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

MADHAV KUMAR

Birbal Sahni Institute of Palaeosciences, 53 University Road, Lucknow 226 007, India.
Email: madhavbsip@gmail.com

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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 समुच्च्य 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

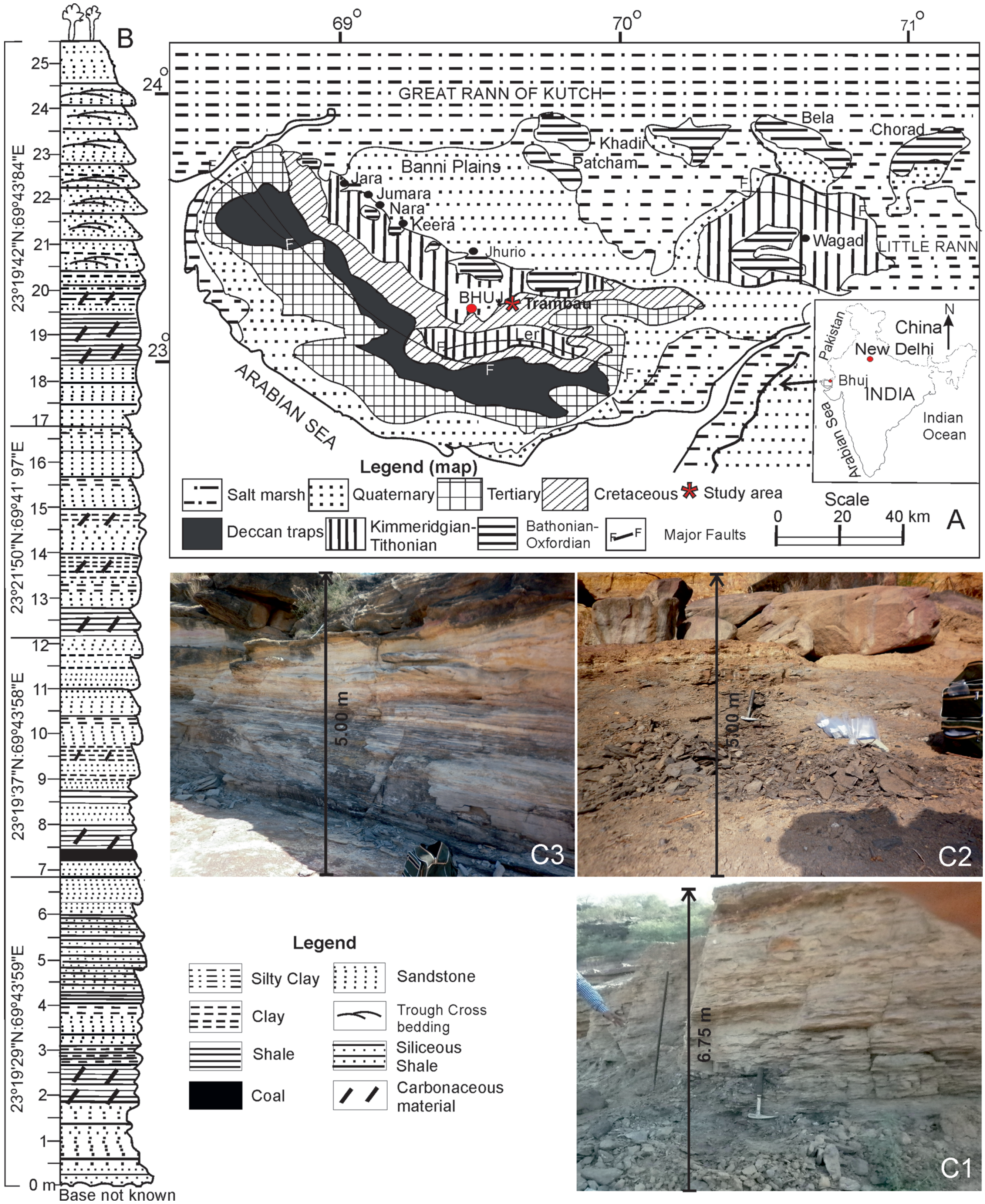

Fig. 1—A. Geological map showing location of the study area in Kutch (partially modified after Fürsich *et al.*, 1991), B. Litholog of the studied succession, C. Images of the Early Cretaceous sedimentary successions exposed along Pur River near Trambau Village at the locations C1–23°19'37" N: 69°43'58" E, C2–23°21'50" N: 69°41'97" E, C3–23°19'42" N: 69°43'84" 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.

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. *Bacularericulosporites 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.

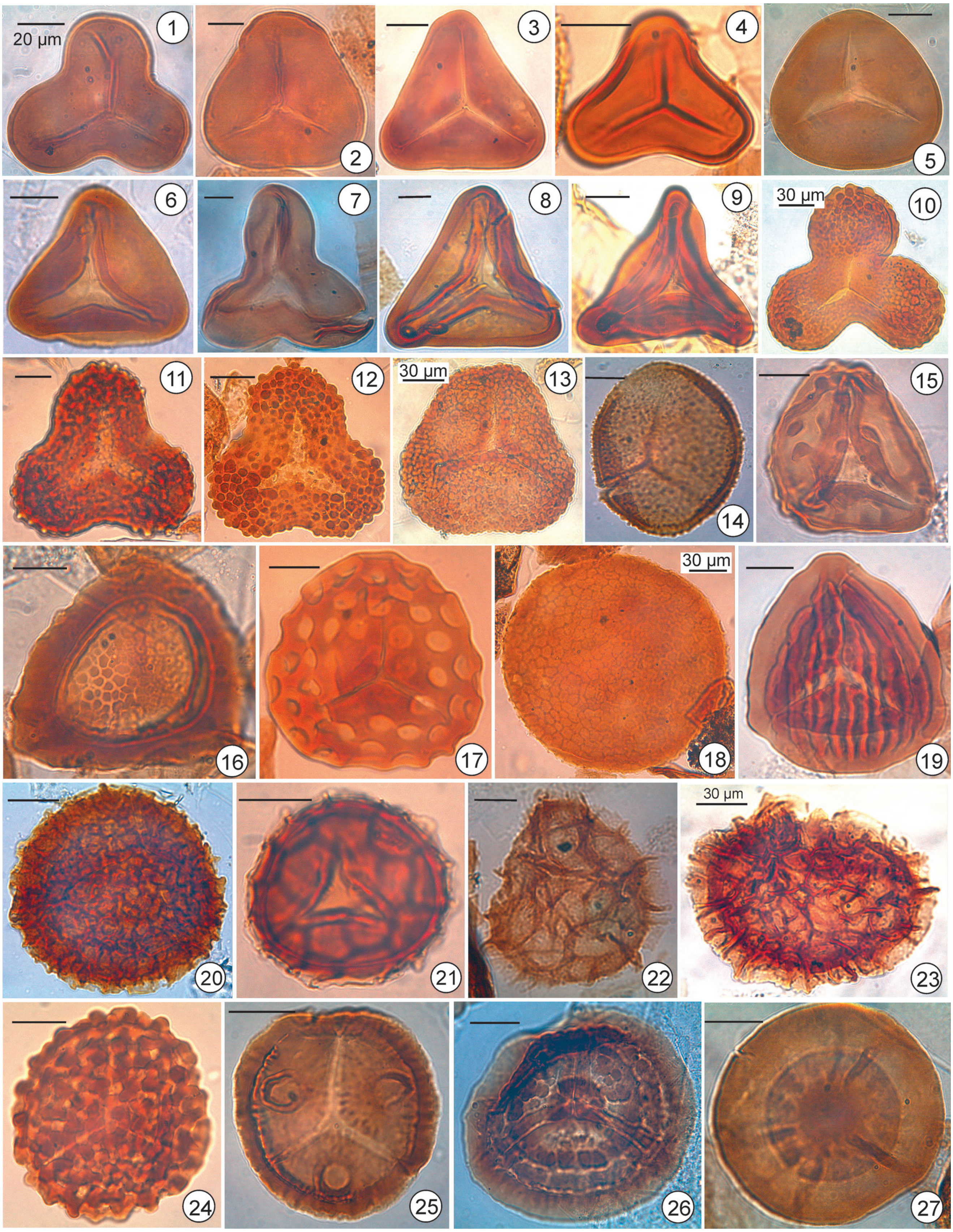
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PLATE 1

