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# Palynostratigraphic, palaeoenvironmental and palaeogeographic significance of the Early Cretaceous palynoflora of Kachchh Basin, western India

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## Abstract

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Sediments of Bhuj Formation (Early Cretaceous) occur in the Kachchh Basin, western India containing abundant and diverse plant fossils. Sedimentary successions of the formation exposed along Pur River comprise variably thickened shale, carbonaceous shale, thin coal seam, siliceous clays, etc. and have yielded abundant megaspores, microspores, conifer pollen grains, dinoflagellate cysts and colonies of *Botryococcus* alga. Two palynozones are recognized in the recorded palynoassemblage, viz. *Minerisporites cutchensis* megaspore zone at the basal part, derived mostly from herbaceous vegetation growing along pro–deltaic swampy habitat. The succeeding *Araucariacites australis* zone in the upper part of the succession probably derived from conifer–dominated forest inhabited along the freshwater swamps, flourishing in a more humid and warm temperate climate. The palynofloras of both palynozones are biostratigraphically very significant indicating Late Aptian–Early Albian age of the succession. A majority of the palynotaxa recorded from the studied sedimentary succession show resemblance with the contemporaneous deposits of other Gondwana continents of the Southern Hemisphere.

**Key–words**—Palynostratigraphy, Palaeoecology, Palaeobiogeography, Early Cretaceous, Kachchh, India.

## पश्चिम भारत में कच्छ घाटी के प्रारंभिक क्रिटेशस परागाणु वनस्पतियों का परागाणुस्तरिक, पुरापर्यावारणीय एवं पुराभौगोलिक महत्व

माधव कुमार

## सारांश

पश्चिम भारत में कच्छ घाटी के भुज शैलसमूह (प्रारंभिक क्रिटेशस) तलछट में विविध प्रकार के पादप जीवाश्म पाए जाते हैं। इस शैलसमूह के क्रमवत उत्तराधिकार तलछट जो घाटी में पुर नदी के किनारे अनावरित विभिन्न मोटाई के शैल, कार्बनमय शैल, महीन कोयला सीम तथा सिलिकायुक्त मिट्टी इत्यादि में प्रचुर मात्रा में स्थूलबीजाणु, सूक्ष्मबीजाणु, शंकुधर वृक्षों के पराग कण, डाइनोफ्लेजिलेट सिस्ट तथा *बॉट्रीओकोक्कस* शैवाल की कालोनी प्राप्त हुए हैं। इस शैल समूह के तलछट में दो प्रकार के परागाणु समुच्चयों की पहचान की गई है, उदाहरणस्वरूप बुनियादी तलछट में *मिनेरीस्पोराइटिस कचेन्सिस* स्थूलबीजाणु समूह में समाहित सामान्यतः शाकमय वनस्पतियां जो प्रारंभिक डेल्टा के दलदल में निवास करतीं थीं, प्राप्त हुई है। इस शैल समूह के उत्तरवर्ती तलछट भाग में *एरोकेरियासाइटिस ऑस्ट्रेलिस* परागाणु समुच्य में समाहित शंकुधर प्रभुत्व वाले वृक्षों के वन का जो अलवणित जल वाले दलदल में वास करते थे तथा अति नम एवं गर्म समशोष्ण जलवायु में विकसित हुए। दोनों परागाणु समुच्चयों से संबंधित वनस्पतियों का अत्यन्त जैवस्तरिक महत्व है, जो इन तलछटों की उत्पत्ति को विलंब एप्टियन से प्रारंभिक एल्बियन काल की तरफ इंगित करते हैं। भुज शैलसमूह के उत्तराधिकार तलछट से प्राप्त अधिकांश परागाणु वनस्पतियां दक्षिणी गोलार्द्ध के अन्य गोंडवाना महाद्वीपों में पाये जाने वाली समकालीन तलछट अवसादों से प्राप्त परागाणु वनस्पतियों से समानता दर्शाती है।

**सूचक शब्द**—परागाणुस्तरिकी, पुरापारिस्थितिकी, पुराजैवभूगोल, प्रारंभिक क्रिटेशस, कच्छ, भारत।

## INTRODUCTION

Early Cretaceous epoch is recognized for the most fundamental changes in the Mesozoic terrestrial ecosystem and diversification of terrestrial plants in India. During this time Indian subcontinent was in the process of separation from the Gondwana land and moving toward the Asia (Norton & Sclater, 1979; Biswas, 1987; Parrish, 1993). The drifting processes led to create passes of shorelines between the adjoining Gondwanic continents and bringing out changes in palaeoecological and environmental conditions, caused diversification in flora and fauna (Krassilov, 2003). Thus, a majority of spores, pollen grains and dinoflagellate cysts recorded from India and other adjacent continents are significant in establishing an intercontinental palynofloral relationship. Amongst them, some fossil plants show restricted distribution because they evolved independently in the individual continent (McLoughlin, 2001).

A rich and diverse megafloral remains have been documented from Bhuj Formation of the Kachchh Basin by Banerjee *et al*. (1984) and Bose & Banerjee (1984). These fossil floras are significant in understanding geological history of the basin and developing concepts of the floral relationship with other Gondwana continents. The Early Cretaceous palynological study of the basin began about half–century ago, when Singh *et al*. (1964) first reported spores and pollen grains from the Bhuj Formation. Later, Venkatachala (1967, 1969a, b), Venkatachala & Kar (1970) and Banerjee *et al*. (1984) focused mainly on descriptions of the fossil palynomorphs. Maheshwari & Jana (1987) outlined a broad palynozonation (*Araucariacites australis* zone) by combining Jhuran (Late Jurassic) and Bhuj (Early Cretaceous) formations. In the present study, recognition of finer palynozonations in the Bhuj Formation is much helpful in defining precise palynostratigraphic details and changes in depositional and topographical conditions during development and succession of the vegetation. A change in the abundances of pteridophytic microspores, megaspores and gymnosperm pollen grains explain thriving of herbaceous and arboreal flora in different habitats of the basin.

During the present study, two palynozones have been proposed. The *Minerisporites cutchensis* palynozone, recognized in the basal part of the section includes many megaspores, microspores and dinoflagellate cysts. The upper *Araucariacites australis* zone contains abundant conifer pollen grains and pteridophytic spores. Palynoassemblage of these two palynozones is significant, because (i) it provides an understanding of the Aptian–Albian marginal marine and terrestrial ecosystems, which controlled distribution, development and succession of the vegetation situated along the coastal regions of the basin; and (ii) a majority of palynotaxa represented in contemporaneous deposits of other continents, once were part of the United Gondwana.

## GEOLOGICAL SETTING

Kachchh (also spelled Kutch) Basin covers a vast land area of about 43,000 square km in Gujarat State of the western India. The western border of the basin extended to the Pakistan and Arabian Sea, while eastern to the Rajasthan State of India. Bhuj Formation of the basin comprises youngest Gondwanic deposits bearing paralic and non–marine sedimentary successions at various places in the Kachchh District (Biswas, 1977, 1980, 1982). The western margin of the basin developed due to early syn– and post–rifting phases, consequent to which a series of local and regional horsts and grabens came into existence. These events gave rise to unique geological settings at land and offshore regions (Biswas, 1982). Approximately 1500–2500 m Mesozoic and about 550 m thick organic–rich Cenozoic sediments on land, and up to 4500 m thick Tertiary sediments in the offshore regions filled the grabens. Mesozoic sediments comprised mainly of rift fill by non–marine sediments in the late Triassic, fluvial–deltaic during the middle to late Jurassic transgressive, and by regressive phases during latest Jurassic (Tithonian) to Early Cretaceous (Biswas, 1987, 1999, 2002).

Biswas (1977) categorized various formations in sedimentary sequences of the basin. These are, (i) mainland–consisting Jurio (Bathonian–Callovian), Jumara (Callovian–Oxfordian), Jhuran (Kimmeridgian–Neocomian) and Bhuj (Neocomian–Albian); (ii) Pachham Island (Bathonian and Late Callovian) and (iii) Eastern Kachchh consisting of Khadir (Bathonian–Oxfordian), Wastava (Argonian) and Wagad (Kimmeridgian–Neocomian). Further, Biswas (1991) included early Cretaceous sediments in the Bhuj Formation by incorporating three members, viz. Upper (Albian), Ukra (Aptian) and Lower Member (Neocomian). At the last stage of the Cretaceous probably during ~66–65 Ma, the eruptions of continental flood basalts of Deccan Traps covered large tracts in the central and western India. The intense magmatic activities, intruding, filling of dykes, sill, plugs, laccoliths and ring dikes affected Mesozoic sediments at various places in the basin (Ray *et al*., 2006; Paul *et al*., 2008).

The studied sedimentary successions of Bhuj Formation outcropped along the Pur River near Trambau Village (23º18'–20' N: 69º43'–44' E, Δ 35–60 m above the mean sea level) is situated 22 km north of the Bhuj Town (Fig. 1). These deposits contain rhythmics of sandstone, cross–bedded ripple marked shale, irregular thin coal beds and thin lenses of limestone in the lower part and carbonaceous shale, grey shale, clay and siliceous clay bands containing fragmentary megafloral remains in the upper part of the succession.

## MATERIAL AND METHODS

Sixty samples were collected approximately at the interval of 15 cm from 25.5 m thick section exposed along

