The Palaeobotanist 55(2006): 51-66
0031-0174/2006 $2.00

Palynology of Vastan lignite (Surat District), Gujarat: its age, palaeoecology and depositional environment

J. MANDAL AND J.S. GULERIA

Birbal Sahni Institute of Palaeobotany, 53 University Road, Lucknow 226 007, India.

(Received 21 July, 2005; revised version accepted 22 February, 2006)

ABSTRACT

Mandal J & Guleria JS 2006. Palynology of Vastan lignite (Surat District), Gujarat: its age, palaeoecology and depositional environment. The Palaeobotanist 55(1-3): 51-66.

The paper deals with the palynological investigation of lignite of Vastan lignite mine, located near Surat in Gujarat, western India. A rich and diverse palynoassemblage comprising 71 genera and 82 species of pollen-spores, algal-fungal remains and dinoflagellate cysts has been recovered for the first time from the mine. The study has added to our knowledge the occurrence of one new genus and four new species of angiospermous pollen. The assemblage is dominated by angiospermous pollen and can be distinguished from contemporaneous assemblages by high frequency of polycolpate taxa and scarcity of pteridophytic spores. The assemblage suggests deposition of Vastan lignite during the early Eocene in deltaic conditions under brackish water influence and depicts prevalence of humid tropical climate.

Key-words—Palaeopalynology, Palaeoecology, Early Eocene, Vastan lignite, Gujarat.

गुजरात के वास्तन लगुडांगार (सूरत जिले) का परागाणुविज्ञान : इसकी आयु, पुरापारिस्थितिकी तथा निक्षेपणीय पर्यावरण

जे. मंडल एवं जे.एस. गुलेरिया

सारांश

यह शोध-पत्र पश्चिमी भारत में गुजरात के सूरत जिले के निकट स्थित वास्तन लगुडांगार (खान) के परागाणविक अन्वेषण की जानकारी प्रदान करता है। परागकणों-बीजाणुओं, शैवालीय-कवकी अवशेषों तथा घूर्णीकशाभ पुटियों के 71 वंशों व 82 प्रजातियों से युक्त प्रचुर एवं विविधमय परागाणु समुच्चय को इस खान से प्रथम बार खोजा गया है। इस अध्ययन द्वारा आवृतबीजी परागकण के एक नये वंश व 4 नयी प्रजातियों की उपस्थिति से हमारे ज्ञान में वृद्धि हुई है। इस समुच्चय में आवृतबीजी परागकणों की प्रमुखता है और इसके समकालीन समुच्चयों से इसे पोलीकॉल्पेट वर्गकों की प्रचुरता तथा टेरिडोफाइटी बीजाणुओं की अल्पता द्वारा अलग कर सकते हैं। यह समुच्चय प्रारम्भिक ईओसीन के दौरान डेल्टीय परिस्थितियों में खारे पानी के अंतर्गत वास्तन लगुडांगार के निक्षेपण को प्रस्तावित करता है तथा आर्द्र उष्णकटिबंधीय जलवायु की व्यापकता अंकित करता है।

संकेत-शब्द—पुरापरागाणुविज्ञान, पुरापारिस्थितिकी, प्रारम्भिक ईओसीन, वास्तन लगुडांगार, गुजरात।

INTRODUCTION

LIGNITE deposits in Gujarat are confined to four districts, namely Kachchh, Bhavnagar, Bharuch and Surat. Of these, detailed palynological studies have been done on the lignites of Kachchh and Bharuch districts (Kar, 1985; Kar & Bhattacharya, 1992; Kumar, 1996; Samant & Phadtare, 1997) and some work has been done on Bhavnagar lignite (Samant, 2000). Lignite of Surat district has not been investigated palynologically so far. Presently Gujarat Industries Power Company Limited (GIPCL) is exploiting lignite of the Vastan lignite mine (Surat District) for production of electricity. This mine is situated about 60 km northwest of Surat. No megaplant fossils have been recorded so far from this mine though one of the authors (JSG) has collected some fossil woods, which are under investigation. A preliminary investigation of the fossil woods has shown that they belong to dicotyledonous group of angiosperms. Recently Alimohammadian *et al.* (2005) recorded fungal bodies, cuticular structures, a flower with projecting stamen-like structures, *Proxapertites*, insects and spiders preserved in amber nodules from the Vastan lignite mine. Beside this, fish remains, molluscs, benthic foraminifera, ostracodes and marsupials have also been reported (Bajpai & Kapur, 2004; Bajpai *et al.*, 2005; Bhandari *et al.*, 2005). In the present paper the authors have put on record the palynoassemblage of Vastan lignite and deduced age, palaeoclimate and palaeoecology on the basis of palynoflora.

