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Palynological investigation and environmental interpretation on Akli Formation (Late Palaeocene) from Barmer Basin, western Rajasthan, India

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ABSTRACT

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Akli Formation of Barmer Basin, mainly a claystone, shale and lignite sequence, is divided into two members viz., Thumbli Member and Kapurdi Fuller's earth Member. Palynological studies on samples from the Thumbli Member exposed near Barmer, western Rajasthan were carried out and a rich palynological assemblage constituted by dinoflagellate cysts, fungal remains, pteridophytic spores and angiospermic pollen was recorded from shale and lignite samples. The assemblage is dominated by angiospermic pollen which are assigned to the families Arecaceae, Liliaceae, Oleaceae, Caesalpiniaceae, Rubiaceae, Meliaceae, Myricaceae, Onagraceae and Lamiaceae. Palynotaxa having affinity with Arecaceae are abundant indicating deposition of sediments in coastal environment. Many pteridophytic spores and abundant fungal remains in the assemblage indicate warm and humid climate with high precipitation. Presence of dinoflagellate cysts indicates marine influence.

Most of the families represented in the assemblage are presently confined to tropical to subtropical areas. Considering the high frequency of *Nypa/Nypa*-like pollen in the assemblage it is inferred that sediments were deposited in an area which was fringed by thick vegetation of mangrove chiefly constituted by *Nypa*.

Key-words—Palynology, Palaeoenvironment, Akli Formation, Late Palaeocene, Western Rajasthan (India).

भारत के पश्चिमी राजस्थान की बाड़मेर द्रोणी के अकली शैलसमूह (अन्तिम पेलियोसीन) का परागाणविक अन्वेषण तथा पर्यावरणीय निर्वचन

सूर्यकान्तमणि त्रिपाठी, यू.के. सिंह एवं एम.एस. सिसोदिया

सारांश

बाड़मेर द्रोणी का अकली शैलसमूह, मूलतः मृत्तिका प्रस्तर, शेल तथा लगुडांगार अनुक्रम है, को दो सदस्यों, थुम्बली सदस्य तथा कापुर्डी फुलर के मृदा सदस्य में विभाजित किया गया है। पश्चिमी राजस्थान के बाड़मेर के समीप अनावरित थुम्बली सदस्य से प्राप्त नमूनों का परागाणविक अध्ययन किया गया तथा शेल एवं लगुडांगार नमूनों से घूर्णीकशाभ पुटियों,

कवकीय अवशेषों, टेरिडोफाइटी बीजाणुओं तथा आवृतबीजी परागकणों द्वारा निर्मित एक सम्पन्न परागाणविक समुच्चय अंकित किया गया। इस समुच्चय में आवृतबीजी परागकणों की प्रधानता है, जो एरीकेसी, लिलिएसी, ओलिएसी, सीज़ेलपिनेसी, रूबिएसी, मीलिएसी, माइरिकेसी, ओनाग्रेसी तथा लेमिएसी कुलों से संदर्भित हैं। एरीकेसी से सन्दर्भनीय परागाणु वर्गक प्रचुरता में हैं, जो तटीय पर्यावरण में अवसादों का निक्षेपण इंगित करते हैं। समुच्चय में अनेक टेरिडोफाइटी बीजाणु तथा प्रचुर कवकीय अवशेष उच्च वर्षण के साथ उष्ण तथा आर्द्र जलवायु इंगित करते हैं। घूर्णीकशाभ पुटियों की उपस्थिति समुद्री प्रभाव का संकेत करती है।

समुच्चय में निरूपित अधिकांश कुल वर्तमान में उष्णकटिबन्धीय से उपोष्ण कटिबन्धीय क्षेत्र में संवितरित हैं। समुच्चय में *नाइपा/नाइपा* की भाँति के परागकणों की उच्च आवृत्ति के आधार पर यह अनुमानित किया जाता है कि अवसाद एक ऐसे क्षेत्र में निक्षेपित थे, जो मुख्यतः *नाइपा* द्वारा निर्मित मोटी मैंग्रोव वनस्पतियों द्वारा किनारों पर अवस्थित था।

संकेत शब्द—परागाणुविज्ञान, पुरापर्यावरण, अकली शैलसमूह, अन्तिम पेलियोसीन पश्चिमी राजस्थान ;भारतद्ध.

