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Palynostratigraphy and age of the Bhavnagar Lignite, Gujarat, India

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ABSTRACT

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A good frequency of pollen and spore taxa are recovered during the palynological study of the Bhavnagar Lignite of Gujarat. Pollen assemblage consist of 66 genera and 85 species. Of these, eight genera and 12 species are of pteridophytic spores, one genus of gymnosperms and 57 genera and 74 species of angiosperms. Amongst these, one genus and nine species are described as new. On the basis of abundance, the Bhavnagar palynoassemblage is divided into two cenozones in ascending order as *Triplanosporites sinuous* Cenozone and *Arengapollenites achinatus* Cenozone. Palynoflora suggests deposition of this lignite during Early Eocene period under warm humid tropical climatic conditions.

Key-words—Palynology, Lignite, palaeoclimate, palaeoenvironment, Early Eocene.

भारत के गुजरात प्रान्त के भावनगर लगुडांगार का परागाणुस्तरिकीय एवं काल निर्धारण

बन्दना सामन्त

सारांश

गुजरात के भावनगर लगुडांगारों के परागाणविक अध्ययन के दौरान उत्कृष्ट मात्रा में परागकण एवं बीजाणु वर्गक प्राप्त हुए हैं. परागाणु समुच्चय में 66 वंश तथा 85 प्रजातियाँ हैं, जिनमें से 8 वंश और 12 प्रजातियाँ टेरिडोफ़ाइटी बीजाणुओं की हैं, एक वंश अनावृतबीजियों का है तथा 57 वंश एवं 74 प्रजातियाँ आवृतबीजियों की हैं. इनमें से एक वंश तथा नौ प्रजातियों को नए के रूप में अभिलक्षणित किया गया है. प्रचुरता के आधार पर *ट्राइप्लेनोस्पोराइटीज़ साइनुअस* एवं *एरेंगापोलेनाइटीज़ एकिनेटस* नामक दो समुच्चय मण्डलों में आरोही क्रम में विभाजित किया गया है. परागाणु वनस्पतिजात से प्रारंभिक इओसीन युग के दौरान आर्द्र-उष्णकटिबन्धीय जलवायु की परिस्थितियों के अन्तर्गत इस लगुडांगार का निक्षेपण प्रस्तावित होता है.

संकेत शब्द—परागाणुविज्ञान, लगुडांगार, पुराजलवायु, पुरापर्यावरण, प्रारंभिक इओसीन.

INTRODUCTION

THE Bhavnagar Lignite deposits are associated with Tertiary rock exposures around western margin of the Cambay Basin between latitude N 21°26", 21°43" and longitude E 72°7"30', 72°16"30' (Fig.1). The Tertiary exposures in this area extend to about 202 sq km, with an extension of 60 to 70 km in length (North-south) and 2-3 km in width (West-East).

The Directorate of Geology and Mining (DGM), Gujarat has carried out detailed geological study of the area. Accord-

ing to the DGM (unpublished report) Deccan traps form the basement for the Supratrappean (Paleocene-Eocene) sequence. Supratrappeans are unconformably overlain by Kharsalia Clay Formation of Eocene age. About 2-10 m thick lignite sequence is a part of the Kharsalia Clay Formation. This formation is unconformably overlain by the Gaj Formation of Miocene age. All these formations are concealed under the thick alluvial deposits of Sub Recent to Recent age. The generalised lithology this sequence is given Fig. 2.

The comprehensive palynological study of the Bhavnagar Lignite has shown good frequencies of pollen and spore taxa. The present paper discusses in detail some of the new fossil taxa recovered from the deposits. With the help of palynotaxa recovered an attempt is made to interpret the palaeoclimate, palaeoecology and depositional environment of the basin. The palynoassemblage is also used for the demarcation of palynostratigraphic cenozones and evaluation of age of the deposits.

MATERIAL AND METHODS

About 55 samples of the Bhavnagar Lignite were received from Petrography and Mineral Chemistry Laboratory at Gandhinagar, with due permission of the Directorate of Geology and Mining, Ahmedabad. Generalised lithology of the bore holes is given in Fig. 3. The material studied consists of grey clay, carbonaceous clay and lignite. Almost all the samples collected have yielded microfossils. For the recovery of microfossils, the samples were subjected to standard maceration techniques. Ten slides of each sample have been prepared for the microscopic study.

All the type and figured specimens are deposited in the repository of the Department of Geology, Nagpur University, Nagpur.

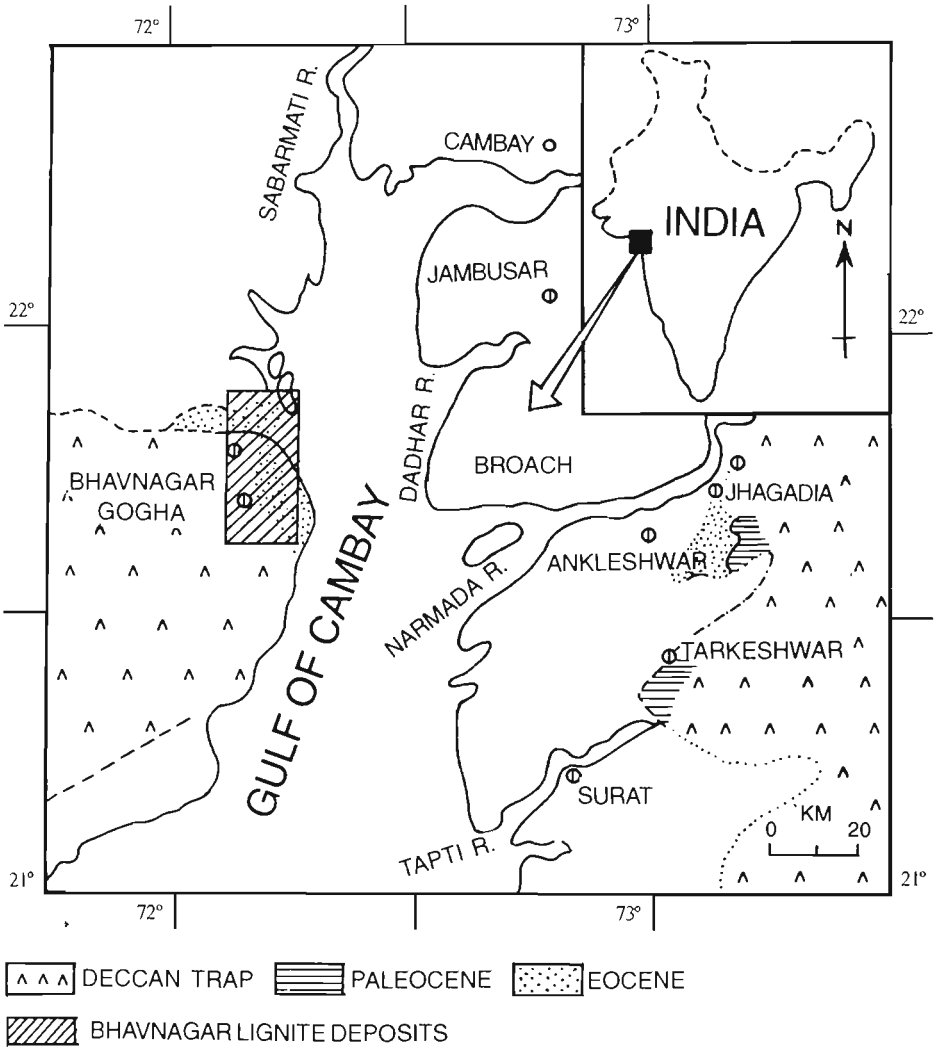

Fig. 1— Geological map of the Cambay basin (Modified after Mathur *et al.*, 1968).

Lithology	Formation	Age
Soil and Alluvium Dunes and Beach sand	Recent Deposits	Recent to Subrecent
——————Unconformity——————		
Variegated shales with Gypsum, sandstone Marl and conglomerate	Gaj Formation	Lower Miocene
——————Unconformity——————		
Grey to greenish grey clays, fossiliferous grey clays, sandstones Lignite with siderite nodules	Kharsalia Clay Formation	Eocene
——————Unconformity——————		
Bentonite, Laterite and reworked Bentonite clay	Supra- trappean	Paleocene to Lower Eocene
Trap flows with intrusions	Deccan Trap	Upper Cretaceous to Lower Eocene

Fig. 2— Geological formations and lithology of the area (after DGM).

SYSTEMATICS

PTERIDOPHYTES

Genus—POLYPODIISPORITES (Potonié) Potonie 1956.

Type species—POLYPODIISPORITES FAVUS (Potonié) Potonié 1956

POLYPODIISPORITES CONNUS sp. nov.

Pl. 1·10

Diagnosis—Spores slightly concavo-convex; monolete; laesura less than half the longer axis of the spore; exosporium thick; conate, coni coalesce together to form reticulations.

Description—Spores bilateral, slightly concavo-convex; 34-36 x 61-65 µm in size; monolete; laesura less than half the longer axis of the spore, almost closed, ends pointed; exosporium 1-2 µm thick; conate, coni pointed, coni coalesce together to give reticulate appearance.

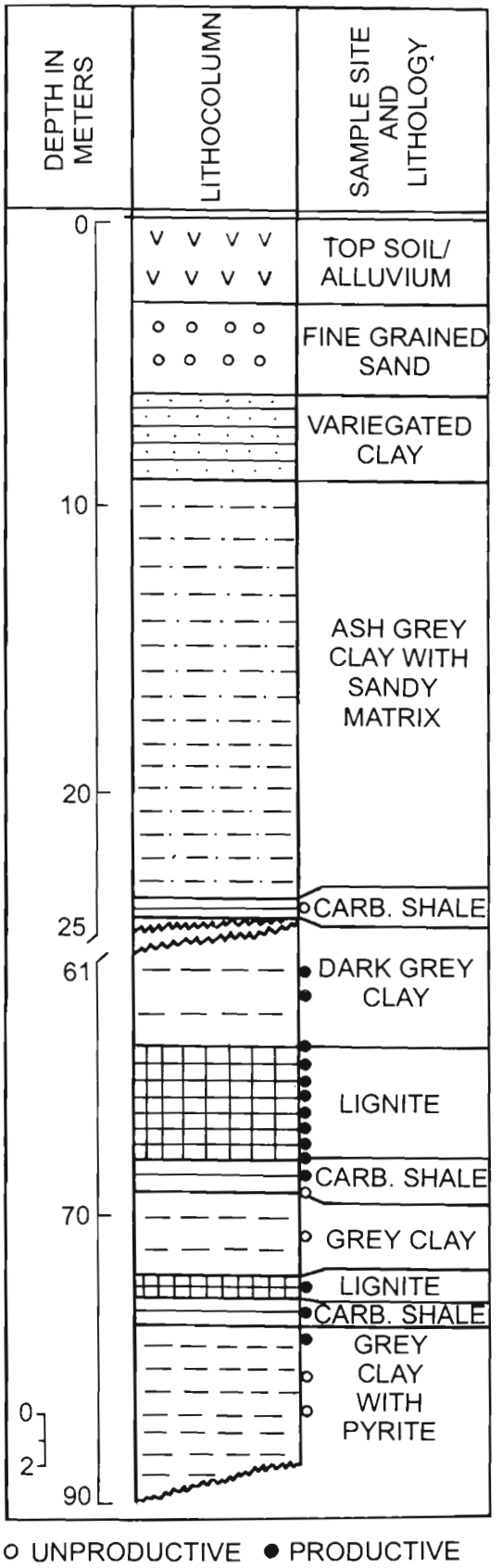

Fig. 3—Generalised lithocolumn of the Bhavnagar Lignite. →

Remarks—The above described spore differs from all the known species of the genus in having short laesura and conate sculptural elements which coalesce together to give reticulate appearance.