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

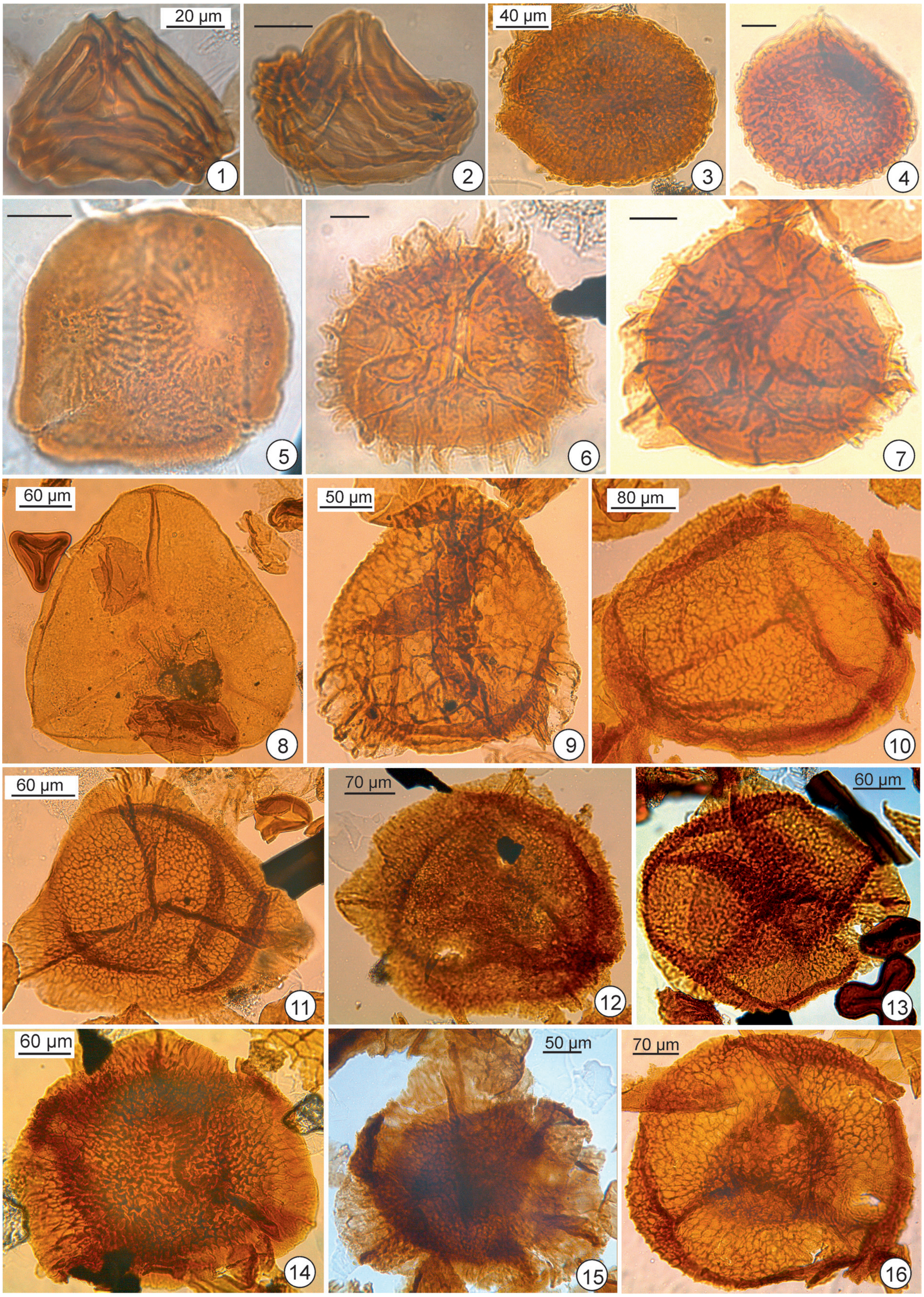
Asterisporites chlonovae Venkatachala & Rawat
Bacularericulosporites cutchensis Singh, Srivastava & Roy
Biretisporites spectabilis Dettmann
Cicatricosisporites ludbrooki Dettman
Concavissimisporites kutchensis Venkatachala
Concavissimisporites variverrucosus Delcourt, Sprumont & McKeller
Concavissimisporites 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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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

