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Palynological investigations, facies analysis and palaeoenvironmental interpretations from Late Palaeocene to Early Eocene lignites and associated sediments of Barmer, western India

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ABSTRACT

Tripathi SKM & Srivastava D 2010. Palynological investigations, facies analysis and palaeoenvironmental interpretations from Late Palaeocene to Early Eocene lignites and associated sediments of Barmer, western India. The Palaeobotanist 59(1-3) : 1-32.

A lignite bearing sequence located in an open-cast mine near Barmer, Rajasthan, western India, identified as Akli Formation is investigated for palynological and palynofacies studies. The palynoflora from about 13.5 m thick succession mainly comprised of clay, shale and lignite, composed of spore/pollen, dinoflagellate cysts and fungal remains, is dominated by angiospermic pollen particularly those showing affinity with the family Arecaceae. The succession, palynologically divisible into three zones, is dated as Thanetian to Ypresian in age. Studies on the dispersed organic matter isolated from macerated residues indicate prevalence of anoxic conditions during deposition of lower part of the sequence which progressively changed into moderately oxic depositional conditions.

Key-words—Lignite, Western India, Palynology, Palaeoenvironment, Thanetian-Ypresian, Coastal elements.

पश्चिमी भारत में बाड़मेर के अंतिम पैलियोसीन से प्रारंभिक ईओसीन लिग्नाइटस तक एवं सहयोगी अवसादों से परागाणविक अन्वेषण, संलक्षणी विश्लेषण तथा पुरापर्यावरणीय व्याख्याए

एस.के.एम. त्रिपाठी एवं दिव्या श्रीवास्तव

सारांश

अकली शैलसमूह के रूप में पहचानी गई, पश्चिमी भारत में राजस्थान के बाड़मेर के निकट विवृत-खान खदान में स्थित एक लिग्नाइट धारी अनुक्रम को परागाणविक एवं परागाणुसंलक्षणी अध्ययन हेतु अन्वेषित किया गया है। मृतिका, शैल एवं लिग्नाइट, बीजाणु/पराग सहित, घूर्णीकशाभ पुटियों तथा कवकी अवशेषों से मुख्यतः भरी हुई लगभग 13.5 मी. मोटी अनुक्रम से परागाणु वनस्पतिजात में आवृतबीजियों पराग, विशेषकर वे जो एरीकेसी कुल से सजातीयता दर्शाते हैं, की प्रमुखता है। इस अनुक्रम को परागाणविक रूप से तीन मंडलों में बांटा गया है तथा इसकी थानेशियन से येप्रेशियन तक की आयु निर्धारित की गई है। मसृणित अवशेषों से वियुक्त परिक्षिप्त जैव पदार्थों पर अध्ययन से अनुक्रम के निम्न भाग के निक्षेपण के दौरान अनॉक्सिक अवस्थाओं की व्यापकता इंगित होती है जो मंदरूप से ऑक्सिक निक्षेपणीय अवस्थाओं को प्रगामी रूप से बदलती है।

संकेत-शब्द—लिग्नाइट, पश्चिमी भारत, परागाणुविज्ञान, पुरापर्यावरण, थानेशियन-येप्रेशियन, तटीय तत्व।

INTRODUCTION

THE northward drift of Indian landmass after its separation from Gondwana land in Cretaceous had profound biotic, geographic and tectonic influences (Sahni & Kumar, 1974; Sahni *et al*., 2004; Sahni, 2006). During the last three decades, workers of different disciplines have tried to study the changes in ecosystems brought in due to this separation and finally the collision of Indian landmass with Asia. Early Palaeogene sequences along the western margin of Indian subcontinent provide excellent opportunity for the study of biotic responses during pre and post-collision phase of Indian landmass. A lignite bearing sequence in Barmer District, western India was studied with a view to make assessment of palynofloral succession and the environment of deposition. During these studies both terrestrial as well as marine microfossils were recovered but the present communication focuses on the results derived from spore/pollen assemblages. Dinoflagellate cysts have been dealt with separately and are considered here only for palaeoenvironmental interpretations and dating of strata. The environment of deposition has been interpreted through an added parameter, the palynofacies studies.

Covering an area of about 1,20,000 sq km, the sedimentary sequences in northwestern Rajasthan are predominantly intracratonic. These sediments form a part of western Rajasthan Shelf and are divided into several basins that were deposited in Jaisalmer, Barmer, Bikaner-Nagaur and Sanchor. The sedimentary rocks of Barmer Basin, mainly constituted by Middle Jurassic to Early Eocene sediments (Figs 1, 2, 3), are mostly covered with extensive desert sand. Sedimentation in Barmer Basin took place in a narrow, elongated, roughly N-S trending linear graben (Roy & Jakhar, 2002). Peripheries of this basin are bounded by the faults, which are the result of the break up of the Indian Craton during Late Cretaceous-Early Palaeocene time. The northern side of the basin is limited by Fatehgarh fault whereas, its southern limit is marked by another fault

Kapurdi Fm. Akli Fm.	Palaeocene to Eocene	POST-RIFT
--------*UNCONFORMITY*--------		
Mataji ka Dungar Fm.	Palaeocene to Eocene	
--------*UNCONFORMITY*--------		
Fatehgarh Fm. Barmer Fm.	Cretaceous to Palaeocene	SYN-RIFT
Lathi Fm. Sarnu Fm. Birmaria Fm. Randha Fm. Malani Igneous Suite	Precambrian to Jurrasic	PRE-RIFT

Fig. 1—The lithological succession in Barmer Basin.

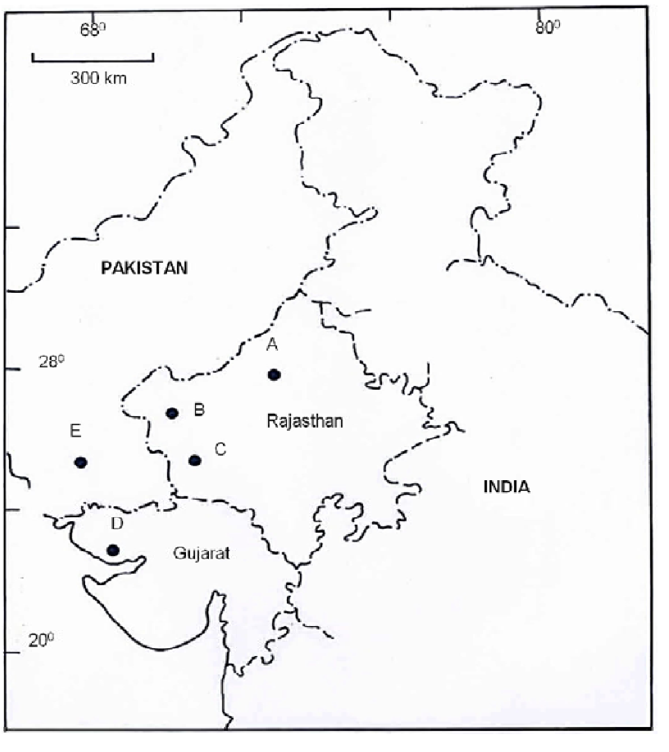


Fig. 2—Map showing localities discussed in paper for the palynological works (A. Bikaner, B. Jaisalmer, C. Barmer, D. Kutch, E. Indus coal region).

exposed at the Barmer Hill. A fault passing through Sarnu demarcates its eastern limit. In the west, the basin terminates due to the presence of fault of younger age (Sisodia & Singh, 2000).

GEOLOGY OF BARMER BASIN

Sediments of the Barmer Basin got deposited over variety of older rocks including Late-Mesozoic formations. The Barmer Basin is a narrow N-S trending graben and is a north extension of Cambay rift (Sisodia, 1996; Sisodia & Singh, 2000). Peripheries of the Barmer Basin are constituted by the faults which are the result of the break up of the Indian craton during Late Cretaceous-Early Palaeocene. Considering this rifting as a major event in the history of Barmer Basin, sediments of this basin are classified into **pre-rift**, **syn-rift** and **post-rift** sediments (Fig. 1). The post-rift sediments, representing Mataji-ka-Dungar, Akli and

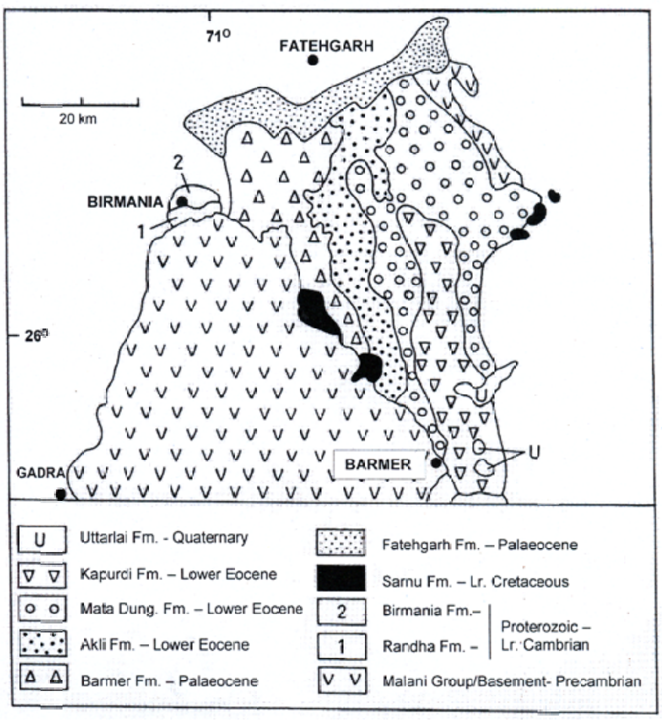


Fig. 3—Geological map of the Barmer Basin (after Roy & Jakhar, 2002).

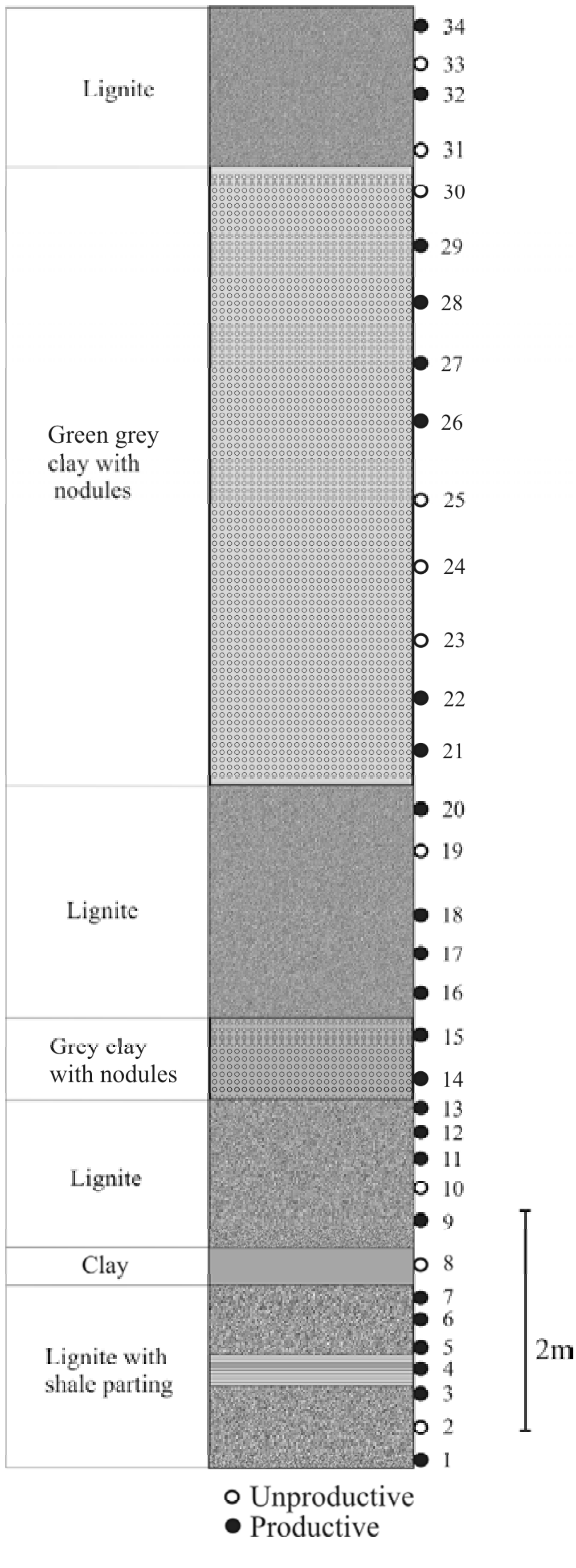


Fig. 4—Lithological succession of Akli Formation in the studied area.

Kapurdi formations, largely fill the Barmer Basin. Mataji-ka-Dungar Formation is exposed at the northern end and margins of the basin at 26º06' N 71º12' E, 26º24' N 71º12' E and 26º13' N 71º15' E. The Akli Formation overlies the Mataji-ka-Dungar Formation and is made up of sand-poor bentonitic claystone, grey bituminous claystone, light yellow claystone and lignites. It is exposed at the central part of the basin (Fig. 3). The studied section of Akli Formation is about 45 m thick but collection of samples was limited to a thickness of 13.5 m (Fig. 4). This formation is divisible into two members: 1. Thumbli-Shale Member and Kapurdi Fuller's Earth Member. The succeeding Kapurdi Formation is lacustrine in origin and contains Fuller's Earth deposits.

PREVIOUS PALYNOLOGICAL WORKS FROM RAJASTHAN

Palynological studies in Rajasthan Basin (Fig. 2) have been made in Barmer (Bose, 1952; Jain *et al*., 1973; Naskar & Baksi, 1978; Tripathi, 1994, 1995, 1997; Tripathi *et al*., 2003; Divya Srivastava, 2008; Tripathi *et al*., 2009), Jaisalmer (Lukose, 1974), Bikaner-Nagaur (Singh & Dogra, 1988; Kar, 1995, 1996; Ambwani & Singh, 1996; Kar & Sharma, 2001; Tripathi *et al*., 2008) and Palana beds (Rao & Vimal, 1950, 1952; Sah & Kar, 1974). Considering the theme of the present communication, the palynological studies previously conducted in Barmer Basin are discussed below. These studies have been carried out on bore-hole samples and those from Akli Formation exposed in open-cast lignite mine located at Giral.