Holotype—Slide no. DGN/C-112/7/7.

Affinity—Polypodiaceae.

ANGIOSPERMS

Genus—JACOBIPOLLENITES Ramanujam, 1966

Type species—JACOBIPOLLENITES MAGNIFICUS Ramanujam, 1966

JACOBIPOLLENITES RAMANUJAMII sp. nov.

Pl. 3·1

Diagnosis—Pollen grains spheroidal; monoporate; pore small, almost circular, distinct margins; exine thick reticulate heterobrochate.

Description—Pollen grains spheroidal; 25-30 µm in diameter; monoporate; pore almost circular, small, 4-6 µm in diameter, slightly crassimarginate, pore margins smooth, regular; exine 2-3 µm thick, nexine slightly thinner than sexine, nexine smooth to slightly undulating, columellate, semitectate; reticulate, simple to duplibaculate, heterobrochate, muri 1-1·5 µm thick, lumina about 1 µm wide, circular to polygonal.

Remarks—The genus *Jacobipollenites* Ramanujam (1966) incorporates spheroidal, monoporate pollen grains with retipilate sculpture pattern. *Jacobipollenites magnificus* Ramanujam (1966, pl. 5, figs 88 and 89) has almost indistinct pore margins, homobrochate retipilate sculpture pattern and wide lumina. *J. magniporus* Singh & Mishra (1991) has very large pore and polygonal lumina. *J. cressimurus* Singh & Mishra (1991) appears similar to the proposed specimen, however distinctly large size (80-95 µm), thick exine (10-15 µm) and fused pila heads differentiate this morphotype from the *J. Ramanujamii* sp. nov. *J. arthungalensis* Rao (1990) possess thick annulus around pore and retipilariate sculpture. Small size, distinct aperture margin and reticulate heterobrochate sculpture pattern are the diagnostic characters of this specimen. This is a common morphotype of the Bhavnagar lignite assemblage.

Holotype—Slide no. DGN/CDT-97/5A/30.

Affinity—*J. ramanujamii* appears similar to extant Madagascaran palm *Ravena (Lauvelia) albicans*.

Genus—NYMPHAEACIDITES Sah 1967

Type species—NYMPHAEACIDITES TYPICUS Sah 1967

NYMPHAEACIDITES sp.

Pl. 4·3

Description—Pollen grains prolate; 72 x 57 µm in size; monosulcate; sulcus open at two ends, tenuimarginate, sulcus margins beset with bacula; exine about 0·5 µm thick, intectate, sexine and nexine undifferentiable; baculate, bacula sparsely distributed, intrabaculate exine psilate.

Remarks—*N. spinosus* Saluja *et al.* (1980) is spinulate. *N. decoratus* Venkatachala & Rawat (1973) is granulate. Distinct monosulcate aperture and baculate sculpture pattern differentiate this palynomorph from other known species. Single species, could be recovered from the assemblage.

Affinity—Nymphaeaceae.

Genus—POLYBREVICOLPORITES Venkatachala & Kar 1969

Type species—POLYBREVICOLPORITES CEPHALUS Venkatachala & Kar 1969

POLYBREVICOLPORITES RETICULATA sp. nov.

Pl. 4·7-8

Diagnosis—Pollen grains isopolar; circular in polar view; 7-8 colporate; colpi short; ora almost indistinct; exine distinctly thick, reticulate nexinal thickening in intercolpal region.

Description—Pollen grains isopolar, circular, about 40-41 µm in size; 7-8 colporate; colpi short, open, margins smooth to slightly irregular, extention of sculpture pattern up to colpal

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PLATE 1 →

(All magnification x 1000 unless otherwise mentioned)

1. *Cyathidites australis* Couper, DGN/C-122/6/7.
2. *Dandotiaspora plicata* (Sah & Kar) Sah, Kar & Singh, DGN/C-110/8/43. x 40.
3. *Laevigatosporites lakiensis* Sah & Kar, DGN/C-111/6/4.
4. *L. gracilis* Wilson & Webster, DGN/C-116/8/15.
5. *Laevigatosporites* sp., DGN/C-117/6/16.
6. *Pteridacidites triangulatus* Sah, DGN/C-114/7/10.
7. *Lygodiumsporites lakiensis* (Sah & Kar) Rao & Singh, DGN/CDT-98/1/31
8. *Polypodiisporites ratnamii* (Ramanujam) Rao & Ramanujam, DGN/C-112/7/7.
9. *Polypodiisporites constrictus* Kar, DGN/C-111/7/5.
10. *P. conus* sp. nov., DGN/C-112/7/7.
11. *Todisporites major* Couper, DGN/C-110/6/1
12. *T. flavatus* Sah & Kar, DGN/C-113/6/38.
13. *Triplanosporites sinuous* Pflug, DGN/C-72/1/22.
14. *Schizaeoisporites multistriatus* Rao & Ramanujam, DGN/C-74/4/23.
15. *Podocarpidites* sp., DGN/C-116/8/15.

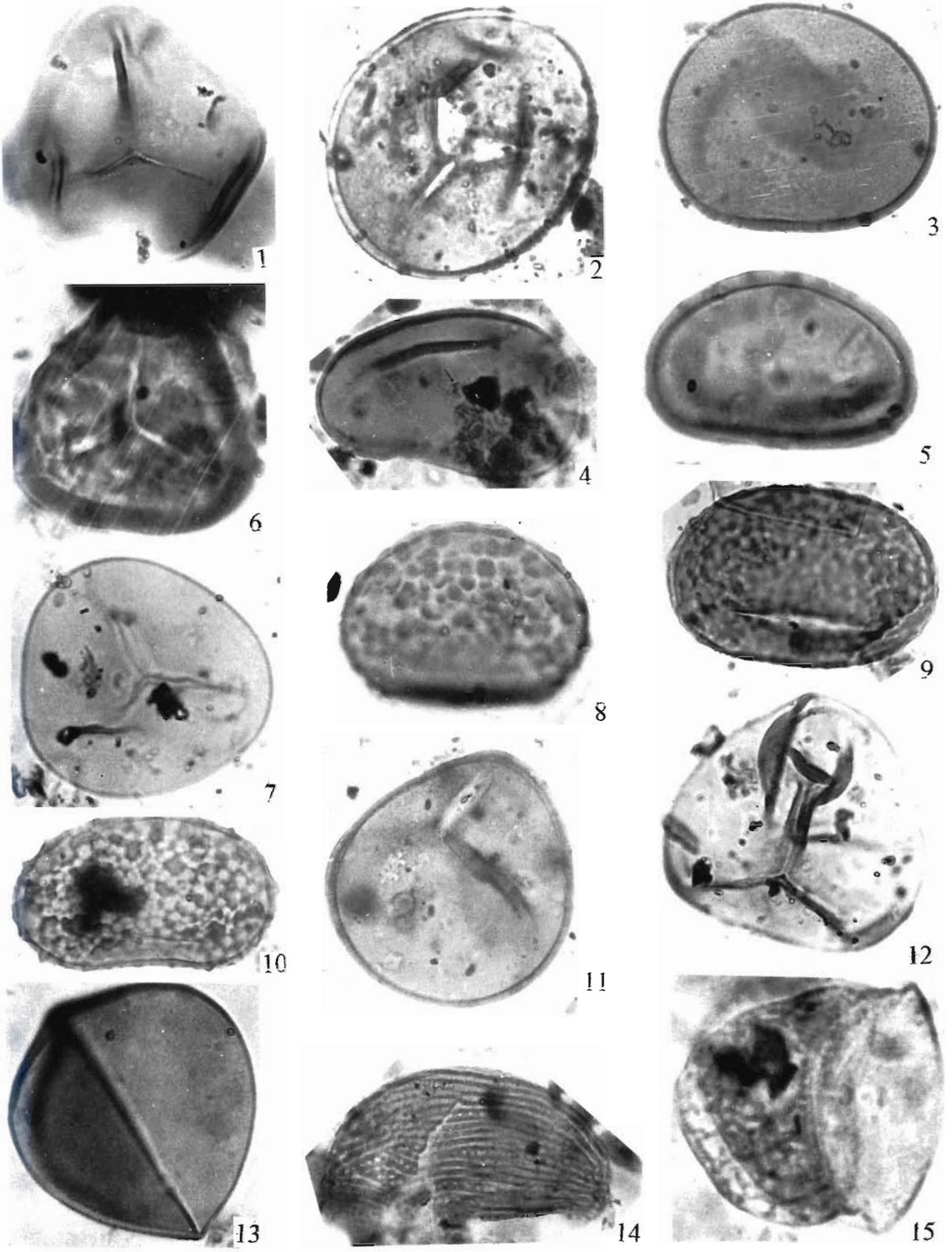


PLATE 1

margins, tenuimarginate, ends pointed to blunt; ora almost indistinct; endexinous, circular to lalongate; exine 5 µm thick, distinctly thicker (3 µm) than sexine (2 µm), nexine forms crescent shaped thickening in the intercolpial region, thin at the aperture margins, columellate, semitectate, reticulate, simply baculate, homobrochate.

Remarks—*Polybrevicolporites cephalus* Venkatachala & Kar (1969) is 5 lobed with intrabaculate sculpture pattern. *P. antiquum* (Ramanujam) Kar (1978) is six colporate and reticulate to granulate. *P. karii* Rao & Ramanujam (1982) is 5 colporate with thin exine and intrareticulate sculpture. *P. distinctus* Samant & Phadtare (1996) has crescent shaped thickening at colpal ends. This palynomorph differs from all the known species in having 7-8 colporate aperture, reticulate sculpture and distinctly crescent shaped nexinal thickening in the intercolpal region.

Holotype—Slide no. DGN/C-116/6/14.

Affinity—Unknown.

Genus—POMETIAPOLLENITES gen. nov.

POMETIAPOLLENITES RETICULATUS gen. *et* sp. nov.