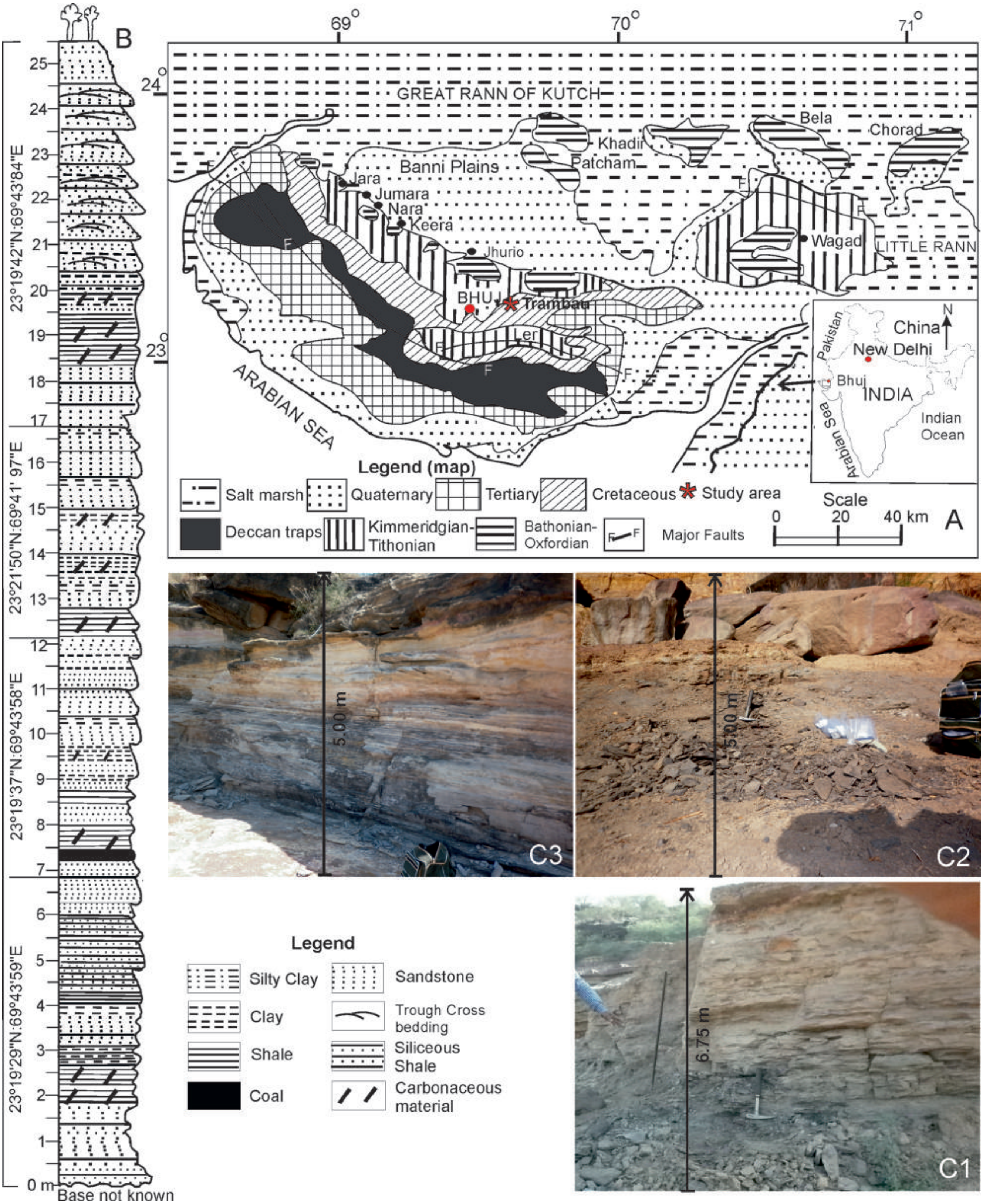


Fig. 1—A. Geological map showing location of the study area in Kutch (partially modified after Fürsich *et al.*, 1991), B. Litholog of the studied succession, C. Images of the Early Cretaceous sedimentary successions exposed along Pur River near Trambau Village at the locations C1–23º19'37" N: 69º43'58" E, C2–23º21'50" N: 69º41'97" E, C3–23º19'42" N: 69º43'84" E.

Pur River near a mining site of the Trambau Village, Kachchh for palynological analysis. Standard procedure was followed to avoid contamination during collection of samples. The position of samples is shown in Fig. 1. To isolate various palynomorphs types from the collected samples, techniques proposed by Brown (1960) and Batten & Morrison (1983) were followed. About 50 grams of samples were crushed with hammer (< 2 mm grain size) and treated with dilute hydrochloric acid for 18 hours in the plastic containers for dissolving traces of carbonates. After neutralization of the acidic medium with water and decantation thereafter, 30–40 ml of 30% hydrofluoric acid was added to dissolve siliceous contents. Dilute nitric acid (30%) was used for digestion of humic ingredients. The acid free digested materials were treated with 3–4% aqueous solution of potassium hydroxide for two–three minutes and the liberated residues were sieved through 500–mesh strainer. The collected residue was smeared on glass coverslips after mixing with few drops of concentrated polyvinyl alcohol solution and dried at room temperature. The coverslips were mounted permanently on the glass slides with Canada balsam and dried in oven at 70ºC for 4–5 days. Out of 60 samples 24 were found to be rich in having microspores, megaspores, pollen grains and dinoflagellate cysts, etc. The frequency of palynoflora was determined by counting approximately 200 palynotaxa in slides made for each productive sample. Stratigraphic distribution of the recovered palynoflora and their frequency in sedimentary succession is shown in the Fig. 2. Morphological detail of a newly recorded species is described in the morpho–taxonomy section. Slides containing the palynomorphs illustrated in plates along with their location in England finder are housed in the repository of Birbal Sahni Institute of Palaeosciences, Lucknow.

## Morphotaxonomy of new species

**Genus—MINERISPORITES** Potonié 1956 emend. Batten & Koppelhus 1993

**Type species—*Minerisporites (Selaginellites) mirabilis*** (Minor) Potonié 1956

***Minerisporites trambauensis*** sp. nov.

(Pl. 2.12–15)

*Holotype*—Pl. 2.14 slide no. 15707.

*Paratype*—Pl. 2.12, slide no. 15708.

*Specimens studied*—8.

*Type locality and horizon*—Trambou, Kachchh, Bhuj Formation, Aptian–Albian.

*Etymology*—The specific epithet '*trambauensis*' refers to the fossil plant locality Trambau Village near the Bhuj Town, Kachchh.

*Diagnosis*—Trilete megaspore, triangular to sub–triangular, subcircular in proximal/distal views, size 350–435 µm. Mesospore, exospores and perispore distinct, outer margin of the spore auriculate. Laesurae thick, straight to sinuous, reaches up to apices. Ornamentation microreticulate to infra–reticulate.

*Description*—Megaspores amb convexly sub–triangular to sub–circular. Equatorial diameter of spore body 360–435 µm including auriculae. Trilete mark prominent, triradiate, rays straight or sinuous, evenly extends to the outer margin of the zona, height of triradiate lamellae 5–18 µm. Spore wall distinctly layered. Three principal layers–perisporium, exosporium and mesosporium discernible. Mesosporium prominent, triangular to subcircular, entirely attached with exosporium. Exosporium reticulate, more or less circular, forming central body of spores and covered by perisporium.

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**PLATE 1**

(Scale bar–20 µm, otherwise mentioned) →

1. *Cyathidites australis* Couper, slide no. 15687, V23.
2. *Cyathidites grandis* Singh, Srivastava & Roy, slide no. 15684, S49.
3. *Dictyosporites complex* Cookson & Dettmann, slide no. 15685, U32.
4. *Biretisporites spectabilis* Dettman, slide no. 15686, J31.
5. *Deltoidospora* sp. slide no. 215683, N38.

6–7. *Dictyophyllidites* sp., slide nos. 15688, M18; 15695, N38/2.

8–9. *Gleichenidites senonicus* (Ross) Skarby, slide nos. 15689, V44; 15690, F33.

10. *Concavissimisporites kutchensis* Venkatachala, slide no. 15691, F39/4.

11–12. *Concavissimisporites variverrucosus* Delcourt, Sprumont & Mc Keller, slide nos 15692, U15; 15693 E17/3.

13. *Concavissimisporites* sp., slide no. 15683, N7.
14. *Foraminisporis assymmetricus* (Cookson, Dettmann), Dettmann, slide no. 15688, S40/2.
15. *Striatella* sp., slide no. 15694, G47/3.
16. *Cooksonites variabilis* Pocock slide no. 15692, S11.
17. *Retitriletes nodosus* (Dettmann) Srivastava, slide no. 15696, M44/2.
18. *Bacularetictulosporites cutchensis* Singh, Srivastava & Roy, slide no. 15696, J45.
19. *Contignisporites glebulentus* Dettmann, slide nos 15695, L46/2.
20. *Crybelosporites striatus* (Cookson & Dettmann) Dettmann, slide no. 15697, E24.
21. *Lycopodiumsporites nodosus* Dettmann, slide no. 15698, U22/3.
22. *Lycopodiumsporites austroclavatidites* Cookson, slide no. 15699, L33/1.
23. *Lycopodiumsporites* sp., slide no. 15695, K12/4.
24. *Leptolepidites major* Couper, slide no. 15690, O33.
25. *Asterisporites chlonovae* Venkatachala & Rawat, slide no. 15695, R36/1.
26. *Taurocusporites segmentatus* Stover, slide no. 15700, J42.
27. *Inaperturopollenits turbatus* Balme, slide no. 15701, S46/4.

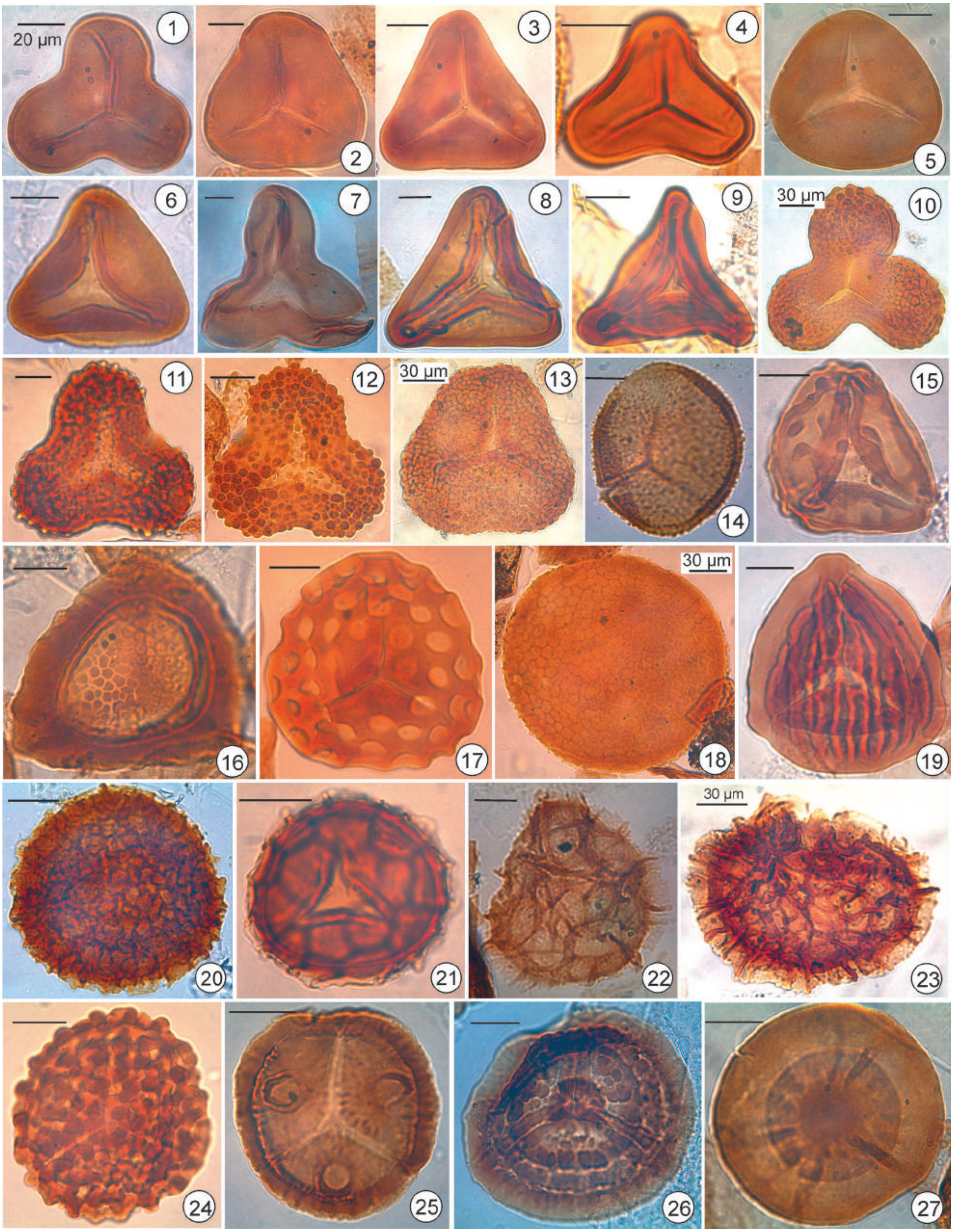
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**PLATE 1**

Perispore distinctly microreticulate, muri 3–4 µm thick in central region and 1.5–2.0 µm towards the periphery. Luminae diameter 4–5 µm at central part and 5–10 µm towards the zona. Zona covers entire spore body, 20–70 µm wide, wavy to smooth, more extensive at the end of apices, infra–reticulate, sometimes weakly striate, poorly projected towards the apices, sometimes folded to make spores sub–triangular in shape.