Studies on bore-hole samples—Rock samples from bore-holes drilled at Kapurdi and Jalipa near Barmar yielded Late Palaeocene-Early Eocene palynological assemblages which were dominated by angiospermic pollen (Tripathi, 1994, 1995, 1997). The recorded palynofloras were overwhelmingly represented by forms which appear to be related with the family Arecaceae (Palmae). These forms were ascribed to different species of *Spinizonocolpites, Kapurdipollenites, Retiverrumonosulcites, Acanthotricolpites, Spinomonosulcites, Proxapertites, Palmidites* and *Palmaepollenites* (morphotypes discussed in later part of the text). Tripathi (1997) established two informal palynozones in two of these bore-hole sequences and demarcated Palaeocene and Eocene sediments.

Studies on lignite mine samples—Rock samples collected from open-cast lignite mine situated near Giral in Barmer were investigated palynologically by Tripathi *et al*. (2003). The studied section is constituted by bentonite, shale and lignite sequences. Palynological assemblage recorded from the section is dominated by angiosperm pollen whereas pteridophytic spores and dinoflagellte cysts were represented as the subdominant elements. Based on quantitative analysis of palynoflora, this sequence was divided into two palynozones (Tripathi *et al*., 2009). The lower palynozone was found to be characterized by high frequency of dinoflagellate cysts and pteridophytic

PLATE 1 ⟶

(The bar in figures is equal to 10 µm)

1. *Cyathidites australis* Couper, 1953; BSIP Slide No. 13543; Coordinates: 48.7 x 73.5.
2. *Dandotiaspora dilata* Sah *et al*., 1971; BSIP Slide No. 13572; Coordinates: 56.4 x 76.6.
3. *Dandotiaspora telonata* Sah *et al*., 1971; BSIP Slide No. 13621; Coordinates: 46.4 x 65.2.
4. *Dictyophyllidites laevigatus* Kar, 1985; BSIP Slide No. 13642; Coordinates: 58.7 x 71.5.
5. *Lycopodiumsporites eocenicus* Venkatachala & Rawat, 1972; BSIP Slide No. 13545; Coordinates: 45.4 x 67.3.
6. *Lycopodiumsporites sahii* Kar & Kumar, 1986; BSIP Slide No. 13549; Coordinates: 54.8 x 63.5.
7. *Lycopodiumsporites speciosus* Dutta & Sah, 1970; BSIP Slide No. 13606; Coordinates: 46.5 x 54.3.
8. *Monolites discordatus* (Pflug in Thomson & Pflug) Potonie, 1956; BSIP Slide No. 13642; Coordinates: 48.5 x 72.6.
9. *Monolites mawkmaensis* Dutta & Sah, 1966; BSIP Slide No. 13642; Coordinates: 43.4 x 82.2.
10. *Inaperturopollenites dubius* (Potonie & Venitz) Thomson & Pflug, 1953; BSIP Slide No. 13547; Coordinates: 54.2 x 83.3.
11. *Inaperturopollenites laevigatus* Takahashi, 1963; BSIP Slide No. 13546; Coordinates: 52.3 x 77.6.
12. *Todisporites plicatus* Sah & Kar, 1969; BSIP Slide No. 13547; Coordinates: 44.5 x 75.6.

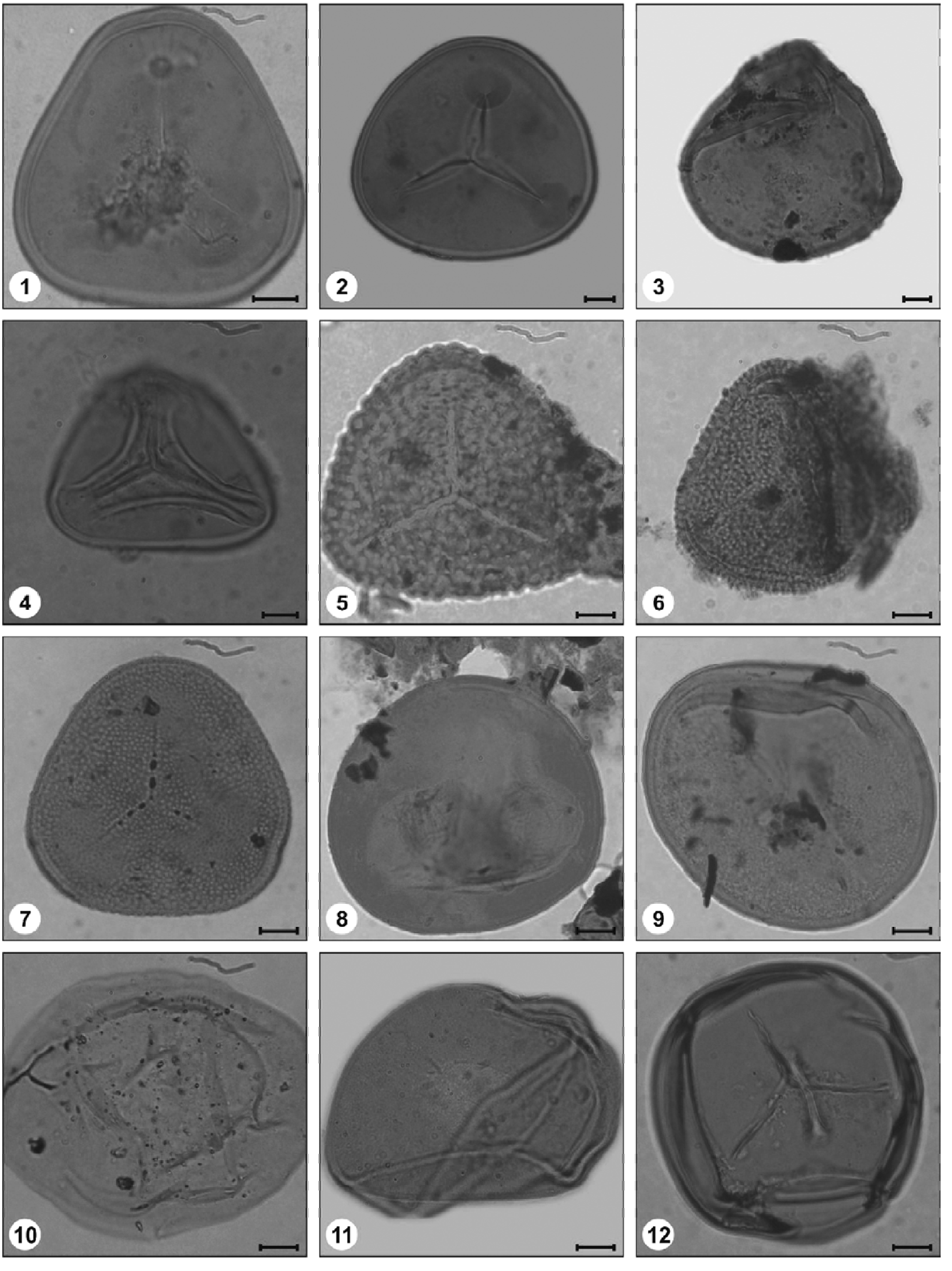


PLATE 1

spores while, the upper palynozone is distinctly dominated by angiosperm pollen grains having affinity with coastal elements, particularly the palms.

MATERIAL AND METHODS

Rock samples from Akli Formation were palynologically investigated during the present studies. Detailed geological studies on this formation were made by Sisodia and Singh (2000). The Akli Formation overlies the Mataji-ka-Dungar Formation and is made up of sand-poor bentonitic claystone, grey bituminous claystone, light yellow claystone and lignites. It is exposed at the central part of the basin. The top of the Akli Formation is covered by dune sand and gravel. The base of Akli Formation is represented by shale which has burrows and nodules (Fig. 4). The soft greyish shale often contains leaf impressions and fossil woods. The upper horizons of shale are mixed with bentonite which also contains fossil woods. The lignite is grey-black in colour, friable and occurs as lenses. The clay beds are poorly bedded, pale blueish-grey in colour and vary in thickness (few inches to 8 m). These are provided with ferruginous nodules, chert and phosphate cores. The beds dip 35º - 40º to SW. Montmorillonite is major component in bentonite and silt content is generally 1-2%.

Palynofossil extraction techniques

Rock samples were collected from a section selected in the open-cast lignite mine located near Barmer, Rajasthan (Fig. 3). Taking all precautions to avoid contamination, collection of samples was made from freshly exposed limestone, shale, lignite, coal and siltstone lithologies. Rock samples were cleaned thoroughly with water to ensure the removal of any extraneous matter. Mineral components of the rock samples were removed with the help of acids. Carbonates, commonly found as calcites, were removed by hydrochloric acid (HCI); sulphates, sulphides and carbon contents by concentrated nitric acid (HNO_3) and silicates by 40-60% hydrofluoric acid (HF). If carbonates were present in the samples, these were treated with HCI before the HF treatment. After removal of minerals, samples were treated with solution of sodium carbonate or potassium hydroxide. Concentration of these solutions and duration of treatment was decided considering the organic contents in the sample. Part of residue was left untreated with alkali for the study of Dispersed Organic Matter. Alkali treatment is essential to remove the humic acids released during the process of demineralization. Very fine mineral particles still remaining in the macerated residue were removed by heavy liquid separation method. Water-free macerated residue was mixed with a few drops of polyvinyl alcohol and was uniformly spread over the cover glass with the help of a glass rod. The cover glass was dried in oven for about thirty

PLATE 2 ⟶

(The bar in figures is equal to 10 µm)

1. *Inaperturopollenites parvus* Takahashi, 1963; BSIP Slide No. 13612; Coordinates: 53.6 x 76.6.
2. *Inaperturopollenites punctatus* Saxena & Bhattacharyya, 1987; BSIP Slide No. 13628; Coordinates: 34.4 x 67.2.
3. *Arecipites bellus* Sah & Kar, 1970; BSIP Slide No. 13541; Coordinates: 27.3 x 63.4.
4. *Arecipites intrapunctatus* Kar & Saxena, 1981; BSIP Slide No. 13611; Coordinates: 43.5 x 72.6.
5. *Arecipites matanomadhensis* (Saxena) Kar, 1985; BSIP Slide No. 13543; Coordinates: 45.2 x 73.2.
6. *Liliacidites magnus* Jain *et al*., 1973; BSIP Slide No. 13610; Coordinates: 45.6 x 62.3.
7. *Longapertites discordis* Frederiksen, 1994; BSIP Slide No. 13549; Coordinates: 47.4 x 72.7.
8. *Longapertites punctatus* Federiksen, 1994; BSIP Slide No. 13553; Coordinates: 48.5 x 72.6.
9. *Longapertites retipilatus* Kar, 1985; BSIP Slide No. 13553; Coordinates: 43.2 x 68.4.
10. *Matanomadhiasulcites kutchensis* (Saxena) Kar, 1985; BSIP Slide No. 13552; Coordinates: 43.5 x 62.4.
11. *Matanomadhiasulcites major* (Singh) Saxena & Khare, 2004; BSIP Slide No. 13616; Coordinates: 48.3 x 75.4.
12. *Matanomadhiasulcites maximus* (Saxena) Kar, 1985; BSIP Slide No. 13611; Coordinates: 46.3 x 72.6.

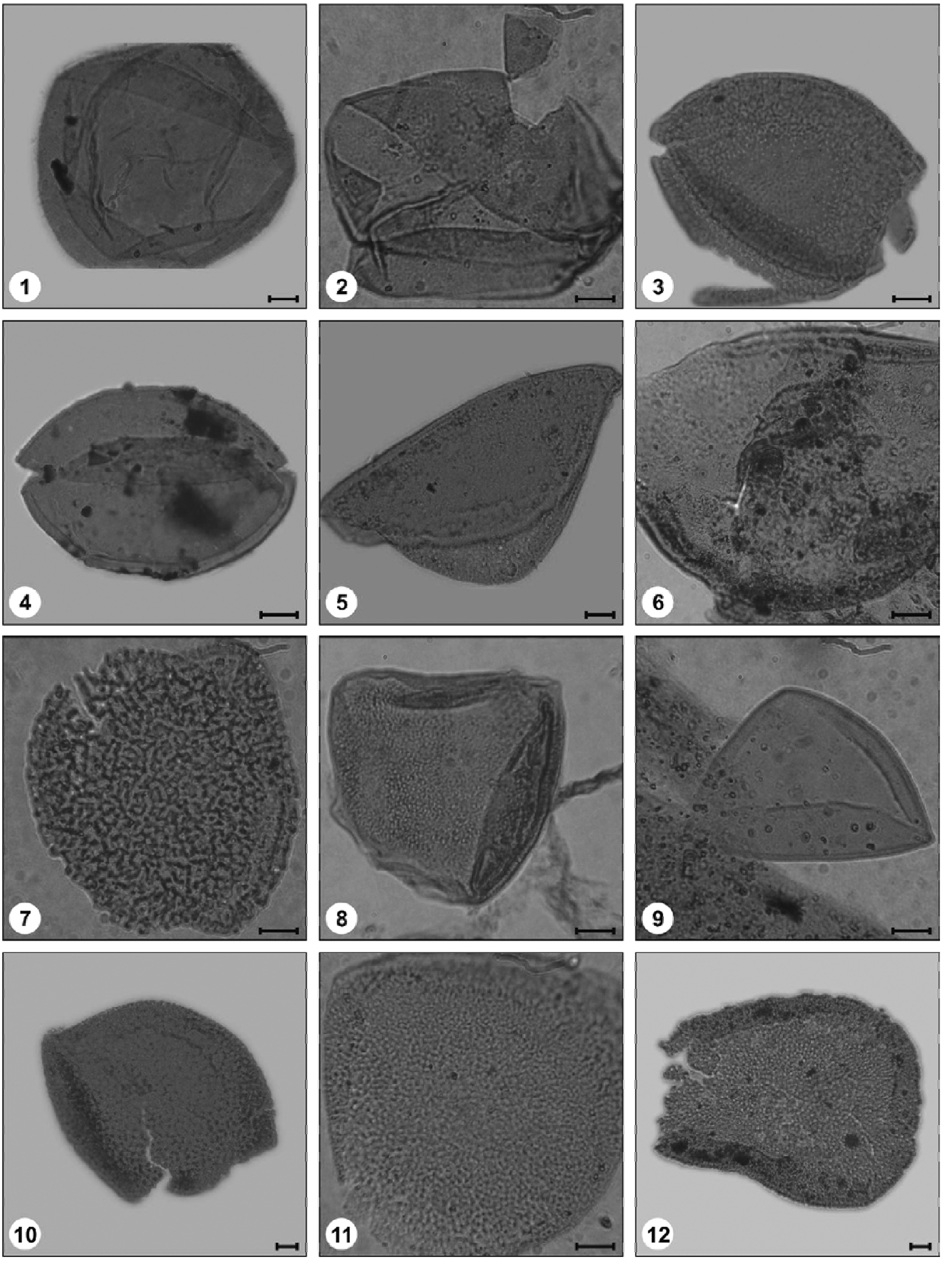


PLATE 2

minutes and was then mounted in Canada balsam. The prepared slides were kept in oven at 50-60°C for 7-8 days.