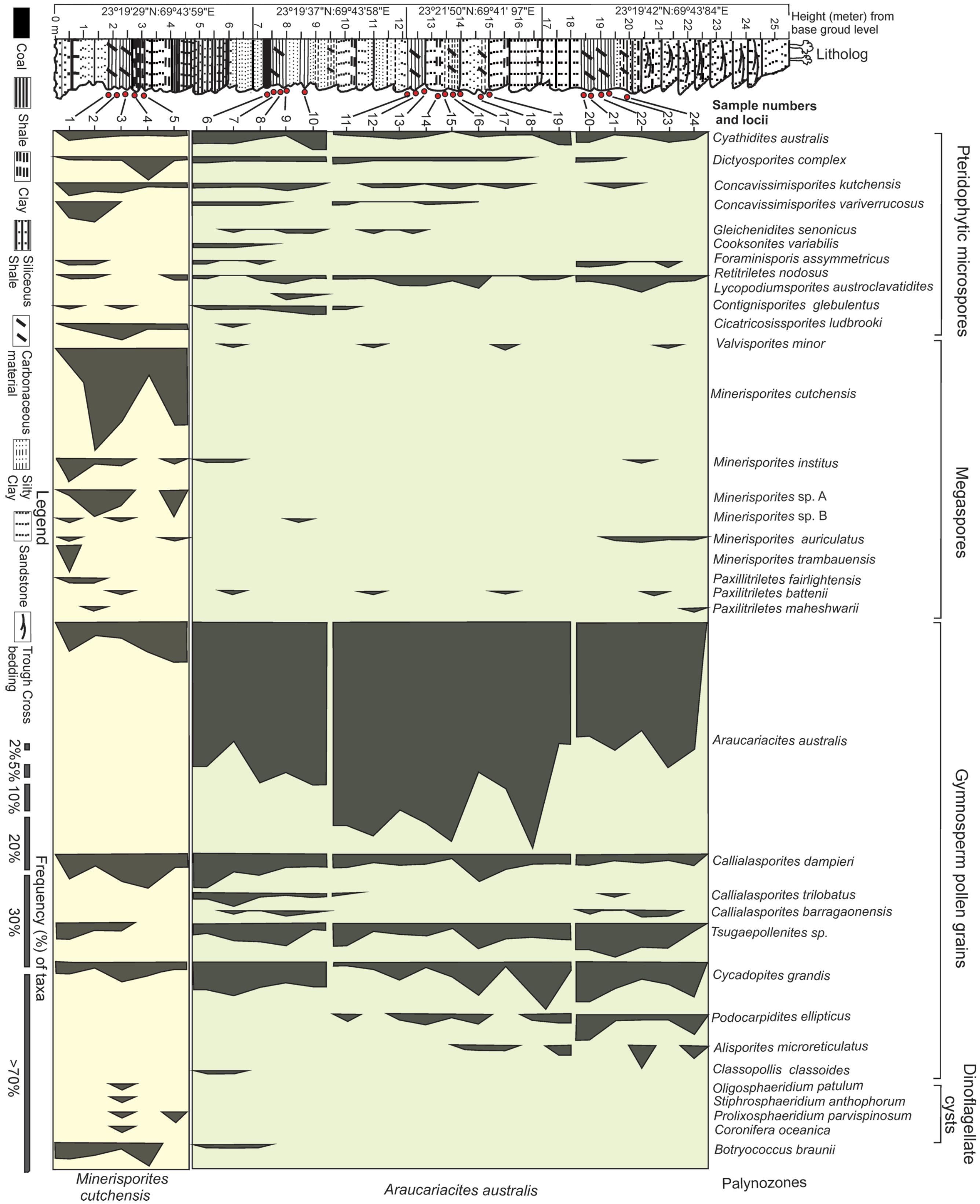

Fig. 2—Palynomorph distribution and palynozonations in the sedimentary succession of Bhuj Formation, Kachchh Basin.

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.

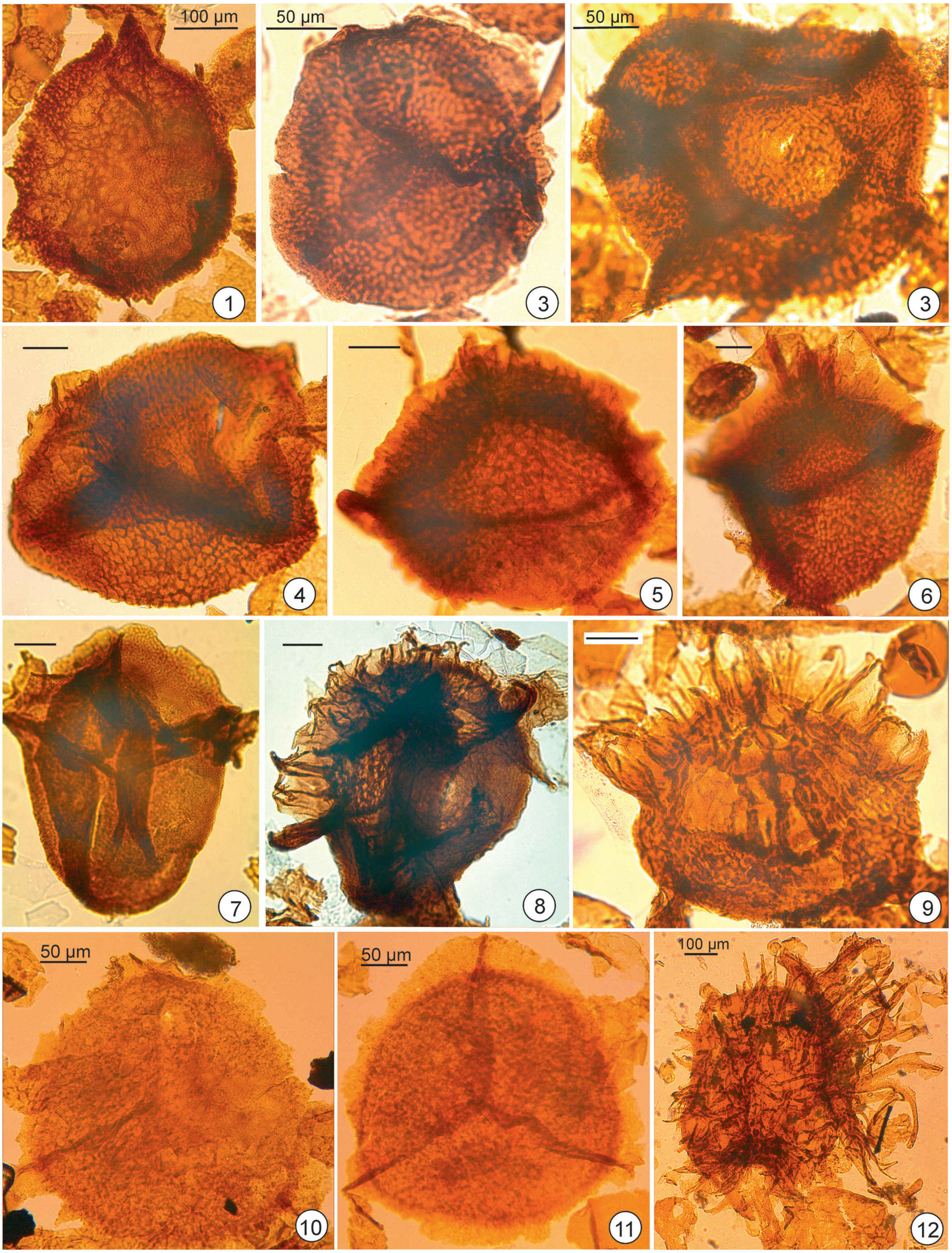

PLATE 3

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–Godawari 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.