Generic Diagnosis—Pollen grains suboblate, tricolporate, slightly protruding aperture; colpi short; exine thin; reticulate.

Remarks—The genus *Symplocoipollenites* Potonié (1960) includes oblate, triangular pollen grains, short colpi with vestibulum and granulate to rugulate sculpture pattern. The genus *Cupanidites* (Cookson & Pike) Chumura (1973) includes triangular, tricolpate pollen grains, nonsyncolpate, syncolpate or parasyncolpate colpi, inconspicuous pore and reticulate to scabrate sculputre. The proposed genus can be differentiated from these genera in having suboblate shape, slightly protruding aperture, very short colpi, aspidate ora and distinctly reticulate sculpture pattern.

POMETIAPOLLENITES RETICULATUS gen. *et* sp. nov.

Pl. 5·4

Diagnosis—Pollen grains suboblate; triangular tribrevicolporate; colpi short; ora aspidate, circular; exine thin, reticulate sculpture.

Description—Pollen grains suboblate, triangular; 20-21 x 20-22 µm in size; tricolporate; apertures situated at angles, slightly protruding; colpi short, 2-3 µm long in polar view, tenuimarginate, ends pointed, almost inconspicuous, colpal margins smooth; ora endexinous, circular, 1-2 µm; exine about 1-1·5 µm thick, nexine and sexine of same thickness at intercolpal region, nexine around aperture 2 µm thick, columellate, reticulate, heterobrochate, brochi rather irregular in outline; lumina about 1 µm wide and muri about 1 µm thick.

Holotype—Slide no. DGN/C-73/2/39.

Affinity—This described palynomorph resembles the extant *Pometia pinnata* (Pl. 5·5, 6) of Sapindaceae (Samant, 1996a). The comparative morphology of the fossil and extant pollen of *Pometia pinnata* is given below:

	Pometiapollenites reticulatus gen. *et.* sp. nov.	*Pometia pinnata*
1.	Shape : triangular	triangular
2.	Size : 20-21 x 20-22 µm	16-29 x 20-38 µm
3.	Aperture : tribrevicolporate	tribrevicolporate
	a) Colpi : 2-3 µm in diameter	2-6 µm in diameter (Polar view)
	b) Pori : 1-2 µm in diameter	2-5 µm in diameter
4.	Sculpture : reticulate to microreticulate	reticulate to microreticulate
5.	Exine: 1-1·5 µm thick	1·3-2 µm thick

Genus—PSILODIPORITES (Varma & Rawat) Venkatachala & Rawat 1972

Type species—PSILODIPORITES HAMMENII Varma & Rawat 1963

PSILODIPORITES sp. A

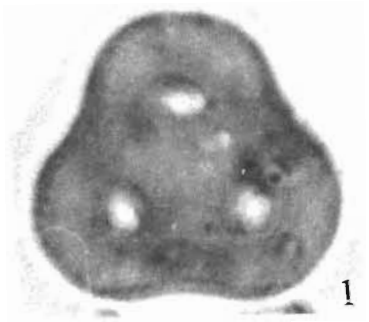
Pl. 5·10

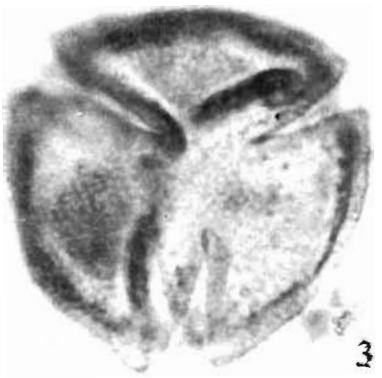
Description—Pollen grain oval in shape; 26 x 28 µm in size; diporate; pores elliptical, about 8 µm long, distinct collar-like thickening at pore, margins rugged; exine about 1·5 µm thick, nexine thinner than sexine; psilate.

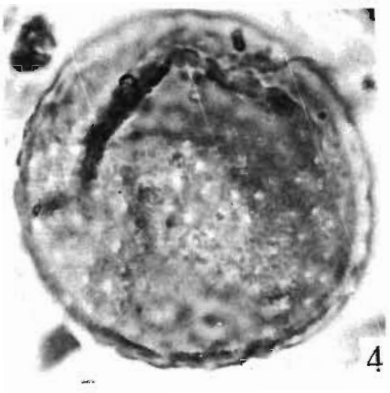
PLATE 2 →

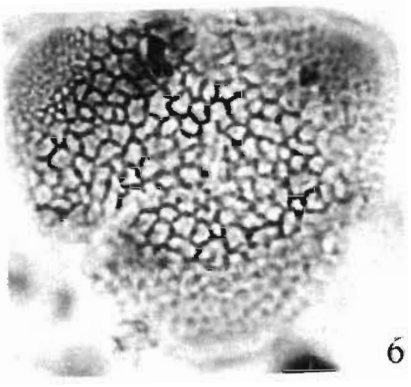
(All magnification x 1000 unless otherwise mentioned)

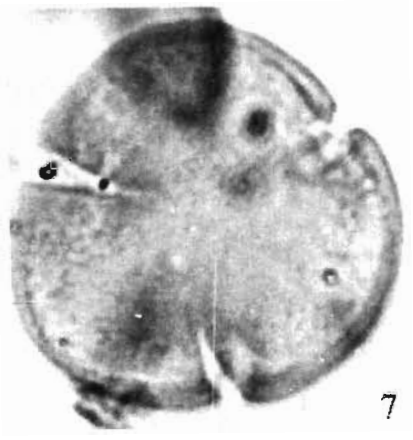
1. *Anacolosidites trilobatus* Venkatachala & Rawat, DGN/C-116/7/33.
2. *Arecipites bellus* Sah & Kar, DGN/C-115/8/13.
3. *Araliaceoipollenites descretus* Venkatachala & Rawat, DGN/C-111/6/4.
4. *Cryptopolyporites cryptus* Venkatachala & Kar, DGN/C-111/6/4.
5. Extant pollen of *Gonystylus borneensis*, DGN/G/35.
6. *Bombacacidites triangulatus* Kar, DGN/111/8/36.
7. *Intrareticulites brevis* (Sah & Kar) Kar, DGN/C-112/7/7.
8. *Arengapollenites echinatus* Kar, DGN/C-112/7/7.
9. *Ctenolophonidites costatus* van Hoeken Klinkenberg, DGN/C-117/7/17.
10. *Cupanidites flaccidiformis* Venkatachal & Rawat, DGN/CDT-70/8/19.
11. *Haloragidacidites neyvelii* Ramanujam, DGN/C-111/2/3.
12. *Iugopollis tetraporites* Venkatachala & Rawat, DGN/C-70/3/18.

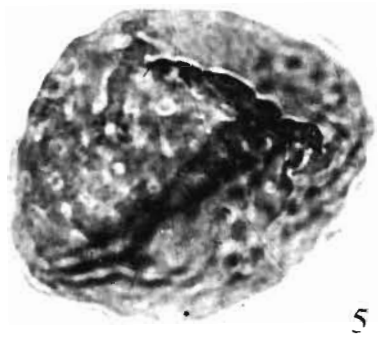


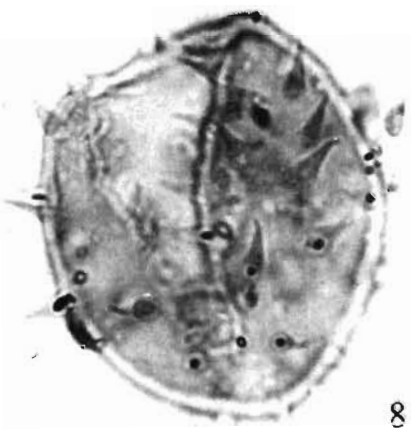


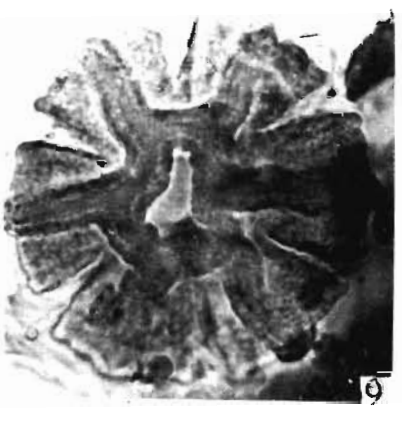


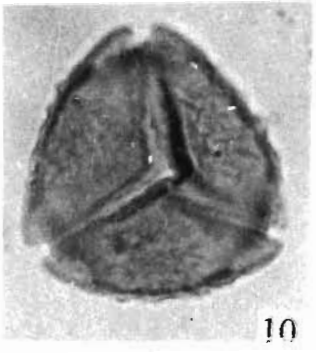












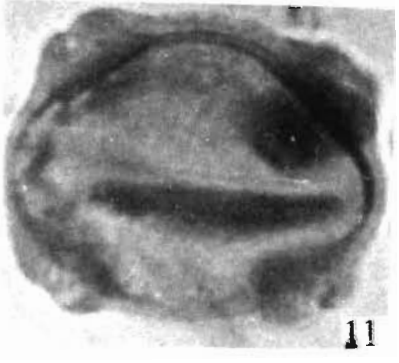


PLATE 2

Remarks—Distinctly oval shape and collar-like thickening around the pore differentiates the recovered palynomorph from all the recorded specimens of *Psilodiporites*. A single specimen could be recovered from the assemblage.

Affinity—Uncertain.

PSILODIPORITES sp. B

Pl. 5·9

Description—Pollen grain barrel-shaped; 25 x 26 µm in size; diporate; pores of unequal size, pores about 10-12 µm long margins thin, rugged; exine about 1·5 µm thick, sexine and nexine undifferentiable; psilate.

Remarks—Presence of pores of unequal size is the differentiating character of this specimen. A single specimen could be recovered from the assemblage hence no specific name is given.

Affinity—Uncertain.

Genus—RACEMONOCOLPITES Guzman 1967

Type species—RACEMONOCOLPITES RECEMATUS (van der Hammen) Guzman 1967

RACEMONOCOLPITES BHAVNAGARENSIS sp. nov.

Pl. 5·13

Diagnosis—Pollen grains triangular; trichotomosulcate; exine thick; heteroclavate; intrasculpture exine psilate.

Description—Pollen grains triangular, about 34-35 x 41-46 µm in size; trichotomosulcate; sulcus long extending up to margins; tenuimarginate, margins beset with clavae, smooth, sulcus open or closed; exine 1·5 to 2 µm thick, sexine and nexine undifferentiable, exine slightly undulating; clavate, heteroclavate, clava 2-4 µm long, intrasculpture exine smooth.