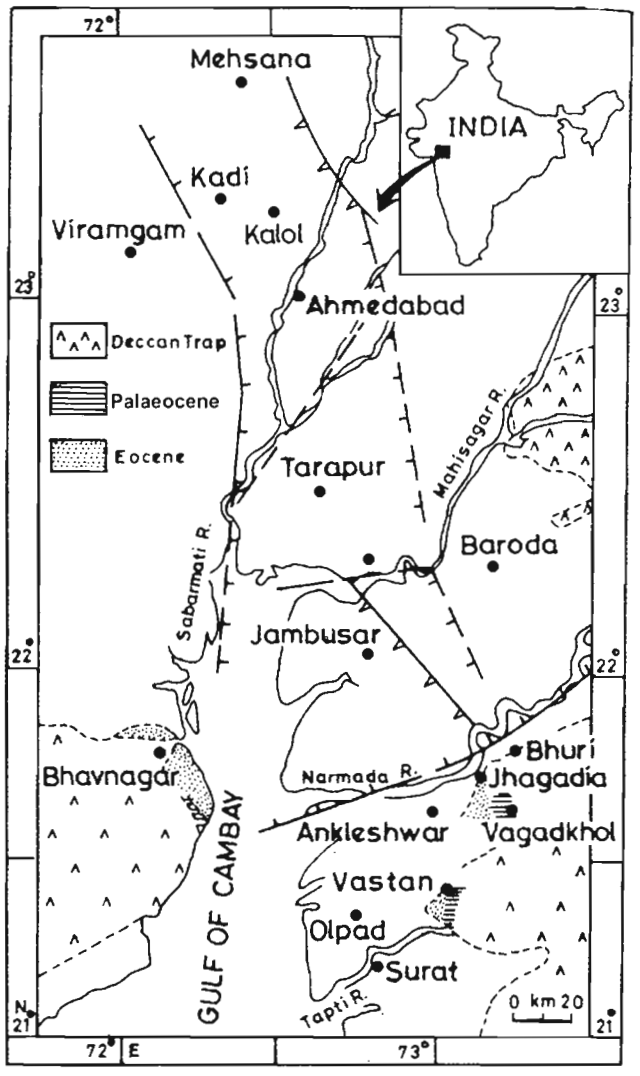

Fig. 1—Location map showing Vastan (after Chandra & Chowdhury, 1969).

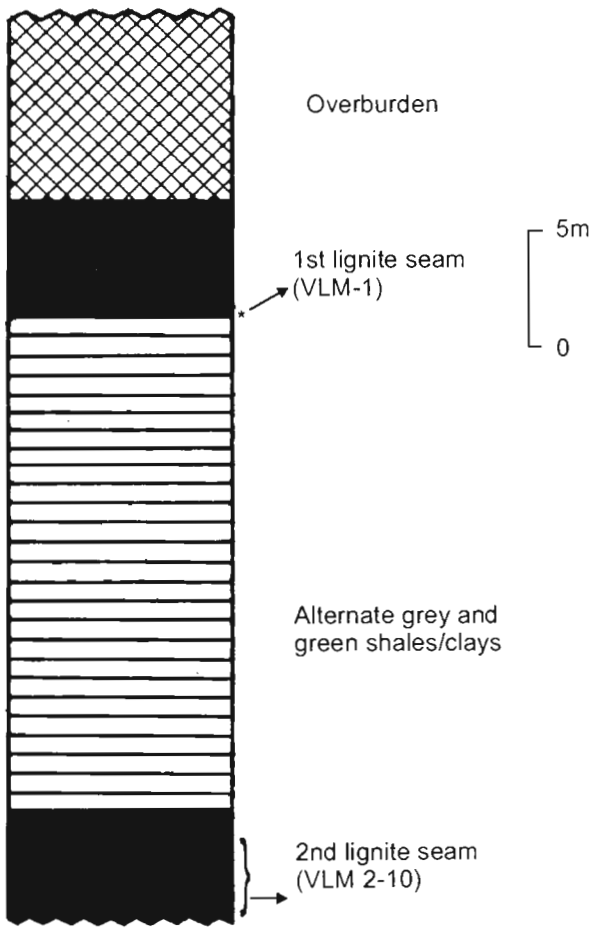

Fig. 2—Lithocolumn showing two lignite seams from where samples were collected.