*Comparison*—*Minerisporites alius* Batten (1969) differs from the present species, because of indistinct mesosporium. *Minerisporites institus* Marcinkiewicz (1960) shows well–developed tri–radiate flange, while *M. lacerates* Archangelsky & Villar de Seoane (1990) represents broadly reticulate mesosporium and small auriculae at the end of lasurae. *Minerisporites cutchensis* and *M. auriculatus* Singh *et al*. (1964) differ from the present species due to absence of mesosporium and indistinct zona. *Minerisporites dharensis* Banerjee *et al*. (1984) does not resembles the present species because of bearing nipple like protuberances at the end of rays. *Minerisporites mirabilis* (Minor), Potonié (1956) differs in having reticulated spore body, relatively narrow zona and triangular shape. *Minerisporites alius* Batten (1969) differs because of showing relatively thin zona and robust lasurae. The present species is also differs from *Minerisporites glossoferum* (Dijkstra) Tschudy (1976) in having irregular exinal reticulation with 4–8 µm thick muri and wide luminae. *Minerisporites pseudorichardsoni* Gunther and Hills (1972) also differs due to elongated lasurae, striate zona and projection of muri on the reticulations of exosporium.

## LIST OF RECORDED PALYNOTAXA

### PTERIDOPHYTES

#### Microspores

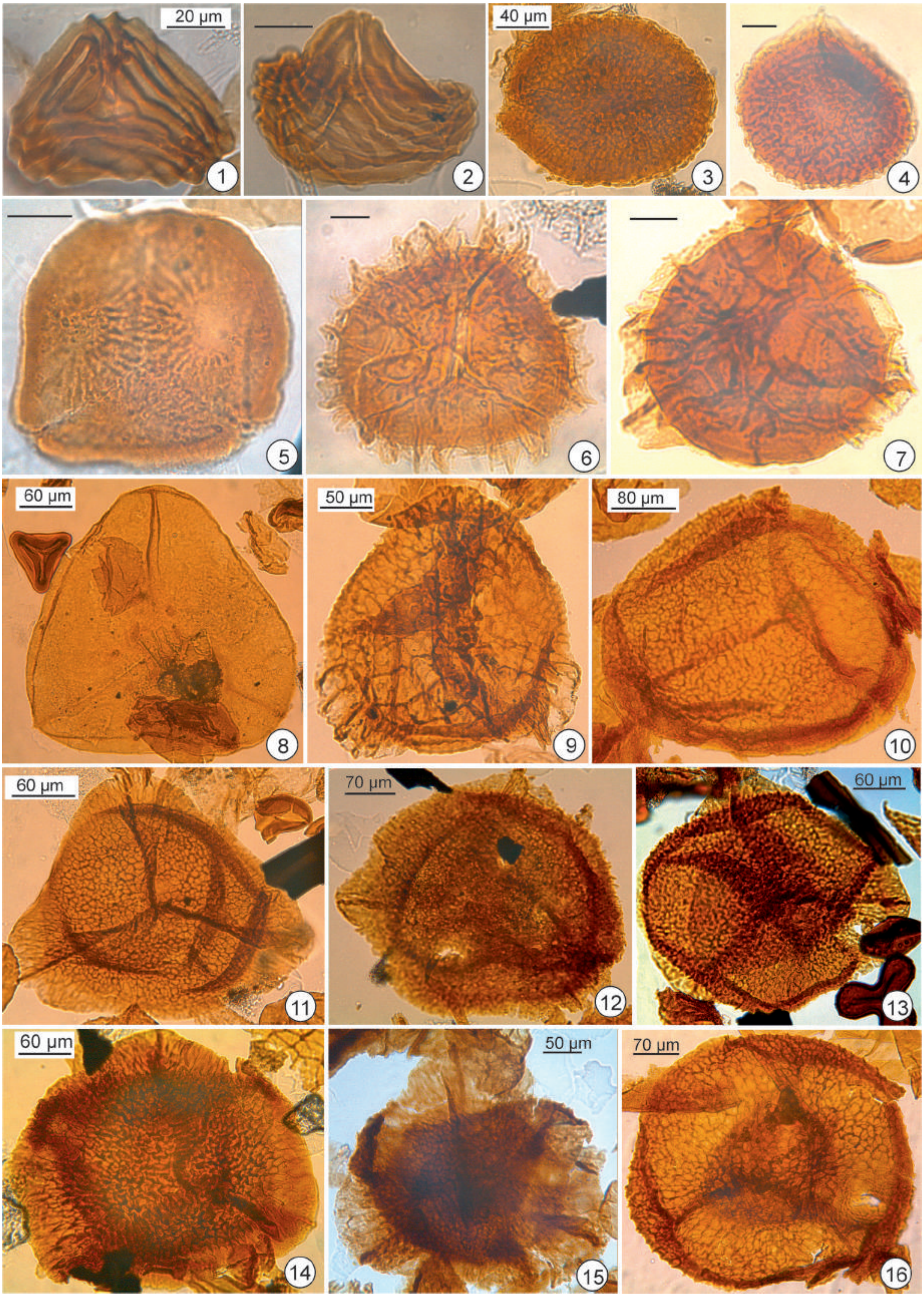
*Asterisporites chlonovae* Venkatachala & Rawat
*Bacularericulosporites cutchensis* Singh, Srivastava & Roy
*Biretisporites spectabilis* Dettmann
*Cicatricosisporites ludbrooki* Dettman
*Concavissimisporites kutchensis* Venkatachala
*Concavissimisporites variverrucosus* Delcourt, Sprumont & McKeller
*Concavissimisporites* sp.
*Contignisporites glebulentus* Dettmann
*Crybelosporites striatus* (Cookson & Dettmann) Dettmann
*Cyathidites australis* Couper
*Cyathidites grandis* Singh, Srivastava & Roy
*Dictyosporites complex* Cookson & Dettmann
*Dictyophyllidites* sp.
*Foraminisporis assymmetricus* (Cookson & Dettmann) Dettmann
*Gleichenidites senonicus* (Ross) Skarby
*Inaperturopollenits turbatus* Balme
*Lycopodiumsporites austroclavatidites* Cookson
*Lycopodiumsporites nodosus* Dettmann
*Lycopodiumsporites solidus* Burger
*Cooksonites variabilis* Pocock
*Leptolepidites major* Couper
*Retitriletes nodosus* (Dettmann) Srivastava
*Schizosporis reticulates* Cookson & Dettmann
*Taurocusporites segmentatus* Stover
*Striatella* sp.

#### Megaspores

*Ancorisporites* sp.
*Minerisporites alius* Batten
*Minerisporites auriculatus* Singh, Srivastava & Roy
*Minerisporites cutchensis* Singh, Srivastava & Roy
*Minersporites institus* Marcinkiewicz
*Minerisporites reticulates* (Singh *et al*.) Banerjee, Jana & Maheshwari
*Minerisporites trambauensis* sp. nov.
*Minerisporites venustus* Singh
*Minerisporites* sp. A
*Minerisporites* sp. B
*Paxillitriletes battenii* Banerjee, Jana & Maheshwari
*Paxillitriletes fairlightensis* (Dijkstra) Potonié
*Paxillitriletes maheshwarii* Jana & Ghosh
*Valvisisporites minor* Singh, Srivastava & Roy

**PLATE 2**
(Scale bar–20 µm, otherwise mentioned) →

1–2. *Cicatricosisporites ludbrooki* Dettmann, slide nos. 15702, W19; 15703, M35/4.
3–4. *Crybelosporites striatus* (Cookson & Dettmann) Cookson, slide nos 15694, R 49/1; 15702, W35.
5. *Asterisporites chlonovae* Venkatachala & Rawat, slide no. 15704, U42/1.
6–7. *Lycopodiumsporites austroclavatidites* Cookson, slide nos 15694, X31; 15702, N28.
8. *Valvisisporites minor* Singh, Srivastava & Roy, slide no. 15705, O47/1.
9. *Minerisporites reticulates* (Singh *et al*.) Banerjee, Jana & Maheshwari, slide no. 15690, F22/1.
10, 16. *Minerisporites cutchensis* Singh, Srivastava & Roy, slide nos 15697, F32/1; 15708, G47/1.
11. *Minersporites institus* Marcinkiewicz, slide no. 15690, O29/1.
12–15. *Minerisporites trambauensis* sp. nov., slide nos 15708, J11; 15706, O42/1; 15707, R35; 15713, N26/4.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50 µm
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70 µm
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**PLATE 2**

### GYMNOSPERMS

*Alisporites grandis* (Cookson) Dettmann
*Araucariacites australis* Cookson
*Callialasporites dampieri* (Balme) Sukh–Dev
*Callialasporites barragaonensis* Srivastava
*Callialasporites trilobatus* (Balme) Sukh–Dev
*Callialasporites* sp.
*Classopollis classoides* Pflug, emend. Pockock & Jansonius
*Cycadopites grandis* De Jercy & Hamilton
*Podocarpidites ellipticus* Cookson
*Tsugaepollenites* sp.

### ANGIOSPERMS

*Liliacidites* sp.