Remarks—The above described palynomorph resembles *R. trichotomosulcatus* reported by Mandal (1991, pl. 1 figs. 1-4) from Palaeocene sediments of Thanjinath, Meghalaya in having trichotomosulcate aperture pattern, however the later is distinctly bigger in size with clavate, baculate and gammate sculpture pattern and intrasculpture elements microbaculate/granulose.

Holotype—Slide no. DGN/CDT-97/5A/30.

Affinity—Unknown.

Genus—RETITRIBREVICOLPORITES Kar 1985

Type Species—RETITRIBREVICOLPORITES MATANOMADHENSIS (Venkatachala & Kar) Kar 1985

RETITRIBREVICOLPORITES FOVEOLATUS sp. nov.

Pl. 6·3

Diagnosis—Pollen grains almost circular; tribrevicolporate; colpi and os of almost same size; os margin thin; exine thick; foveolate.

Description—Pollen grains circular; about 50-52 µm in size. Tribrevicolporate; colpi short, tenuimarginate, margins smooth, ends rounded, sculpture extending upto colpal margins, colpi ± 6 µm long and ± 6 µm wide; exine about 4 µm thick, sexine and nexine of same thickness; foveolate; pluricolumellate, lumina 1-2·5 µm wide, wider away from the aperture, muri about 2-3 µm thick.

Remarks—The genus *Retitribrevicolporites* as emended by Kar (1985) incorporates retitribrevicolporate pollen grains with colpi and os of same size, thick pore margins and reticulate sculpture pattern. The present study shows that the generic diagnosis of the genus *Retitribrevicolporites* should be emended to incorporate pollen grains with foveolate sculpture pattern. *Retitribrevicolporites rubra* (Dutta & Sah) Kar & Kumar, 1986 (Pl. 8 Fig.18) has thick os margins and distinctly thin exine and faveoraticulate sculpture. *R. matanomadhensis* (Venkatachala & Kar) Kar (1985) possess costate ora had reticulate sculpture pattern. Presence of distinct foveolate sculpture pattern and thin aperture margins are the diagnostic features of this specimen.

Holotype—Slide no. DGN/C-114/4/9.

Affinity—Unknown.

Genus—SYMPLOCOIPOLLENITES (Potonié) Potonié, 1951

Type species—SYMPLOCOIPOLLENITES VESTIBULUM (Potonié) Potonié, 1951

PLATE 3 →

(All magnification x 1000 unless otherwise mentioned)

1. *Jacobipollenites ramanujamii* sp. nov., DGN/CDT-97/5A/30.
2. SEM photograph of the similar type.
3. *Longapertites proxapertoides* van der Hammen & Garcia de Mutis, DGN/CDT-98/1/31.
4. *Longapertites vaneendenburgii* Germeraad *et al.*, DGN/C-111/6/4.
5. *L. hammenii* Rao & Ramanujam, DGN/C-111/7/5.
6. *L. triangulatus* Samant & Phadtare, DGN/C-113/6/38.
7. *L. retipilatus* Kar, DGN/C-113/2/8.
8. *Neotrichotomosulcites acrocomia* Samant & Phadtare, DGN/C-115/8/13.
9. *Dracenoipollis circularis* Sah & kar, DGN/C-112/7/7.
10. *Palaeoaraliaceaepites indistinctus* Samant & Phadtare, DGN/CDT-95/3/41
11. *Marginipollis kutchensis* (Venkatachala & Kar) Kar, DGN/CDT-98/1/31.
12. *Lakiapollis ovatus* Venkatachala & Kar, DGN/C-114/4/9.

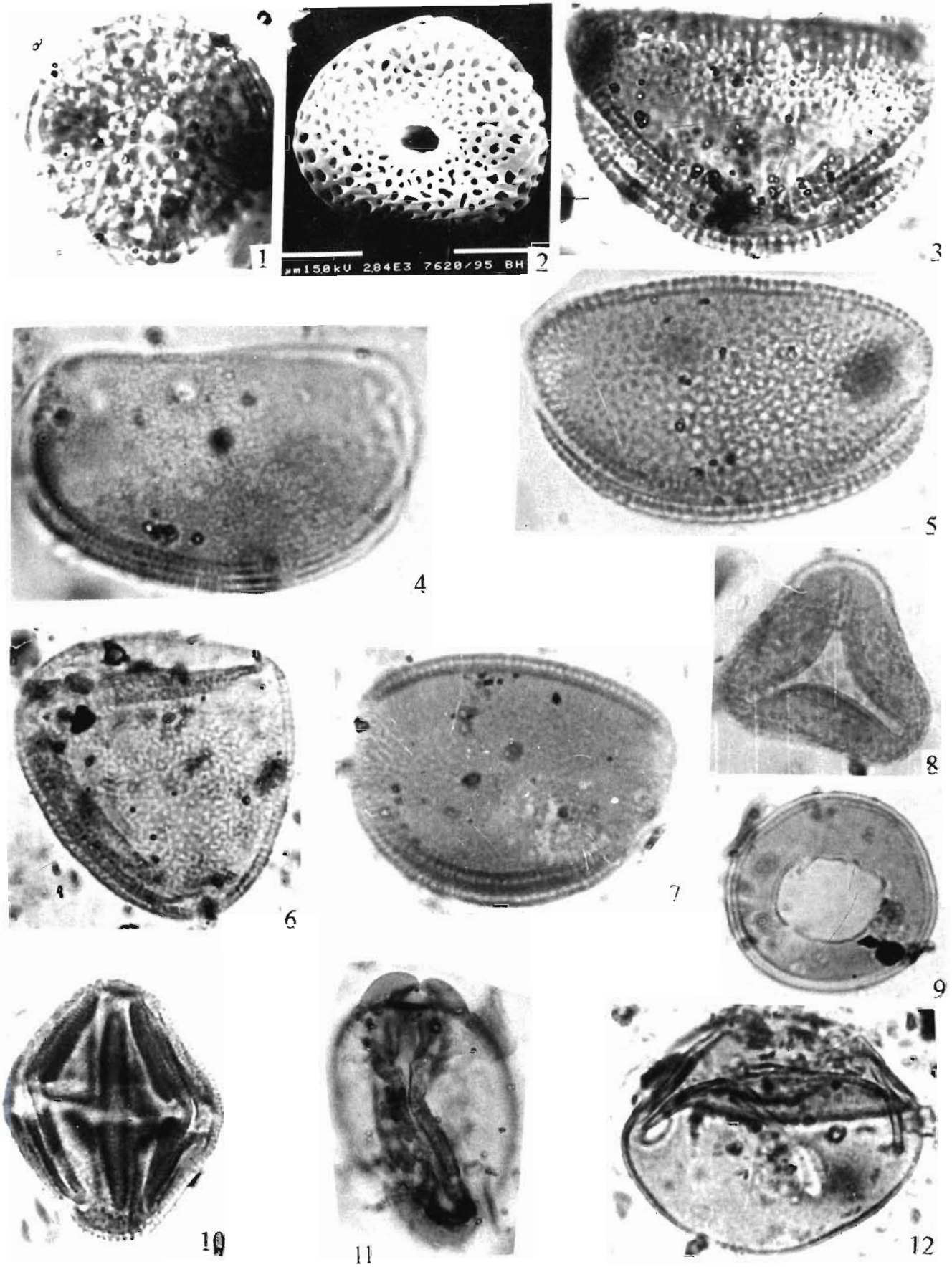


PLATE 3

SYMPLOCOIPOLLENITES BHAVNAGARENSIS sp. nov.

Pl. 6·4

Diagnosis—Pollen grains triangular in polar view; tricolporate; colpi open, broad; ora distinct, lalongate; exine thick; punctate to reticulate.

Description—Pollen grains triangular in polar view; 28-31 x 35-38 µm in size, tricolporate; colpi short, open, margins thin, regular smooth, ends pointed, 3-4 µm long and 2-3 µm broad; os lalongate, crassimarginate, 5-6 µm wide; exine 1·5 to 3 µm thick, exine thinner at aperture margins, generally sexine thicker than nexine, rarely sexine and nexine of same thickness, nexine smooth, columellate, semitectate; generally reticulate, rarely punctate, homobrochate, simply baculate.

Remarks—Symplocoipollenites punctatus reported by Venkatachala & Rawat (1972, Pl. 4. figs 5-7) is punctate, however it has distinctly small size and slit like aperture. *S. jacksonious* Traverse (1955) is small in size with scarsely visible pores. *S. baksii* Ramanujam (1987, Pl. 3, fig. 6) is smaller in size with very short, narrow, streak like colpi and punctate to microreticulate sculpture pattern. The above described palynomorph can be differentiated from the known species in possessing long, open colpi, distinctly thick margined os and reticulate to punctate sculpture pattern.

Holotype—Slide no. DGN/CDT-93/2/40.

Affinity—Symplocaceae.

Genus—TRIORITES (Erdtman & Cookson) Couper 1953

Type species—TRIORITES MAGNIFICUS Cookson 1950

TRIORITES PROTRUDUS sp. nov.

Pl. 6·12

Diagnosis—Pollen grains rounded triangular; triporate; pores protruding, tenuimarginate; exine thick; psilate.

Description—Pollen grains rounded triangular, anguloaperturate, 26-27 x 24-26 µm in size; triporate; pores distinctly protruding, pore margins thin, irregular; exine about 2 µm thick, sexine and nexine of almost same thickness except at aperture region where sexine is distinctly thick; psilate.

PLATE 4

(All magnification x 1000 unless otherwise mentioned)

1 *Margocolporites venkatachalii* Samant & Phadtare, DGN/C-112/7/7.
2. *M. sitholeyii* Ramanujam, DGN/CDT-98/1/31.
3. *Nymphaecidites* sp. DGN/C-114/4/9. x 40.
4. *Pellicieroipollis langenhemii* Sah & Kar, DGN/C-111/2/3.
5. *Palmaepollenites elongatus* Samant & Phadtare, DGN/C-114/4/9.
6. *P. eocenicus* (Biswas) Sah & Dutta, DGN/C-115/6/12.
7.&8. *Polybrevicolporites reticulatus* sp. nov., DGN/C-116/6/14.
9. *Polycolpites ornatus* Dutta & Sah, DGN/C-115/6/12.
10. *P. flavatus* Sah & Kar, DGN/CDT-70/3/18.
11 *Polybrevicolporites indistinctus* Samant & Phadtare, DGN/CDT-97/1A/17.
12. *Proteacidites triangulatus* Kar & Jain, DGN/C-111/6/4.
13. *Racimonocolpites bhavnagarensis* sp. nov., DGN/CDT-97/5A/30.