Data collection and interpretation

Distinguishable morphotypes were identified and were described under the artificial system of classification. Frequency of each palynotaxa was determined by counting 200 or 100 palynofossils in every sample. In each sample, the Dispersed Organic Matter contents were categorized into four groups, viz. (a). structured terrestrial (leaf cuticle, woody particles of stem, root tissue and other hyaline or membranous tissues), (b). biodegraded terrestrial, (c). amorphous and (d). pyritized amorphous. Depositional environments were determined on the basis of different organic matter types.

THE PALYNOLOGICAL ASSEMBLAGE

The palynofloral assemblage recorded from Akli Formation, Akli, Barmer is represented by Pteridophytic spores (7 genera, 12 species), Gymnosperm pollen (one genus, 5 species), Angiosperm pollen (25 genera, 37 species), Fungal remains (14 genera, 16 species) and Dinoflagellate cysts (detailed taxonomy not dealt with here). An attempt has been made to assign the botanical affinity of these palynotaxa.

List of Palynotaxa

Pteridophytic spores

Cyathidites australis Couper, 1953
Dandotiaspora dilata (Mathur) Sah *et al*., 1971
Dandotiaspora telonata Sah *et al*., 1971
Lycopodiumsporites eocenicus Venkatachala & Rawat, 1972
Lycopodiumsporites sahii Kar & Kumar, 1986
Lycopodiumsporites speciosus Dutta & Sah, 1970
Lygodiumsporites eocenicus Dutta & Sah, 1970
Lygodiumsporites lakiensis Sah & Kar, 1969
Todisporites minor Couper, 1958
Todisporites subtriangulatus Mathur & Mathur, 1980
Monolites discordatus (Pflug in Thomson & Pflug) Potonie, 1956
Monolites mawkmaensis Dutta & Sah, 1966

Gymnospermic pollen

Inaperturopollenites dubius (Potonie & Venitz) Thomson & Pflug, 1953
Inaperturopollenites laevigatus Takahashi, 1963
Inaperturopollenites minimus Takahashi & Jux, 1989
Inaperturopollenites parvus Takahashi, 1963
Inaperturopollenites punctatus Saxena & Bhattacharyya, 1987

Angiospermic pollen
Monocolpate/Monosulcate:

Arecipites bellus Sah & Kar, 1970

PLATE 3 ⟶
(The bar in figures is equal to 10 μm)

1. *Matanomadhiasulcites microreticulatus* (Dutta & Sah) Kar & Kumar, 1986; BSIP Slide No. 13609; Coordinates: 44.3 x 62.6.
2. *Retimonosulcites ovatus* (Sah & Kar) Kar, 1985; BSIP Slide No. 13618; Coordinates:36.3 x 62.6.
3, 4. *Retiverrumonosulcites barmerensis* Tripathi, 1994; BSIP Slide Nos. 13609 & 13617; Coordinates: 28.3 x 62.6 & 56.2 x 74.5 respectively.
5. *Proxapertites assamicus* (Sah & Dutta) Singh, 1975; BSIP Slide No. 13605; Coordinates: 33.4 x 76.4.
6. *Proxapertites crassimurus* (Sah & Dutta) Singh, 1975; BSIP Slide No. 13622; Coordinates: 26.3 x 62.6.
7. *Proxapertites cursus* von Hoeken-Klinkemberg, 1966; BSIP Slide No. 13640; Coordinates: 27.3 x 64.4.
8. *Proxapertites emendatus* (Sah & Dutta) Kar & Kumar, 1986; BSIP Slide No. 13640; Coordinates: 27.3 x 64.4.
9. *Proxapertites hammenii* Venkatachala & Rawat, 1972; BSIP Slide No. 13622; Coordinates: 23.3 x 78.7.
10. *Proxapertites marginatus* (Venkatachala & Kar) Singh, 1975; BSIP Slide No. 13653; Coordinates: 34.3 x 74.6.
11. *Proxapertites microreticulatus* Jain *et al*., 1973; BSIP Slide No. 13615; Coordinates: 27.5 x 66.5.
12. *Proxapertites operculatus* (van der Hammen) van der Hammen, 1956; BSIP Slide No. 13606; Coordinates: 22.3 x 68.3.

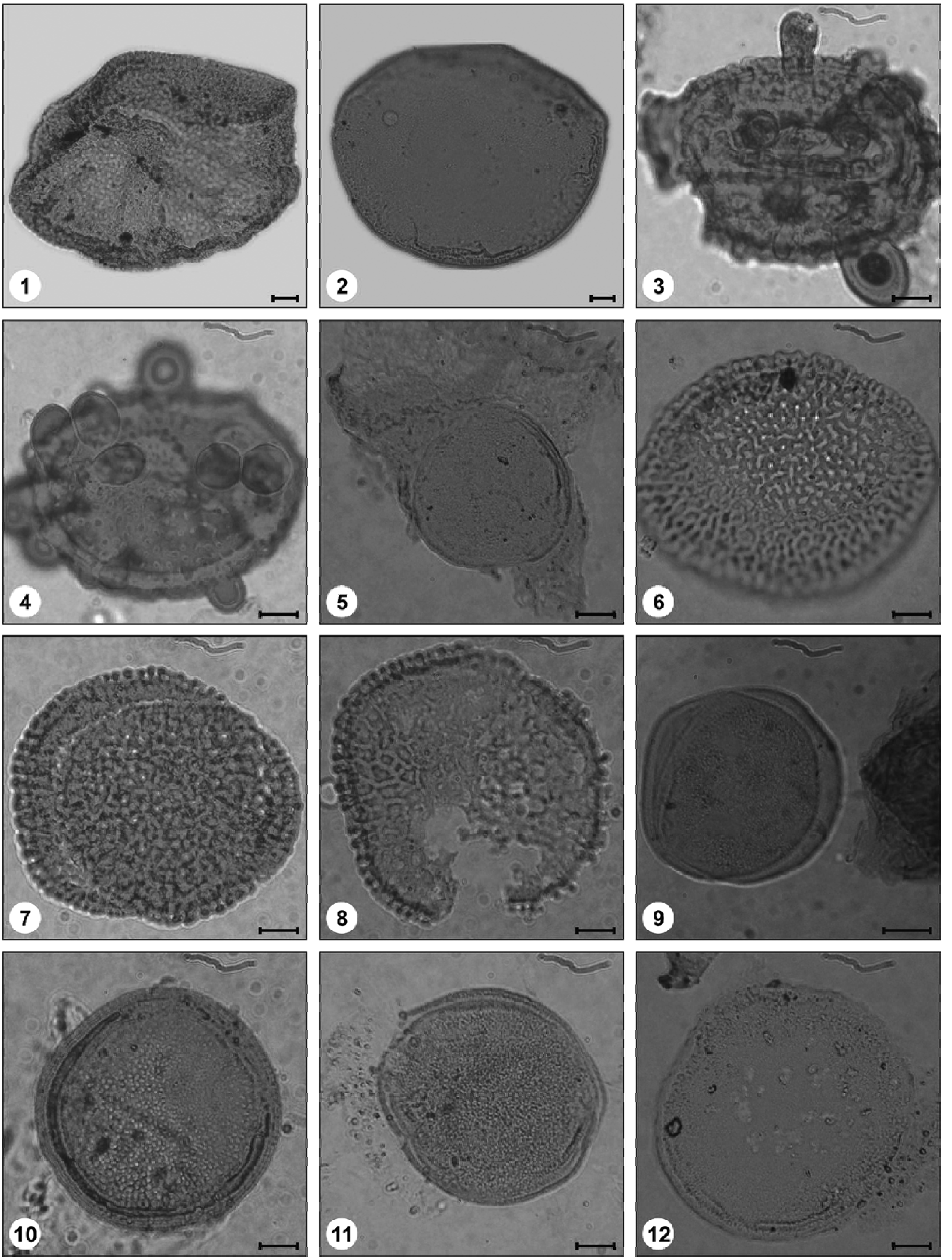


PLATE 3

Arecipites intrapuntatus Kar & Saxena, 1981
Arecipites matanomadhensis (Saxena) Kar, 1985
Liliacidites magnus Jain *et al*., 1973
Longapertites discordis Frederiksen, 1994
Longapertites punctatus Frederiksen, 1994
Longapertites retipilatus Kar, 1985
Matanomadhiasulcites kutchensis (Saxena) Kar, 1985
Matanomadhiasulcites major (Singh) Saxena & Khare, 2004
Matanomadhiasulcites maximus (Saxena) Kar, 1985
Matanomadhiasulcites microreticulatus (Dutta & Sah) Kar & Kumar, 1986
Retimonosulcites ovatus (Sah & Kar) Kar, 1985
Retiverrumonosulcites barmerensis Tripathi, 1994
Spinomonosulcites brevispinosus (Biswas) Kumar, 1994

Zonisulcate:

Proxapertites assamicus (Sah & Dutta) Singh, 1975
Proxapertites crassimurus (Sah & Dutta) Singh, 1975
Proxapertites cursus von Hoeken-klinkenberg, 1966
Proxapertites emendatus (Sah & Dutta) Kar & Kumar, 1986
Proxapertites hammenii Venkatachala & Rawat, 1972
Proxapertites marginatus (Venkatachala & Kar) Singh, 1975
Proxapertites microreticulatus Jain *et al*., 1973
Proxapertites operculatus (van der Hammen) van der Hammen, 1956
Proxapertites rugulatus Samant & Phadtare, 1997
Proxaperitites scabratus Jain *et al*., 1973
Kapurdipollenites baculatus Tripathi, 1994
Kapurdipollenites gemmatus Tripathi, 1994
Kapurdipollenites clavatus sp. nov.
Kapurdipollenites ovatus sp. nov.
Neocouperipolis robustus (Saxena) Saxena & Khare, 2004
Spinizonocolpites adamanteus Frederiksen, 1994
Spinizonocolpites bulbospinosus Singh, 1990
Spinizonocolpites baculatus Muller, 1968
Spinizonocolpites echinatus Muller, 1968
Spinizonocolpites kutchensis (Venkatachala & Kar) Frederiksen, 1994
Spinizonocolpites prominatus (McIntyre) Stovar & Evans, 1973
Spinizonocolpites venkatachalae Saxena & Khare, 2004
Spinizonocolpites wodehousii Singh, 1990
Spinizonocolpites sp.1
Spinizonocolpites sp. 2
Spinizonocolpites sp. 3

Tricolpate:

Barringtoniapollenites retibaculatus Kar & Sharma, 2001

Tricolporate:

Chiranthodendronpollenites bikanerensis Kar & Sharma, 2001
Cupanieidites flaccidiformis Venkatachala & Rawat, 1972

Diporate:

Clavadiporopollenites raneriensis Ambwani & Singh, 1996

PLATE 4

(The bar in figures is equal to 10 μm) ⟶

1. *Proxapertites rugulatus* Samant & Phadtare, 1997; BSIP Slide No. 13614; Coordinates: 32.4 x 64.2.

2, 3. *Kapurdipollenites baculatus* Tripathi, 1994; BSIP Slide Nos. 13629 & 13633; Coordinates: 34.4 x 74.2 & 34.4 x 65.3 respectively.

4, 5. *Kapurdipollenites gemmatus* Tripathi, 1994; BSIP Slide Nos. 13544 & 13609; Coordinates: 35.3 x 84.3 & 44.5 x 75.4 respectively.

6, 7, 8. *Kapurdipollenites clavatus* sp. nov; BSIP Slide Nos. 13549 & 13637; Coordinates: 45.3 x 84.3, 35.3 x 84.3 & 44.5 x 75.4 respectively.

9,10,11. *Kapurdipollenites ovatus* sp. nov; BSIP Slide Nos. 13627, 13636 13637; Coordinates: 44.2 x 73.2, 37.3 x 64.1 & 47.5 x 65.3 respectively.

12. *Neocouperipollis robustus* (Saxena) Saxena & Khare, 2004; BSIP Slide No. 13543; Coordinates: 45.3 x 84.3.

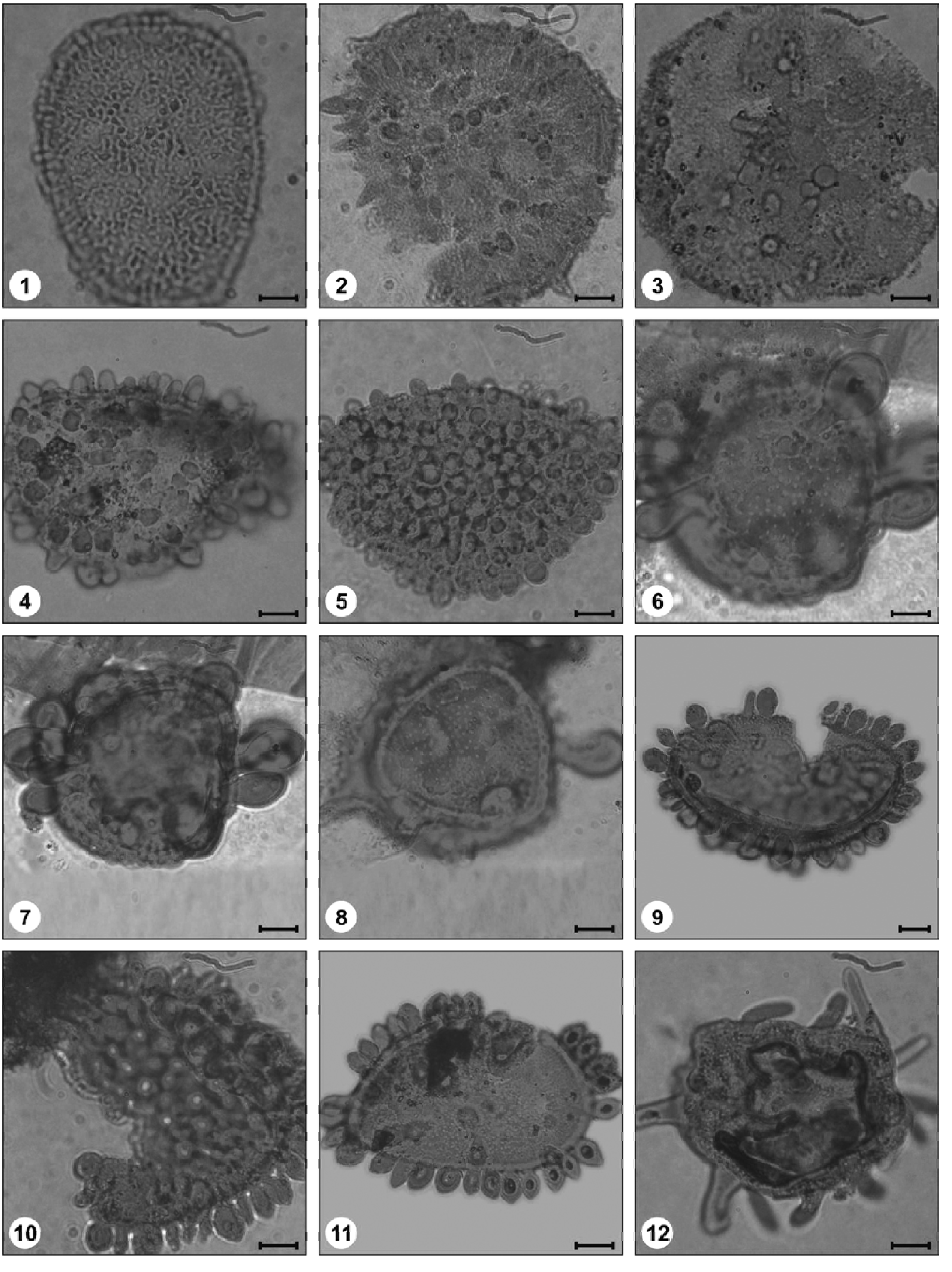


PLATE 4

Triporate:

