of flooding made lesser transportation of pollen-spores from nearby or distant places.

c. The uppermost unit shows rich spore-pollen which suggests that the facies were deposited under high flooding condition in lake system surrounded by rich conifer forest. The streams with faster velocities flowed towards lake sites and brought detritus from distant places including pre-existing Permian deposits probably from the Mohpani and Pench- Kanhan coalfields.

The palynological and lithological analyses (Text-figures 2, 3) of first unit indicate deposition under high flooding condition where river had high gradient forces for carrying clay suspensions with rich spores, pollen grains and other plant fragments. These flooding events are recognized by occurrence of high frequency of microfossils with their specific and relative abundance (Mancini & Tew 1997). In second phase, the river channel diverted to ox-bow lake condition under low flooding stage that carried finer material of which its suspension settled under low energy condition. During deposition of the third or upper unit the previous condition of high flooding was repeated for a shorter period resulting into accumulation of further rich spores and pollen grains. The topmost layer of this unit contains low frequency of recycled palynomorphs (*Parasaccites* sp., *Lunatisporites* sp., *Vertcipollenites* sp. *Rhizomaspora indica*, *Distriatites bilateralis*, *Ibisporites diplosaccus* and *Trabeculisporites* sp.) transported here after erosion from nearby Permian deposits possibly from Mohpani and Pachmarhi areas. Input of in-situ spore-pollen indicates luxuriant vegetation around the lake. The episodes of expansion in lake margin due to flooding and contraction by non-flooding conditions observed in upper strata show effect of local depositional phenomenon by levees that brought detritus by erosion of adjacent landscapes.

## COMPARISON WITH OTHER CONTEMPORANEOUS PALYNOFLORAS

The spore-pollen recorded from the sediments exposed at Sher River show close relationship with other Upper Gondwana deposits, as given below:

### Indian Peninsula

**Satpura Basin:** The *Araucariacites-Callialasporites-Cycadopites* palynoassemblage zone recorded by Kumar (1993, 1994) from Hathnapur shows much similarity with the present assemblage. The palynoflora of Chui Hills by Dogra et al. (1988) also shows similarity but differs by absence of *Crybellosporites* and *Coptospra* in present assemblage.

**South Rewa Basin:** Maheshwari (1974) recorded abundant *Araucariacites australis* (23-58%) and *Callialasporites* spp. (19-34%) with *Cyathidites australis*, *Cycadopites*, *Contignisporites* which also occur in the present assemblage.

**West Bengal:** The palynoflora of the Palynozone III (depth 342-229.6 m) of Borehole PGD-6 of Rajmahal Formation (Vijaya 1997) also shows dominance of *Araucariacites* and *Callialasporites* with common occurrence of *Cicatricosisporites*, *Concavissimisporites*, *Contignisporites*, *Foveotriletes, Alisporites,* etc.

**Other Gondwanic continents**

**Antarctica**: Truswell et al. (1999) recorded high frequency of *Araucariacites* (44%), *Cicatricosisporites* spp., *Concavissimisporites variverrucatus*, *C. glebulentus, Contignisporites* spp., *Cyathidites australis*, *Alisporites grandis*, *Callialasporites dampieri*, *C. trilobatus* with some other species of *Araucariacites* spp., from core no. 3 of Mc Roberts Shelf of East Antarctica. These palynofossils are found to be common in both the assemblages.

**Australia:** Occurrence of palynoflora in Southwest Australia, e.g. *Cicatricosisporites* spp., *Gleicheniidites* spp., *Concavissimisporites variverrucatus* and *Aequitriradites acusus* in *Retitriletes watherwensis* and *Biretisporites eneabbaensis* palynozone are found to be common with those of Sher River Section. Sajjadi and Playford (2002 a, b) recorded rich spore-pollen assemblage from Eromanga Basin of central Australia of which some taxa, viz. *Concavissimisporites variverrucatus*, *Contignisporite glebulentus, Callialasporites* spp., *Alisporites grandis*, *Araucariacites australis*, *Cycadopites grandis*, *C. crassimarginis* etc. are also found in the palynoassemblage of Sher River.

## PALAEOVEGETATION AND PALAEOCLIMATIC INTERPRETATION

The history of vegetation recorded in the Sher River Section shows changes and variations in vertical section that deposited under continental fluvio-lacustrine set-up. Three distinct phases (units), categorized in the section on the basis of spore-pollen records, exhibit dominance of high canopy evergreen conifers with low canopy cycadales and pteridophytes were spread at the forest floor. The understorey vegetation of cycads and ferns thrived under shaded habitat reported in the basal unit. The understoreyed ferns and other pteridophytes composed mainly of Gleicheniaceae, Dicksoniaceae, Dipteridaceae, Cyatheaceae, Pteridaceae and Osmundaceae preferred to grew in swampy moist habitat, while less frequency of spores of Ceratopteridaceae and Schizaeaceae indicate prominent net works of spring or river channel in flood plain depressions (Tryon & Tryon 1982). The other subsequent units show replacement of the cycadalean pollen followed by conifers. Pteridophytes are found to be scanty in these strata and indicate gradual decline of swampy vegetation in succeeding depositional phases. Kumar (1992) opined that open woodland of Araucariaceae (*Araucariacites* and *Callialasporites*) dominated during the onset of deposition in the basin. The second distinct vegetation phase is marked by the occurrence of high abundance of *Cycadopites* (Cycadales) and Bennettitales followed by the pollen of Araucariaceae. The remarkable feature of this unit is occurrence of megaflora (mainly of *Ptilophyllum* Group) within this facies which indicates that closely spaced larger cycadalean and araucarian trees colonized around the depositional site. The high abundance of biodegraded and amorphous organic matter shows high microbial activities in anaerobic condition in finer clastic sediments. The organic matter is mainly dominated by biodegraded terrestrial, amorphous and black debris. The frequency of spores and pollen grains is comparatively lower (5-13%) than lower and upper units.