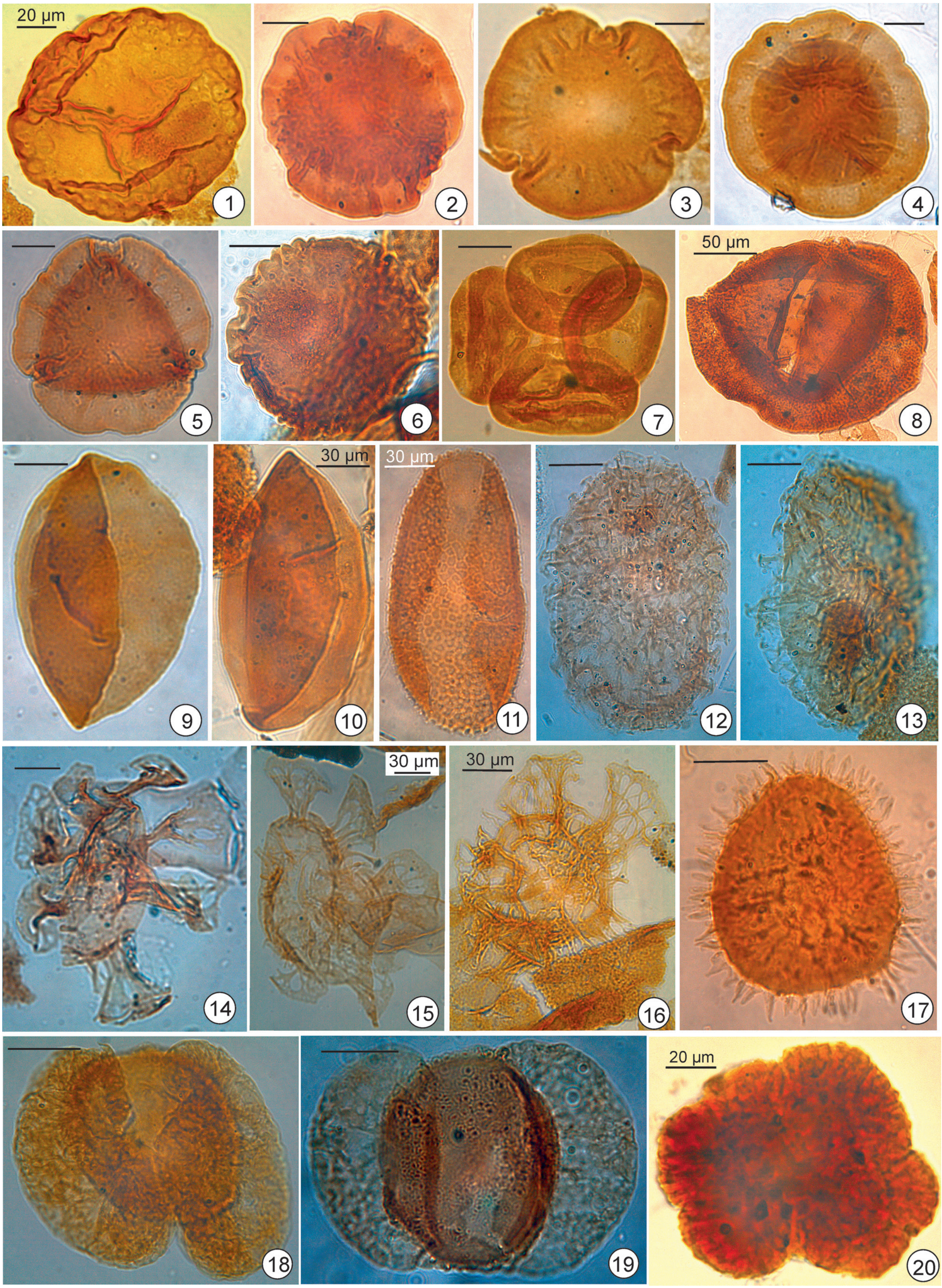
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PLATE 4

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

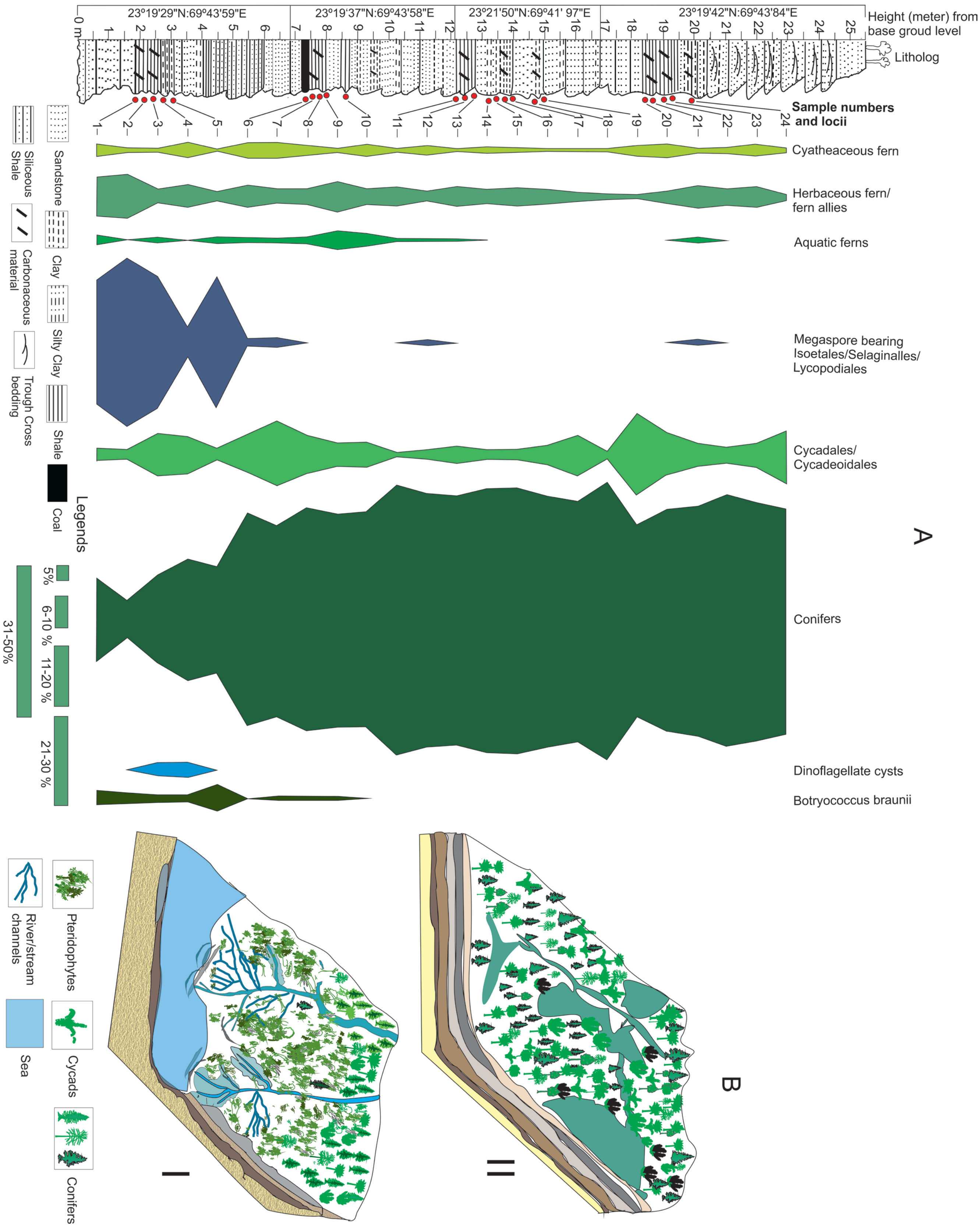

Fig. 3—A. Distribution of various plant groups in the section, B. Vegetation along the deposition sites, (I) Depositional environment of basal strata showing restricted near shore marine tidal flat with riverine channels and coastal marsh/swamp vegetation, (II) Depositional environment of upper strata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

