Abstract


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 megasporangium 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 palynota 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.

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

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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 megafossil 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 ( Araucariaceae australis zone) by combining Jhurian (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 basal part of the section includes many megaspores, microspores and dinoflagellate cysts. The upper Araucariaceae 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 palynotauxa 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–rifing 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, sills, 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, A 35–60 m above the mean sea level) is situated 22 km north of the Bhuj Town (Fig. 1). These deposits contain rhythms 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 megafossil 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 coverslip with the fossil plant locality Trambau Village near the Bhuj Town, Kachchh. 

**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—perispore, exospore and mesospore discernible. Mesosporium prominent, triangular to subcircular, entirely attached with exospore. Exosporium reticulate, more or less circular, forming central body of spores and covered by perispore.
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 (1964) differ from the present species due to absence of mesosporium and indistinct zona. Minerisporites dharenensis 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
Baculareticulosporites cutchensis Singh, Srivastava & Roy
Biretisporites spectabilis Dettmann
Cicatricosisporites ludbrooki Dettman
Concavissimisporites kutchensis Venkatachala

Megasporones

Ancorisporites sp.
Minerisporites alius Batten
Minerisporites auriculatus Singh, Srivastava & Roy
Minerisporites cutchensis Singh, Srivastava & Roy
Minerisporites 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 Dettman, slide nos. 15702, W19; 15703, M35/4.
3–4. Crybelosporites striatus (Cookson & Dettmann) Cookson, slide nos. 15694, R49/1; 15702, W35.
5. Asterisporites chlonovae Venkatachala & Rawat, slide no. 15704, U42/1.
6–7. Lycopodiumsporites austroclavatidites Cookson, slide nos. 15694, X31; 15702, N28.
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. Minerisporites 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.
GYMNOSPERMS

Alisporites grandis (Cookson) Dettmann
Araucariacites australis Cookson
Callialasporites dampieri (Balme) Sukh–Dev
Callialasporites barragoanensis Srivastava
Callialasporites trilobatus (Balme) Sukh–Dev
Callialasporites sp.
Classopolis 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 pulcherrimum (Deflendre & Cookson)
Davey & Williams
Prolixosphaeridium 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 the Bhuj Formation. The palynoassemblage shaped 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).

Palynozone of the zone—The palynozone comprises Cyathidites australis, C. grandis, Biretisporites spectabilis, Dictyosporites complex, Deltoidospora sp., Concavissimisporites varierrucatus, C. kutchensis, Foraminisporis assymetricus, Lycopodiumsporites astroclavatidites, L. nodosus, Retitriletes nodosus, Cicatricosisporites ludbrooki, Asterisporites chlonoae, Taurosporites segmentatus, Valvisporites minor, Minerisporites cutchensis, Minerisporites institus, M. trambauensis, M. auriculatus, Paxillitriletes maheshwarii, Araucariae 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 Spermatisae sp. Dinoflagellate cysts are represented by Oligosphaeridium pulcherrimum, Prolixosphaeridium parvispinosum, Stiphrosphaeridium anthophorum and Coronifera oceanica. Singh et al. (1964) and Banerjee et al. (1984) also recorded Minerisporites cutchensis, Paxillitriletes 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. barragoanensis*, Alisporites grandis, Tsugaepollenites sp., *Classopolis 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. inquisitum*, *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 sononicus*, *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 (Biswa, 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, Antarcctica, 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.

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**PLATE 3**

(Scale bar–50 µm, otherwise mentioned)

1–3. *Minerisporites venustus* Singh, BSIP slide nos 15709, P34/1; 15710, S35; 15711, O32/1.
5–6. *Paxillitriletes fairlightensis* (Dijkstra) Potonié, slide nos 15713, H36/1; 15712, Q35.
8–9. *Paxillitriletes maheshwarii* Jana & Ghosh, slide nos 15707, S25, 15690, H35/1, 15698, K20/2.
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, Concaviissimisporites spp., Contignisporites gubelentus, Lycopodiumsporites austroclavatidites, Araucariacites australis, Callialasporites trilobatus, C. dampiier, Podocarpidites ellipticus, Alisporites grandis and Classopollis classoides are also recorded from the Kachchh Basin.

Rajmahal Basin


Pranhita–Gadodari Basin


Other late Gondwana basins

Many pteridophytic micro– and megaspores, araucareans, podocars 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


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. Araucariaceae australis Cookson, slide no. 15691, H19/3.
2–3. Callialasporites dampieri (Balme) Sukh–Dev, slide nos 15685, S41/2; 15718, O33.
4. Callialasporites barragaonis Srivastava, slide no. 15719, O34.
5. Callialasporites trilobatus (Balme) Sukh–Dev, slide no. 15690, E34.
6. Tsugaepollenites sp., slide no. 15684, W17/3.
9–10. Cycadopteris grandis De Jeramy & Hamilton, slide nos 5719, J28/1; 15720, R32/3.
11. Liliacidites sp., slide no. 15721, E33/3.
12–13. Prolixosphaeridium 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. Strophosphaeridium anthophorum (Cookson & Eisenack) Lentini & 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.

Argentina


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 Itapescurú Formation (Lower Cretaceous) of Paraíba Basin.

Africa


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 fluvo-lacustrine setups, swamp/marsh and arboreal vegetation.
(1992) recorded dinoflagellate cysts, viz. *Coronifera oceanica*, *Oligosphaeridium pulcherimum*, *Prolixosphaeridium parvispinum* and spores and pollen grains of *Foraminisporis asymmetricus*, *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 pulcherimum* from Aptian–Albian beds of the DSDP Leg 79 site 545, Mazagan Plateau, Northwest Africa. Helby and McMinn (1992) recorded *Coronifera oceanica*, *Oligosphaeridium pulcherimum* and *Prolixosphaeridium parvispinosum* from ODP site 765 (Early Cretaceous) at Argo Abyssal Plain, Australia. Burger (1980) recorded dinoflagellate cysts *Oligosphaeridium pulcherimum*, *Coronifera oceanica*, spores and pollen grains, viz. *Araucariacites australis*, *Callialasporites dampieri*, *Podocarpidites ellipictus*, *Lycopodiumsporites astroclavatidites*, *Foraminisporis asymmetricus*, *Cricetisosporis 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 *Paxillitrites* 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 *Palaephycus 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 galebulentus*, *Cicatricosporites ludbrooki* (Schizaeaceae), *Cystidites australis*, *C. grandis* (Cyanobaeae/Dicksoniaceae), *Foraminisporis asymmetricus*, *Lycopodiumsporites nodosus*, *L. astroclavatidites*, *Retitriletes nodosus* (Lycopodiaceae) and *Crybellosporites striatus* (Marsilaceae) 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*, *Cicatricosporites*) and *Crybellosporites* (Marsilaceae) 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*, *Paxillitrites maheshwarii*, *P. cutchensis* and *Valvisporites minor* show 10 to 56 % abundance in the basal part only. A majority of fossil megaspores resembling heterosporous Selaginales 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 *Acrostichum sporoae* 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–Ohsion, 1992; Kumar et al., 2017). Occurrence of dinoflagellate cysts, viz. *Coronifera oceanica*, *Oligosphaeridium 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 (*Classopolis 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
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 pulcherrimum, 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 austroclavatidutes, L. nodosus, Foraminisporis assymmetricus, Retitirletes nodosus) and Cyathaeacea/Dicksoniaence (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, Callialasporespp. (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 biostatigraphically 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 palynoassemblage show wide geographic distribution in India as well as in other Gondwanic continents during the Early Cretaceous.

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