Acanthotricolpites brevispinosus Saxena & Khare, 2004

Acanthotricolpites bulbospinosus Kar, 1985

Acanthotricolpites robustus Saxena & Khare, 2004

Acanthotricolpites tiruchirapalliensis Saxena & Khare, 2004

Acanthotricolpites sp. 1

Acanthotricolpites sp. 2

Crassivestibulites karii Frederiksen, 1994

Echitriporites tranguliformis von Hoeken-klinkenberg, 1964

Proteacidites protrudus Sah & Kar, 1970

Polycolpate/Polycolporate:

Pluricolumelatipollis pachyexinous Kar, 1995a

Duplibaculatepollis pentacolpites Kar & Sharma, 2001

Ocimumpollenites indicus Kar, 1996

Fungal remains:

Brachysporisporites tenuis Kumar, 1990

Callimothallus ramanujamii (Saxena & Singh) Kalgutkar & Jansonius, 2000

Haploxylonites ramanujamii Elsik, 1990a

Hilidicellites henanensis (Song & Li) Kalgutkar & Jansonius, 2000

Inapertisporites conicus Song & Li in Song *et al*., 1989

Inapertisporites kedvesii Elsik, 1968

Inapertisporites major Ke & Shi, 1978

Kalviwadithyrites saxenae Rao, 2003

Kutchiathyrites sp.

Muticellites volubilis (Ke & Shi) Kalgutkar & Jansonius, 2000

Polycellaesporonites bellus Chandra *et al*., 1984

Pluricellaesporites dentatus Trivedi & Verma, 1973

Scolicosporites scalaris (Kalgutkar) Kalgutkar & Jansonius, 2000

Staflosporonites neyveliensis Ambwani, 1983

Palambages colonica Trivedi & Verma ex Kalgutkar & Jansonius, 2000

Fungal body-1

SIGNIFICANT PALYNOTAXA IN THE ASSEMBLAGE

The assemblage is markedly dominated by angiospermic pollen having affinity with the family Arecaceae. These forms have been ascribed to different species of *Spinizonocolpites*, *Kapurdipollenites, Proxapertites, Spinomonosulcites, Retiverrumonosulcites, Acanthotricolpites* and *Clavadiporopollenites*. Species attributed to *Spinizonocolpites* (Fig. 5) are spheroidal to ovoidal in shape, possess an extended sulcus (Meridionosulcate) and have spinose exine. Size of pollen ranges between 50-70 µm. Great deal of variation in shape and size of spine (5-15 µm) was also noticed. Spines, at times, may exhibit a bulbous base. Exine between spines could be smooth to reticulate. Pollen grains assigned to different species of *Spinizonocolpites* are related to modern brackish water Palm *Nypa* (Muller, 1968). The genus *Kapurdipollenites* (Figs 6a, 6b, 6c & 6d) described

PLATE 5

(The bar in figures is equal to 10 µm) ⟶

1, 2, 11. *Spinizonocolpites adamanteus* Frederiksen, 1994; BSIP Slide Nos. 13545, 13549 & 13609; Coordinates: 32.1 x 76.2, 22.4 x 67.7 & 22.7 x 78.5 respectively.

3. *Spinizonocolpites baculatus* Muller, 1968; BSIP Slide No. 13627; Coordinates: 44.3 x 81.2.

4. *Spinizonocolpites bulbospinosus* Singh, 1990; BSIP Slide No. 13548; Coordinates: 45.3 x 84.3.

5. *Spinizonocolpites echinatus* Muller, 1968; BSIP Slide No. 13608; Coordinates: 44.2 x 84.2.

6. *Spinizonocolpites kutchensis* (Venkatachala & Kar) Frederiksen, 1994; BSIP Slide No. 13616; Coordinates: 44.2 x 84.2.

7, 8. *Spinizonocolpites prominatus* (McIntyre) Stovar & Evans, 1973; BSIP Slide Nos. 13548 & 13543; Coordinates: 32.5 x 76.8 & 27.3 x 69.5 respectively.

9. *Spinizonocolpites venkatachalae* Saxena & Khare, 2004; BSIP Slide No. 13544; Coordinates: 24.6 x 74.3.

10. *Spinizonocolpites wodehousei* Singh, 1990; BSIP Slide No. 13617; Coordinates: 18.7 x 67.5.

12. *Spinizonocolpites* sp. 1; BSIP Slide No. 13544; Coordinates: 18.7 x 67.5.

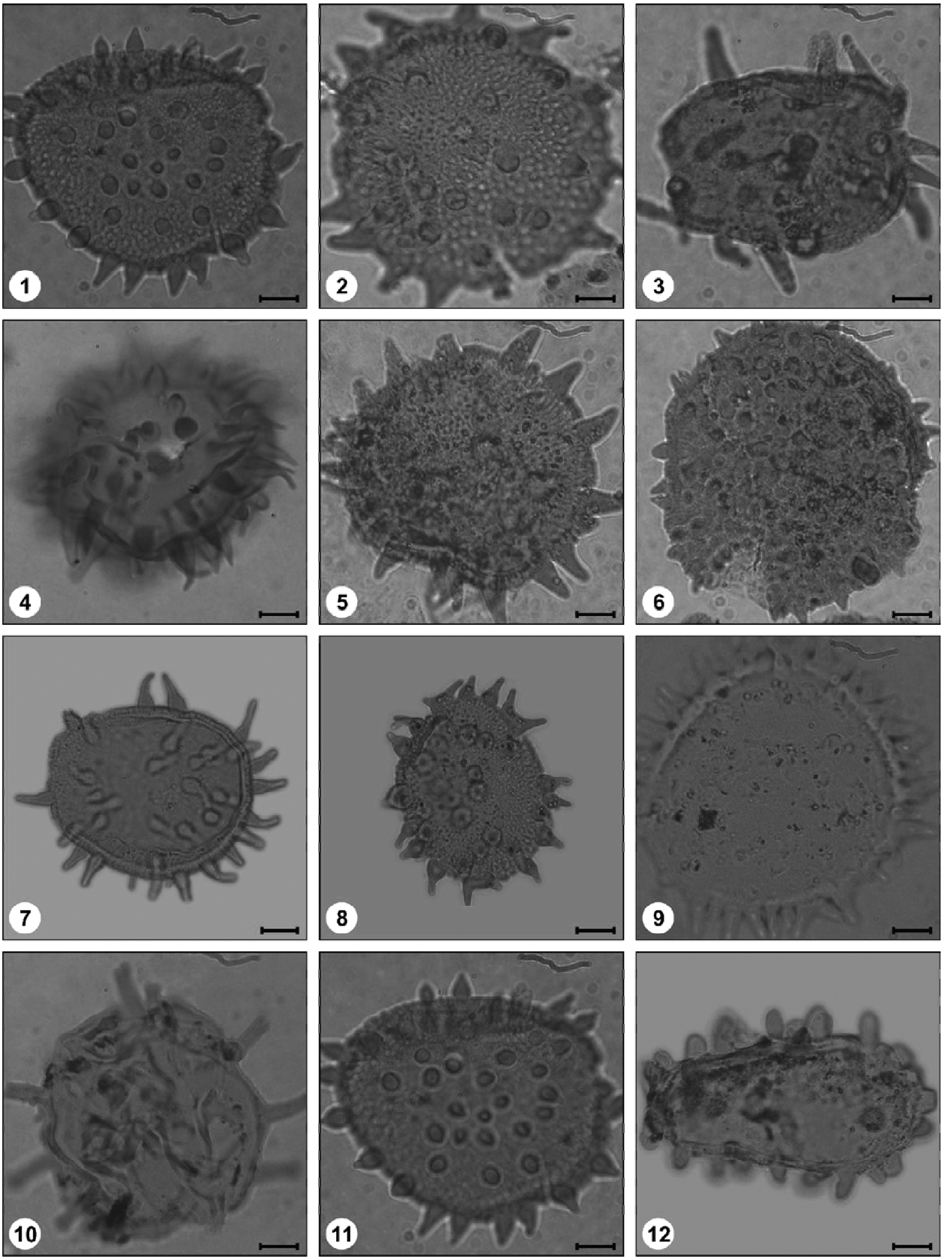
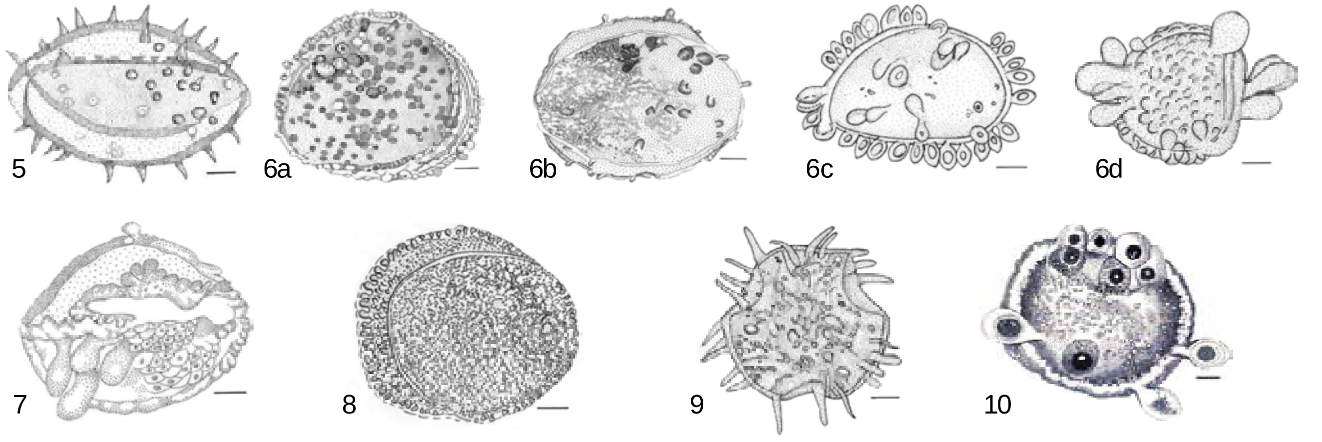


PLATE 5



Figs. 5-10—5. *Spinizonocolpites echinatus*; 6a. *Kapurdipollenites gemmatus*; 6b. *K. baculatus*; 6c. *K. ovatus*; 6d. *K. clavatus*; 7. *Retiverrumonosulcites barmerensis*; 8. *Proxapertites cursus*; 9. *Acanthotricolpites bulbospinosus*; 10. *Clavadiporopollenites ranerensis* (Bar = 10 µm).

with four species, viz. *K. gemmatus*, *K. baculatus*, *K. clavatus* and *K. ovatus* is also monosulcate. The sulcus in this genus is extended and runs along the periphery of pollen. Shape is spherical to ovoidal and the size ranges between 65-70 µm. Exine in these forms is provided with variety of sculptural elements like verrucae, gemmae, clavae and baculae.

Monotypic *Retiverrumonosulcites barmerensis* is spherical to oval in shape, 45-58 µm in size and possesses a short sulcus with thickened margin (Fig. 7). Exine is microreticulate and is provided with clavae or verrucae of varying size. Verrucae are 2-5 µm in diameter whereas, the calvae are 7-20 µm long and 5-10 µm in diameter at the distal part. Morphological features of this genus strongly suggest that these pollen grains also belong to the family Arecaceae. Palynofossils assignable to different species of *Proxapertites* (Fig. 8) are also very common in Barmer Assemblage. These forms, like *Spinizonocolpites* and *Kapurdipollenites*, possess an extended sulcus (zonisulcus) but are provided with micro-reticulate to coarsely reticulate exine. The two halves in this pollen are weakly joined resulting into frequent breakage of the grains into two split parts.

Other common forms in the Barmer Assemblage were assigned to different species of *Acanthotricolpites* (Fig. 9). These pollen were initially described as tricolpate (Kar, 1985) but detailed morphological observations made by Singh and Misra (1991) established that apertures in these forms are pores and not the colpus. These pollen are tri- to tetraporate and possess variety of spines over the exine surface which is so dense in some forms that pores are often obscured. The Barmer Assemblage is also richly

PLATE 6

(The bar in figures is equal to 10 µm)

⟶

1. *Spinizonocolpites* sp. 2; BSIP Slide No. 13622; Coordinates: 25.3 x 57.4.
2. *Spinizonocolpites* sp. 3; BSIP Slide No. 13627; Coordinates: 27.6 x 68.2.
3. *Spinomonosulcites brevispinosus* (Biswas) Kumar, 1994; BSIP Slide No. 13548; Coordinates: 25.6 x 73.2.
4. *Barringtoniapollenites retibaculatus* Kar & Sharma, 2001; BSIP Slide No. 13549; Coordinates: 32.6 x 63.4.
5. *Chiranthodendronpollenites bikanerensis* Kar & Sharma, 2001; BSIP Slide No. 13609; Coordinates: 27.3 x 61.2.
6. *Cupanieidites flaccidiformis* Venkatachala & Rawat, 1972; BSIP Slide No. 13547; Coordinates: 22.3 x 83.4.

7, 8. *Clavadiporopollenites raneriensis* Ambwani & Singh, 1996; BSIP Slide Nos. 13614& 13617; Coordinates: 21.3 x 79.1 & 18.7 x 65.3 respectively.

9. *Acanthotricolpites brevispinosus* Saxena & Khare, 2004; BSIP Slide No. 13572; Coordinates: 25.6 x 73.2.