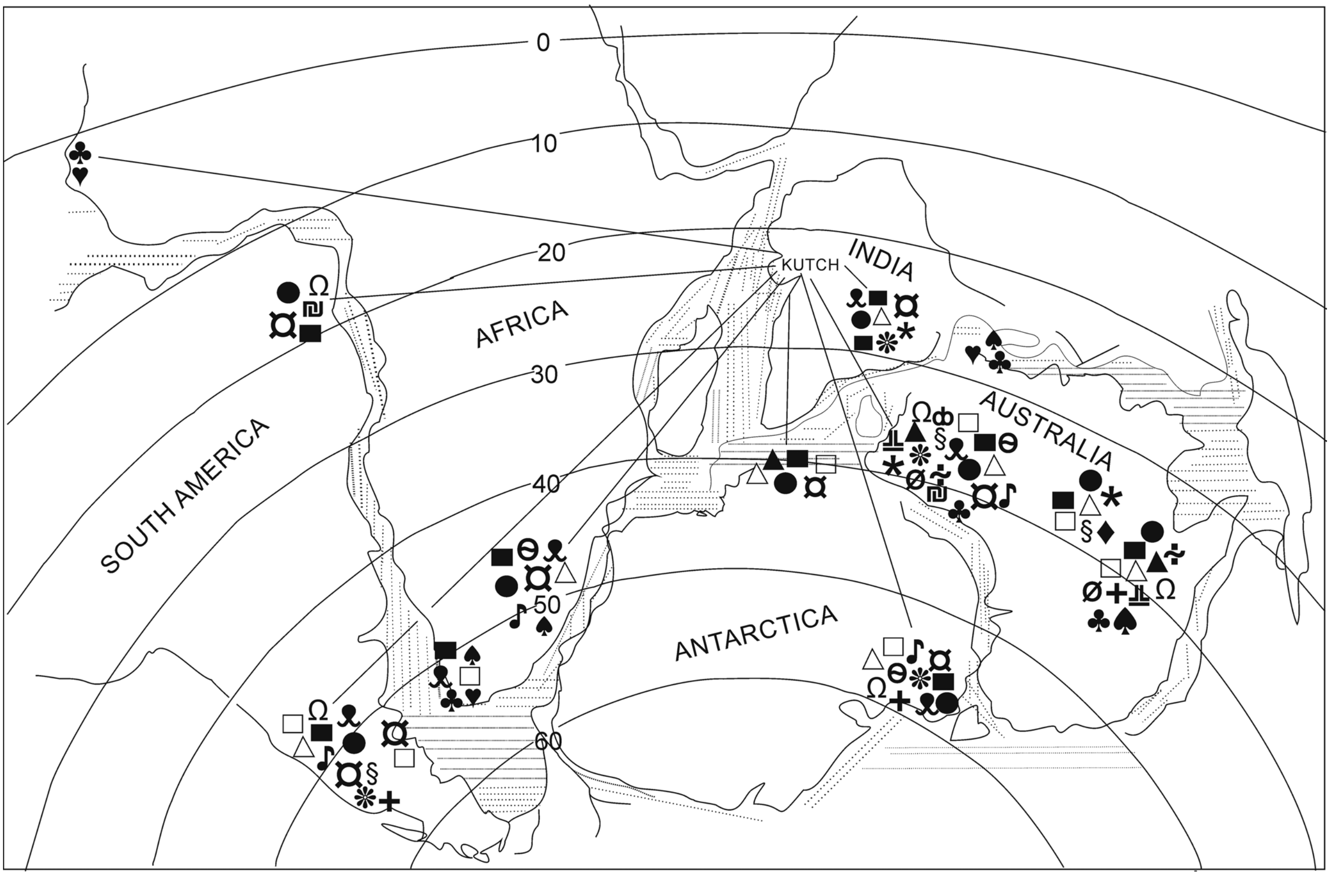

Fig. 4—The occurrence of similar palynotaxa (shown with symbols) in contemporaneous deposits of the Gondwanic continents. (Initial fit map of Gondwana is slightly modified after Ricou *et al.* 1990). ■ *Araucariacites australis*, ● *Callialasporites dampieri*, ¤ *Callialasporites trilobatus*, □ *Podocarpidites 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 *Prolixosphaeridum 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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REFERENCES

Abbink OA, Van Konijnenburg–Van–Cittert JHA & Visscher H 2004. A sporomorph eco–group model for the Northwest European Jurassic–Lower Cretaceous: concepts and framework. Netherlands Journal of Geosciences 83 (1): 17–38.

Archangelsky S & Gamerro JC 1967. Spore and pollen type of the lower Cretaceous in Patagonia (Argentina). Review of Palaeobotany and Palynology 1: 2–217.

Archangelsky S & Villar de Seoane L 1990. Morphologýa y estructura de megaspores Cretácicas de Patagonia. Republica Argentina. Revista Española de Micropaleontología, 22: 419–450.

Babu PVLP 2006. On the Ancient Deltas of India. Journal of the Geological Society of India 67: 569–674.

Backhouse J 1988. Late Jurassic and Early Cretaceous Palynology of the Perth Basin, Western Australia. Geological Survey of Western Australia Bulletin 135: 1–233.

Balme BE 1957. Spores and pollen grains from Mesozoic of Western Australia. Commonwealth Scientific and Research Organization Technical Communications, CSIRO, Coal Research Section 25: 1–48.

Balme BE 1995. Fossil in situ spores and pollen grains: An annotated catalog. Review of Palaeobotany and Palynology 87: 81–323.

Banerjee J, Jana BN & Maheshwari HK 1984. The fossil flora of Kachchh–II. Mesozoic Megaspores. Palaeobotanist 33: 190–227.

Batten DJ 1969. Some British Wealden megaspores and their facies distribution. Palaeontology 12: 333–350.

Batten DJ & Grenfell HR 1996. *Botryococcus*. *In*: Jansonius J & Mc Gregor DC (Editors)–Palynology: Principals and Applications. American Association of Stratigraphic Palynologists Foundation, Dallas, Texas, USA, vol. 1: 205–214.

Batten DJ & Koppelhus EB 1993. Morphological reassessment of some zonate and coronate megaspore genera of mainly post–Palaeozoic age. Review of Palaeobotany and Palynology 78: 19–40.

Batten DJ & Morrison L 1983. Methods of palynological preparation for palaeoenvironmental, source potential and organic maturation studies. Bulletin Petroleum Directorate Stavanger, Norway 2: 35–53.

Batten DJ, Collin J–P & Néraudeau D 2010. Megaspores from mid–Cretaceous deposits in western France and their biostratigraphic and palaeoenvironmental significance. Review of Palaeobotany and Palynology 161: 151–167.

Below R 1984. Aptian to Cenomanian dinoflagellate cysts from the Mazagan Plateau, Northwest Africa, site 545 and 547, Deep Sea Drilling Project

Leg, 79. *In*: Hinz K *et al*. (Editors)–Initial Reports DSDP 79, US Printing Office, Washington, pp. 621–649.

Biswas SK 1977. Mesozoic Rock Stratigraphy of Kutch. Quarterly Journal of the Geological, Mining and Metallurgical Society of India 49: 1–152.

Biswas SK 1980. Structure of Kutch–Kathiawar Region, western India. Proceedings of the 3rd Indian Geological Congress Pune, pp. 255–272.