INTRODUCTION

THE sedimentary sequences in north-western Rajasthan are predominantly intracratonic type and cover an area of about 1,20,000 sq km. These sediments are part of the western Rajasthan Shelf and are subdivided into several basins viz., Jaisalmer Basin, Barmer Basin, Bikaner-Nagaur Basin and Sanchore Basin. The Barmer Basin, mainly constituted by Middle Jurassic to Early Eocene sediments, are mostly covered under extensive desert sand. Exposed in central part of the Barmer Basin, the Akli Formation is made up of sand-poor bentonitic claystone, grey bituminous claystone, shale and lignite. This formation is divided into two members viz., Thumbli Member and Kapurdi Fuller's earth Member. Altogether 17 samples from Thumbli Member representing claystone, shale and lignite were analysed for the palynological studies. Out of these, two shale samples and one lignite sample yielded palynofossils. The recovered assemblage has been described and an attempt has been made to determine the palaeovegetation and depositional environment.

GEOLOGY OF THE BARMER BASIN

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 exposed at Fatehgarh on Barmer Hills near Barmer and at Sarnu. These faults are the result of the break up of the Indian craton during Late Cretaceous-Early Palaeocene time. 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. 2). These sediments were deposited on Late Proterozoic Malani Igneous Suit.

The pre-rift sediments are represented by : 1. siliceous facies comprising shale, sandstone and orthoquartzite (Randha Formation), 2. calcareous facies comprising limestone, phosphorites and dolomudstone (Birmaria Formation), 3. the thinning and fining upward sand bodies with intervening red siltstone (Sarnu Formation) and 4. the medium to coarse grained, fining up ward fluvial sands with fossil logs (Lathi Formation).

The syn-rift sediments are exposed at Barmer and Fatehgarh (Fig. 1) representing Barmer-Hill and Fatehgarh formations. The Barmer-Hill Formation, exposed along the western boundary of basin at N25° 45' : E71° 24', rests unconformably on the basement. The Barmer Hill Formation is comprised of sandstone and clast-supported conglomerate representing rapid deposition in an alluvial fan environment with source from Malani Rhyolite. The Fatehgarh Formation, exposed at the northern boundary of the basin at N26° 26' : E71° 12', shows a mixed sand and mud tidal-flat environment

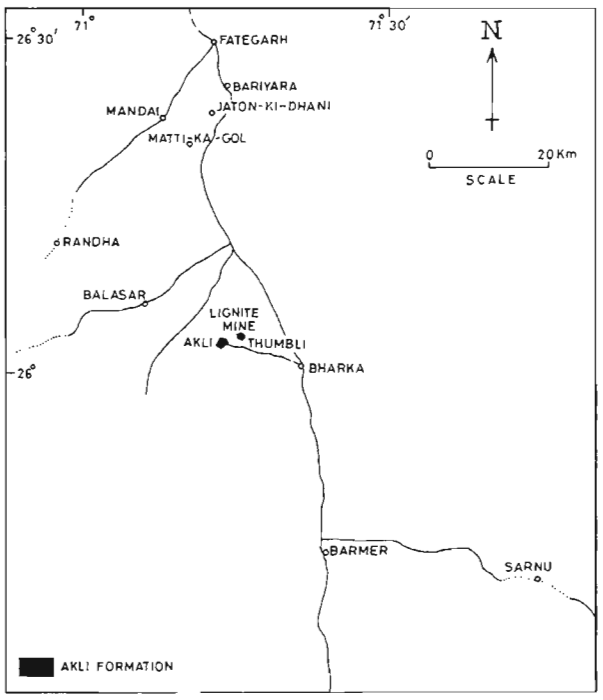

Fig. 1—Location map of the Barmer Basin (after Sisodia & Singh, 2000).