### DINOFLAGELLATE CYSTS AND OTHER ALGAL REMAINS

*Coronifera oceanica* Cookson & Eisenack
*Oligosphaeridium patulum* Riding & Thomas
*Oligosphaeridium pulcherrimum* (Deflendre & Cookson) Davey & Williams
*Prolixosphaeridum parvispinosum* (Deflendre) Davey *et al.*
*Stiphrosphaeridium anthophorum* (Cookson & Eisenack) Lentin & Williams
*Botryococcus braunii* Krützsch

## RESULTS

Diverse and well–preserved palynomorphs of the different plant groups obtained from 24 productive samples of the studied sedimentary successions are very significant for assessing age, stratigraphic distribution of palynotaxa, palaeoecological and palaeovegetational interpretations. Palynoassemblage constituted by different plant groups comprise 20 genera and 25 species of pteridophytic microspores, 4 genera and 14 species of megaspores, 7 genera and 10 species of gymnosperm pollen grains and 4 genera and 5 species of dinoflagellate cysts. Colonies of *Botryococcus braunii* and angiosperm pollen grains *Liliacidites* sp. are also represented in the palynoassemblage. Colours of the palynomorphs ranging from light yellow to orange and light brown indicating low palynomorph thermal maturation during their burial (Pls. 1–4) in the sediments of Bhuj Formation. The palynotaxa represented with more than one percent in the assemblage are shown in the Fig. 2.

### Palynostratigraphy

Occurrence of different palynotaxa in various strata of the sedimentary succession indicates their abundances and depicts palynostratigraphic information of the Bhuj Formation. Based on the quantitative distribution and overwhelming representation of significant genera and species two palynozones are recognized. The lowermost strata lying between 0–6.75 m intervals of the 25.5 m thick sedimentary succession contain large numbers of megaspores dominated by the *Minerisporites cutchensis*. The overlying sediments between 6.80–25.5 m exhibit a variety of conifer pollen grains and pteridophytic spores dominated by pollen grains of *Araucariacites australis*. A total 56 palynotaxa recorded from the studied horizon are mentioned in the list of taxa. Details of two palynozones are given as under:

#### ***Minerisporites cutchensis*** Palynozone

*Type section*—Lower part of the Trambau section exposed along Pur River, Kachchh District, Gujarat.

*Lithology*—This palynozone recognized at basal part (between 0–4.5 m) of the section, which consists of fine–grained sandstone, clay, grey shale, carbonaceous shale and siliceous shale. The carbonaceous shale (0.75 cm) and overlying clay (0.25 cm thick) yielded abundant megaspores, microspores, conifer pollen grains, dinoflagellate cysts and colonial alga *Botryococcus braunii* (sample no. 1–5).

*Palynotaxa of the zone*—The palynozone comprises *Cyathidites australis*, *C. grandis*, *Biretisporites spectabilis*, *Dictyosporites complex*, *Deltoidospora* sp., *Concavissimisporites variverrucatus*, *C. kutchensis*, *Foraminisporis assymmetricus*, *Lycopodiumsporites austroclavatidites*, *L. nodosus*, *Retitriletes nodosus*, *Cicatricosisporites ludbrooki*, *Asterisporites chlonovae*, *Taurosporites segmentatus*, *Valvisporites minor*, *Minerisporites cutchensis*, *Minerisporites institus*, *M. trambauensis*, *M. auriculatus*, *Paxilitriletes maheshwarii*, *Araucariacites australis*, *Callialasporites dampieri*, *C. trilobatus*, *C. barragoanensis*, *Tsugaepollenites* sp., *Cycadopites grandis* and *Botryococcus braunii*. Taxa showing first and last appearance in this cenozone are–*Minerisporites auriculatus*, *M. trambauensis*, *Paxillitriletes fairlightensis*, *P. battenii* and *Spermatites* sp. Dinoflagellate cysts are represented by *Oligosphaeridium patulum, O. pulcherrimum*, *Prolixosphaeridium parvispinosum*, *Stiphrosphaeridium anthophorum* and *Coronifera oceanica*. Singh *et al*. (1964) and Banerjee *et al*. (1984) also recorded *Minerisporites cutchensis*, *Paxilitriletes battenii* and *Valvisporites minor* from sediments of the Bhuj Formation exposed in western regions of the Kachchh Basin.

This megaspore palynozone comprises dinoflagellate cysts *Coronifera oceanica* and *Oligosphaeridium pulcherrimum*, also recorded from other Aptian–Albian sediments of India (Garg *et al*., 1987), Australia (Burger, 1980; Helby & McMinn, 1992) and Africa (Below, 1984). Their first and last appearances in the basal part of the succession exhibit their burial during late Aptian–Albian marine regression in the lowland areas of north western part of the basin. Occurrence of

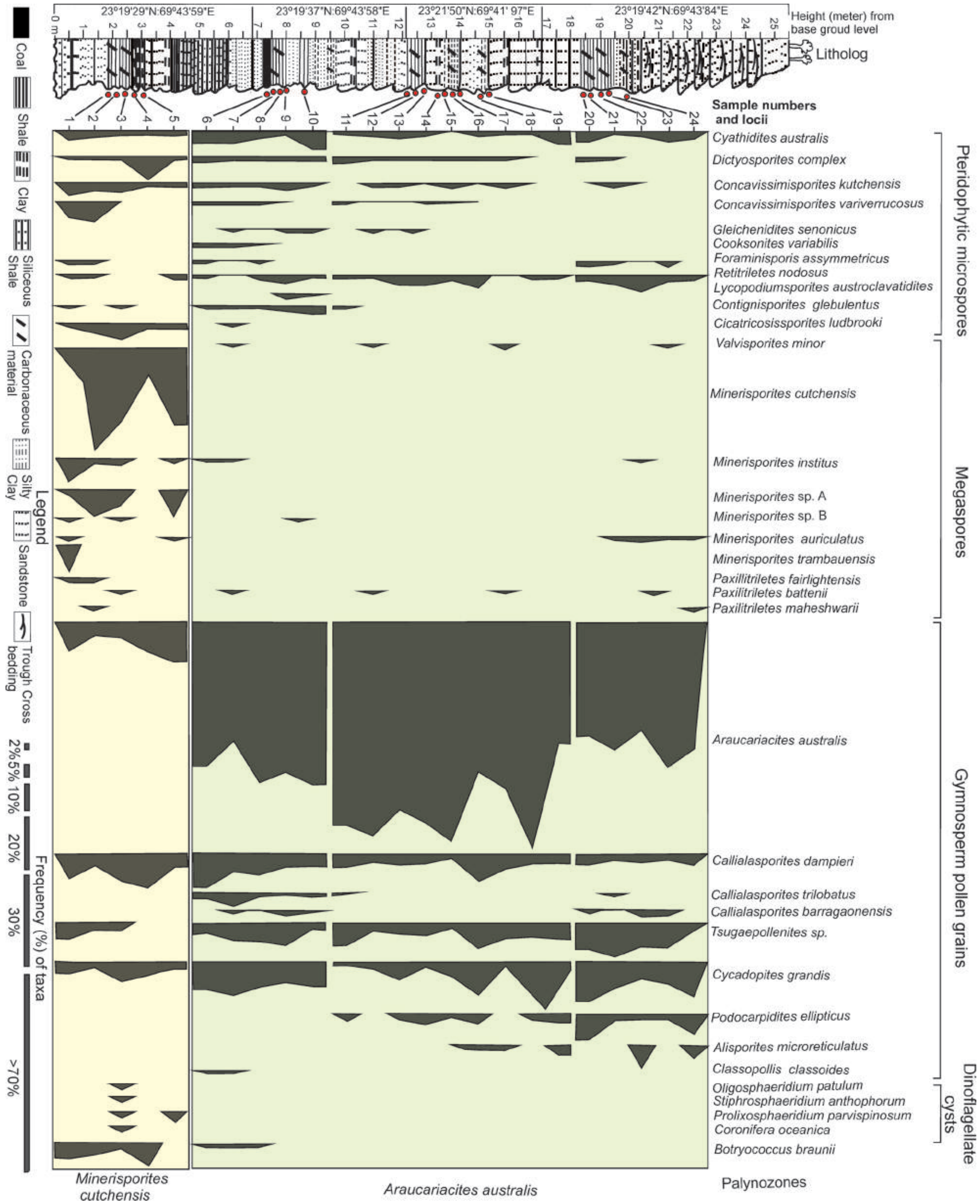


Fig. 2—Palynomorph distribution and palynozonations in the sedimentary succession of Bhuj Formation, Kachchh Basin.

a large number of pteridophytic microspores, megaspores and colonial alga *Botryococcus braunii* with some conifer pollen grains exhibit growth of rich herbaceous pteridophytes with a few arboreal conifers along the swampy hinterland situated at the vicinity of the coast.

### ***Araucariacites australis*** Palynozone

*Type section*—Middle and upper part of the Trambau section exposed along Pur River, Kachchh District, Gujarat.

*Lithology*—This palynozone is recognized in the middle part to top (6.80–13.0 m) of the section comprising 6–10 cm thick coal seam, variably thickened carbonaceous shale (0.4–1.5 m), grey shale, clay, fine siliceous clay and fine to medium coarse–grained sandstone (sample no. 6–24).

*Palynotaxa of the zone*—*Araucariacites australis* palynozone comprises rich pollen grains of *Araucariacites australis*, *Callialasporites dampieri*, *C. trilobatus, C. barragaonensis*, *Alisporites grandis*, *Tsugaepollenites* sp., *Classopollis classoides* and *Cycadopites grandis*. Taxa continuing from the lower *Minerisporites cutchensis* palynozone are–*Cyathidites australis*, *Concavissimisporites variverrucatus*, *C. cutchensis*, *Foraminisporis assymmetricus*, *Cicatricosisporites ludbrooki*, *Contignisporites glebulentus*, *Dictyosporites complex*, *Lycopodiumsporites nodosus*, *L. austroclavatidites*, *Minerisporites cutchensis*, *M. institus*, *M. alius, Paxillitriletes battenii*, *P. maheshwarii*, *Valvisporites minor*, *Callialasporites trilobatus*, *C. barragoanensis*, *Cycadopites grandis*, *Tsugaepollenites* sp. and *Botryococcus braunii*. The taxa appeared in this zone are–*Cooksonites variabilis*, *Gleichenidites senonicus*, *Contignisporites glebulentus*, *Callialasporites* spp., *Podocarpidites ellipticus* and *Alisporites grandis*. The araucarian pollen grains (*Araucariacites australis*, *Callialasporites* spp.) showing dominance in this part of the horizon (Fig. 2), indicate replacement of the plant assemblage from costal swampy herbaceous pteridophytes to the mixed arboreal conifers at the terrestrial habitat.

Both the palynozones indicate presence of heterosporous ferns and conifer dominated vegetation during the deposition of 25.5 m thick sedimentary succession. Representation of various floral groups and their abundances in Bhuj Formation of the Kachchh Basin is given in Figs 2, 3.