PLATE 5

(All magnification x 1000 unless otherwise mentioned)

See page no. 112

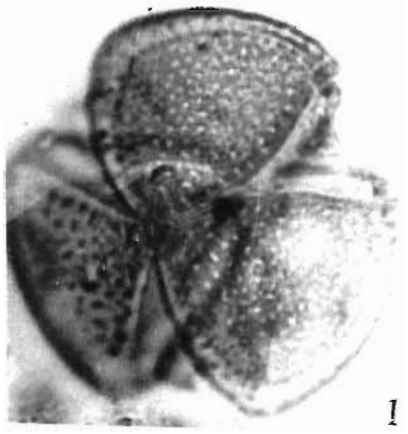
1 *Proxapertites cursus* van Hoeken Klinkenberg, DGN/CDT-98/1/31.
2. *P. marginatus* (Venkatachala & Kar) Singh, DGN/C-115/6/12.
3. *Retitetracolpites medicolpus* Mathur & Jain, DGN/C-114/4/9.
4. *Pometiapollenites reticulatus* sp. nov., DGN/C-73/2/39.
5. Extant pollen of *Pometia pinnata*, DGN/P/34.
6. SEM photograph of similar type.
7. *Psilatricolporites sagittatus* Samant & Phadtare, DGN/C-71/4/20.
8. *Retitricolpites crassireticulatus* (Dutta & Sah) Samant & Phadtare, DGN/CDT-97/5A/30.
9. *Psilodiporites* sp. B , DGN/CDT-95/3/41
10. *Psilodiporites* sp. A, DGN/CDT-95/4/37.
11 *P. magnus* Samant & Phadtare, DGN/C-111/2/3.
12. *Polygalacidites minutus* Samant & Phadtare, DGN/C-111/2/3.
13. SEM Photograph of the similar type.

PLATE 6

(All magnification x 1000 unless otherwise mentioned)

See page no. 113

1 *Pseudonothofagidites bengalensis* (Mathur & Chopra) Samant & Phadtare, DGN/C-111/2/3.
2. *Retipollenites confusus* Gonzalez Guzman, DGN/C-115/6/12.
3. *Retitribrevicolporites foveolatus* sp. nov., DGN/C-114/4/9.
4. *Symplocoipollenites bhavnagarensis* sp. nov., DGN/CDT-93/2/40.
5. *Spinizonocolpites prominatus* (Mc Intyre) Stover & Evans, DGN/CDT-98/1/31
6. *Striacolporites striatus* Sah & Kar, DGN/C-116/8/15.
7. *Umbelliferoipollenites broachensis* Samant & Phadtare, DGN/C-115/6/12.
8. *U. typicus* Samant & Phadtare, DGN/C-115/6/12.
9. *Tricolporopilites robustus* (Kar & Saxena) Kar, DGN/C-111/2/3.
10. *Tricolporocollumellites psilatus* Kar, DGN/C-111/6/16.
11 *Triangulorites minutus* (Sah & Kar) Kar, DGN/C-111/1/2.
12. *Triorites protrudus* sp. nov., DGN/CDT-93/1/28.
13. *T. sahii*, sp. nov., DGN/C-114/8/11.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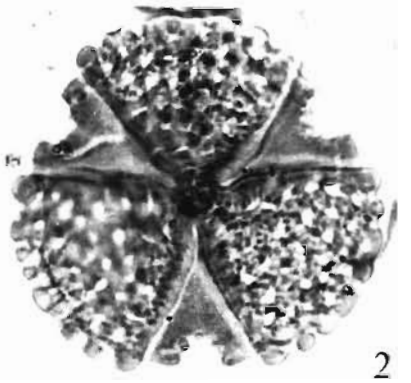
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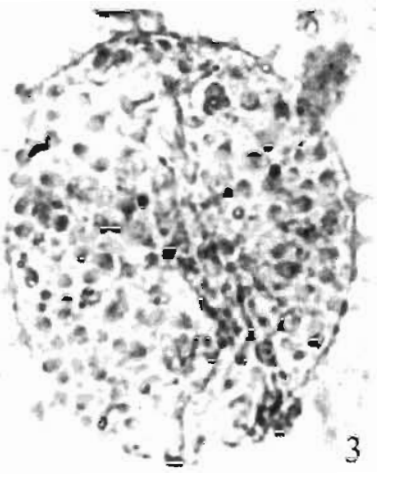
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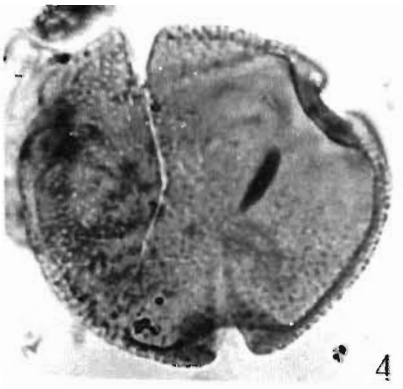
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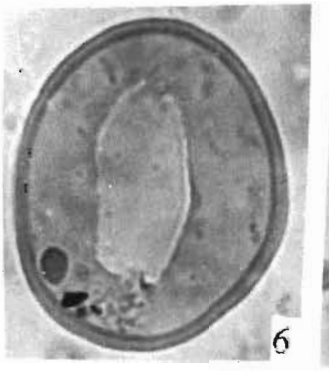
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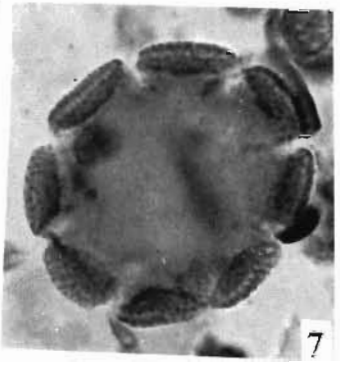
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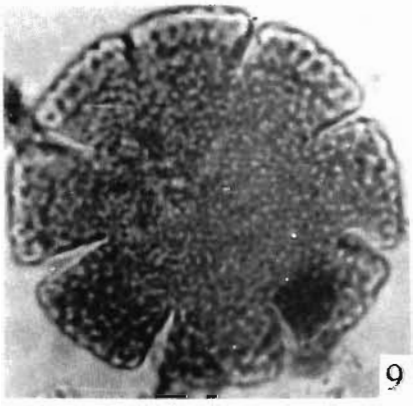
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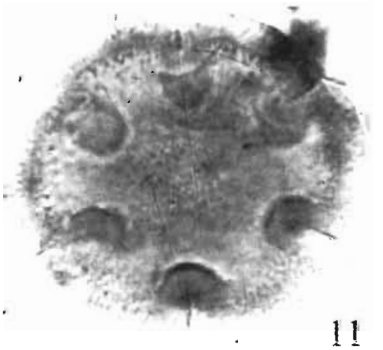
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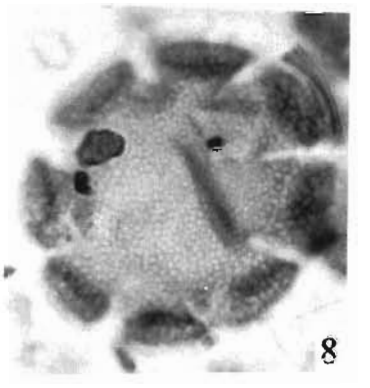
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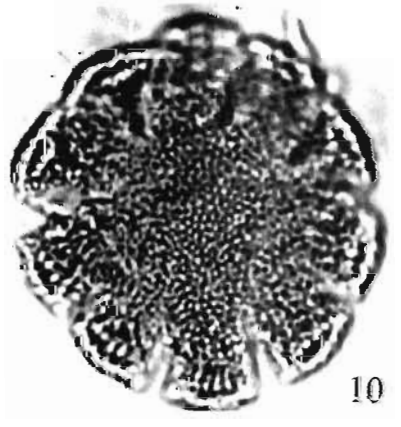
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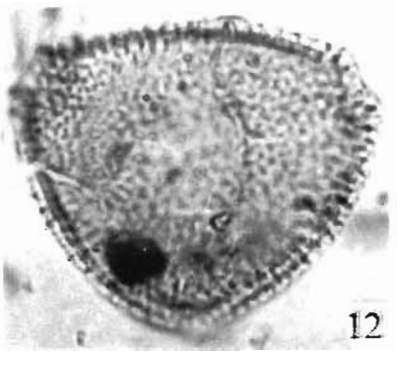
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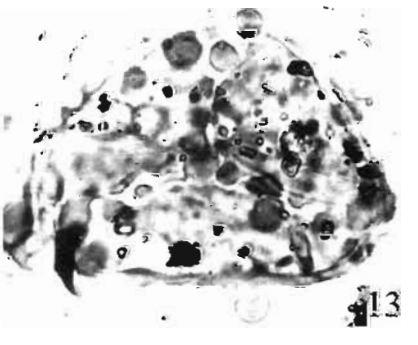
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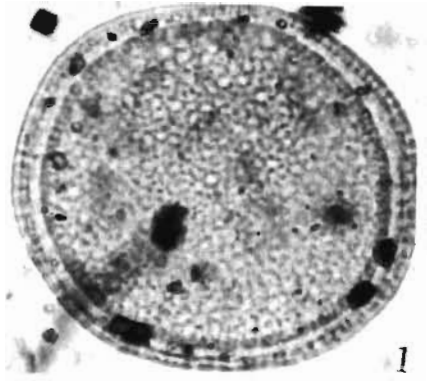
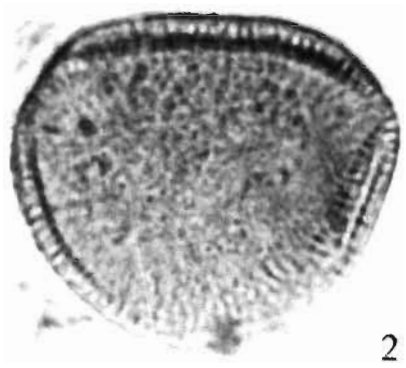
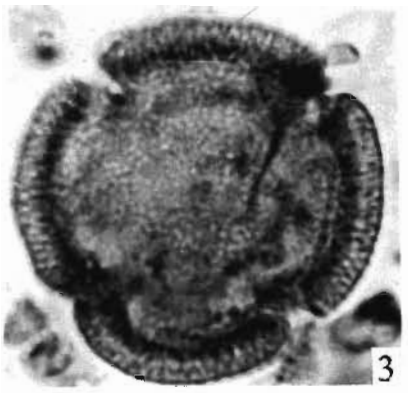
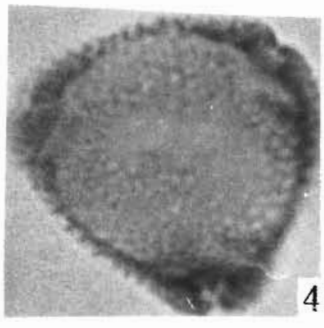
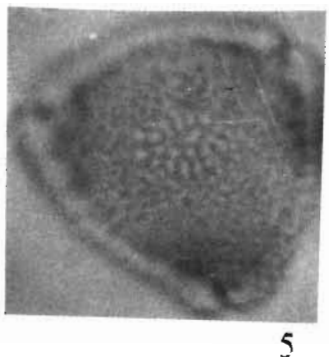
PLATE 4