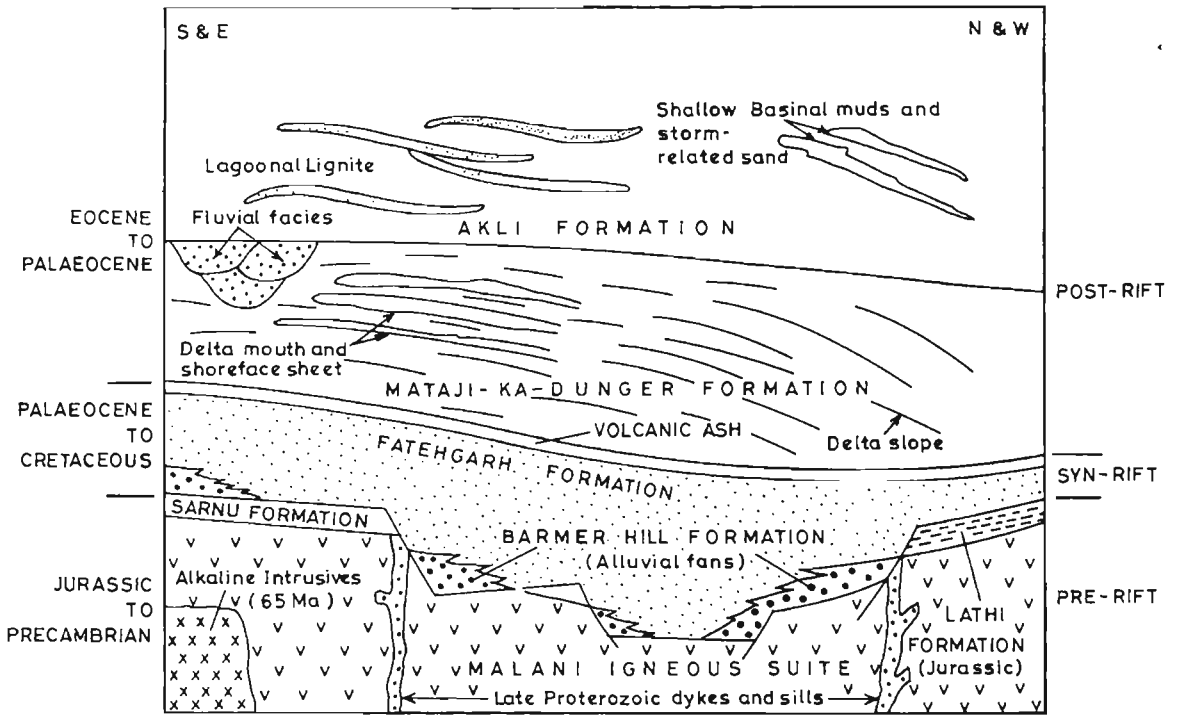

Fig. 2—Lithostratigraphy of Barmer Basin (after Sisodia & Singh, 2000).

and is comprised of conglomerate at base which is overlain by sandstone. The Fatehgarh Formation is overlain by Siliceous Earth of Bariyara Member (base of Mataji-ka-Dungar Formation).

The post-rift sediments representing Mataji-ka-Dungar and Akli formations largely fill the Barmer Basin. Mataji-ka-Dungar Formation is exposed at the northern end and margins of the basin at N26°06' : E71°12'; N26°24' : E71°12' and N26°13' : E71°15'. 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 Akli Formation is divisible into two members: Thumbli-shale Member and Kapurdi Fuller's earth Member. The measured thickness of Akli Formation is about 35 m in Thumbli lignite mine. At Thumbli (N26°03' : E71°15') these beds are arranged in 2-3 m thick cycles commencing with bentonite followed with bituminous claystone and ending up with lignite. The top of the Akli Formation is covered by dune sand and gravel.

The base of Akli Formation in Thumbli mine is represented by shale which has burrows and nodules. 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 bentonite is 10-12 m thick, poorly bedded and pale blueish-grey in colour. It is provided with ferruginous nodules, chert and phosphate cores. The bentonite beds dip 35°-40° to SW. Montmorillonite is major component mineral in bentonite and silt content is generally 1-2%. Lithostratigraphy of the Barmer Basin is given in Fig. 2.