Biswas SK 1982. Rift basins of western margins of India with special reference to hydrocarbon prospects. Bulletin American Association of Petroleum Geologists 66: 1497–1513.

Biswas SK 1987. Regional tectonic framework, structure, and evolution of the western marginal basins of India. Tectonophysics 135: 307–327.

Biswas SK 1991. Stratigraphy and sedimentary evolution of the Mesozoic basin of Kutch, western India. *In:* Tandon SK (Editor)–Stratigraphy and Sedimentary Evolution of India, pp. 54–103.

Biswas SK 1999. A review on the rift basins in India during Gondwana with special reference to western Indian basins and their hydrocarbon prospects. Proceedings Indian National Science Academy 65: 261–283.

Biswas SK 2002. Sedimentation in a Palaeo–Gulf. *In*: Biswas SK & Chamyal LS (Editors)–Structure, Tectonics and Mesozoic Stratigraphy of Kachchh, pp. 30–47. Contact Program cum Field Workshop, Organized by Department of Geology, Maharaja Sayajirao University, Baroda.

Bose MN & Banerjee J 1984. The fossil flora of Kachchh–I. Mesozoic Megafossils. Palaeobotanist 33: 1–189.

Brown CA 1960. Palynological techniques. Baton Rouge, Los Angels.

Burger D 1974. Palynology of subsurface Lower Cretaceous in the Surat Basin, Queensland. Bureau of Mineral Resources, Geology and Geophysics Bulletin 150: 27–42.

Burger D 1980. Palynological studies in Lower Cretaceous of the Surat Basin, Australia. Bulletin Australian Government Publishing Services Canberra 189: 1–211.

Carvalho MD 2004. Palynological assemblage from Aptian/Albian of the Sergipe Basin: palaeoenvironmental reconstruction. Revista Brasileira de Paleontologia 7: 159–168.

Caudales R, Vega Hernádez E, Sánches–Pérez A & Alain Liogier H 2000. Aquatic and wetland plants of Puerto Rico. I. Pteridophyta. Anals del Jardín Botánico de Madrid 57(2): 333–339.

Chinnappa C & Rajanikanth A 2017. Early Cretaceous flora from the Pranhita–Godavari Basin (east coast of India): taxonomic, taphonomic and palaeoecological considerations. Acta Palaeobotanica 57(2): 13–32.

Clausing A 1999. Palaeoenvironmental significance of the green alga *Botryococcus* in the Lacustrine Rotliegend (Upper Carboniferous–Lower Permian). Historical Biology 13: 221–234.

Coiffard C, Gomez B, Kvaček J & Thévenard F 2006. Early angiosperm ecology: evidence from the Albian–Cenomanian of Europe. Annals of Botany 81: 495–502.

Cookson IC & Dettmann ME 1958. Cretaceous "megaspores" and a closely associated microspore from the Australian region. Micropalaeontology 4: 39–49.

Cookson IC & Eisenack A 1958. Microplanktons from Australian and New Guinea Upper Mesozoic sediments. Proceedings of the Royal Society of Victoria 70 (1): 19–79.

Costa LI & Davey RJ 1992. Dinoflagellate cysts of the Cretaceous System. *In*: Powell AJ (Editor)–A Stratigraphic Index of Dinoflagellate Cysts. Chapman and Hall, London, pp. 99–153.

Dettmann ME 1963. Upper Mesozoic microfloras from south–eastern Australia. Proceedings of the Royal Society of Victoria 77: 1–148.

Dettmann ME & Playford G 1968. Taxonomy of some Cretaceous spores and pollen grains from Eastern Australia. Proceedings of the Royal Society of Victoria 81: 69–94.

Dettmann ME & Playford G 1969. Palynology of the Australian Cretaceous: a review. *In*: Campbell KSW (Editor)–Stratigraphy and Palynology Essays in Honour of Dorothy Hill, Australian National University Press, Canberra, pp. 274–210.

Downie C, Hussain MA & Williams GL 1971. Dinoflagellate cysts and acritarch associations in the Palaeogene of southeast England. Geoscience and Man 3: 29–35.

Eisawi AAM, Ibrahim AB, Rahim OBA & Schrank S 2012. Palynozonation of the Cretaceous to Lower Paleogene strata of the Muglad Basin, Sudan. Palynology 36(2): 191–207.

Ferreira NN, Ferreira EE, Ramos RRC & Carvalho IS 2016. Palynological and sedimentary analysis of the Igarapé Ipiranga and Querru outcrops of the Itapecuru Formation (Lower Cretaceous) Paranaíba Basin, Brazil. Journal of the South American Earth Sciences 66: 15–31.

Fürsich FT, Oschmann W, Jaitly AK & Singh IB 1991. Faunal response to transgressive–regressive cycles: examples from the Jurassic of western India. Palaeogeography, Palaeoclimatology, Palaeoecology 85: 149–159.

Garcia Massini JL, Jacobs BP, Pan A, Tabor N & Kappelman J 2006. The occurrence of the fern *Acrostichum* in Oligocene volcanic strata of the Northwestern Ethiopian Plateau. International Journal of Plant Sciences 167(4): 909–918.

Garg R, Khowaja–Ateequzzaman & Jain KP 1987. Jurassic and Lower Cretaceous dinoflagellate cysts from India with some remarks on the concept of upper Gondwana. Palaeobotanist 30: 254–267.

Garret M & Kantvilas G 1992. Morphology, ecology and distribution of *Isoetes* L. in Tasmania. Papers and Proceedings of the Royal Society of Tasmania 126: 115–122.

Goswami S, Meena KL, Das M & Guru BC 2008. Upper Gondwana palynoflora of Mahanadi Master Basin, Orissa, India. Acta Palaeobotanica 48 (2): 171–181.

Guler MV, Lazo DG, Pazos PJ, Borel CM, Ottone EG, Tyson RV, Cesaretti N & Aguirre–Urreta MB 2013. Palynofacies analysis and palynology of the Agua de la Mula Member (Agrio Formation) in a sequence stratigraphy framework, Lower Cretaceous, Neuquén Basin, Argentina. Cretaceous Research 41: 65–81.

Gunther PR & Hills LV 1972. Megaspores and other palynomorphs from the Brazeau Formation (Upper Cretaceous), Nordegg area, Alberta. Geoscience and Man 4: 29–48.

Guy–Ohlson D 1992. *Botryococcus* as an aid in the interpretation of palaeoenvironment and depositional processes. Review of Palaeobotany and Palynology 71: 1–15.

Hallam A 1984. Continental humid and arid zones during the Jurassic and Cretaceous. Palaeogeography, Palaeoclimatology, Palaeoecology 47: 195–223.

Hallam A 1991. Jurassic climates as inferred from the sedimentary and fossil record. Philosophical Transactions of Royal Society, London B 341: 287–296.

Helby R & McMinn A 1992. A preliminary report of early Cretaceous dinocyst floras from site 765, Argo Abyssal Plain, Northwest Australia. *In*: Gradstein FM *et al*. (Editors)–Proceedings of the Ocean Drilling Program, Scientific Results 123, pp. 407–420.

Helby R, Morgan R & Partridge AD 1987. A palynological zonation of the Australian Mesozoic. Memoir Association of the Australian Palaeontologists 4: 1–94.