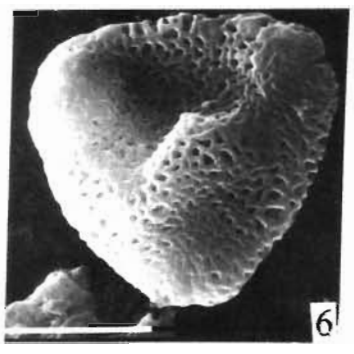


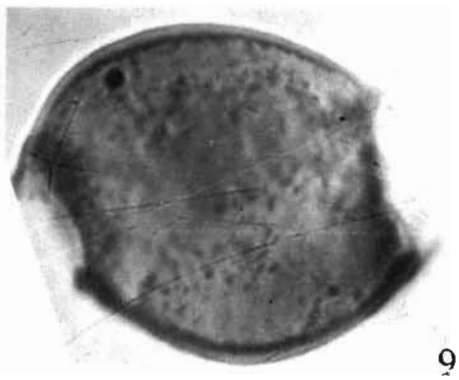


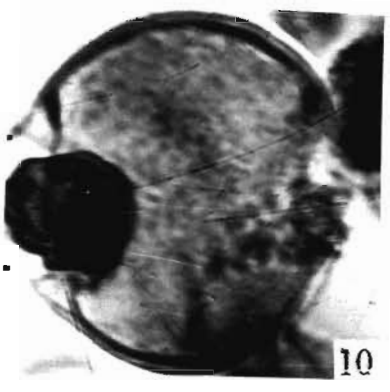


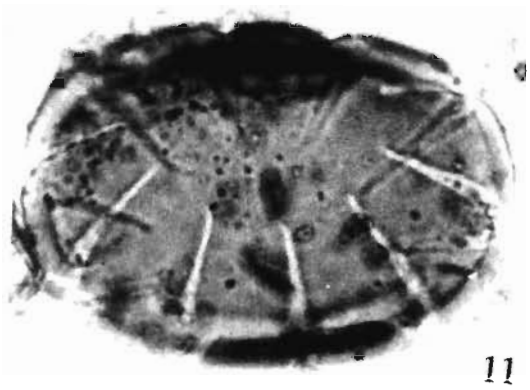












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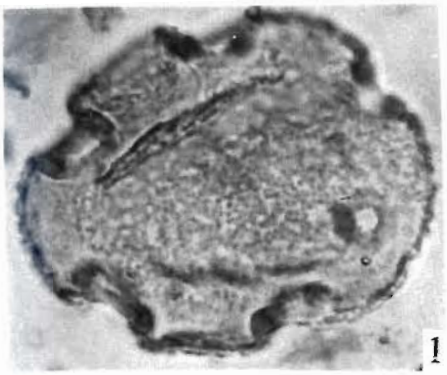
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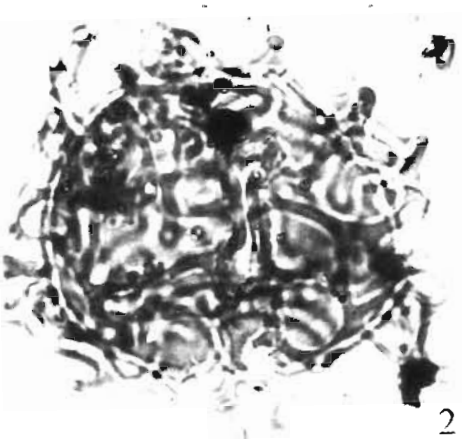
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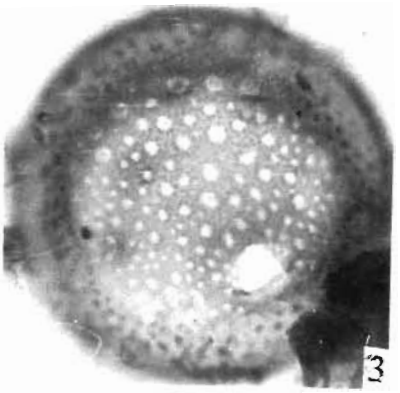
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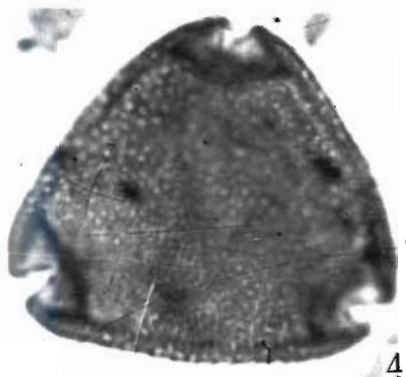
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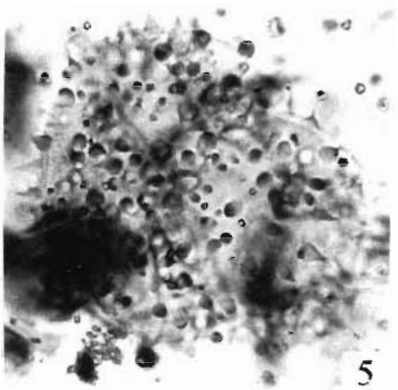
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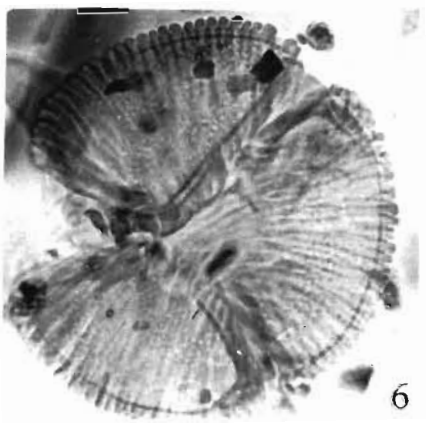
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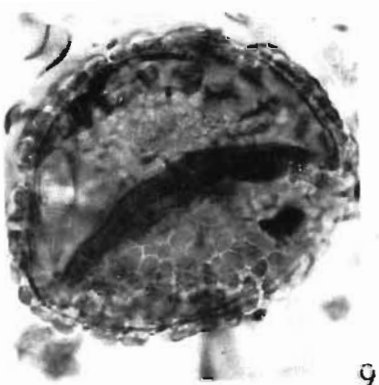
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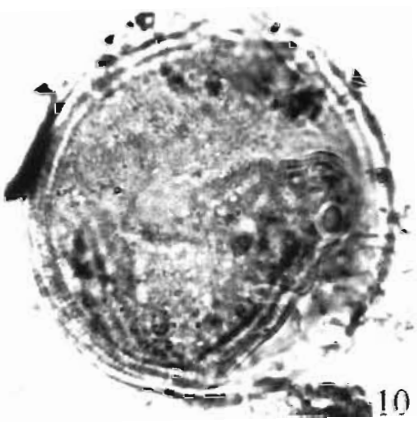
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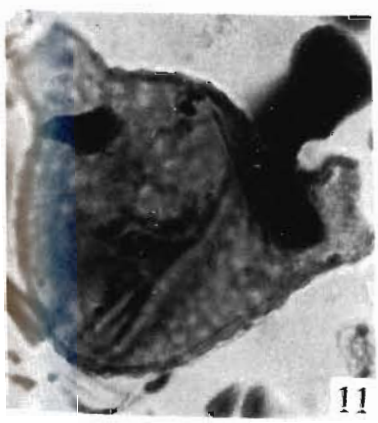
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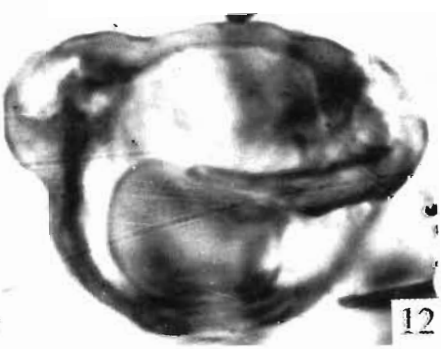
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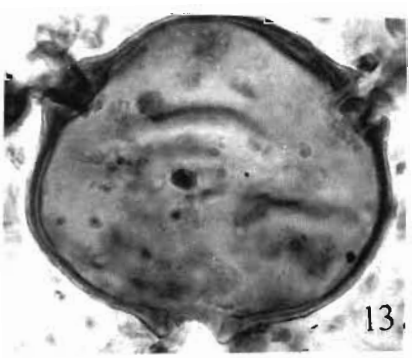
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PLATE 6

Remarks—*Triorites hirsutus* Sah & Kar (1974) possess protruding ora, however, it is baculate to finely reticulate. *T. microreticulatus* Rao & Ramanujam (1982) has reticulate sculpture pattern. Rounded triangular shape and distinctly protruding ora are the diagnostic characters of this specimen.

Holotype—Slide no. DGN/CDT-93/1/28.

Affinity—In overall shape and aperture pattern this pollen resembles with that of extant *Epilobium* (Oenotheraceae).

TRIORITES SAHII sp. nov.

Pl. 6·13

Diagnosis—Pollen grains rounded, triangular; sides convex; triporate; pores slightly protruding, tenuimarginate; exine thick, sexine distinctly thick at aperture margins; psilate.

Description—Pollen grains rounded, triangular; sides convex; 60-65 x 65-67 µm in size, triporate; pores slightly protruding, about 10 µm wide, tenuimarginate, margin smooth to irregular, exine about 3 µm thick, nexine (2 µm) thicker than sexine (1 µm) however at pore margins nexine is distinctly (6 µm) thicker than sexine (1 µm) psilate.

Remarks—*Triorites inferius* Rawat *et al.* (1977) possesses pouting pores and finely reticulate sculpture pattern. *T. protrudus* has small size, distinctly protruding ora with distinctly thick exine at aperture region. Large size, slightly protruding ora, thick nexine at aperture region and psilate sculpture pattern are the differentiating characters of this pollen.

Holotype—Slide no. DGN/C-114/8/11.

Affinity—Unknown.

List of pollen and spores reported from the Bhavnagar Lignite

Pteridophytic spores

Cyathidites australis Couper, 1953
Dandotiaspora plicata (Sah & Kar) Sah, Kar & Singh, 1981
Laevigatosporites lakiensis Sah & Kar, 1969
L. gracilis Wilson & Webster, 1946
L. sp.
Lygodiumsporites lakiensis (Sah & Kar) Rao & Singh, 1978
Polypodiisporites ratnamii (Ramanujam) Rao & Ramanujam, 1978
P. constrictus Kar, 1979
Pteridacidites triangulatus Sah, 1967
Todisporites major Couper, 1968
T. flavatus Sah & Kar, 1969
Triplanosporites sinuosus Pflug, 1953

Gymnosperms

Podocarpidites sp.