## REGIONAL AND GLOBAL PALYNOFLORAL RELATIONSHIP

A majority of Palaeozoic to mid–Mesozoic plant fossils recorded from various Gondwanic continents establish their inter–relationship (Medlicott, 1872; Wadia, 1944; Metcalfe, 1994; McLoughlin, 2001). After break–up of the Gondwana, several oceanic crusts and seaways were created in between the adjacent continents (Fig. 4). The separation of Indian subcontinent possessed transgressive–regressive events in its entire peninsular region, which caused considerable changes in the coastal marine and terrestrial depositional environments during Late Jurassic–Early Cretaceous (Biswas, 1999). The landmasses of nearby continents, viz. northwestern Australia, North Antarctica, southeastern Africa and South America, which were close to the Indian peninsula also had similar climate, favoured growth of similar plants (McLoughlin, 1996, 2001). Earlier plant fossil records from Kachchh (Banerjee *et al*., 1984) and another part of the southern hemisphere prove that a majority of identical plants were growing simultaneously in these Gondwanic continents (Vakhrameev, 1991). Additionally, many endemic taxa were also thrived here (Herngreen *et al*., 1996; McLoughlin, 2001). Record of endemic species in a particular sedimentary basin is significant for understanding its origin and development in a regional environment. Occurrence of such endemic species are much significant in differentiating the floral kingdom of a specific continent (Zhou & Momohara, 2005). In spite of some floral dissimilarities, a large number of palynoflora which are commonly recorded from the Early Cretaceous deposits of India, Australia, Antarctica, Argentina, Brazil and Africa (Fig. 4), are enumerated as under:

### Indian basins

#### *Satpura Basin*

Some palynotaxa, viz. *Contignisporites cooksonii*, *Dictyosporites* complex, *Retitriletes* sp., *Araucariacites australis*, *Callialasporites* spp., *Alisporites grandis* in the *Araucariacites–Callialasporites–Cycadopites* assemblage zone of Hathnapur, Khatma caves, Moraghat, Lametaghat, etc. (Kumar, 1993, 1994) and Sher River section of the Central India (Kumar, 2011) are also represented in the Kachchh Basin.

**PLATE 3**

(Scale bar–50 µm, otherwise mentioned) ⟶

1–3. *Minerisporites venustus* Singh, BSIP slide nos 15709, P34/1; 15710, S35; 15711, O32/1.
4. *Minerisporites* sp. A, slide no. 15712, F41.
5–6. *Paxillitriletes fairlightensis* (Dijkstra) Potonié, slide nos 15713, H36/1; 15712, Q35.
7. *Minerisporites* sp. B., slide no. 15707, R25/3.
8–9. *Paxillitriletes maheshwarii* Jana & Ghosh, slide nos 15707, S25, 15690, H35/1, 15698, K20/2.
10–11. *Minerisporites auriculatus* Singh, Srivastava & Roy, slide nos 15688, G38/4; 15694, S9.
12. *Paxillitriletes battenii* Banerjee, Jana & Maheshwari, slide no.15714, P45.

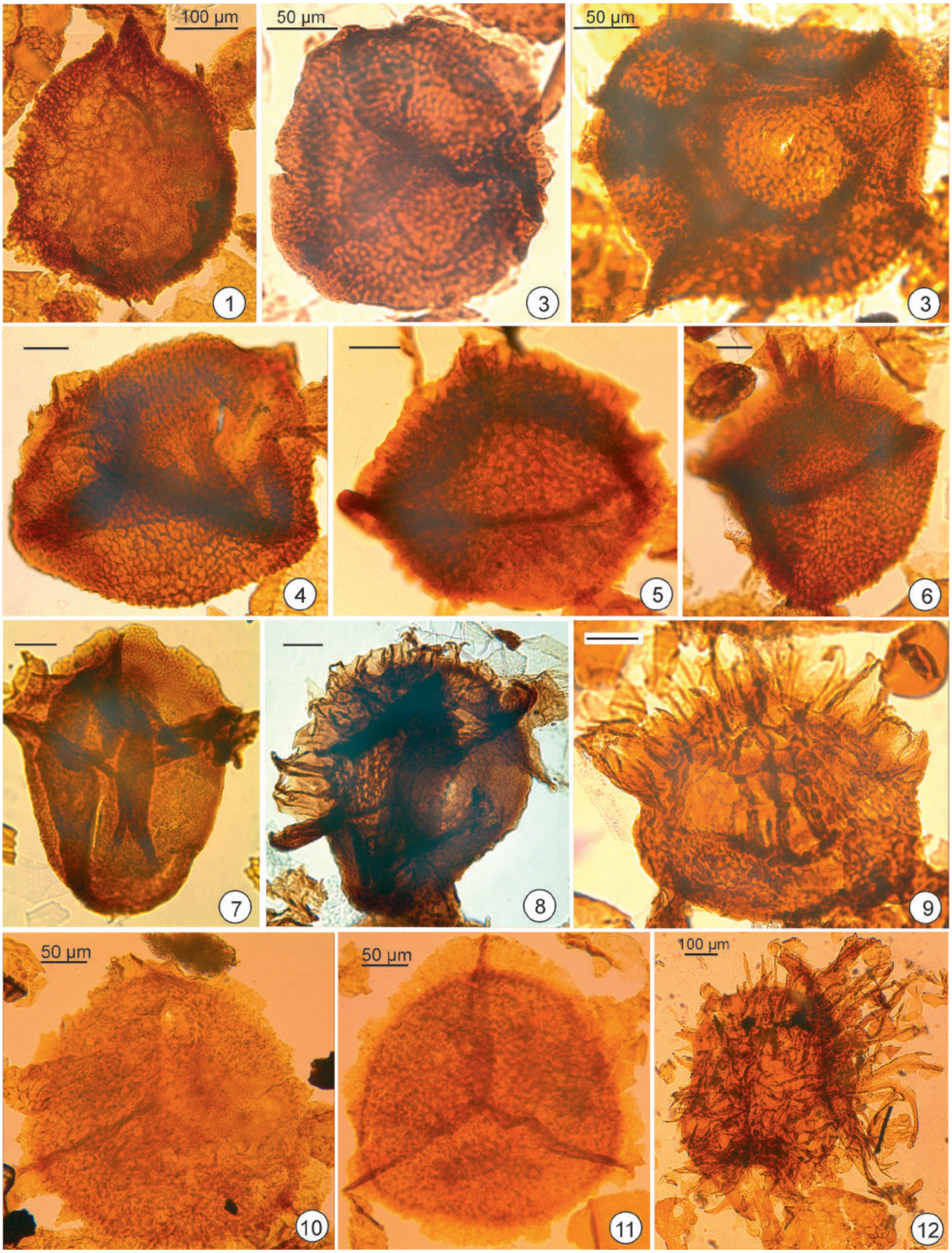


**PLATE 3**

*Mahanadi Basin*

Maheshwari (1975) and Goswami *et al*. (2008) recorded some palynotaxa from the Athgarh Formation. Some spores and pollen grains, viz. *Cyathidites australis*, *Cicatricosisporites ludbrooki*, *Concavissimiporites* spp., *Contignisporites glebulentus*, *Lycopodiumsporites austroclavatidites*, *Araucariacites australis*, *Callialasporites trilobatus*, *C. dampieri*, *Podocarpidites ellipticus*, *Alisporites grandis* and *Classopollis classoides* are also recorded from the Kachchh Basin.

*Rajmahal Basin*

Vijaya & Bhattacharji (2002) and Tripathi (2008) recorded some similar spore–pollen assemblage from Early Cretaceous deposits of Rajmahal, Bihar. They are *Gleichenidites senonicus*, *Cyathidites australis*, *Cicatricosisporites ludbrooki*, *Contignisporites glebulantus*, *Cooksonites variabilis*, *Araucariacites australis*, *Callialasporites dampieri* and *C. trilobatus*.

*Pranhita–Godavari Basin*

Rao *et al*. (1983) and Chinnappa & Rajanikanth (2017) recorded many spore–pollen taxa from Gangapur beds (Neocomian–Aptian) of Pranhita–Godavari Basin. The taxa commonly occur in the Bhuj Formation of the Kachchh Basin are: *Biretisporites spectabilis, Concavissimisporites variverrucosus, Contignisporites glebulentus*, *Cyathidites australis, Gleichenidites senonicus, Cicatricosisporites ludbrooki, Foraminisporis assymmetricus, Lycopodiumsporites austroclavatidites, Alisporites grandis*, *Araucariacites australis*, *Callialasporites dampieri, C. trilobatus, Alisporites grandis* and *Podocarpidites ellipticus.*

**Other late Gondwana basins**

Many pteridophytic micro– and megaspores, araucareans, podocarps and cheirolepid pollen grains, dinoflagellate cysts and colonial alga recorded from Bhuj Formation of the Kachchh Basin, are also represented in contemporaneous deposits of other Gondwanic basins of Australia, Antarctica, Argentina, Brazil and Africa (Fig. 4). Palynotaxa recorded from these continents ascertaining their palaeogeographic distribution in various sedimentary basins are mentioned below:

*Australia*

Abundant spores, pollen grains and dinoflagellate cysts recorded by Balme (1957, 1995), Cookson & Dettmann (1958), Dettmann (1963), Dettmann & Playford (1968, 1969), Burger (1974, 1980), Morgan (1980), Helby *et al*. (1987), Backhouse (1988), Macphail (1999), Sajjadi & Playford (2002a, b) and Wagstaff *et al*. (2012) from Early Cretaceous deposits of various sedimentary basins of Australia are also represented in the contemporaneous deposits of Kachchh Basin. Tosolini *et al*. (2002) recorded rich megaspore assemblages from Early Cretaceous deposits of southeast Australia. Palynofossils which are common in Kachchh and various sedimentary basins of Australia are: *Cyathidites australis*, *Dictyosporites complex*, *Biretisporites spectabilis*, *Concavissimisporites variverrucatus*, *Gleichenidites senonicus*, *Cooksonites variabilis*, *Foraminisporis assymmetricus*, *Lycopodiumsporites nodosus*, *L. austroclavatidites*, *Retitriletes nodosus*, *Cicatricosisporites ludbrooki*, *Contignisporites glebulentus*, *Araucariacites australis*, *Callialasporites dampieri*, *C. trilobatus*, *Alisporites grandis*, *Podocarpidites ellipticus* and *Classopollis classoides*. Helby & McMinn (1992) recorded similar dinoflagellate cysts (*Coronifera oceanica*, *Oligosphaeridium pulcherrimum* and *Prolixosphaeridium parvispinosum*) from site 765, Argo Abyssal plain of the northwest Australia.