10, 11. *Acanthotricolpites bulbospinosus* Kar, 1985; BSIP Slide Nos. 13618 & 13553; Coordinates: 21.6 x 69.1 & 17.4 x 75.3 respectively.

12. *Acanthotricolpites robustus* Saxena & Khare, 2004; BSIP Slide No. 13620; Coordinates: 22.3 x 83.4.

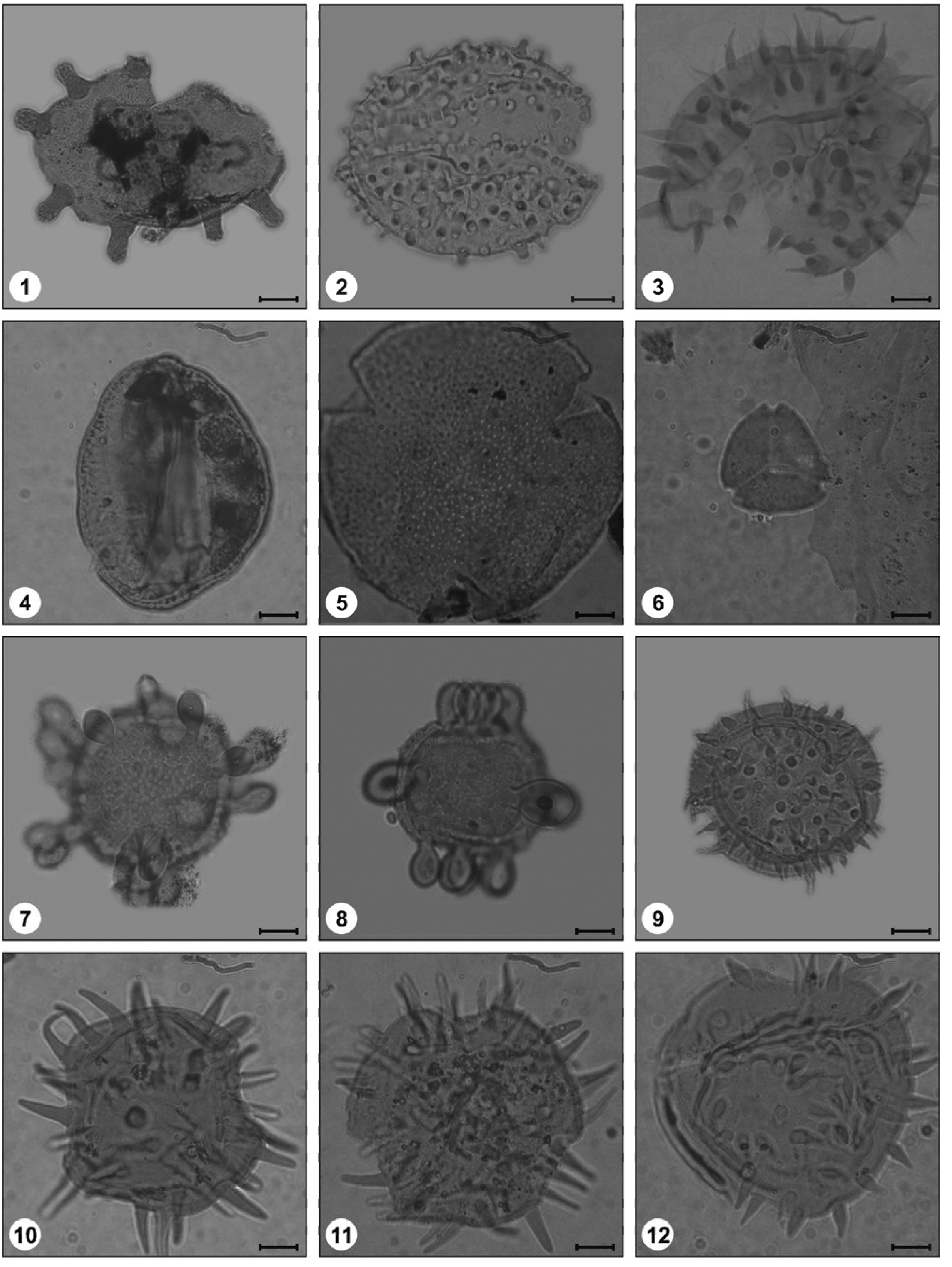


PLATE 6

represented by monosulcate pollen having spinose exine. These have been described as *Spinomonosulcites* by Singh and Misra (1991). These forms exhibit great deal of variation with regard to the shape, size and density of spines. Due to presence of similar kind of spines it is sometimes difficult to distinguish between *Acanthotricolpites* and *Spinomonosulcites* with casual observation. Morphological features of pollen assignable to both of these genera strongly suggest their affinity with the family Arecaceae. The genus *Clavadiporopollenites* (Fig. 10) is diporate. Pores are 25-30 µm across, generally sunken, annulated and are surrounded by a group of Clavae. Clavae are of variable size (15-20 µm).

SYSTEMATICS

The newly proposed species and some species which could not be assigned to any designated species have been described. Slides of all illustrated specimens are deposited in the Repository of Birbal Sahni Institute of Palaeobotany, Lucknow.

Genus—KAPURDIPOLLENITES Tripathi, 1994

Type Species—*Kapurdipollenites gemmatus* Tripathi, 1994

Kapurdipollenites calavatus sp. nov.

(Pl. 4.6, 7, 8)

Holotype—Pl. 4.6, 7; Size 64 µm; BSIP Slide No. 13637.

Type locality—Akli Formation, Akli lignite mine, Akli, Barmer District, Rajasthan.

Repository—Museum, Birbal Sahni Institute of Palaeobotany, Lucknow.

Diagnosis—Pollen grains sub-circular in shape, size range 62 to 68 µm (excluding processes) monosulcate. Sulcus long, meridional, running all along the peripheral region of the pollen. Exine 4-5 µm thick, reticulate, muri 2-2.5 µm thick, lumina 1-1.5 µm across. Exine provided with 8-12 clavae, which are 7-15 µm long and 6-8 µm wide at the distal side.

Comparison—Present species is different from other two species of the genus, *i.e. K. gemmatus* Tripathi (1994) and *K. baculatus* Tripathi (1994) in possessing a reticulate pattern in exine and in exhibiting big clavae over the exine surface.

Kapurdipollenites ovatus sp. nov.

(Pl. 4.9, 10, 11)

Holotype—Pl. 4.9; Size 60 µm; BSIP Slide No. 13627.

Type locality—Akli Formation, Akli lignite mine, Akli, Barmer District, Rajasthan.

Repository—Museum, Birbal Sahni Institute of Palaeobotany, Lucknow.

Diagnosis—Pollen grains oval in shape, size range 60 to 72 µm (excluding ornamentation), monosulcate.

PLATE 7

(The bar in figures is equal to 10 µm)

⟶

1. *Acanthotricolpites tiruchirapalliensis* Saxena & Khare, 2004; BSIP Slide No. 13626; Coordinates: 26.3 x 73.4.
2. *Acanthotricolpites* sp. 1; BSIP Slide No. 13626; Coordinates: 27.6 x 81.2.
3. *Acanthotricolpites* sp. 2; BSIP Slide No. 13549; Coordinates: 22.3 x 83.4.
4. *Crassivestibulites karii* Frederiksen, 1994; BSIP Slide No. 13609; Coordinates: 26.1 x 65.4.
5. *Echitriporites tranguliformis* von Hoeken Klinkenberg, 1964; BSIP Slide No. 13549; Coordinates: 22.6 x 87.4.
6. *Pluricolumellatipollis pachyexinus* Kar, 1995a ; BSIP Slide No. 13619; Coordinates: 18.3 x 76.4.
7. *Proteacidites protrudus* Sah & Kar 1970; BSIP Slide No. 13626; Coordinates: 32.3 x 63.4.
8. *Duplibaculatepollis pentacolpites* Kar & Sharma, 2001; BSIP Slide No. 13617; Coordinates: 25.4 x 67.4.
9. *Ocimumpollenites indicus* Kar, 1996; BSIP Slide No. 13621; Coordinates: 22.3 x 83.4.
10. Pollen Type 1; BSIP Slide No. 13613; Coordinates: 26.3 x 73.4.
11. *Brachysporisporites tenuis* Kumar, 1990; BSIP Slide No. 13612; Coordinates: 21.4 x 63.4.
12. *Haploxylonites ramanujamii* Elsik, 1990a; BSIP Slide No. 13623; Coordinates: 22.3 x 83.4.

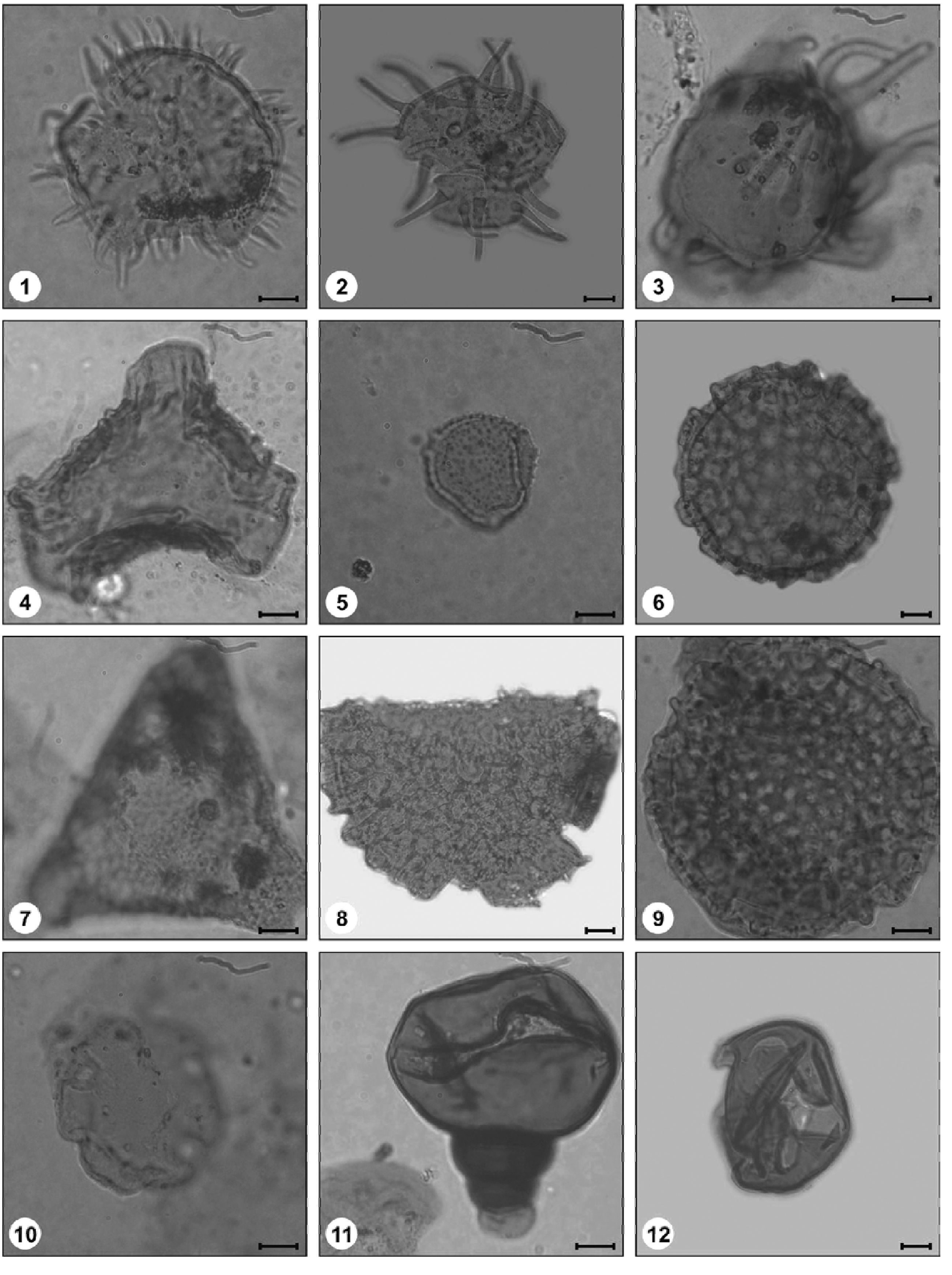


PLATE 7

Sulcus long, meridional, long sulcus generally resulting into splitting of pollen into two almost equal halves. Exine incompletely tectate, foveolate. Exine surface provided with club-shaped processes, which are 4-6 µm long and 4-5 µm wide. Distal ends of processes having obtuse ends.

Comparison—*Kapurdipollenites ovatus* is different from other species of the genus in possessing an oval shape. The exine surface in this species is provided with processes, which are club shaped and have distally obtuse ends, a character which is missing in other species of this genus.

Genus—SPINIZONOCOLPITES Muller, 1968

Type Species—*Spinizonocolpites echinatus* Muller, 1968

Spinizonocolpites sp.1

(Pl. 5.12)

Description—Pollen grain oval in shape, size 28 x 53 µm, zonisulcate, sulcus long, covering almost full perimeter of the pollen resulting into separation of pollen into two halves. Exine 2 µm thick, psilate, provided with short baculae, which are 3-5 µm long and about 2 µm wide.

Remarks—Present form is different from other species of the genus in its shape and the characters of the baculae.

Spinizonocolpites sp. 2

(Pl. 6.1)

Description—Pollen grain oval in shape, size 30 x 65 µm, zonisulcate. Sulcus long, extending up to almost full perimeter of the pollen. Exine very thin, psilate, provided with processes which are 6-9 µm long and about 4 µm wide. Processes with blunt ends and slightly constricted in the middle region.

Remarks—Present form is different from other species of the genus in possessing rod like processes, which are slightly constricted in the middle.

Spinizonocolpites sp. 3

(Pl. 6.2)

Description—Pollen grain oval in shape, size range 58 x 40 - 63 x 42 µm, zonisulcate. Sulcus long, covering more than 2/3 of the pollen length. Exine 1 µm thick, provided with baculae/warts of variable size (2-3 µm wide, 2-4 µm long), area between baculae finely structured.