Angiosperms

Anacolosidites trilobatus Venkatachala & Rawat, 1972
A. luteoides Cookson & Pike, 1954
Araliaceoipollenites descretus Venkatachala & Rawat, 1973
Arecipites bellus Sah & Kar, 1970
A. intrapunctatus Kar & Saxena, 1981
Arengapollenites achinatus Kar, 1985
Bombacacidites triangulatus Kar, 1985
Clavapalmidites hammenii Rao & Ramanujam, 1978
Clavaperiporites homoclavatus Samant & Phadtare, 1997
Cryptopolyporites cryptus Venkatachala & Kar, 1969
Ctenolophonidites costatus van Hoeken Klinkenberg, 1966
Cupanidites flaccidiformis Venkatachala & Rawat, 1972
Dracenoipollis circularis Sah & Kar, 1970
Echitriporites minutus Samant & Phadtare, 1997
Favitricolporites retipilatus Samant & Phadtare, 1997
Florschuetzia rajpardiensis Samant & Phadtare, 1997
Haloragidacidites neyvelii Ramanujam, 1966
Intrareticulites brevis (Sah & Kar) Kar, 1985
Iugopollis tetraporites Venkatachala & Rawat, 1972
Lanagiopollis rugulatus Phadtare & Thakur, 1990
Liliacidites minireticulatus Mathur & Mathur, 1969
L. clubensis Samant & Phadtare, 1997
Longapertites vanendenburgii Germeraad *et al.*, 1968
L. proxapertoides van der Hammen & Garcia de Mutis, 1965
L. hammenii Rao & Ramanujam, 1978
L. retipilatus Kar, 1985
L. triangulatus Samant & Phadtare, 1997
Lakiapollis ovatus Venkatachala & Kar, 1969
Margocolporites venkatachalii Samant & Phadtare, 1997
Marginipollis kutchensis (Venkatachala & Kar) Kar, 1985
Neotrichotomosulcites acrocomiae Samant & Phadtare, 1997
Palaeoaraliaceaepites indistinctus Samant & Phadtare, 1997
P. distinctus Samant & Phadtare, 1997
Paripollis broachensis Samant & Phadtare, 1997
Palmaepollenites eocenicus (Biswas) Sah & Dutta, 1968
P. kutchensis Venkatachala & Kar, 1968
P. ovatus Sah & Kar, 1970
P elongatus Samant & Phadtare, 1997
Pellicieroipollis langenhemii Sah & Kar, 1970
Polybrevicolpites indistinctus Samant & Phadtare, 1997
Polycolpites ornatus Dutta & Sah, 1970
P. flavatus Sah & Kar, 1970
Polygalacidites minutus Samant & Phadtare, 1997
P. magnus Samant & Phadtare, 1997
Prectenolophonidites primitiva Samant & Phadtare, 1997
P. distinctus Samant & Phadtare, 1997
Proteacidites triangulatus Kar & Jain, 1981
P. retusus Anderson, 1960
Proxapertites cursus van Hoeken klinkenberg, 1966
P. marginatus (Venkatachala & Kar) Singh, 1975
Psilatricolporites sagittatus Samant & Phadtare, 1997
Psilodiporites hammenii Varma & Rawat, 1963
Pseudonothofagidites bengalensis (Mathur & Chopra) Samant & Phadtare 1997
Quilonipollenites minutus Samant & Phadtare, 1997
Retimonocolpites thanikaimonii Samant & Phadtare, 1997
Retistephanocolpites williamsii Germeraad *et al.*, 1968
Retitetracolpites medicolpus Mathur & Jain, 1988
Retipollenites confusus Gonzalez Guzman, 1967
Retitricolpites crassireticulatus (Dutta & Sah) Samant & Phadtare, 1997
Spinizonocolpites prominatus (Mc Intyre) Stover & Evans, 1973

Striacolporites striatus Sah & Kar, 1970
Triangulorites minutus (Sah & Kar) Kar, 1985
Tricolporocolumellites psilatus Kar, 1985
Tricolporopilites robustus (Kar & Saxena) Kar, 1985
Umbelliferoipollenites broachensis Samant & Phadtare, 1997
U. typicus Samant & Phadtare, 1997

Photomicrographs of some of the important palynomorphs are shown in Plate 1-6.

DISCUSSION

A good frequency of pollen and spore are present in the Bhavnagar lignite assemblage. The microflora is represented by 66 genera encompassing 86 species. Out of these, pteridophytes composed of both monolete as well as of trilete spores and are classified under 8 genera and 12 species. Monolete spores are the most dominating members amongst pteridophytes.

A few grains of gymnosperm pollen taxon represented by *Podocarpidites* could be recovered from this lignite. A relatively low frequency of this wind pollinated plant in the assemblage suggests its location some distance away from the deposition site.

Angiosperms are represented by the pollen of both monocotyledons and dicotyledons which are distributed in about 57 genera and 74 species. Out of these, one genus and seven species are described as new. Monocot pollen grains account for 13 genera and 25 species and dicot pollen by 44 genera and 49 species. During the present study an attempt has been made to establish botanical affinities of the recovered fossil palynomorphs.

One of the interesting finding of the present study is the record of fossil pollen of *Pometiapollenites reticulatus* sp. nov. This pollen in overall morphology, resembles that of extant *Pometia pinnata* of the family Sapindaceae. Muller (1981) asserted that so far the oldest report of the genus *Pometia* – type pollen of subfamily Nephaleae is from the Miocene of Borneo (Muller, 1972; Anderson & Muller, 1975). Graad der van *et al.* (1990) while discussing the origin of *Pometia*, postulated that this pollen might have originated in Malaysia. Record of the *Pometia* – type pollen from the Early Eocene deposits of the Bhavnagar Lignite suggests its much older existence (Samant, 1996).

Similarly, the botanical affinity of fossil pollen *Triorites protrudus* sp. nov. is proposed with that of extant tropical genus *Epilobium* of Oenotheraceae.

Apart from the above discussed palynomorphs, a good number of the recovered taxa show affinities with extant families (Fig. 4).

PALEOECOLOGY AND PALEOCLIMATE

The study shows that palynological assemblage of the Bhavnagar Lignite has good frequency of fern spores represented by Osmundaceae (*Todisporites*), Schizeaceae (*Lygodiumsporites*), Polypodiaceae (*Polypodiisporites* and *Laevigatosporites*) and Gleicheniaceae (*Triplanosporites*). *Cyathea* (*Cyathidites*) and *Pteris* (*Pteridacidites*) as well as tree ferns. The presence of fern taxa suggests warm humid tropical climatic condition.

The dominance of palm pollen *Arengapollenites*, *Palmaepollenites*, *Longapertites* and *Neotrichotomosulcites* in the Bhavnagar Lignite indicates prevalence of thick and closed vegetation. Similarly the record of aquatic herbs of Nymphaeaceae (*Nympheacedites*), Lentibulariaceae (*Polycolpites ornatus*), *Myriophyllum* (*Haloragacidites*) in the assemblage indicates some fresh water influence in the basin. Characteristic swamp elements such as *Gonystylus* (*Cryptopolyporites*) of Gonystylaceae, *Gunnera* (*Intrareticulites*) of Gunneraceae, *Durio* (*Lakiapollis*) of Bombacaceae, *Ctenolophon* (*Ctenolophonidites*, *Prectenolophonidites*) and *Retistephanocolpites williamsii*) of

Fossil Taxa	Botanical affinity
a) Pteridophytic spores	
Dandotiaspora plicata	? Matoniaceae
b) Angiosperms	
Monocots	
Arengapollenites achinatus	Arecaceae (*Arenga*)
Clavapalmidites hammenii	-do- (*Iriartea pinanga*)
Jacobipollenites ramanujamii	-do- (*Ravena albicans*)
Neotrichotomosulcites acrocomiae	-do- (*Acrocomia*)
Retipollenites confusus	-do- (*Borassoidae*)
Spinizonocolpites prominatus	-do- (*Nypa*)
Dicots	
Anacolosidites trilobatus	Olacaceae (*Anacolosa*)
Bombacacidites triangulatus	Bombacaceae
Cryptopolyporites cryptus	Gonystylaceae (*Gonystylus*)
Ctenolophonidites costatus	Ctenolophonaceae (*Ctenolophon*)
Cupanidites flaccidiformis	Sapindaceae
Dracaenoipollis circularis	Dracenaceae (*Dracena*)
Intrareticulites brevis	Gunneraceae (*Gunnera*)
Lakiapollis ovatus	Bombacaceae (*Durio*)
Marginipollis kutchensis	Lecyethidaceae (*Barringtonia*)
Pometiapollenites reticulatus	Sapindaceae (*Pometia*)
Proteacidites retusus	Proteaceae
Psilatricolporites sagittatus	Ebenaceae
Symplocoipollenites microreticulatus	Symplocaceae
Triorites protrudus	Oenotheraceae (*Epilobium*)

Fig. 4 — List of fossil pollen taxa showing affinities with distinctly tropical families.

Ctenolophonaceae and *Pometia* (*Pometiapollenites*) of Sapindaceae have also been recorded from this assemblage. The presence of montane evergreen flora in the nearby region is indicated by Proteaceae (*Proteacidites*) and Symplocaceae (*Symplocoipollenites*). Deltaic or near deltaic conditions are suggested by record of *Nypa* (*Spinizonocolpites*) of Arecaceae and *Barringtonia* (*Marginipollis*).

Presence of exclusively tropical families (Fig. 4) : Arecaceae, Araceae, Dracenaceae, Bombacaceae, Ebenaceae, Ctenolophonaceae, Gonystylaceae, Gunneraceae, Lecythidaceae, Olacaceae, Oenothograceae, Proteaceae, Sapotaceae, Sapindaceae, and Sonneratiaceae coupled with high frequency of fern spores and epiphyllous fungal fruiting bodies (Samant, 1999) in the assemblage collectively point towards warm humid tropical climate and high degree of rainfall.

PALYNOSTRATIGRAPHIC ZONATIONS

On the basis of qualitative analysis of the samples the pollen/spore assemblage of the Bhavnagar Lignite is divided into two cenozones (Fig. 5) in the descending order as.

1) *Arengapollenites achinatus* Cenozone

2) *Triplanosporites sinuosus* Cenozone

Triplanosporites sinuosus Cenozone

Lithology—Grey clay, Lignite and Carbonaceous shale.

Position—From Sample no. C-76 to 96.

Important taxa—This Cenozone is marked by the significant dominance of *Triplanosporites sinuosus*, *Pometiapollenites reticulatus*, *Lygodiumsporites lakiensis* and *Proxapertites*. Other important taxa of the Cenozone are *Todisporites major*, *Lakiapollis ovatus* and *Anacolosidites*.

Lower limit—Lower limit of this Cenozone is marked by dominance of *Triplanosporites sinuosus* and *Pometiapollenites*.