Previous palynological works in Rajasthan Basin

Palynological reports from Rajasthan Basin are meagre and are chiefly confined to the description of recorded palynotaxa only. These studies have been taken up in Barmer (Bose, 1952; Jain *et al.*, 1973; Naskar & Baksi, 1978; Tripathi, 1994, 1995, 1997), Bikaner (Singh & Dogra, 1988; Kar, 1995, 1996a; Ambwani & Singh, 1996; Kar & Sharma, 2001) and Palana beds (Rao & Vimal, 1950, 1952; Sah & Kar, 1974). Due to non-availability of palynostratigraphical information from these sediments interrelationship of these sediments is less understood. However, Singh and Dogra (1988), considering the distribution of palynotaxa vis-a-vis marine fauna, attempted to correlate Palaeocene sequences of Rajasthan Basin with other strata of the same age in India. Palynological assemblage from five bore-holes drilled near Kapurdi and Jalipa in Barmer District were described by Tripathi (1994, 1995). Continuing these studies Tripathi (1997) established two informal palynozones in two of these bore-hole sequences and

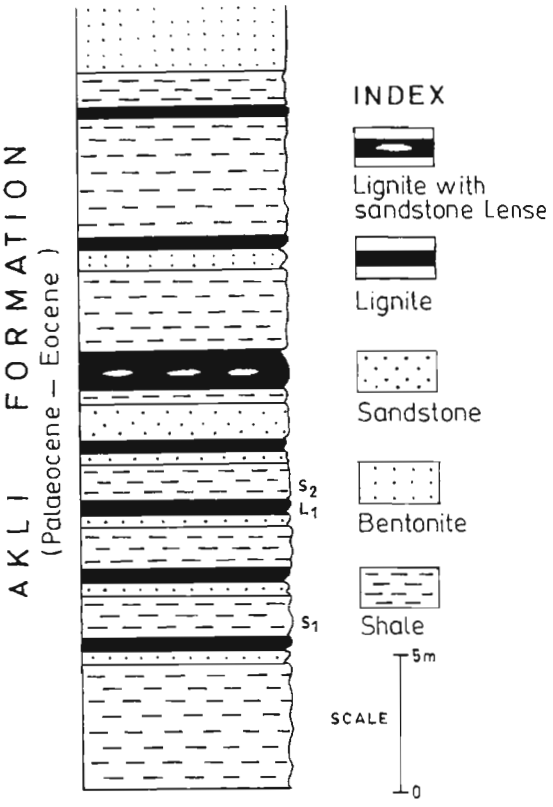

Fig. 3—Stratigraphical Section of Akli Formation at Thumbli Lignite Mine and sample position.

demarcated Palaeocene and Eocene sediments. Kar and Sharma (2001) carried out palynostratigraphical studies on subsurface Late Palaeocene and Early Eocene sediments of Bikaner-Nagaur Basin, Rajasthan.

PRESENT STUDY

Rock samples for the present study were collected from the Akli Formation which is mainly made up of bentonite, shale and lignite sequences. In all 17 samples were collected and processed for the recovery of palynofossils, of which, two shale samples S-1 and S-2 and one lignite samples L-1 (Fig. 3) proved productive. Good suits of palynofossils represented by algal cysts, fungal remains, pteridophytic spores and angiospermic pollen were recovered from the two shale samples. Angiospermic pollen are dominant in the assemblage and are followed by pteridophytic spores. Dinoflagellate cysts are few in number and have not been included in the present communication. The assemblage from lignite sample is not rich and is mainly constituted by monosulcate palm pollen. In the assemblage 5 genera and 6 species belong to fungi, 5 genera and 7 species belong to pteridophytic spores and 16 genera and 29 species belong to angiospermic pollen.

PALYNOLOGICAL ASSEMBLAGE

The assemblage is noticeably dominated by monosulcate pollen appearing to be related to the family Arecaceae. Of these, four species have been assigned to *Spinizonocolpites*. These forms are related to modern brackish water Palm *Nypa*. The pollen grains of *Nypa* are characteristic in possessing an extended sulcus parallel to the polar axis (meridionosulcate) and a spinose exine. Shape and size of spines are quite variable. Inter-spinal area is smooth to microreticulate. Besides these, the assemblage is also richly represented by two species of *Kapurdipollenites* viz., *K. gemmatus* and *K. baculatus* and one species of *Retiverrumonosulcites* viz., *R. barmerensis*. These two genera had earlier been reported from Late Palaeocene subsurface samples of Barmer, Rajasthan (Tripathi, 1994). Other pollen genera in the assemblage which also show affinity with Arecaceae are *Proxapertites, Palmidites* and *Palmaepollenites*.