PLATE 8

(The bar in figures is equal to 10 µm)

⟶

1. *Hilidicllites henanensis* (Song & Li) Kalgutkar & Jansonius, 2000; BSIP Slide No. 13549; Coordinates: 24.3 x 79.4.
2. *Inapertisporites conicus* Song & Li in Song *et al*., 1989; BSIP Slide No. 13630; Coordinates: 23.3 x 78.4.
3. *Inapertisporites kedvesii* Elsik, 1968; BSIP Slide No. 13625; Coordinates: 22.6 x 83.4.
4. *Multicellites volubilis* (Ke & Shi) Kalgutkar & Jansonius, 2000; BSIP Slide No. 13624; Coordinates: 28.3 x 83.4.
5. *Polycellaesporonites bellus* Chandra *et al*., 1984; BSIP Slide No. 13635; Coordinates: 33.3 x 63.4.
6. *Pluricellaesporites dentatus* Trivedi & Verma, 1973; BSIP Slide No. 13631; Coordinates: 22.3 x 83.4.
7. *Scolecosporites scalaris* (Kalgutkar) Kalgutkar & Jansonius, 2000; BSIP Slide No. 13641 Coordinates: 25.2 x 66.7.
8. *Staphlosporonites neyveliensis* Ambwani, 1983; BSIP Slide No. 13637; Coordinates: 21.4 x 67.4.
9. *Callimothallus ramanujamii* (Saxena & Singh) Kalgutkar & Jansonius, 2000; BSIP Slide No. 13637; Coordinates: 22.7 x 73.4.
10. *Kalviwadithyrites saxenae* Rao, 2003; BSIP Slide No. 13632; Coordinates: 22.3 x 83.4.
11. *Kutchiathyrites* sp.; BSIP Slide No. 13634; Coordinates: 25.3 x 76.3.
12. Fungal Body 1; BSIP Slide No. 13638; Coordinates: 18.3 x 67.4.

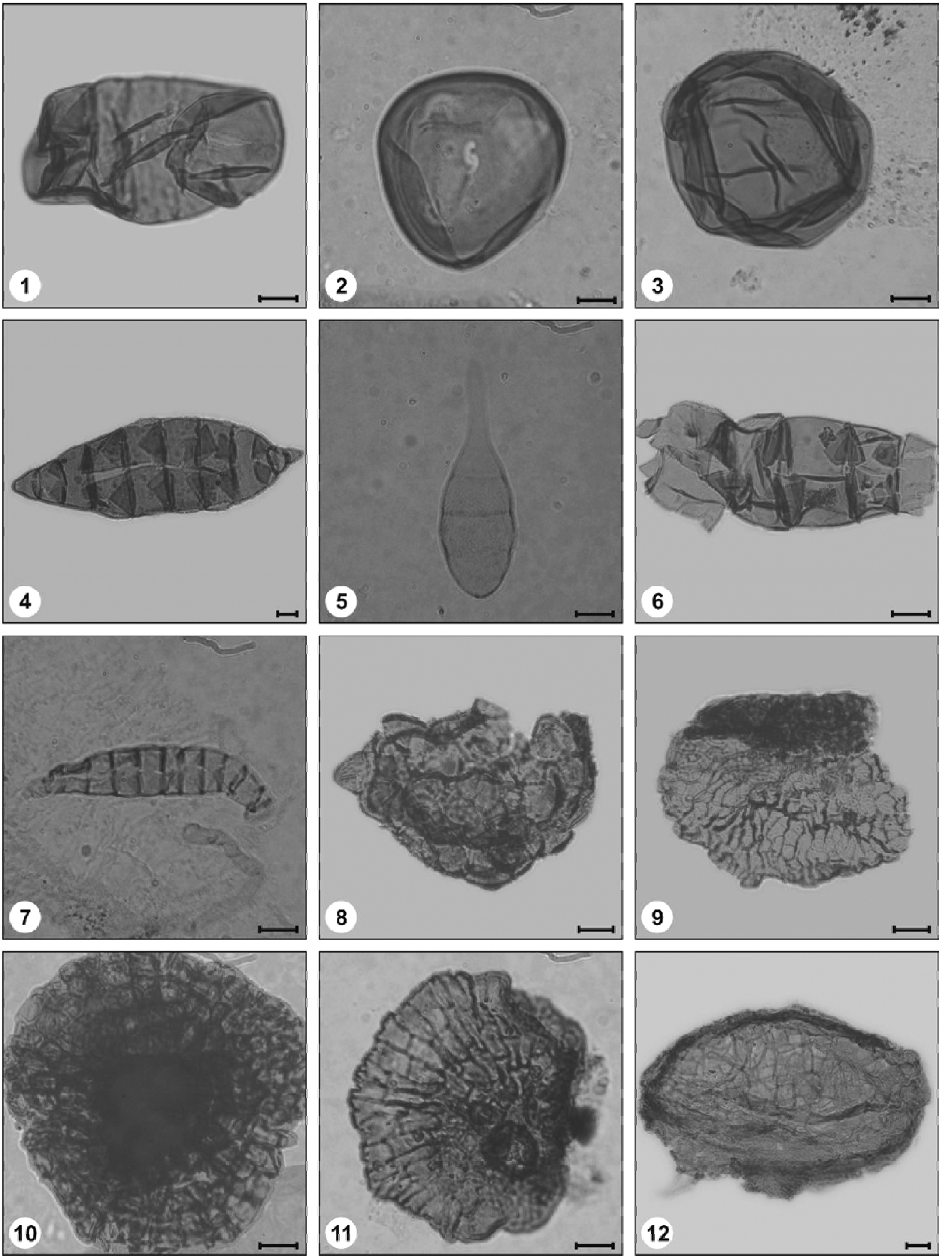


PLATE 8

Genus—ACANTHOTRICOLPITES Kar, 1985 emend. Singh & Misra, 1991

Type Species—*Acanthotricolpites bulbospinosus* Kar, 1985

Acanthotricolpites sp. 1

(Pl. 7.2)

Description—Pollen grains sub-triangular in shape, size 52 µm (excluding the spines), triporate, pores distinct, without thickened margins. Exine 1.5 µm thick, spinose, spines 12-16 µm long with tapering ends, inter-spinal area psilate.

Remarks—Present form differs from other species of the genus in possessing extraordinary long and stout spines.

Acanthotricolpites sp. 2

(Pl. 7.3)

Description—Pollen grain sub-circular in shape, size range 65-71 µm, triporate. Pores circular, 10-12 µm across, with thin margins, surrounded by whorl of spines. Exine 2 µm thick, spinose, spines 15-20 µm long, slender, gently tapering.

Remark—Present form is distinct from other species of the genus in having perfectly circular body and possibly the longest spines/processes, which are slender in nature.

Pollen type -1

(Pl. 7.10)

Description—Pollen grain sub-circular in shape, size 50 µm, tetraporate. Pores circular in shape, provided with thickened margin. Exine 2 µm thick, psilate, irregularly folded.

Genus—KUTCHIATHYRITES Kar, 1979

Type Species—*Kutchiathyrites eccentricus* Kar, 1979

Kutchiathyrites sp.

(Pl. 8.11)

Description—Microthyriaceous ascostromata sub-circular in shape, eccentrically developed, size range 60-100 µm. Stromata dimidiate, non-ostiolate, hyphae interconnected with each other. Peripheral pseudoparenchymatous cells elongated, central cells more or less isodiametric.

Fungal body-1

(Pl. 8.12)

Description—Fungal body ovoidal in shape, size range 62-75 µm. Body wall about 1 µm thick, showing irregularly arranged mesh.

Remarks—The fungal body appears to be a top swollen part of hyphae.

PALAEOECOLOGY AND PALAEOCLIMATE

Majority of the families represented in the Akli Assemblage (Schizaeaceae, Anonaceae, Arecaceae, Oleaceae, Lamiaceae, Guttiferae and Sapindaceae) are presently distributed in tropical to subtropical regions while other families (Osmundaceae, Matoniaceae, Lycopodiaceae, Liliaceae and Onagraceae) are cosmopolitan. Temperate elements are completely absent. Abundant pteridophytic spores and fungal elements also indicate a tropical flora, while the good representation of Microthyriaceous fungal fruiting bodies suggests warm and humid conditions with heavy precipitation. This palaeoclimatic interpretation is fully coincident with the palaeogeographic reconstructions proposed by Parrish *et al*. (1982), which suggest that, after getting separated from Madagascar, the Indian Plate started drifting in NNE direction positioning this subcontinent into a humid equatorial zone during Late Palaeocene.

BIOSTRATIGRAPHIC CONSIDERATIONS

Frequency of individual palynotaxa was determined by counting 200 palynofossils in each sample (Fig. 12). However, in samples where the recovery was poor, 100 palynofossils were counted. Considering the frequency of individual palynotaxa, general quantitative assessment at generic or family level has been presented with the help of bar diagram (Fig. 13). The Akli palynoflora is dominated by angiospermic pollen and share about 45% of the total assemblage. Pteridophytic spores, sharing about 20% of the assemblage are sub-dominantly represented. Gymnosperms are represented by different species of a single genus *Inaperturopollenites*. Taxonomic allocations of dinoflagellate cysts have not been attempted in present communication and their frequencies have been counted as a group only.

Pteridophytes are represented in the assemblage by the families Lycopodiaceae, Schizaeaceae, Matoniaceae and Osmundaceae. Among the pteridophytic spores, different species of *Dandotiaspora* constitute the most dominant element of the assemblage. Spores having affinity with the family Lycopodiaceae are also present in fairly good number. Angiospermic pollen show affinity with the families Anonaceae, Arecaceae, Liliaceae, Lamiaceae, Proteaceae and Sapindaceae. Amongst these, the pollen having affinity with Arecaceae are most abundant and share about 70% of the total angiosperm pollen assemblage. Pollen grains assigned to this family have been described under genera *Arecipites*, *Proxapertites*, *Spinizonocolpites*, *Kapurdipollenites*, *Retiverrumonosulcites*, *Clavadiporopollenites* and *Acanthotricolpites*. Among these, different species of *Spinizonocolpites* are most frequent. Other Arecaceous pollen recorded in high frequency belong to the genera *Proxapertites* and *Acanthotricolpites*. Different species of *Kapurdipollenites*, *Retiverrumonosulcites* and *Clavadiporopollenites* are moderately represented. Palynotaxa ascribed to different species of *Liliacidites* and *Retimonosulcites* show affinity with the family Liliaceae whereas, pollen genus *Matanomadhiasulcites* shows affinity with the family Anonaceae. These taxa are moderately represented in the assemblage. Palynotaxa assigned to different species of *Ocimumpollenites* and *Duplibaculatepollis* have been referred to the family Lamiaceae. These forms are recorded in few samples only and occur in low frequency.

Dinoflagellate cysts are mostly present in samples from top of the lithosection. Different species of *Apectodinium* constitute the abundant fraction of this group. Fungal remains are registered in high frequency in upper half part of the section. This group is represented by variety of spores and fungal hyphae.

Based on the distribution and abundance of palynotaxa the studied succession of Akli Formation has been divided into three palynozones (Fig. 13). The biostratigraphic zonation is based on presence of various palynotaxa, especially the pteridophytic spores and the angiospermous pollen grains reflecting coastal environment. The cenozones have been named after the most dominantly represented genus. Significant palynotaxa have been quantitatively categorized into six classes (Fig. 11), *viz.* Rare (1-3%), Frequent (4-10%), Profuse (11-19%), Abundant (20-29%), Dominant (30-50%) and Overdominant (51-80%). Three cenozones established in the studied succession are given below in the order of stratigraphy.

3. *Spinizonocolpites prominatus* Cenozone

2. *Lycopodiumsporites eocenicus* Cenozone

1. *Dandotiaspora dilata* Cenozone

The biostratigraphic characteristics of the formally instituted cenozones are as follows:

1. *Dandotiaspora dilata* Cenozone

Type locality—Lower part of Akli Formation, Akli, Barmer District, Rajasthan.

Reference locality—Akli Formation exposed in the open-cast lignite mine, Akli, Barmer, Rajasthan.

Lithology—The cenozone is constituted by grey shale. Thickness of the shale is about 5 m.

Characteristic palynotaxa of the cenozone—*Cyathidites australis*, *Dandotiaspora dilata*, *Dandotiaspora telonata*, *Lycopodiumsporites speciosus*, *Lygodiumsporites eocenicus*, *Liliacidites*

Families/ Affinity	**Palynotaxa**	**Present day distribution and habitats (Family wise)**
Cyatheaceae/ Diksoniaceae	*Cyathidites australis*	Tropical to sub-tropical; tree fern of thick tropical forest
Matoniaceae	*Dandotiaspora dilata*, *Dandotiaspora telonata*	Tropical to sub-tropical, subaquatic to swampy
Dictyophyllum	*Dictyophyllidites* sp.	Cosmopolitan
Lycopodiaceae	*Lycopodiumsporites eocenicus*, *L. sahii*, *L. speciosus*	Tropical species, predominantly epiphytes in thick forests
Schizaeaceae/ *Lygodium*	*Lygodiumsporites eocenicus*, *L. lakiensis*	Tropical-sub-tropical; climbing fern
Osmundaceae	*Todisporites minor, T. subtriangulatus*	Tropical to sub-tropical, sub-aquatic to swampy
Polypodiaceae	*Monolites discordatus*, *M. mawkmaensis*	Tropical
Cupressaceae/ Taxodiaceae	*Inaperturopollenites dubius* *I. laevigatus, I. minimus, I. parvus*, *I. punctatus*	Tropical
Arecaceae	*Arecipites bellus, A. intrapunctatus*, *A. matanomadhensis*	Tropical-sub tropical; wet evergreen elements
	Proxapertites assamicus, P. crassimurus, P. cursus, P. emendatus, P. hammenii, P. marginatus, P. microreticulatus, P. operculatus, P. rugulatus, P. scabratus	Chiefly tropical; climbers in evergreen forest.
	Kapurdipollenites baculatus, *K. gemmatus, K. clavatus* sp. nov., *K. ovatus* sp. nov.	Chiefly tropical (*Nypa*-like pollen, back mangrove)
	Spinizonocolpites adamanteus, *S. baculatus, S. bulbospinosus*, *S. echinatus, S. kutchensis*, *S. prominatus, S. venkatachalae*, *S. wodehousii, Spinizonocolpites* sp. 1, *Spinizonocolpites* sp. 2, *Spinizonocolpites* sp. 3	
	Neocouperipollis robustus, *Spinomonosulcites brevispinosus*	
	Retiverrumonosulcites barmerensis	
	Clavadiporopollenites raneriensis	Chiefly tropical
	Acanthotricolpites brevispinosus, *A. bulbospinosus, A. robustus*, *A. tiruchirapalliensis*, *Acanthotricolpites* sp. 1, *Acanthotricolpites* sp. 2	Chiefly tropical
	Longapertites discordis, *L. punctatus, L. retipilatus*	Tropics of Malasia; Lowland evergreen palms

Liliaceae	*Liliacidites magnus*, *Retimonosulcites ovatus*	Cosmopolitan
Anonaceae	*Matanomadhiasulcites kutchensis*, *M. major*, *M. maximus*, *M. microreticulatus*	Tropical; Evergreen
Sapindaceae	*Cupanieidites flaccidiformis*	Warm climate
Proteaceae	*Proteacidites protrudes*	Tropical to subtropical
Lamiaceae	*Ocimumpollenites indicus* *Duplibaculatepollis pentacolpites*	Tropical
Unknown	*Barringtoniapollenites retibaculatus*	
Unknown	*Chiranthodendronpollenites bikanerensis*	
Unknown	*Crassivestibulites karii*	
Unknown	*Echitriporites tranguliformis*	
Unknown	*Pluricolumellatepollis pachyexinous*	
Unknown	Pollen type -1	

Fig. 11—Palynotaxa from Akli Formation, Barmer and their present-day distribution.

magnus, *Proxapertites microreticulatus*, *Spinizonocolpites venkatachalae*, *Acanthotricolpites karii*.