Herman AB 2002. Late Early–Late Cretaceous floras of the North Pacific Region: florogenesis and early angiosperm invasion. Review of Palaeobotany and Palynology 122: 1–11.

Herngreen GFW, Kedves M, Rovnina LV & Smirnova SB 1996. Cretaceous palynofloral provinces: A review. *In*: Jansonius J & McGregor D (Editors)–Palynology: Principles and applications. American Association of Stratigraphic Palynologists Foundation, Dallas, Texas, USA, vol. 3, pp. 1157–1188.

Hickey LJ & Doyle JA 1977. Early Cretaceous fossil evidence for angiosperm evolution. The Botanical Review 43(1): 1–104.

Ied IM & Lashin GMA 2016. Palynostratigraphy and palaeobiogeography of the Jurassic–Lower Cretaceous succession in Korbit–1 well, northeastern Egypt. Cretaceous Research 58: 69–85.

Krassilov VA 2003. Terrestrial Palaeoecology and Global Change. Pensoft Publishers, Sofia, 481 pp.

Krauspenhar PM, Carvalho MA, Fauth G & Lana CC 2014. Albian Palynostratigraphy of ODP Leg 207 (Holes 1257A, 1258C and 1260B, Demerara Rise, Equatorial Atlantic. Revue de Micropaleontology 57: 1–13.

Kumar M 2011. Palynofloral and sedimentary organic matter analyses of early Cretaceous sediments exposed along Sher River in Satpura Basin,

Madhya Pradesh, India. Geophytology 41: 9–23.
Kumar M, Monga P, Shukla A & Mehrotra RC 2017. *Botryococcus* from the early Eocene lignite mines of western India: inferences on morphology, taphonomy and palaeoenvironment. Palynology 41(4): 462–471.
Kumar P 1993. Palynology of Chaugan Bed exposed near Khatima caves, Hoshangabad District, Madhya Pradesh, India. Biological Memoirs 19: 1–6.
Kumar P 1994. The Jabalpur Formation of Satpura Basin, Palynology and Palaeoclimate. Proceedings 9th International Gondwana Conference, Hyderabad, Volume 1: 369–385.
Lindström S & Erlström M 2011. The Jurassic–Cretaceous transition of the Fårarp–1 core, southern Sweden: Sedimentological and phytological indications of climate change. Palaeogeography, Palaeoclimatology, Palaeoecology 308: 445–475.
Loinaze VSP, Archangelsky S & Cladera G 2012. Palynostratigraphic study of the Early Cretaceous Río Mayer and Kachaike formations at the Quebrada El Moro Section, Austral Basin, southwestern Argentina. Cretaceous Research 34: 161–171.
Macphail MK 1999. Palynostratigraphy of the Murray Basin, inland southeastern Australia. Palynology 23: 197–240.
Maheshwari HK 1975. Palynology of the Athgarh Formation near Cuttack, Orissa. Palaeobotanist 22: 23–28.
Maheshwari HK & Jana BN 1987. Palynozonation of Jhuran and Bhuj formations in Kutch Basin. Palaeobotanist 36: 177–182.
Marcinkiewicz T 1960. Analiza Megasporowa osdów Jurajskich Gorzówa Śląkiego–Praszki (Summary Megaspore Analysis of Jurassic sediments near Gorzówa Śląkie–Praszki (Cracow–Wielunń Region). Kwartnik Geologiczeny Warszawa 4 (3): 713–733.
Marshall KL & Batten DJ 1988. Dinoflagellate cyst associations in Cenomanian–Turonian 'black shale' sequences of northern Europe. Review of Palaeobotany and Palynology 54: 85–103.
Masure E 1988. Albian–Cenomanian dinoflagellate cysts from site 627 and 635, leg 101, Bahamas. *In*: Austin JA Jr *et al*. (Editors)–Proceedings Ocean Drilling Program, Scientific Results 101, pp. 101–138.
McElhinni MW 1970. Formation of the Indian Ocean. Nature 228: 977–979.
McLachlan IR & Pieterse E 1978. Preliminary palynological results: Site 361, Leg 40, Deep Sea Drilling Project. *In:* Bolli H *et al*. (Editors)–Initial Reports of the Deep Sea Drilling Project 40, U.S. Government Printing Office, Washington, DC, pp. 857–881.
McLoughlin S 1996. Early Cretaceous macrofloras of Western Australia. Records of the Western Australian Museum 18: 19–65.
McLoughlin S 2001. The breakup history of Gondwana and its impact on pre–Cenozoic floristic provincialism. Australian Journal of Botany 49(3): 271–300.
Medina E, Cuevas E, Popp M & Lugo AE 1990. Soil salinity, sun exposure, and growth of *Acrostichum aureum*, the mangrove fern. Botanical Gazette 151(1): 41–49.
Medlicott HB 1872. Note on the exploration of coal in the northern region of the Satpura Basin. Records Geological Survey of India 31: 1–62.
Metcalfe I 1994. Gondwanaland origin, dispersion, and accretion of East and Southeast Asian continental terranes. Journal of South American Earth Sciences 7: 333–347.
Mohr BAR 1990. Early Cretaceous palynomorphs from ODP sites 692 and 693, the Weddell Sea, Antarctica. *In*: Barker PF *et al*. (Editors)–Proceedings of the Ocean Drilling Program Scientific Results 113, pp. 449–464.
Morgan R 1980. Palynostratigraphy of the Australian Early and Middle Cretaceous. Memoir Geological Survey New South Wales. Palaeontology 18: 1–153.
Mude SN, Raut SD & Wagh R 2012. Palaeo–environmental significance of Ichnofossils from the Bhuj Formation (Gondwana sediments) of the Kachchh Region, Northwestern India. World Journal of Environmental Biosciences 1: 25–29.
Norton IO & Sclater JG 1979. A model for the evolution of the Indian Ocean and the breakup of Gondwanaland. Journal of Geophysical Research 84: 6803–6830.
Ogg G 1992. Early Cretaceous Palynomorphs of the Western Pacific Ocean. *In*: Larson RL *et al*. (Editors)–Proceedings of the Ocean Drilling Program, Scientific Results 129, pp. 221–228.
Parrish JT 1993. Climate of the supercontinent Pangaea. Journal of Geology 101: 215–233.
Passalia MG, Llorens M, Césari SN, Limarino CO, Loinaze VSP & Vera EI 2016. Revised stratigraphic framework of the Cretaceous in the Bajo Grande area (Argentinean Patagonia) inferred from new U–Pb ages and palynology. Cretaceous Research 60: 152–166.
Paul DK, Ray A, Das B, Patil SK & Biswas SK 2008. Petrology, geochemistry and paleomagnetism of the earliest magmatic rocks of Deccan Volcanic Province, Kutch, Northwest India. Lithos 102: 237–259.
Potonié R 1956. Synopsis der Guttungen der Spore Dispersae. I. Teil: Sporites. Beih. Geologisches Jahrbuch 23: 1–103.
Quattrocchio ME, Martínez MA, Pavisich AC &Volkheimer W 2006. Early Cretaceous palynostratigraphy, palynofacies and palaeoenvironments of well sections in northeastern Tierra del Fuego, Argentina. Cretaceous Research 27(4): 584–602.
Rao PVR, Ramanujam CGK & Varma YNR 1983. Palynology of the Gangapur beds, Pranhita–Godavari Basin, Andhra Pradesh. Geophytology 13(1): 22–45.
Ray A, Patil SK, Paul DK, Biswas SK, Das B & Pant NC 2006. Petrology, geochemistry and magnetic properties of Sadara sill: Evidence of rift–related magmatism from Kutch Basin, northwest India. Journal of Asian Earth Sciences 27: 907–921.
Retallack GJ 1997. Earliest Triassic origin of *Isoetes* and Quillwort evolutionary radiation. Journal of Paleontology 71(3): 500–521.
Retallack GJ & Dilcher DL 1986. Cretaceous angiosperm invasion of North America. Cretaceous Research 7(3): 227–252.
Ricou L–E, Besse J, Marcoux J & Patria TP 1990. Un fit Gondwanien revise sur donnees pluridisciplinaires. Comptes rendus de l' Académie des sciences Series 2.
Riding JB, Crame JA, Dettmann ME & Cantrill DJ 1998. The age of the base of the Gustav Group in the James Ross Basin, Antarctica. Cretaceous Research 19: 87–105.
Saad SI 1978. Palynological studies in the Egyptian Western Desert: Umbarka IX borehole. Pollen et Spores 20(2): 261–301.
Sajjadi F & Playford G 2002a. Systematic and Stratigraphy of Late Jurassic–Earliest Cretaceous strata of the Eromanga Basin, Queensland, Australia, Part I. Palaeontographica B 261: 1–97.
Sajjadi F & Playford G 2002b. Systematic and Stratigraphy of Late Jurassic–Earliest Cretaceous strata of the Eromanga Basin, Queensland, Australia, Part II. Palaeontographica B 261: 99–165.
Scotese CR, Boucot AJ & Mckerrow MS 1999. Gondwanan palaeogeography and palaeoclimatology. Journal of African Earth Sciences 28: 99–114.
Scott L 1976. Palynology of lower Cretaceous deposits from the Algoa Basin (Republic of South Africa). Pollen et Spores 18(4): 563–609.
Singh HP, Srivastava SK & Roy SK 1964. Studies on the Upper Gondwana of Cutch–I. Mio– and Macrospores. Palaeobotanist 12: 282–306.
Taylor WC & Hickey RJ 1992. Habitat, evolution and speciation in *Isoetes*. Annals of the Missouri Botanical Garden 79: 613–622.
Taylor WC, Luebke NT, Britton DM, Hickey RJ & Brunton DF 1993. Isoëtaceae HGI Reichenback–Quillwort Family. *In*: Argus GW *et al*. (Editors)–Flora of North America, Oxford University Press, Oxford volume 2, pp. 64–75.
Torres T, Barale G, Méon H, Philippe M & Thévenard F 1997. Cretaceous floras from Snow Island (South Shetland Islands, Antarctica) and their biostratigraphic significance. The Antarctic Region: Geological evolution and Processes: 1023–1028.
Tosolini A–MP, McLoughlin S & Drinnan AN 2002. Early Cretaceous megaspore assemblages from southeastern Australia. Cretaceous Research 23: 807–844.
Traverse A 1955. Occurrence of oil–forming alga *Botryococcus* in lignites and other Tertiary sediments. Micropaleontology 1: 343–350.
Tripathi A 2008. Palynochronology of Lower Cretaceous volcano–sedimentary succession of the Rajmahal Formation in the Rajmahal Basin, India. Cretaceous Research 29: 913–924.
Truswell EM, Dettman ME & O'Brien PE 1999. Mesozoic palynofloras from