The third phase of vegetation history again began with flooding stage signaled by the high occurrence of abundant pollen of arboreal araucarian taxa (*Araucariacites australis* and *Callialasporites* spp.) followed by *Cycadopites grandis*. Their abundance in the palynoassemblage suggests prominence of densely covered araucarian trees which preferred to thrive under increased precipitation in subtropical condition. The low frequencies of spores of *Cicatricosisporites* (Ceratopteridaceae) and *Contignisporites* (Pteridaceae) are also incorporated in the assemblage. Occurrence of some Permian saccate pollen of *Parasaccites* sp., *Rhizomaspora indica*, *Lunatisporites* sp., *Ibisporites diplosaccus* and *Trabeculisporites* sp. indicates incursion of allochthonous material to the depositional site. The high frequency of structured terrestrial and black debris indicates moderate oxidizing condition during deposition of the unit. The more siliceous nature of the sediments oxidizes plant fragments by its entrapped air in the pore spaces. The plant community recorded throughout the section indicates predominance of deciduous forests of araucarian and cycadalean plants along with ferns in these fossiliferous beds and the area enjoyed relatively high rainfall with moderately cool climate under subtropical condition.

## PHYTOGEOGRAPHY

The palynoassemblage recorded from the Sher River Section near Sehora Village exhibits major similarities with the palynofloras from other sedimentary basins of southern hemisphere. It is well understood that during Early Cretaceous the continental margin of Indian Plate was surrounded by the northern edge of East Antarctica (Mc Robertson Shelf and Pedersan Formation) and north-western Australian basins (Dettmann 1963, Dettmann & Playford 1969, Truswell et al. 1999, Sajjadi & Playford 2002 a, b). The Satpura Basin, South Rewa and Late Gondwana basins of East Coast in India were closely connected by land with East Antarctic and Western Australian basins encompassing similar vegetation during Early Cretaceous. The palaeofloral assemblage in these continents made an arena of similar floral association under similar climatic control and made congenial condition for migration of several taxa from one place to other through various transporting agents and fluvial channels existing in these connected land masses. The minor difference in fossil flora recorded in these landmasses are due to the prevalence of local ecological and edaphic factors (Dettmann & Playford 1969, Truswell et al. 1999). Therefore, it can be presumed that the flora in these united or partially fragmented landmasses was dominated by conifers mainly of Araucariaceae with other plants that thrived with under-storeyed habitat, e.g. Cycadales and ferns (Dettmann 1963, Dettmann et al. 1992, Vakhrameev 1988). Such flora mostly occurs in non-marine deposits. These non-marine floral assemblages existed in Australia, Antarctica and India making forests of araucarian, cycadalean and bennettitalean plants and ferns spread in the entire landmass until complete separation of these peninsulas (Truswell et al. 1999). The ferns, e.g. *Cicatricosisporites* (Ceratopteridaceae) and other cicatricose and murate trilete spores affiliated to Schizaeaceae, Cyatheaceae, Dicksoniaceae, Pteridaceae and Gleicheniaceae flourished in widest non-marine swampy landmass (Dettmann & Clifford 1991).

## CONCLUSION

1. The stratigraphic sequence was deposited under three major phases during Early Cretaceous (Barremian-Aptian). The luxuriant vegetation of arboreal conifers and cycadales was commonly distributed among the continents of southern hemisphere.
2. The sedimentary sequence, mainly argillaceous type, encompasses taxonomically diverse palynoflora and abundant sedimentary organic matter.
3. The earliest phase of deposition reflects inclusion of rich pteridophytic spores, conifer pollen and allied genera under high flooding condition, whereas during the deposition of middle phase vegetation was dominated by cycadales followed by plants of Araucariaceae.
4. During the deposition of upper unit (last phase), the vegetation was further covered by araucarian trees followed by some cycadales. The ferns were scarcely distributed. A large amount of detritus, brought here by the erosion of older sediments, shows incorporation of Permian saccate pollen.
5. All argillaceous beds, except below the gritty/pebble beds, in the upper unit yielded rich black debris, woody fragments and biodegraded terrestrial organic matter showing moderate oxic condition during their burial stage.
6. Overall palynoassemblage indicates non-marine depositional set-up for the stratigraphic sequence exposed near Sehora Village and greater similarity with contemporaneous Upper Gondwana deposits of Satpura, South Rewa and West Bengal basins of India and also with West Antarctic and Western Australian basins.

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