Remarks—This cenozone is characterized by high frequency of *Dandotiaspora* spp., *Proxapertites* spp. and moderate representation of *Inaperturopollenites* spp., *Arecipites* spp. and *Spinizonocolpites* spp.

2. *Lycopodiumsporites eocenicus* Cenozone

Type locality—Middle part of Akli Formation, Akli, Barmer District, Rajasthan.

Reference locality—Akli Formation exposed in the open-cast lignite mine, Akli, Barmer, Rajasthan.

Lithology—The cenozone is represented by shale-lignite sequences which is about 6 m thick.

Characteristic palynomorphs of the cenozone—*Lycopodiumsporites eocenicus*, *Lycopodiumsporites sahii*, *Lycopodiumsporites speciosus*, *Lygodiumsporites lakiensis*, *Matanomadhiasulcites major*, *Retiverrumonosulcites barmerensis*, *Proxapertites assamicus*, *Proxapertites hammenii*, *Proxapertites microreticulatus*, *Kapurdipollenites clavatus*, *Spinizonocolpites prominatus*, *Clavadiporopollenites raneriensis*, *Duplibaculatepollis pentacolpites*, *Ocimumpollenites indicus*.

Remarks—This cenozone is characterized by high frequency of *Lycopodiumsporites eocenicus*, *Lycopodiumsporites sahii* and different species of *Spinizonocolpites*.

3. *Spinizonocolpites prominatus* Cenozone

Type locality—Upper part of Akli Formation, Akli, Barmer District, Rajasthan.

Reference locality—Akli Formation exposed in the open-cast lignite mine, Akli, Barmer, Rajasthan.

Lithology—The cenozone is represented by lignite and clay sequences which are collectively about 16 m thick.

Characteristic palynomorphs of the cenozone—*Todisporites major*, *Todisporites minor*, *Matanomadhiasulcites kutchensis*, *Matanomadhiasulcites microreticulatus*, *Matanomadhiasulcites major*, *Retiverrumonosulcites barmerensis*, *Proxapertites assamicus*, *Proxapertites operculatus*, *Proxapertites microreticulatus*, *Spinizonocolpites bulbospinosus*, *Spinizonocolpites venkatachalae*, *Spinizonocolpites prominatus*, *Acanthotricolpites complexus*, *Acanthotricolpites karii*, *Acanthotricolpites intermedius* and *Kapurdipollenites ovatus*.

Remarks—The cenozone is characterized by high frequency of different species of *Proxapertites, Kapurdipollenites, Spinizonocolpites* and *Acanthotricolpites.*

PALYNOFLORAL COMPARISON

Comparison with other Early Palaeogene palynological assemblages from Rajasthan

Palynological records from Palaeogene successions of Rajasthan (Fig. 2) are from Barmer (Bose, 1952; Jain *et al*., 1973; Naskar & Baksi, 1978; Tripathi, 1994, 1995, 1997; Tripathi *et al*., 2003; Tripathi *et al*., 2009), Bikaner-Nagaur (Rao & Vimal, 1950, 1952; Sah & Kar, 1974; Singh & Dogra, 1988; Kar, 1995, 1996; Ambwani & Singh, 1996; Kar & Sharma, 2001; Tripathi *et al*., 2008) and Jaisalmer (Lukose, 1974).

The palynological assemblages described from Late Palaeocene-Early Eocene samples of bore-holes drilled near Jalipa and Kapurdi in the Barmer District of Rajasthan (Tripathi, 1994, 1995) are very similar to the Akli Assemblage as, different species of *Kapurdipollenites, Retiverrumonosulcites, Acanthotricolpites* and *Spinizonocolpites* are of common occurrence. In particular, the assemblage of Zone A described from bore-holes MK-327 and MK-332 (Tripathi, 1997) resemble closely with the Akli Assemblage. Palynotaxa recorded in both assemblages are: *Dandotiaspora dilata, Dandotiaspora telonata, Proxapertites assamicus, Proxapertites microreticulatus, Palmidites plicatus, Palmidites naviculus, Spinizonocolpites echinatus, Retimonosulcities ovatus* and *Matanomadhia-sulcites maximus.* The palynological assemblage described by Tripathi *et al.* (2009) from the Thanetian-Ypresian sequence at Giral lignite mine, Barmer is very similar to the present assemblage. Many species of *Dandotiaspora, Lygodiumsporites, Todisporites, Arecipites, Palmaepollenites, Proxapertites, Kapurdipollenites, Matanomadhiasulcites, Retiverrumonosulcites, Clavadiporopollenites* and *Acanthotricolpites* are common to both the assemblages. A rare but very conspicuous form *Clavadiporopollenites raneriensis* described from Early Tertiary of Bikaner (Ambwani & Singh, 1996) is recorded in the present assemblage also. The Akli Assemblage is also comparable with that described by Kar and Sharma (2001) from the Upper Palaeocene bore-hole BH-125 drilled near Bithnok, Bikaner, as both show the occurrence of *Dandotiaspora dilata, Proxapertites cursus, Spinizonocolpites baculatus* and *Ocimumpollenites indicus*. However, the abundance of Arecaceous pollen in the Akli Assemblage is a distinctive feature.

Comparison with Early Palaeogene palynological assemblages from Kutch (Gujarat)

Similarities between the present assemblage and those from Palaeocene-Eocene sediments of Kutch, Gujarat are striking (Fig. 2). Resemblances with palynoflora from Matanomadh and Naredi formations, Kutch (Saxena, 1978, 1979, 1980, 1981; Kar, 1978, 1985) are noteworthy. Palynomorphs common between assemblages of *Dandotiaspora dilata* and *Neocouperipollis brevispinosus* cenozones (Saxena, 1981) of Matanomadh Formation and the present assemblage are: *Dandotiaspora dilata, D. telonata, Lygodiumsporites eocenicus, L. lakiensis, Palmaepollenites eocenicus, P. kutchensis* and *P. nadhamunii*. Two species of *Acanthotricolpites*, namely *A. bulbospinosus* and *A. kutchensis* (= *Couperipollis kutchensis*), described from the subsurface Palaeogene sediments of Kutch (Venkatachala & Kar, 1969) abundantly occur in the Akli Assemblage. However, some differences must also be stressed. Several palynotaxa recorded from the aforementioned two cenozones of Matanomadh Formation but absent in the Akli Assemblage are: *Tricolpites minutus, Trilatiporites, Sonneratiopollis* and *Lakiapollis*.

Comparison with palynoflora of the Indus Region (Pakistan)

The Late Palaeocene Assemblage recorded from subsurface samples of Indus coal region, Pakistan (Frederiksen, 1994) resembles the present assemblage.

TAXA	SAMPLE NUMBER																	
		1	3	4	5	6	7	9	12	13	14	18	20	21	26	28	29	34
Dandotiaspora dilata			★	★	★						★	★						★
Lycopodiumsporites eocenicus									■	■	×	★		★	★			
Lygodiumsporites eocenicus			+									×		★				★
Lygodiumsporites lakiensis			+									+						
Lygodiumsporites pachyexinous			+		+													
Arecipites matanomadhensis		+	+			+						+	+					
Liliacidites magnus				+	+								+	+			+	
Matanomadhiasulcites kutchensis											×	+	×		+		+	
Matanomadhiasulcites major											×		+	+				×
Matanomadhiasulcites maximus				+	+						+		+					
Matanomadhiasulcites microreticulatus				×									+				+	
Retimonosulcites ovatus		+		+							+			+	+			
Retiverrumonosulcites barmerensis				+							×							
Proxapertites assamicus		×									+	×		+		+		+
Proxapertites crassimurus												×	+	+		×		×
Proxapertites cursus			+									+		+				×
Proxapertites emendatus														×				✦
Proxapertites hammenii		×									×	×			×	×		
Proxapertites marginatus		×			+							×		+				★
Proxapertites operculatus			★	+									+		+	+	×	×
Kapurdipollenites baculatus														×	+		✦	
Kapurdipollenites gemmatus			+	+										×		+	×	
Kapurdipollenites clavatus											×						×	
Kapurdipollenites ovatus																		
Spinizonocolpites adamanteus			+	+							+			+			+	+
Spinizonocolpites baculatus				+			+				+			+				+
Spinizonocolpites bulbospinosus			+								×		★	+				
Spinizonocolpites echinatus			×								+	+	×	+		×	★	+
Spinizonocolpites kutchensis			×	×							×		×	+	+			
Spinizonocolpites prominatus			×	×							★		×	×	×			×
Spinizonocolpites venkatachalae			★	×							×					×		
Clavadiporopollenites raneriensis										+	+							
Acanthotricolpites brevispinosus				+										×			+	+
Acanthotricolpites bulbospinosus			+								+			×	×			
Acanthotricolpites complexus			+										+			+	★	
Acanthotricolpites intermedius			+	+							×			×		×	★	+
Acanthotricolpites karii			+	×				+			×			×		+	★	
Acanthotricolpites kutchensis						+					+							
Acanthotricolpites robustus						+			+									
Acanthotricolpites tiruchirapalliensis											+		+					
Duplibaculatepollis pentacolpites											+							
Ocimumpollenites indicus										+								
Dinoflagellate cysts			×	×				+					■	×	×	✦	■	
Fungal remains								×		+	+	★	✦	✦	■	✷	★	★

+ Rare: 1-3%
× Frequent: 4-10%
★ Profuse: 11-19%
✦ Abundant: 20-29%
■ Dominant: 30-50%
✷ Overdominant: 51-80%

Fig. 12—Frequency of palynotaxa present in Akli Formation, Barmer, Rajasthan.

Palynotaxa of common occurrence are: *Spinizonocolpites* spp., *Proxapertites cursus* and *Matanomadhiasulcites maximus*.

AGE CONSIDERATIONS

Indian Palaeocene sediments are characterized by dominance of different species of *Dandotiaspora, Lycopodiumsporites, Neocouperipollis, Proxapertites, Spinizonocolpites, Palmidites* and *Kielmeyerapollenites, Longapertites, Liliacidites* and *Matanomadhiasulcites* (Singh, 1977; Saxena, 1980, 1988; Thanikaimoni *et al.*, 1984; Tripathi & Singh, 1985; Kar, 1985; Kar & Kumar, 1986; Venkatachala *et al.*, 1989; Tripathi, 1995, 1997; Kar & Sharma, 2001). In the Eocene these forms either dwindle or disappear and other palynofossils become more frequent (Kar, 1992). Age determination and distinction of Palaeocene and Eocene sediments based on ranges of spore/pollen taxa is therefore, rather difficult. However, a few attempts have been made in this regard in the Rajasthan Basin (Singh & Dogra, 1988; Tripathi, 1997).

Palynological assemblages from bore-holes drilled near Kapurdi and Jalipa have indicated occurrence of Palaeocene and Eocene deposits in the Barmer District (Tripathi, 1995, 1997). Lignites of these bore-holes, dated as Late Palaeocene, yielded different species of *Dandotiaspora, Lycopodiumsporites, Matanomadhiasulcites, Proxapertites, Spinizonocolpites* and *Palmidites*. Abundance of these pollen characterizes the Late Palaeocene (Kar, 1996; Tripathi, 1997). In the Akli Formation, different species of *Dandotiaspora, Proxapertites, Spinizonocolpites* and *Matanomadhiasulcites* are profusely recorded.

Singh and Dogra (1988) identified five zones in the Palaeocene to Lower Eocene deposits of the Bikaner Basin. The lower SP-1 and SP-2 zones represent the Early Palaeocene, SP-3 and SP-4 zones correspond to the Late Palaeocene and SP-5 zone characterizes the Early Eocene. Since many palynotaxa typical of SP-3 and SP-4 zones (*Dandotiaspora dilata, Lygodiumsporites lakiensis, Proxapertites cursus* and *Palmidites plicatus*) have been identified in the studied Akli Succession, a Late Palaeocene age is quite probable. The dinoflagellate assemblage from the lower part of Akli Formation shows presence of *Apectodinium parvum, Apectodinium quinquelatum* and *Muratodinium fimbriatum*. These forms have also been recorded from late Palaeocene to earliest Eocene deposits of India (Garg *et al.*, 1995; Garg & Khowaja-Ateequzzaman, 2000; Vandana Prasad *et al.*, 2006). Considering the spore/pollen and dinoflagellate assemblages, this formation has been dated as Thanetian to Ypresian in age. Presence of foraminifera assigned to *Nummulites burdigalensis*, referred to shallow benthic zones SBZ10–SBZ11 and *Assilina daviesi* suggesting planktonic foraminiferal zones P7–P9 from the Akli Formation (Sahni *et al.*, 2004) further corroborates this age assignment.

PALYNOFACIES ANALYSIS

The abundance and distribution of different types of organic matter in each sample were studied (Fig. 14). These studies were based on the compositional characteristics and the quantitative assessment of dispersed organic matter. For quantitative analyses three hundred plant derived organic particles were counted in each sample.

The lowermost part of the grey shale unit that overlies the basal shale bed with siderite nodules and burrows is highly siliceous and is devoid of plant microfossils. However, most samples from this unit proved suitable for palynofacies analyses. The relative abundance of structured terrestrial palynodebris, such as leaf cuticle and woody tissues, decreases upwards from 40 to 12%. Biodegraded terrestrial contents vary between 20 and 40%. Amorphous matter content gradually increases upwards from 6 to 40%. Black debris ranges from 10 to 12%, whereas the relative abundance of spore pollen is about 2-4%.