Species attributed to *Spinizonocolpites* are spheroidal to ovoidal in shape, possess an extended sulcus and are provided with a spinose exine. Size of pollen ranges between 50-70 μm. Shape and size of spines (5-15 μm) are variable being straight to slightly curved at the tip and may exhibit a bulbous base. Inter-spinal area is smooth to reticulate. The two species of *Kapurdipollenites* are also spherical to ovoidal in shape, possess an extended sulcus and range in size between 65-70 μm. Exine in these forms is provided with variety of sculptural elements like verrucae, gemmae, clavae and baculae. Both of these species possess an extended sulcus like that in *Spinizonocolpites* and appear to be related to *Nypa*. Studies suggest that fossil *Nypa* plants either produced pollen with more variable exine ornamentation or more species/varieties constituted this genus which probably produced pollen described under *Kapurdipollenites*.

The genus *Retiverrumonosulcites* is spherical to oval in shape, 45-58 μm in size and possesses single sulcus which is not extended. The sulcal margins are thickened. Exine is microreticulate and is provided with clavae or verrucae of varying size. Verrucae are 2-5 μm in diameter whereas the clavae 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 may also belong to plants of the family Arecaceae.

The list of recorded palynotaxa is given below.

Fungal remains :
Dicellaesporites popovii Elsik, 1986
D. minutus Kar & Saxena, 1976
Diporicellaesporites pluricellus Kar & Saxena, 1976
Diporisporites elongatus van der Hammen, 1954
Pluricellaesporites planus Trivedi & Verma, 1973
Inapertisporites kedvesii Elsik, 1968
Pteridophytic spores :
Lygodiumsporites eocenicus Dutta & Sah, 1970
L. lakiensis Sah & Kar, 1969

TAXA	SAMPLE NUMBER		
	S-1	S-2	L-1
Lygodiumsporites eocenicus	o	o	
L. lakiensis	o	o	
Todisporites kutchensis	+		
Dandotiaspora dilata	x	o	
D. telonata		o	
Foveotriletes pachyexinous	o		
Arecipites bellus		o	
Palmidites plicatus		o	o
P. naviculus	o	o	
P. ovatus	o		o
P. kutchensis	o	+	
Spinizonocolpites echinatus	o	+	
S. baculatus		o	o
S. prominatus	o	o	
S. adamanteus		o	
Retimonosulcites ovatus		o	
Matanomadhiasulcites maximus	o	o	
M. microreticulatus	o	+	
Proxapertites assamicus	o		
P. microreticulatus	+	x	
Kapurdipollenites baculatus	o	x	
K. gemmatus	o	+	
Retiverrumonosulcites barmerensis	+	+	
Clavadiporopollenites raneriensis	o	o	
Acanthotricolpites bulbospinosus	o	o	o
A. kutchensis	o	o	
A. complexus	o		
Tricolpites baculatus	o		
Grevilloidaepites eocenicus	o		
Fungal remains	+	+	
Dinoflagellate cysts	o	o	

o < 10%, + 11-20%, x 21-30%

Fig. 4—Frequency of palynotaxa.

Todisporites kutchensis Sah & Kar, 1969
Dandotiaspora dilata (Mathur) Sah *et al.*, 1971
D. telonata Sah *et al.*, 1971
Lycopodiumsporites palaeocenicus Dutta & Sah, 1970
Foveotriletes pachyexinous Dutta & Sah, 1970

Angiospermic pollen :