Upper limit—Significant drop in *Triplanosporites sinuosus* and appearance and dominance of *Proxapertites cursus*. *Prectenolophonidites primitiva* also appeared in the upper part of the Cenozone.

Arengapollenites achinatus Cenozone

Lithology—Lignite and carbonaceous shale.

Position—From C-95 to C-10.

Important taxa—Important taxa of this Cenozone are *Umbelliferoipollenites brochensis*, *U. typicus*, *Arengapollenites achinatus*, *Palmaepollenites tenuimarginatus*, *Haloragacidites*, *Cryptopolyporites cryptus*, *Ctenolophonidites costatus*, *Proteacidites*, *Quilonipollenites minutus*, *Araliaceoipollenites*, *Neotrichotomosulcites* spp. and *Spinizonocolpites prominatus*.

Lower limit—Lower limit of this Cenozone is marked by first appearance of *Quilonipollenites minutus* and *Araliaceoipollenites*.

Upper limit—Upper limit is marked by appearance of *Spinizonocolpites* and drop in pollen population of

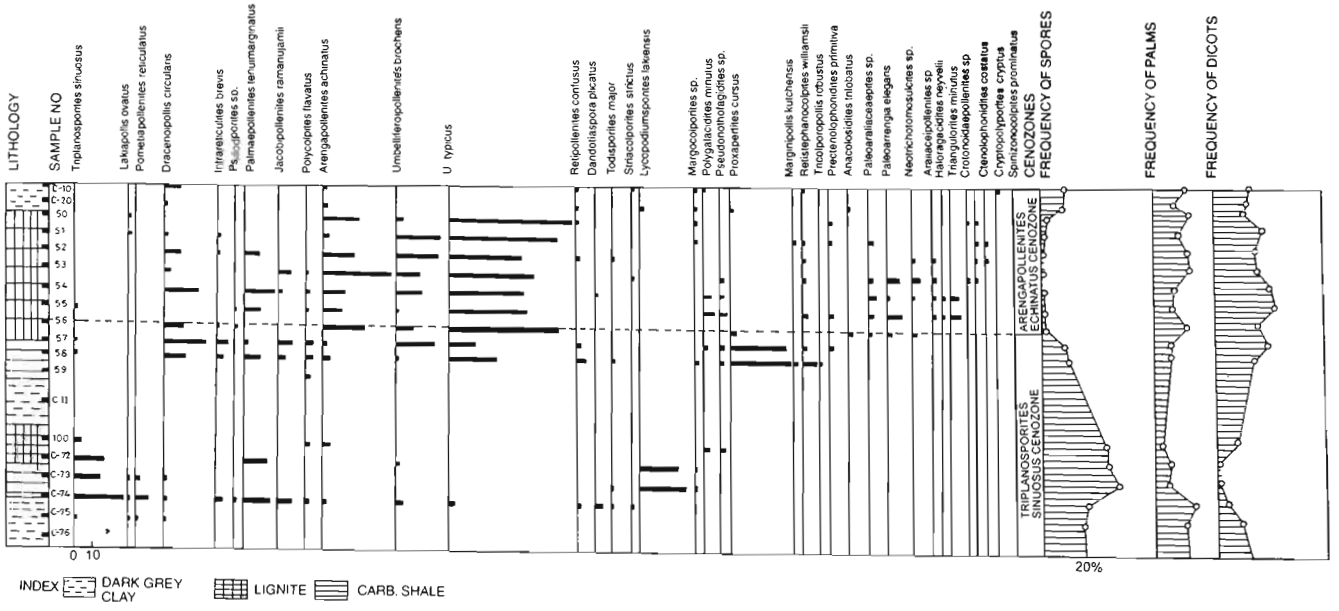

Fig. 5 — Pollen diagram of Bhavnagar Lignite.

Cryptopolyporites cryptus, *Arengapollenites achinatus*, *Umbelliferoipollenites brochenis* and *U. typicus*.

DEPOSITIONAL ENVIRONMENT

Plant taxa recovered during the palynofloristic study of the Bhavnagar Lignite are indicators of depositional environment.

The lowermost grey clay sequence has yielded very few palynomorphs, however, thin lignite bed (Fig. 5) overlying it has shown high frequency of fungal hyphae and pteridophytic spores along with some angiosperms. The dominance of fern spores of Polypodiaceae and Schizaeaceae along with *Pometiapollenites (Pometia)*, *Margocolporites*, *Lakiapollis (Durio)* and *Gunnera (Intrareticulites)* in this part indicate the existence of a small marsh. Above the lower most thin lignite bed, is a grey clay sequence which is practically devoid of microfossils. This sudden change of lithologic condition from lignite to grey clay (i.e. reducing to oxidizing environmental condition) could be due to transgression of the sea or overflooding of the basin.

Some climatic change is indicated at the upper part of the *Triplanosporites sinuosus* Cenozone by steep decline of spores and gradual increase in dicot pollen population. The record of typical back mangrove element *Marginipollis (Baringtonia)* of Lecythidaceae in this part suggest some brackish water influence in the basin.

The *Arengapollenites achinatus* Cenozone shows ameliorating trend in the ecological and climatic conditions. During the deposition of this Cenozone, dicots and palms were fairly well established in comparison to *Triplanosporites sinuosus* Cenozone which was dominated mostly by pteridophytes.

In the middle horizon of the *Arengapollenites achinatus* Cenozone typical woody taxa of Araliaceae, Ebenaceae, Proteaceae and Symplocaceae along with swamp dwellers such as *Durio (Lakiapollis)*, *Gunnera (Intrareticulites)* and *Gonystylus (Cryptopolyporites)* and members of Ctenolophonaceae were fairly well established.

The basin experienced transgression during the deposition of the uppermost part of the *Arengapollenites achinatus* Cenozone. The record of typical mangrove element *Nypa (Spinizonocolpites)* in the uppermost horizon undoubtedly indicates the deltaic environmental condition. Recovery of megafossils like shells of lammelibranchs and foraminifers from this horizon corroborates this assumption. It is further supported by the record of Early Eocene transgression in the Cambay Basin (Bhandari & Raju, 1991).

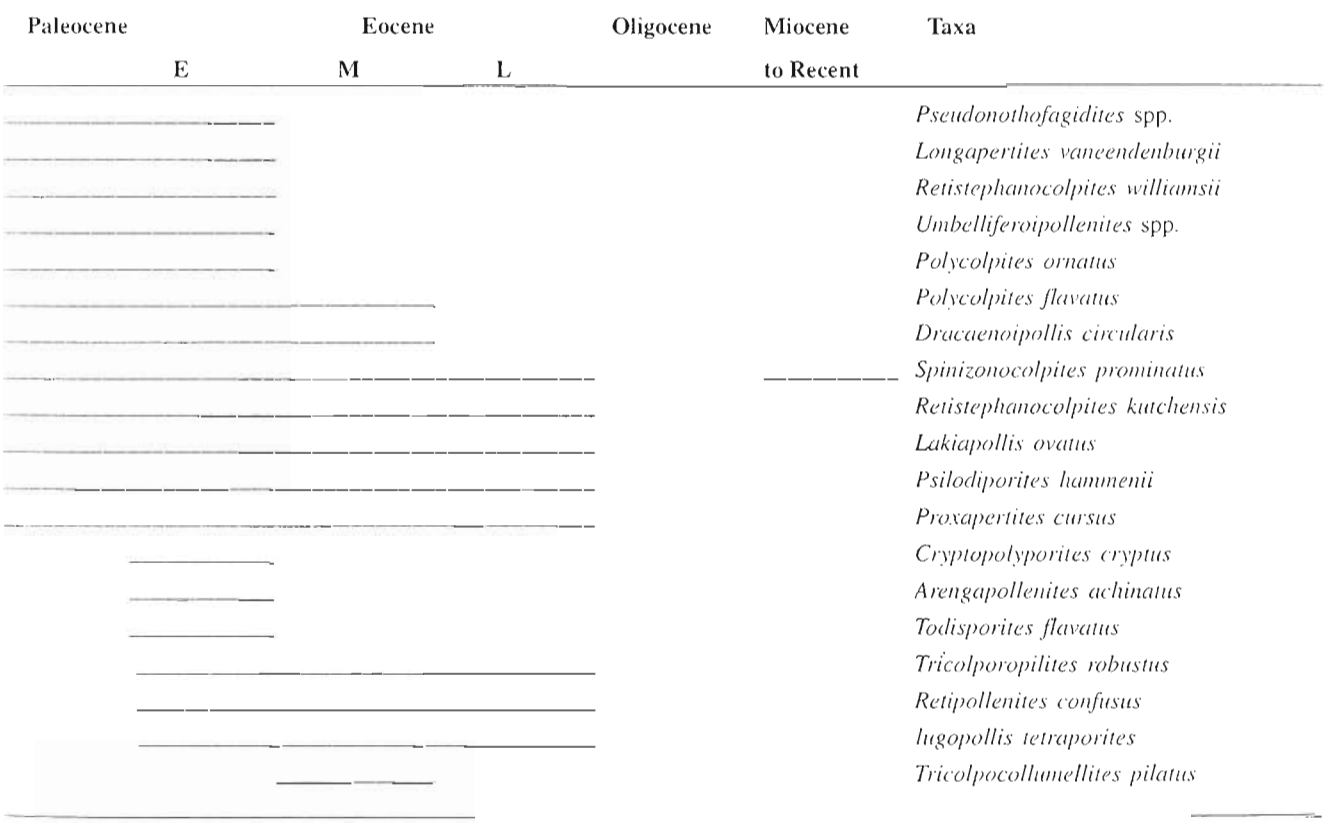

Fig. 6 — Important pollen spore taxa of the Bhavnagar Lignite with their stratigraphic range in other Tertiary deposits of India.

AGE OF THE BHAVNAGAR LIGNITE

According to DGM, Gujarat (Unpublished report) the Bhavnagar Lignite deposit is part of the Kharsalia Clay Formation of Eocene.

Palynostratigraphic literature of Indian Tertiary sediments reveals record of some stratigraphic marker taxa. Detailed palynological studies of the lignite, clay shale sequence reveal the presence of some significant palynotaxa which could help in unveiling the geological age of this lignite. Fig. 6 shows chronostratigraphic range of some important palynomorphs of the Bhavnagar Lignite.

Presence of *Anacolosidites trilobatus, Retipollenites confusus, Tricolporopilites robustus, Arengapollenites achinatus* and *Cryptopolyporites cryptus* collectively indicate the Early Eocene age for this lignite. Overall palynotaxa of the Bhavnagar Lignite also agrees with that of Early Eocene deposits of Naredi Formation of Kachchh (Kar, 1978) and Rajpardi Lignite of Broach (Kar & Bhattacharya, 1992; Samant & Phadtare, 1997).

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