the Mac. Robertson shelf, East Antarctica: geological and phytogeographic implications. Antarctic Science 11(2): 239–255.

Tryon RM & Tryon AF 1982. Ferns and Allied Plants. Springer–Verlag, Berlin, 857 pp.

Tschudy RH 1976. Stratigraphic distribution of species of the megaspore genus *Minerisporites* in North America. United States Geological Survey Professional Paper 743E: E1–E10.

Vakhrameev VA 1991. Phytogeography, palaeoclimates and position of the continents in the Mesozoic. *In*: Hughes NF (Editor)–Jurassic and Cretaceous floras and climates of the Earth, Cambridge University Press, Cambridge, pp. 242–296.

Venkatachala BS 1967. Palynology of the Umia plant beds of Kutch, western India–1. Stratigraphic palynology of the Bhuj exposures near Walkamata (Kutch District, Gujarat State). Review of Palaeobotany and Palynology 5: 163–177.

Venkatachala BS 1969a. Palynology of the Umia plant beds of Kutch, western India–2. Bhuj exposures near Walkamata. Kutch District, Gujarat State–Systematic Palynology. Palaeobotanist 17: 1–8.

Venkatachala BS 1969b. Palynology of the Mesozoic sediments of Kutch–4. Spores and pollen from Bhuj exposures near Bhuj, Gujarat District. Palaeobotanist 17: 208–219.

Venkatachala BS & Kar RK 1970. Palynology of the Mesozoic sediments of Kutch, W. India–10. Palynological zonation of Katrol (Upper Jurassic) and Bhuj (Lower Cretaceous) sediments of Kutch, Gujarat. Palaeobotanist 18: 75–86.

Vijaya 1999. Palynological dating of the Neocommian–Aptian succession in the Indian Peninsula. Cretaceous Research 20: 597–608.

Vijaya & Bhattacharji TK 2002. An Early Cretaceous age for the Rajmahal traps, Panagarh area, West Bengal: Palynological evidence. Cretaceous Research 23: 789–805.

Villar de Seoane L & Archangelsky S 2008. Taxonomy and biostratigraphy of Cretaceous megaspores from Patagonia, Argentina. Cretaceous Research 29: 345–372.

Volkheimer W, Gallego OF, Cabaleri NG, Armella C, Narváez PL, Nieto DGS & Páez MA 2009. Stratigraphy, palynology, and conchostracans of a Lower Cretaceous sequence at the Cañadón Calcáreo locality, Extra–Andean central Patagonia: age and palaeoenvironmental significance. Cretaceous Research 30: 270–282.

Wadia DN 1944. Geology of India. MacMillan and Company Limited, London.

Wagstaff BE, Gallagher SJ & Trainor JK 2012. A new subdivision of the Albian spore–pollen zonation of Australia. Review of Palaeobotany and Palynology 171: 57–72.

Williams GL 1978. Palynological biostratigraphy, Deep Sea Drilling Project Sites 367 and 370. *In*: Lancelot Y *et al*. (Editors)–Deep Sea Drilling Project, Washington, Initial Report 4l: 783–815.

Williams GL, Fensome RA & Macrae RA 2017. The Lentin and Williams Index of Fossil Dinoflagellate. American Association of Stratigraphic Palynologists Contributions Series 48: 1–1097.

Zhou Z–K & Momohara A 2005. Fossil history of some endemic seed plants of East Asia and its phytogeographic significance. Acta Metallurgical Sinica 27(5): 449–470.