Arecipites bellus Sah & Kar, 1970
Palmidites plicatus Singh in Sah & Singh, 1974
P. naviculus Kar & Saxena, 1981
Palmaepollenites eocenicus (Biswas) Sah & Dutta, 1966
P. kutchensis Venkatachala & Kar, 1969
P. nadhamunii Venkatachala & Kar, 1969
P. ovatus Venkatachala & Kar, 1969
Spinizonocolpites echinatus Muller, 1968
S. baculatus Muller, 1968
S. prominatus (McIntyre) Stover & Evans, 1972
S. adamanteus Fredriksen, 1994
Retimonosulcites ovatus (Sah & Kar) Kar, 1985
Matanomadhiasulcites maximus (Saxena) Kar, 1985
M. microreticulatus (Dutta & Sah) Kar & Kumar, 1986
Incrotonipollis burdwanensis (Baksi *et al.*) Jansonius & Hills, 1981
Proxapertites assamicus (Sah & Dutta) Singh, 1975
P. cursus Hoeken-Klinkenberg, 1966
P. microreticulatus Jain *et al.*, 1973
Kapurdipollenites baculatus Tripathi, 1994
K. gemmatus Tripathi, 1994
Retiverrumonosulcites barmerensis Tripathi, 1994
Clavadiporopollenites raneriensis Ambwani & Singh, 1996
Acanthotricolpites bulbospinosus Singh & Misra, 1991
A. kutchensis (Venkatachala & Kar) Singh & Misra, 1991
A. complexus Singh & Misra, 1991
Tricolpites baculatus Kar & Jain, 1981
Grevilloideaepites eocenica Biswas emend. Singh & Misra, 1991
Ocimumpollenites indicus Kar, 1996
Kielmeyerapollenites eocenicus Sah & Kar, 1974

Quantitative analysis of palynoflora

In two shale samples S-1 and S-2 two hundred specimens were counted to determine the frequency of spores and pollen whereas, in lignite sample L-1 due to less productivity only one hundred specimens were counted. Angiospermic pollen share 48% of the total assemblage whereas pteridophytic spores are represented by 30%. Frequency of dinoflagellate cysts (6%) and fungal remains (16%) was counted as groups only (Fig. 4).

Most dominant taxa in sample S-1 are: *Lygodiumsporites eocenicus, Todisporites kutchensis* and *Dandotiaspora dilata*. Other abundant forms in this sample are *Proxapertites cursus* and *Retiverrumonosulcites barmerensis*. In the sample S-2 the palynotaxa present in high frequency are: *Spinizonocolpites echinatus, Matanomadhiasulcites microreticulatus, Proxapertites cursus, P. microreticulatus, Kapurdipollenites gemmatus* and *Retiverrumonosulcites barmerensis*. Palynological assemblage from the lignite sample L-1 is very poor and is constituted by only few pollen having affinity with the family Palmae.

PALYNOFLORAL COMPARISON

Present assemblage is closely comparable with those recorded from Palaeocene-Eocene sediments of Rajasthan (Tripathi, 1994, 1995, 1997; Kar & Sharma, 2001), Kutch (Kar, 1978, 1985; Saxena, 1981) and Indus Coal Region, Pakistan (Frederiksen, 1994).

Comparison with known Rajasthan palynological assemblages

The palynological assemblages described from samples of bore-holes drilled near Jalipa and Kapurdi in Barmer District, Rajasthan (Tripathi, 1994, 1995) are very similar to the present assemblage as in both of these occurrence of different species of *Kapurdipollenites, Retiverrumonosulcites, Acanthotricolpites* and *Spinizonocolpites* has been noticed in high frequency.

Palynoassemblages of Assemblage Zone-A from subsurface Late Palaeocene sediments of two bore-holes MK 327 and MK 332 drilled near Kapurdi in Barmer District, Rajasthan, (Tripathi, 1997) resemble closely with the present assemblage. Palynotaxa common between the two assemblages are: *Dandotiaspora dilata, D. telonata, Proxapertites assamicus, P. microreticulatus, Palmidites plicatus, P. naviculus, Spinizonocolpites echinatus, Retimonosulcites ovatus* and *Matanomadhiasulcites maximus*.

Present palynological assemblage is also comparable with that recorded by Kar and Sharma (2001) from Late Palaeocene part of the bore-hole BH-125 drilled near Bithnok, Bikaner, Rajasthan as both the assemblages show presence of *Dandotiaspora dilata, Proxapertites cursus, Spinizonocolpites baculatus* and *Ocimumpollenites indicus*. However, many arecaceous pollen such as *Kapurdipollenites baculatus, K. gemmatus* and *Retiverrumonosulcites barmerensis* occurring in high frequency in the present assemblage are missing in the Bithnok bore-hole assemblage.