*Antarctica*

Some common palynotaxa recorded from the Alexander Island and Mac. Robertson Shelf, Antarctica by Trusswell *et al*. (1999) and Bhuj Formation, Kachchh are:

**PLATE 4**

(Scale bar–20 µm, otherwise mentioned) →

1. *Araucariacites australis* Cookson, slide no. 15691, H19/3.
2–3. *Callialasporites dampieri* (Balme) Sukh–Dev, slide nos 15685, S41/2; 15718, O33.
4. *Callialasporites barragaonensis* Srivastava, slide no. 15719, 034.
5. *Callialasporites trilobatus* (Balme) Sukh–Dev, slide no. 15690, E34.
6. *Tsugaepollenites* sp., slide no. 15684, W17/3.
7. *Classopollis classoides* (Pflug) Pockock & Jansonius, slide no. 15707, W22.
8. *Callialasporites* sp., slide no. 15711, O49/4.
9–10. *Cycadopites grandis* De Jercy & Hamilton, slide nos 5719, J28/1; 15720, R32/3.
11. *Liliacidites* sp., slide no. 15721, E33/3.
12–13. *Prolixosphaeridum parvispinosum* (Deflendre) Davey *et al*., slide nos 15700, D33/4; 15708, S42/3.
14–15. *Oligosphaeridium pulcherrimum* (Deflendre & Cookson), Davey & Williams, slide nos 15710, V27/1; 15708, O32.
16. *Stiphrosphaeridium anthophorum* (Cookson & Eisenack) Lentin & Williams, slide no. 15707, V20.
17. *Coronifera oceanica* Cookson & Eisenack, slide no. 15686, D40.
18. *Alisporites grandis*, slide no. 15722, R44/3.
19. *Podocarpidites ellipticus* Cookson, slide no. 15687, V21/3.
20. *Botryococcus braunii* Krützsch, slide no. 15691, G 18/4.

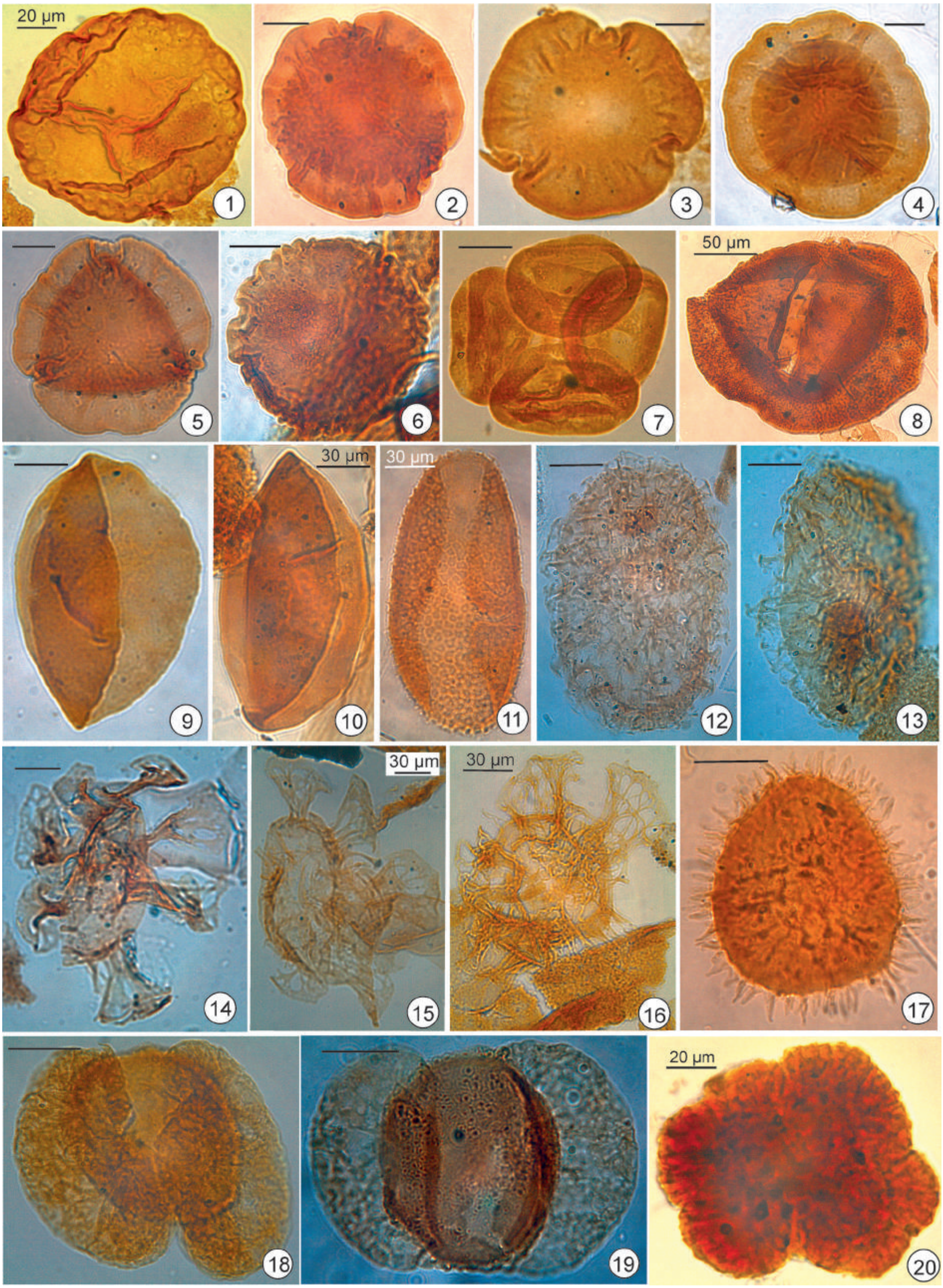
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**PLATE 4**

*Cyathidites australis*, *Concavissimisporites variverrucatus*, *Contignisporites glebulentus*, *Cicatricosisporites ludbrooki*, *Araucariacites australis*, *Alisporites grandis*, *Callialasporites dampieri*, *Callialasporites trilobatus*, *Classopollis classoides*, *Podocarpidites ellipticus* and *Botryococcus braunii*. Mohr (1990) recorded *Gleichenidites senonicus*, *Alisporites grandis*, *Araucariacites australis*, *Callialasporites dampieri*, *Callialasporites* spp. and dinoflagellate cyst of *Prolixosphaeridium parvispinosum* from Early Cretaceous deposits of the DSDP site 692 and 693 at the Weddell Sea, while Torres *et al*. (1997) recorded *Cyathidites australis*, *Contignisporites cooksonii*, *Callialasporites* sp. and *Podocarpidites ellipticus* from the South Shetland Islands. From sediments of the Gustav Group (Aptian) of the James Ross Basin, Riding *et al*. (1998) recorded similar palynoflora comprised of *Contignisporites glebulentus*, *Dictyosporites complex*, *Dictyophyllidites speciosus*, *Dictyophyllidites* sp., *Lycopodiumsporites austroclavatidites*, *Araucariacites australis*, *Podocarpidites ellipticus*, *Alisporites grandis*, *Callialasporites dampieri* and *C. trilobatus* from James Ross Basin.

*Argentina*

Spore–pollen assemblages recorded by Archangelsky & Gamerro (1967) from Lower Cretaceous deposits of Patagonia are also represented in the Kachchh Basin are: *Cyathidites australis*, *Alisporites grandis*, *Araucariacites australis* and *Podocarpidites ellipticus*. Quattrocchio *et al*. (2006) recorded *Cyathidites australis*, *Contignisporites glebulentus*, *Gleichenidites senonicus*, *Concavissimisporites variverrucosus*, *Araucariacites australis*, *Callialasporites dampieri*, *C. trilobatus* and *Podocarpidites ellipticus* from subsurface (Early Cretaceous) section of Tierra del Fuego. Volkheimer *et al*. (2009) recorded *Lycopodiumsporites austroclavatidites*, *Leptolepidites major*, *Araucariacites australis, Callialasporites dampieri*, *C. trilobatus*, *Podocarpidites ellipticus* and *Classopollis classoides* from Early Cretaceous sequences of Cañadón Calcáreo locality of central Patagonia. Loinaze *et al*. (2012) recorded spores of *Cyathidites australis*, *Dictyosporites complex*, *Gleichenidites senonicus* and *Cicatricosisporites ludbrooki* from Early Cretaceous Río Mayer and Kachaike formations of the Austral Basin, southwest Argentina. Representation of *Araucariacites australis* pollen grains and well–preserved leaves of family Araucariaceae in the sedimentary sequences of the Sloggett Formation prove the existence of such gymnosperms during the Cretaceous in Patagonia (Villar de Seoane & Archangelsky, 2008). These authors also recorded many identical megaspores from Kachaike Formation, Patagonia with different names. Guler *et al*. (2013) recorded *Concavissimisporites* sp., *Callialasporites trilobatus* and *Araucariacites australis* from Agrio Formation (Lower Cretaceous) Neuquén Basin. Passalia *et al*. (2016) recorded *Cyathidites australis*, *Gleichenidites senonicus*, *Foraminisporis assymmetricus*, *Cicatricosisporites* spp., *Araucariacites australis*, *Callialasporites trilobatus*, *Alisporites grandis*, *Podocarpidites ellipticus* and *Classopollis* spp. from Aptian of Bajo Grande area, Patagonia.

*Brazil*

Carvalho (2004) recorded some common palynoflora comprised by *Cyathidites, Pilosisporites, Callialasporites* and *Araucariacites* in the palynoassemblage no. 4 and *Prolixosphaeridium* and *Oligosphaeridium* dinoflagellate cysts in palynoassemblage no. 1 from the Aptian–Albian sediments of the Sergipe Basin of north Brazil. Ferreira *et al*. (2016) recorded *Araucariacites australis*, *Callialasporites dampieri*, *Liliacidites* sp. cf. *L. variegates* and *Botryococcus* from the Itapecuru Formation (Lower Cretaceous) of Paranaíba Basin.

*Africa*

Some common spores and pollen grains recorded from Lower Cretaceous deposits of the Algoa Basin, South Africa (Scott, 1976) and Kachchh Basin are: *Cyathidites minor, Contignisporites glebulentus*, *Araucariacites australis*, *Callialasporites dampieri*, *C. trilobatus*, *Alisporites grandis* and *Classopollis classoides*. McLachlan & Pieterse (1978) recorded *Contignisporites glebulentus, Araucariacites australis*, *Podocarpidites ellipticus*, *Coronifera oceanica*, *Oligosphaeridium pulcherrimum* and *Prolixosphaeridium* sp. cf. *P. parvispinosum* from the Lower Cretaceous sediments of Leg 40 of Deep Sea Drilling Project Site 361 at 180 mile southwest of Cape Town, South Africa. These are also represented in the Bhuj Formation. Below (1984) recorded dinoflagellate cysts *Coronifera oceanica* from the Aptian–Albian and *Oligosphaeridium pulcherrimum* from Albian sediments of the Mazagan Plateau, DSDP site 464 and 547 leg 79 of the North West Africa. Eisawi *et al*. (2012) recorded *Gleichenidites senonicus*, *Araucariacites australis* and *Classopollis* sp. in palynozones II and III (Aptian–Albian) in well Azx–1 of the Muglad Basin of Sudan.