In shale and lignite samples, well-preserved structured phytoclasts (3-10%) were noticed. However, phytoclasts derived from clay and shale samples show better preserved morphological details than those recovered from lignite. In beds with fine lithologies compaction plays a major role in the

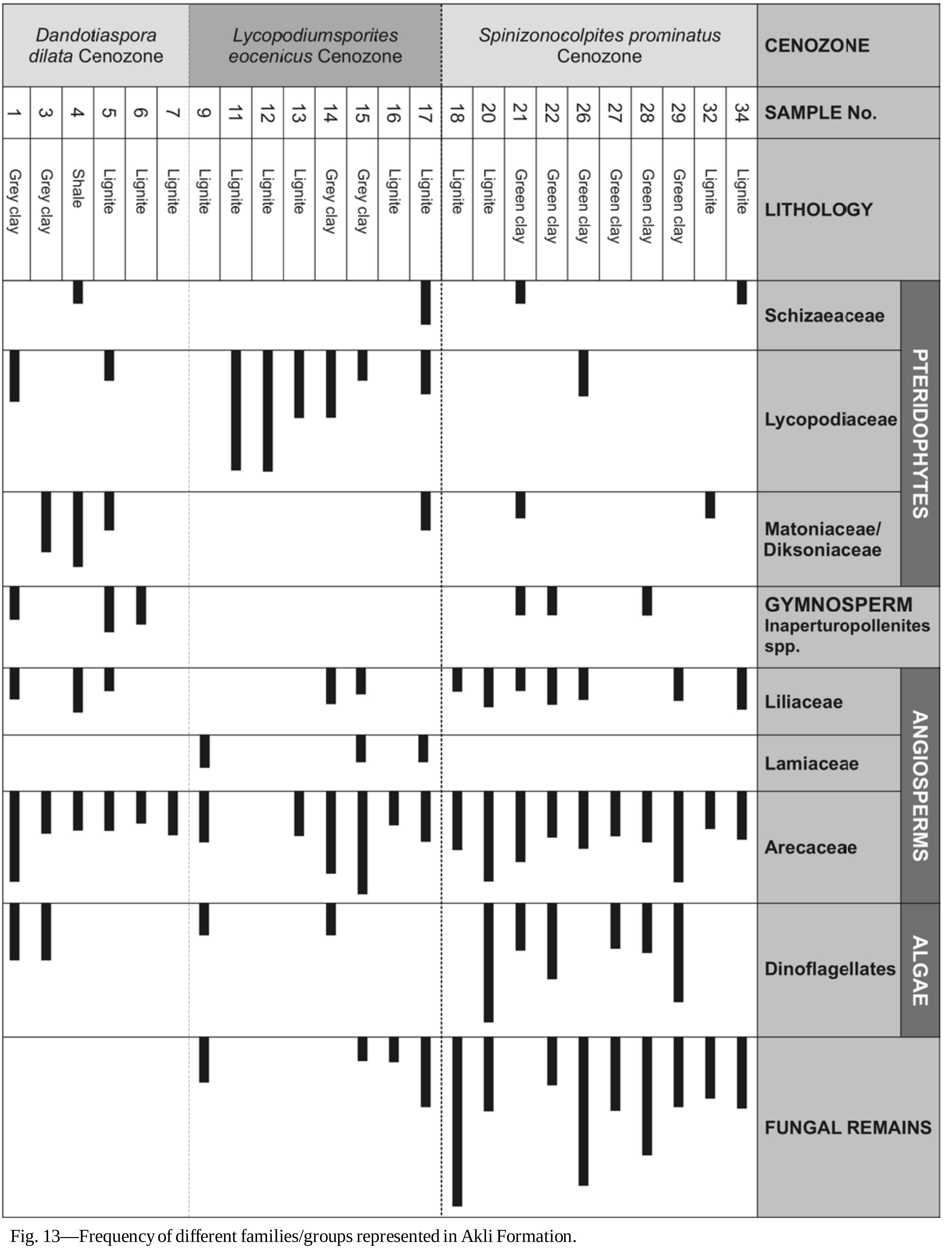


Fig. 13—Frequency of different families/groups represented in Akli Formation.

preservation of organic matter (Demaison & Moore, 1980). All lignite seams show almost uniform distribution patterns of various types of organic matter, though some variation in the relative abundance of amorphous and black debris is noticeable. The relative abundance of biodegraded phytoclasts (biodegraded terrestrial and amorphous organic matter) is higher in comparison to other lithotypes. Another remarkable feature observed in lignite beds is the occurrence of pyritized amorphous matter. The clay beds intercalated between lignite seams are characterized by rich structured terrestrial (10–35%) and biodegraded terrestrial (up to 50–65%) organic matter, abundance of black debris and lack of pyritized amorphous organic matter.

Degree of organic matter degradation shows the intensity of microbial activity in different lithotypes. The abundance of biodegraded terrestrial and amorphous organic matter throughout the succession may be attributed to high microbial activity and overall anoxic burial conditions. Thus, lignite beds contain very abundant biodegraded amorphous and pyritized amorphous organic matter, which indicate prevalence of anoxic conditions after burial. Palynodebris content in the clayey beds is also characterized by large amounts of biodegraded and amorphous matter (50% in average). Structured and black debris (9% each in average) indicate moderate anoxic condition. The microbial action during diagenesis of clayey beds was comparatively less intense than that in the lower and middle lignite seams.

Both the relative lower abundance of biodegraded terrestrial and amorphous matter at the upper part of the succession, together with an increased amount of black debris, indicate the progressive prevalence of moderately oxic burial conditions. This was favoured by an originally lower supply of organic detritus and by the comparatively coarser size of the sediment (Tripathi *et al.*, 2009). This situation allowed structural phytoclasts to come into contact with air for longer periods, thus resulting in oxidation and transformation of organic detritus into black-coloured or opaque matter.

DEPOSITIONAL ENVIRONMENT

Many species attributed to fossil pollen genus *Spinizonocolpites* occurring in the Akli Assemblage show affinity with the extant *Nypa*. Similarly, *Proxapertites*, based on its morphological features, has been interpreted to represent an extinct group of palms possibly related to *Nypa* (Muller, 1968; Frederiksen, 1985). The genus *Acanthotricolpites*, in all likelihood, also related to *Nypa* (Venkatachala *et al.*, 1996) is profusely recorded in the Akli Assemblage. Fossil records show that different species of this genus produced pollen with a great morphological diversity (Kar, 1985; Kar & Kumar, 1986; Frederiksen, 1994; Tripathi, 1994; Singh, 1999; Tripathi *et al.*, 2003; Divya Srivastava, 2008). The genus *Nypa*, represented by one extant species (*N. fruticans*), is a mangrove palm growing in tidal mud flats fringing the tidal reaches of large fresh water rivers (Morley, 2000). Presence of *Nypa* and *Nypa*-like pollen in abundance is significant for interpretation of sedimentary environment as, this genus is known to have low pollen productivity (Muller, 1964; Frederiksen, 1985) and its occurrence, even in low number indicates a good representation of this genus at the time of sediment accumulation. Large *Nypa* pollen cannot be transported to long distances towards the sea from the mangrove environment (Chaloner, 1968). Frequent occurrence of these pollen therefore, suggests that accumulation of the Akli sediments took place in a coastal swamp fringed by thick mangrove vegetation chiefly constituted by *Nypa*. It is further inferred that pteridophytic spores and other angiospermic elements in the assemblage were transported to the site of deposition through river channels. Following the same line of reasoning, existence of mangrove forests at the beginning of Eocene in some basins of Tasmania was also inferred by Pole (1998) and Pole and Macphail (1996) on the basis of abundant occurrences of *Spinizonocolpites prominatus*. Presence of different species of *Proxapertites* and *Spinizonocolpites* in other deltaic and shallow marine sediments has been confirmed by many palynological works (Muller, 1979; Mandal, 1987; Tripathi & Singh,

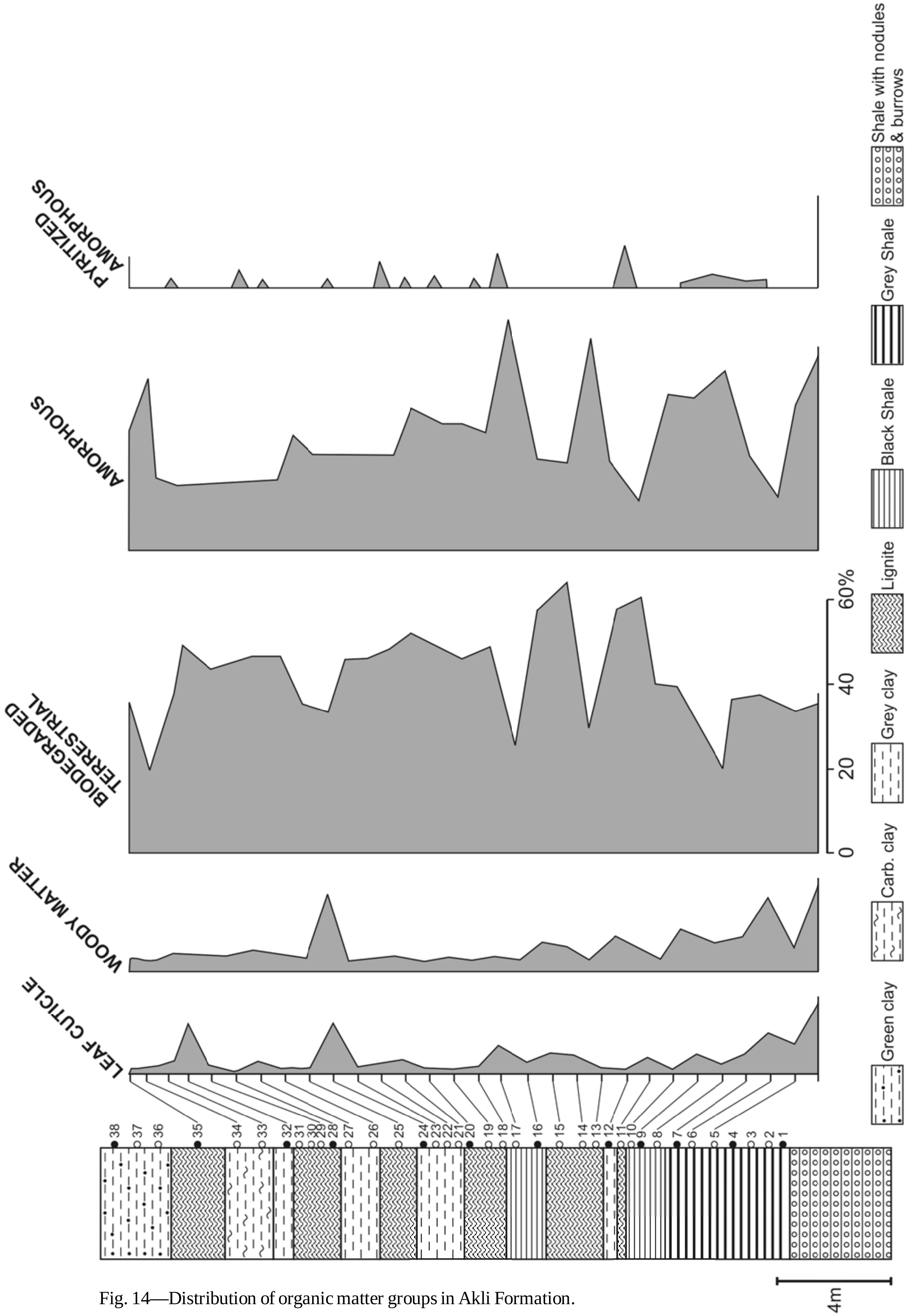


Fig. 14—Distribution of organic matter groups in Akli Formation.

1985; Kar & Kumar, 1986, 1987; Kar & Sharma, 2001).

It is inferred that the Akli Formation was deposited in a palaeoshoreline with extensive swamps fringed by abundant mangrove Palm *Nypa* and huge amounts of detritus derived from adjacent areas were brought to the site of deposition. The neighbouring areas were inhabited by vegetation chiefly dominated by plants of the families Arecaceae, Liliaceae, Oleaceae, Guttiferae, Lamiaceae and Onagraceae. Prevalence of fragments of land plants and their transportation to the depositional site indicates the dominance of higher plants in the surrounding vegetation. Occurrence of resin lumps indicates the involvement of higher plant groups, mostly the arboreal angiosperm trees (Masron & Pocock, 1981; Batten, 1996). The occurrence of dinoflagellate cysts in some black shale and grey clay beds indicates mixing with marine water near the shore and their low frequency can be attributed to the high influx of terrestrial components.

Sedimentological studies suggested that the Akli Formation represents a floodplain which underwent marine incursions (Sisodia, 1996; Sisodia & Singh, 2000). These conclusions were mainly drawn on the basis of the inferred channel fill sedimentation and fining upward nature of each lignite cycle in the Akli Formation. The dominant bentonitic claystones represent low-energy shallow-water conditions, whereas occasional thin sandstone beds and siltstone within claystone show that the area was periodically affected by flood events. These inferences are supported by palynological studies.

Occurrence of both terrestrial organic matter and dinoflagellate cysts in some black shales and grey clay beds (sample nos. 7, 9, 12 and 16) certainly suggests proximity to the palaeo-shoreline (Habib *et al.*, 1994). Furthermore, the occurrence of different species of *Proxapertites*, *Palmaepollenites*, *Palmidites* and *Arecipites bellus* in the assemblage clearly indicates coastal environments.

CONCLUSIONS

1. Palynological assemblage from Akli Formation, Barmer is rich in angiospermic pollen having preponderance of forms showing affinity with *Nypa* mangrove. The studied sequence is divisible into three palynozones. The lower zone is characterized by variety of pteridophytic spores along with the pollen of arecaceous affinity. The middle zone is marked with high frequency of spores of the family Lycopodiaceae. The upper zone is rich in dinoflagellate cysts, fungal remains and the arecaceous pollen.
2. The Akli Assemblage is closely comparable to those from Late Palaeocene to Early Eocene sequences of western regions of India, particularly from Rajasthan and Gujarat (Kutch). Striking palynological resemblance has also been noticed with the assemblage from Late Palaeocene subsurface rocks of Indus Coal region, Pakistan.
3. Palynological studies indicate that the Akli Sequence was deposited in the flood plain with frequent marine incursions. Sedimentological studies also support these inferences.
4. Abundance of biodegraded terrestrial and amorphous organic matter throughout the sequence is noticed. It shows dominance of anoxic conditions after burial of organic matter. The occurrence of black debris in increasing amount in top of the section shows gradual change to moderately oxic burial conditions.
5. Grey shales contain well-preserved structured phytoclasts whereas, lignite beds contain biodegraded amorphous and pyritized amorphous organic matter in good amount. Presence of these components suggests prevalence of anoxic conditions. Clay beds show the presence of biodegraded and amorphous organic matter in higher frequency indicating moderate anoxic conditions.
6. Considering the known ranges and frequencies of recorded palynotaxa and dinoflagellate assemblages, the studied sequence of Akli Formation is dated as Thanetian to Ypresian.

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