Comparison with Kutch palynoflora

Resemblance between the present assemblage and that from Matanomadh Formation of Kutch is striking. Forms common between *Dandotiaspora dilata* Cenozone (Saxena, 1981) and *Neocouperipollis brevispinosus* Cenozone (Saxena, 1981) of Matanomadh Formation of Kutch and the present assemblage are: *Dandotiaspora dilata, D. telonata, Lygodiumsporites eocenicus, L. lakiensis, Palmaepollenites eocenicus, P. kutchensis* and *P. nadhanunii*. Forms recorded from the above mentioned two cenozones of Matanomadh Formation but absent in the present assemblage are: *Tricolpites minutus, Trilatiporites, Sonneratiopollis* and *Lakiapollis*. The present assemblage exhibits high frequency of *Spinizonocolpites*, a pollen which is absent in the Matanomadh Formation assemblage. Two species of *Acanthotricolpites* viz., *A. bulbospinosus* and *A. kutchensis* (= *Couperipollis kutchensis*) described from subsurface Tertiary sediments of Kutch (Venkatachala & Kar, 1969) are abundant in the present assemblage.

Comparison with Pakistan palynoflora

Late Palaeocene assemblage from core-hole samples of the Lower Indus coal region, Pakistan (Frederiksen, 1994) resembles with the present assemblage in exhibiting common occurrence of different species of *Spinizonocolpites, Proxapertites cursus* and *Matanomadhiasulcites maximus*.

AGE CONSIDERATIONS

Indian Palaeocene sequences are marked with the presence of *Dandotiaspora dilata, Lycopodiumsporites* spp., *Neocouperipollis* spp., *Proxapertites* spp., *Spinizonocolpites* spp., *Palmidites* spp. and *Kielmeyerapollenites* in high frequency (Singh, 1977; Saxena, 1980,1988; Tripathi & Singh, 1984; Kar, 1985; Kar & Kumar, 1986; Tripathi, 1995, 1997; Kar & Sharma, 2001). In Eocene these forms either dwindle or disappear and the sequences are marked with other dominant palynofossils (Kar, 1992). Age determination and recognition of Palaeocene and Eocene sediments based on ranges of palynotaxa alone is therefore rather difficult. However a few attempts have been made to define these sequences in the Rajasthan Basin also (Singh & Dogra, 1988; Tripathi, 1997).

Based on palynological studies Singh and Dogra (1988) identified five zones in Palaeocene to Early Eocene sequences

Families	Palynotaxa	Present day distribution
Osmundaceae	*Todisporites kutchensis*	cosmopolitan
Matoniaceae	*Dandotiaspora dilata, D. telonata*	cosmopolitan
Lycopodiaceae	*Lycopodiumsporites palaeocenicus, Foveotriletes pachyexinous*	cosmopolitan
Schizaeaceae	*Lygodiumsporites eocenicus, L. lakiensis*	tropical-subtropical
Arecaceae	*Palmidites plicatus, P. naviculus, Palmaepollenites eocenicus, P. kutchensis, P. nadhamunii, Proxapertites assamicus, P. cursus, P. microreticulatus, Spinizonocolpites baculatus, S. prominatus, S. adamenteus, S. echinatus, Kapurdipollenites baculatus, K. gemmatus, Arecipites bellus, Retiverrumonosulcites barmerensis*	tropical-subtropical
Liliaceae	*Retimonosulcites ovatus*	cosmopolitan
Oleaceae	*Tricolpites baculatus*	chiefly tropical
Guttiferae	*Kielmeyerapollenites eocenicus*	tropical
Lamiaceae	*Ocimumpollenites indicus*	tropical
Onagraceae	*Grevilloideaepites eocenica*	cosmopolitan

Fig. 5—Palynotaxa with present-day distribution of related families.