## PALYNOFLORAL AGE CONSIDERATION

Sedimentary succession of Bhuj Formation comprises rich palynofloral assemblage, of which a majority of palynomorphs especially dinoflagellate cysts are widely recorded from the Aptian–Albian sediments of other Gondwanic and non–Gondwanic continents. Significant dinoflagellate cyst *Coronifera oceanica* shows its presence in Aptian of the northwest Europe (Costa & Davey, 1992), Ocean Drilling Program (ODP) Leg 101 (Late Albian) of the Bahamas (Masure, 1988) and Albian sediments of Demerara Rise, Equatorial Atlantic (Krauspenhar *et al*., 2014). Ogg

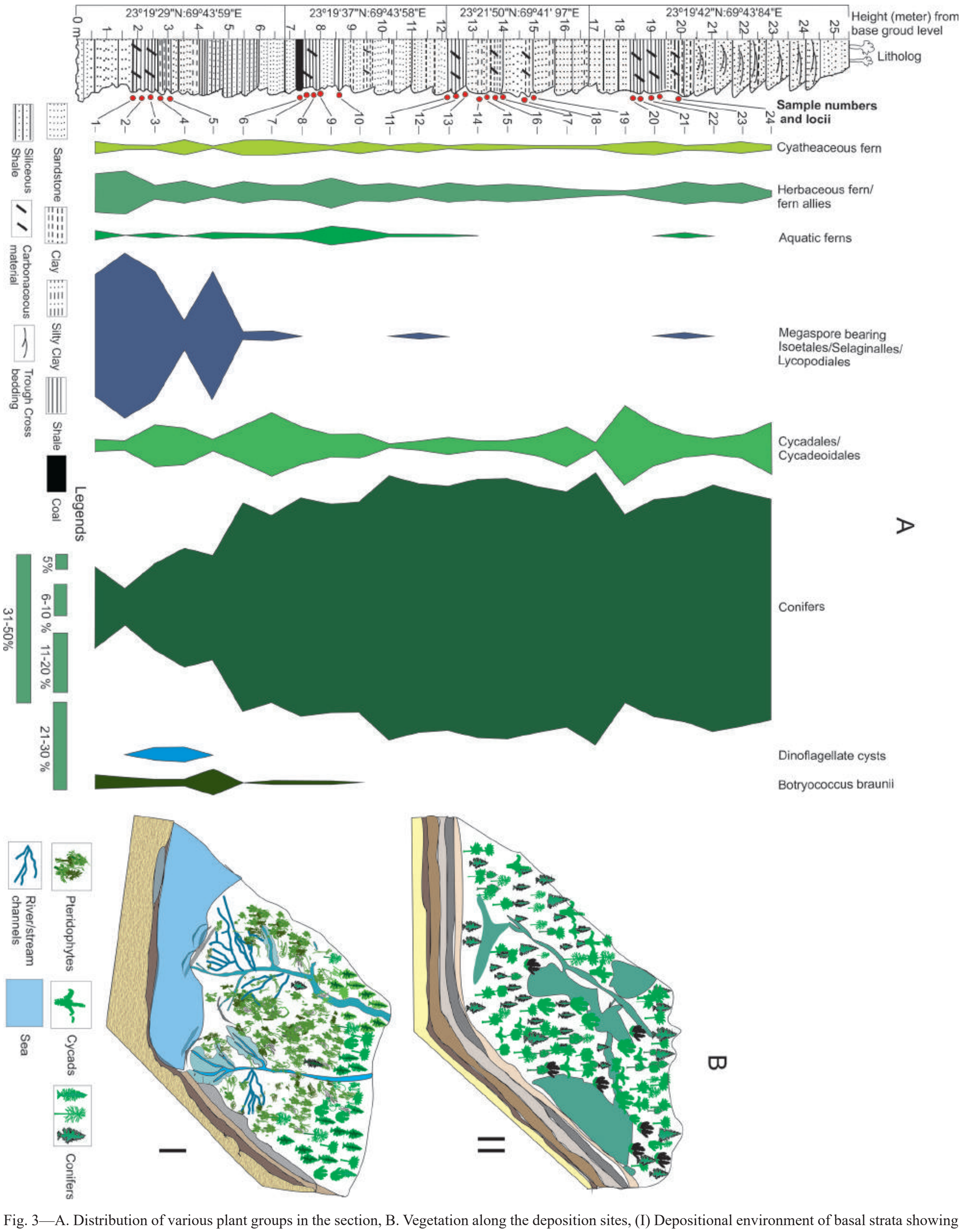


Fig. 3—A. Distribution of various plant groups in the section, B. Vegetation along the deposition sites, (I) Depositional environment of basal strata showing restricted near shore marine tidal flat with riverine channels and coastal marsh/swamp vegetation, (II) Depositional environment of upper strata showing fluvio–lacustrine setups, swamp/marsh and arboreal vegetation.

(1992) recorded dinoflagellate cysts ,viz. *Coronifera oceanica, Oligosphaeridium pulcherrimum*, *Prolixosphaeridium parvispinum* and spores and pollen grains of *Foraminisporis assymmetricus*, *Araucariacites australis* and *Callialasporites dampieri* from the Early Cretaceous sediments of ODP Leg 129 (Sites 800, 801 and 802) and Deep Sea Drilling Project (DSDP) sites 167, 195, 196 and 463 of the western Pacific Ocean. Below (1984 ) recorded *Coronifera oceanica* and *Oligosphaeridium pulcherrimum* from Aptian–Albian beds of the DSDP Leg 79 site 545, Mazagan Plateau, Northwest Africa. Helby and McMinn (1992) recorded *Coronifera oceanica*, *Oligosphaeridium pulcherrimum* and *Prolixosphaeridium parvispinosum* from ODP site 765 (Early Cretaceous) at Argo Abyssal Plain, Australia. Burger (1980) recorded dinoflagellate cysts *Oligosphaeridium pulcherrimum*, *Coronifera oceanica*, spores and pollen grains, viz. *Araucariacites australis*, *Callialasporites dampieri, Podocarpidites ellipticus, Lycopodiumsporites astroclavatidites, Foraminisporis assymmetricus*, *Cicatricosisporites ludbrooki* and *Dictyosporites speciosus* from Lower Cretaceous of the Surat Basin. Garg *et al*. (1987) proposed a stratigraphic range of *Coronifera oceanica* in the Hauterian–Albian sediments of India. *Stiphrosphaeridium anthophorum* also recorded from various Aptian–Albian sediments of Australia and New Guinea (Cookson & Eisenack, 1958; Williams *et al*., 2017). Inspite of the global distribution of such dinoflagellate cysts, many pteridophytic spores listed above are also represented in various Early Cretaceous horizons e.g., Hauterian--Aptian of Australia (Cookson & Dettmann, 1958; Balme, 1995), Aptian of the Rajmahal, India (Vijaya, 1999), Antarctica (Truswell *et al*., 1999) and Egypt (Saad, 1978; Ied & Lashin, 2016). A large number of megaspores assigned to various species of the genera *Minerisporites* and *Paxillitriletes* have been reported from Late Aptian to Early Albian sediments of USA (Tschudy, 1976), Europe (Batten *et al*., 2010) and Argentina (Villar de Seoane & Archangelsky, 2008). Maheshwari & Jana (1987) recorded dominance of *Araucariacites australis* and *Callialasporites* spp. from the lower part of the Bhuj Formation, Kachchh. They are also represented in the Trambau palynoassemblage. Mude *et al*. (2012) reported ichnofossils *Palaeophycus heberti*, *P. tubularis* and *Skolithos linearis* in Upper member of Bhuj Formation and assigned Late Aptian–Early Albian age. Thus, based on the recorded palynomorphs, the age of lower strata of the studied sedimentary succession is not likely to be older than Late Aptian.

## PALAEOVEGETATION AND PALAEOECOLOGY

Palynoassemblage of the Bhuj Formation comprising abundant megaspores, microspores, gymnosperm pollen grains derived from under storied ferns, mid–storied cycads and arboreal conifers indicate existence of the well–developed vegetation during Early Cretaceous. Ferns and its allies represented mostly by spores of *Dictyosporites complex, Gleichenidites senonicus* (Gleicheniaceae), *Contignisporites glebulentus*, *Cicatricosisporites ludbrooki* (Schizaeaceae), *Cyathidites australis*, *C. grandis* (Cyatheaceae/Dicksoniaceae), *Foraminisporis assymmetricus*, *Lycopodiumsporites nodosus*, *L. austroclavatidites*, *Retitriletes nodosus* (Lycopodiaceae) and *Crybellosporites striatus* (Marsiliaceae) represented with abundance between 2–15% (Figs 2, 3). These pteridophytic plants were thriving in shady and moist habitat situated along the lakes or riversides. Members of the family Schizaeaceae (*Contignisporites, Cicatricosisporites*) and *Crybellosporites* (Marsiliaceae) prefer to grow in wetland habitats, and their roots propagate in muddy soil near the lakes, lagoons, dams, and marshes or swamps (Caudales *et al*., 2000; Abbink *et al*., 2004). Many megaspore species, viz. *Minerisporites cutchensis*, *M. institus*, *M. reticulatus*, *M. trambauensis*, *Paxillitriletes maheshwarii*, *P. cutchensis* and *Valvisporites minor* show 10 to 56 % abundance in the basal part only. A majority of fossil megaspores resembling heterosporous Selagenales and Isoetales (Dettmann, 1963; Balme, 1995; Tosolini *et al*., 2002) are an indicator of wet and humid climate. Hallam (1984) and Taylor *et al*. (1993) have suggested that members of both groups require moist swampy habitat for their reproduction and propagation. Sometimes they grow along the sandy or rocky exposed sites (Retallack, 1997; Garret & Kantvilas, 1992; Taylor & Hickey, 1992; Tosolini *et al*., 2002). Spores of *Concavissimisporites variverrucosus* resembling the modern fern *Acrostichumsporites aureum* Linn. (Pteridaceae), grow widely along the habitats situated near deltaic coasts (Tryon & Tryon, 1982; Medina *et al*., 1990; Garcia Massini *et al*., 2006). Representation of colonial alga *Botryococcus braunii* in the palynoassemblage is very significant for proving the existence of fresh or brackish water habitats as the alga flourishes well in freshwater or low saline estuarine lakes (Guy–Ohlson, 1992; Kumar *et al*., 2017). Occurrence of dinoflagellate cysts, viz. *Coronifera oceanica*, *Prolixosphaeridium parvispinosum*, *Oligosphaeridium pulcherimum* and *Stiphrosphaeridium anthophorum* in the assemblage of the *Minerisporites cutchensis* palynozone indicate that during early phase the vegetation thrived along the coastal swamp in the basin where inundation of low energy fluvial and brackish waters was common.