of Bikaner Basin, Rajasthan. Of these, the two lower zones viz., SP-1 and SP-2 represent Early Palaeocene, SP-3 and SP-4 zones represent Late Palaeocene and SP-5 zone represents Early Eocene. Many palynotaxa recorded in SP-3 and SP-4 zones have been recorded during the present study. These are: *Dandotiaspora* spp., *Lygodiumsporites lakiensis, Proxapertites* spp., *Kielmeyerapollenites eocenicus* and *Palmidites plicatus*. Palynological studies on bore-hole samples drilled near Kapurdi and Jalipa in Barmer District, Rajasthan also indicate presence of Palaeocene and Eocene sediments (Tripathi, 1995) and considering the palynotaxa distribution and frequency Late Palaeocene and Early Eocene sediments were demarcated in two bore-hole sequences (MK 327 and MK 332) of Kapurdi, Barmer (Tripathi, 1997). The lignite sequences in these bore-holes were dated as Late Palaeocene and have yielded *Dandotiaspora* spp., *Lycopodiumsporites* spp., *Matanomadhiasulcites* spp. *Proxapertites* spp. *Spinizonocolpites* spp. and *Palmidites* spp. Presence of these pollen in high frequency characterizes a Late Palaeocene age (Kar, 1996b, Tripathi, 1997). In the present assemblage different species of *Dandotiaspora, Proxapertites, Spinizonocolpites* and *Matanomadhiasulcites* are registered in high frequency. Considering the known ranges and frequencies of these palynotaxa in the assemblage the studied sequence is dated as Late Palaeocene in age.

PALAEOCLIMATE, PALAEOECOLOGY AND ENVIRONMENT OF DEPOSITION

Majority of angiospermic families represented in the assemblage (Schizaeaceae, Arecaceae, Oleaceae, Lamiaceae and Guttiferae) are tropical to subtropical in present day distribution. Other families (Osmundaceae, Matoniaceae, Lycopodiaceae, Liliaceae and Onagraceae) are cosmopolitan in distribution. Palynotaxa assigned to these families along with their present day distribution is summarised in Fig. 5. Temperate elements are completely missing in the assemblage. Abundance of pteridophytic spores and fungal elements indicate a tropical flora in the vicinity of deposition site. Dinoflagellate cysts in the assemblage indicate marine influence.

Characteristic elements of the present palynoflora are pollen having affinity with extant plants of *Nypa* suggesting that it was an important component of the vegetation. These are *Spinizonocolpites* spp., *Proxapertites* spp., *Kapurdipollenites* spp., *Retiverrumonosulcites barmerensis* and *Clavadiporopollenites raneriensis*. 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. Presence of these pollen are very useful in interpreting the sedimentary environment as this genus has a low pollen productivity (Muller, 1964; Frederiksen, 1985) and its occurrence, even in low frequency, may indicate a good representation of this genus in the extant vegetation. Presence of these pollen further suggests monsoonal conditions. Considering the high frequency of *Nypa/Nypa*-like pollen in the assemblage it is inferred that deposition of sediments took place in an area which was fringed by thick vegetation of mangrove chiefly constituted by *Nypa*.

Chaloner (1968) suggested that large *Nypa* pollen are not transported to long distances towards the sea from the mangrove environment. Present assemblage is rich in large-sized *Nypa*-like pollen suggesting that the site of deposition,

in all probability, was a mangrove swamp. These inferences are in conformity with the conclusions drawn by Pole and Macphail (1996) and Pole (1998), who on the basis of abundant pollen *Spinizonocolpites prominatus*, suggested existence of mangrove forest at the beginning of Eocene in some basins of Tasmania.

Proxapertites, based on the morphological features, has been interpreted to represent an extinct group of palms which were possibly related to *Nypa* (Muller, 1968). *Proxapertites* and *Nypa* pollen both had a pantropical distribution and have been recorded in high frequency in deltaic and shallow marine sediments (Muller, 1979; Mandal, 1986; Kar & Kumar, 1986; Tripathi, 1997; Kar & Sharma, 2001). The genus *Acanthotricolpites*, possibly related with *Nypa* (Venkatachala *et al.*, 1986), is also recorded in good number in the assemblage.

Different species of *Proxapertites, Palmaepollenites, Palmidites* and *Arecipites bellus* in the assemblage clearly indicate a coastal area close to the site of deposition. Pteridophytic spores and other angiospermic elements in the assemblage were driven to the site of deposition through the river channels. Marine influence at the time of deposition is evidenced by the presence of dinoflagellate cysts in the assemblage. Good representation of fungal remains suggests warm and humid conditions with high precipitation.

Sedimentological studies, supporting the palynological inferences, indicate that the sequence from which samples were collected was deposited in the flood plain with marine incursions (Sisodia & Singh, 2000). These conclusions were 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 claystone facies of this formation represent low energy shallow basinal sedimentation. Occasional thin sandstone beds and siltstone within claystone show that the basin was periodically interrupted by flood events.

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