Pollen grains, viz. *Araucariacites australis, Callialasporites dampieri*, *C. trilobatus, C. barragaonensis* of the family Araucariaceae and *Cycadopites grandis* of the Cycadaceae occur with 30–80 % abundance in the upper part of the section. Cheirolepidiaceae (*Classopollis classoides*) pollen grains are represented here with less quantity. Banerjee *et al*. (1984) recorded well–preserved leaves of Araucariaceae from Bhuj Formation supporting existence of araucarean plants during Early Cretaceous in the Kachchh Basin. Existence of high–canopied araucarians, podocarps and mid storied cycads is considered as representative of the deciduous evergreen forest, which was thriving during later

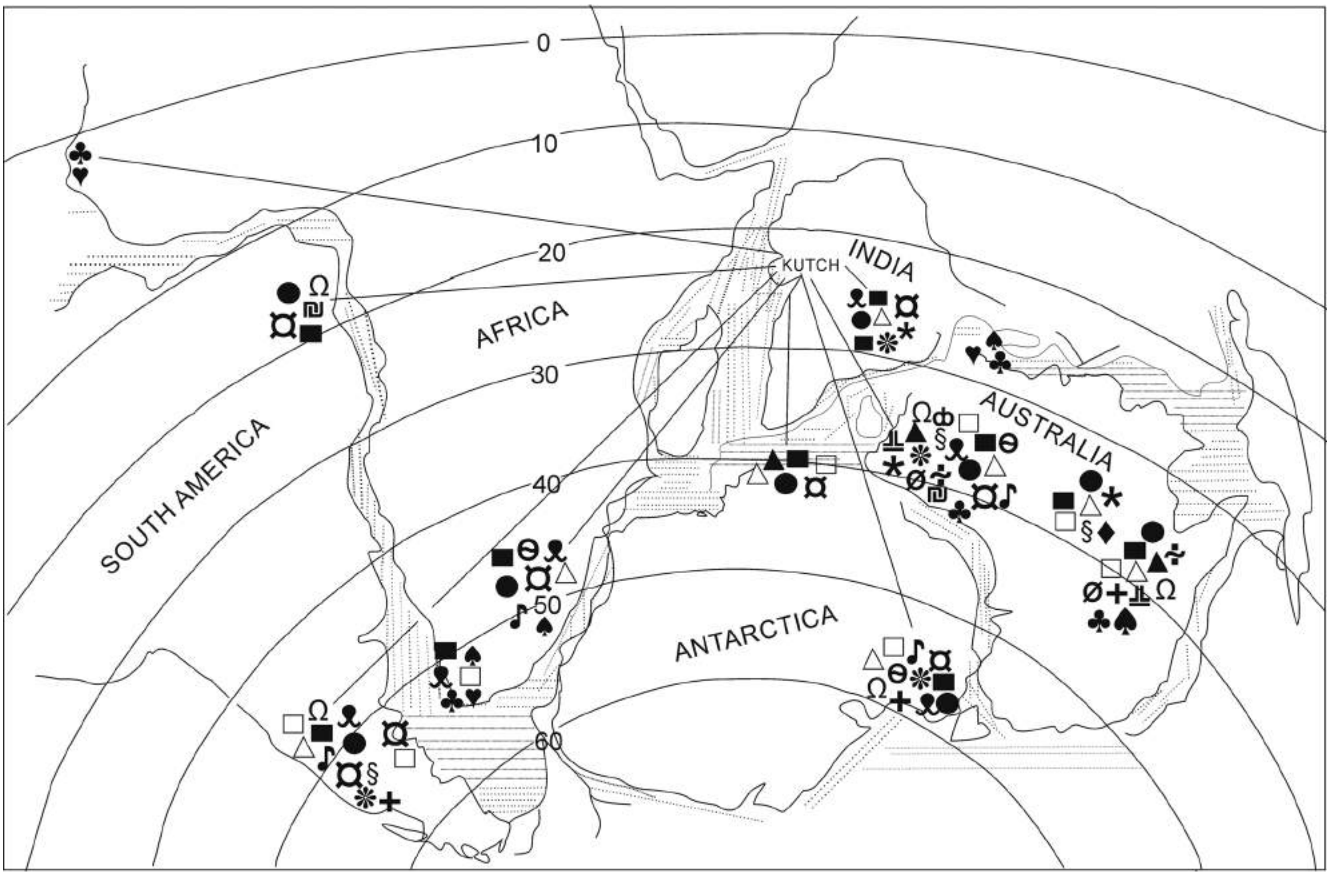


Fig. 4—The occurrence of similar palynotaxa (shown with symbols) in contemporaneous deposits of the Gondwanic continents. (Initial fit map of Gondwana is slightly modified after Ricou *et al*. 1990). ■ *Araucariacites australis*, ● *Callialasporites dampieri*, ¤ *Callialasporites trilobatus*, □ *Podocarpidites ellipticus*, △ *Alisporites grandis*, ♪ *Classopollis classoides*, ♦ *Cycadopites grandis*, Ω *Cyathidites australis*, ϴ *Cyathidites minor*, + *Cicatricosisporites ludbrooki*, Ø *Lycopodiumsporites austroclavatidites*, ▲ *Dictyosporites complex*, § *Gleichenidites senonicus*, ★ *Cooksonites variabilis*, ╨ *Biretisporites spectabilis*, ❋ *Concavissimisporites variverrucosus*, ∻ *Foraminisporis assymmetricus*, ȸ *Retitriletes nodosus*, ᴥ *Contignisporites glebulentus*, ₪ *Pilosisporites notensis*, ♣ *Coronifera oceanica*, ♠ *Prolixosphaeridum parvispinosum*, ♥ *Oligosphaeridium pulcherrimum*, …………… Oceanic seaway.

phases of deposition of the studied horizon. A significant change in the vegetation from herbaceous pteridophytes to the dominantly mixed arboreal gymnosperm reflects the gradual shift of vegetation from coastal marine to open terrestrial habitats (Fig. 3).

## DEPOSITIONAL ENVIRONMENT

Palynomorphs obtained from shale, carbonaceous shale, clay and fine siliceous shale from the basal part (between 0–6.75 m) of section show presence of different plant groups (Figs 2, 3). In this part occurrence of *Coronifera oceanica, Oligosphaeridium pulcherimum*, *Stiphrosphaeridium anthophorum* and *Prolixosphaeridium parvispinosum* with their frequency between 5–8 % in palynoassemblage, proves its deposition in inner shelf condition (Downie *et al*. 1971; Williams, 1978; Marshall & Batten, 1988). These sediments also contain abundant megaspores of heterosporous ferns. Villar de Seoane & Archangelsky (2008) have suggested that the heterosporous ferns generally flourish in a climate of high humidity along shallow water bodies, edges of ponds, lakes or rivers and require raised temperature for their colonization. Spores of *Concavissimisporites variverrucosus* resembling the modern mangrove plant *Acrostichum aureum* of the family Pteridaceae along with terrestrial fresh water ferns *Contignisporites glebulentus* and *Cicatricosisporites ludbrooki* (family Schizaeaceae) indicate their deposition in the terrestrial–aquatic habitat along the mangrove swamps. Occurrence of such fresh water inhabiting ferns may also suggest transportation of detritus through fluvial sources towards the pro–deltaic inner shelf zone of the shallow marine coast. Representation of the colonial alga *Botryococcus braunii* in the assemblage of both palynozones indicates prevalence of well–oxygenated estuarine lakes near the inner shelf coastal zone where input of the fluvial water was high, but transportation of sediments was very low (Guy–Ohlson, 1992; Lindström & Erlström, 2011; Kumar *et al*., 2017). The alga mostly occurs in freshwater lacustrine, fluvial, lagoonal and deltaic environments in a wide range of temperatures and habitats (Traverse, 1955; Batten & Grenfell, 1996; Clausing, 1999). Microspores of the family Lycopodiaceae (*Lycopodiumsporites austroclavatidites*, *L. nodosus*, *Foraminisporis assymmetricus*, *Retitriletes nodosus*) and Cyatheaceae/Dicksoniaceae (*Cyathidites* spp.) recorded in the palynoassemblage indicate their dense population along the lakesides. Modern counterparts of such Mesozoic pteridophytes prefer to thrive in the moist, shady habitats of the swamp or along the bank of lakes or rivers (Hallam, 1991).

The upper part of the succession (6.80–13.0 m) comprises pollen grains of *Araucariacites australis*, *Callialasporites* spp. (family Araucariaceae), *Alisporites grandis* and *Podocarpidites ellipticus* (family Podocarpaceae) with 65 to 94 % abundance, indicate luxuriant growth of such conifers during later stages of the deposition of sediments (Figs 2, 3). Their uniform distribution in the upper horizon indicate persistence of a stable climate and continuous supply of the detritus through fluvial sources towards the deposition site. One angiosperm pollen grain, viz. *Liliacidites* sp. recorded in the palynoassemblage with low frequency indicate that this herbaceous angiosperm species was competing for survival in conifer and fern dominated vegetation where deltaic and fluvial depositional processes were prevalent and not favourable for the colonization of such emerging angiosperms (Hickey & Doyle, 1977; Retallack & Dilcher, 1986; Herman, 2002; Coiffard *et al*., 2006).

Biswas (1987, 1999) and Babu (2006) suggested that during Middle Jurassic fine clastics and carbonates of the Kachchh Basin were deposited in a shallow marine inner shelf environment during transgression; while during Late Jurassic–Early Cretaceous regressive phases many thick clastic wedges, alternations of current–bedded sandstone and shales were deposited at the marginal marine sites. The opening of the sea at western margin of the basin towards the Indian Ocean through the splitting of India–Madagascar–Antarctica during Middle Jurassic–Middle Cretaceous (McElhinni, 1970), favoured growth of the luxuriant vegetation in the basin. In the narrowly opened passages, thick piles of the sediments from marine and terrestrial sources were accumulated in shallower to deeper lakes resulting deposition of the basal part of the section. After the withdrawal of sea the existing estuarine lakes superseded by freshwater ponds offered development of swamps and hinterlands where herbaceous fern, tree ferns, and conifer–dominated vegetation occupied in a wider area of the basin.

## CONCLUSIONS

(1) Diverse palynoassemblages of the Bhuj Formation comprising many taxa are biostratigraphically and ecologically significant. Such taxa also reveal development of the vegetation from mixed ferns to arboreal conifer–dominated forests during Late Aptian to Early Albian in the Kachchh Basin.

(2) Occurrence of Aptian–Albian dinoflagellate cysts in the basal part of the sedimentary succession suggests inner–neritic depositional conditions. Their absence in middle and upper part of the succession indicates deposition of overlying sediments under riverine settings only.

(3) The vegetation of the basin flourished under wet, humid conditions of a warm temperate climate in the subtropical zone of the Indian peninsula.

(4) A majority of palynotaxa show wide geographic distribution in India as well as in other Gondwanic continents during the Early Cretaceous.

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