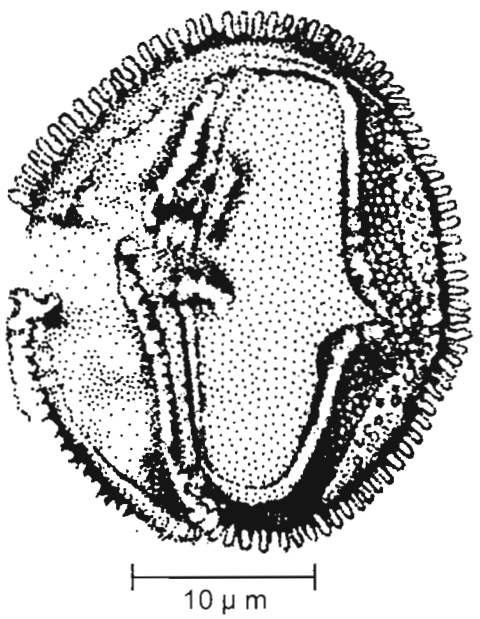

Fig. 3—*Intectocolporites baculatus* showing free columellae.

The material was collected from an open pit of Vastan lignite mine situated about 5 km northeast of village Nani Naroli, Surat District, Gujarat (Fig. 1). There are two lignite seams in this mine. The seams are separated by alternation of grey to greenish clay and shale. When the samples were collected, the seam-I has been fully exploited and only one lignite sample (VLM-1) was collected. Nine lignite samples (VLM-2-10) were collected from seam-II (about 5 m thick). The lithocolumn and position of samples are shown in Fig. 2.

The slides, photo negatives and samples are deposited in the Museum of Birbal Sahni Institute of Palaeobotany, Lucknow.

SYSTEMATICS

The study records one new genus and four new species of angiosperm pollen. These along with a few little known taxa from India are described below.

Genus—INTECTOCOLPORITES gen. nov.

Type species—*Intectocolporites baculatus* sp. nov.

Diagnosis—Pollen grains subprolate to prolate, tricolporate, colpi long, exine intectate.

Comparison—There is no known comparable tricolporate, intectate fossil genus.

Intectocolporites baculatus sp. nov.

[Pl. 2.13, 14-15(Holotype); Fig. 3]

Diagnosis—Pollen grains subprolate in equatorial and triangular in polar views; tricolporate, exine intectate, columellate, columellae baculate, free.

Description—Pollen grains radially symmetrical, isopolar, mostly preserved in equatorial position, subprolate in equatorial view and triangular with convex sides in polar view, 27-30 x 28-34 µm (equatorial), 36-40 x 31-36 µm (polar) in size. Tricolporate, colpi 22-24 µm long, tenuimarginate; pore simple, elliptical, 5 x 3 µm. Exine 1.5-2 µm thick; nexine 0.5 µm at mesocolpia and 1 µm thick near apertures; sexine columellate, columellae baculate, free, closely placed, about 1 µm long, 0.5 µm broad. Surface granular at top focus.

Remark—Ten specimens recorded in the assemblage.

Genus—VERRUTRICOLPITES Pierce, 1961

Type species—*Verrutricolpites sphaeroides* Pierce, 1961

Verrutricolpites longicolpus sp. nov.

[Pl. 2.25, 26 (Holotype)]

Diagnosis—Pollen grains prolate, tricolpate, colpi long, exine verrucate.

Description—Pollen grains radially symmetrical, isopolar, large, 50-55 x 68-78 µm in equatorial view, 64 x 66 µm in polar view, amb sub triangular. Tricolpate, colpi 55-60 µm long, nearly touching the poles, margin uneven due to verrucae. Exine 2 µm thick; nexine uniformly 0.5 µm thick; sexine verrucate, verrucae larger and closely placed at equatorial area which reduces gradually in size toward poles and appear nearly smooth

at places; larger verrucae 3-4 μm broad and 1 μm high. Surface negatively reticulate.

Comparisons—*Verrutricolpites perverrucatus* Ramanujam (1966) is smaller (26 μm) and has short colpi. *V. triangulus* Sah and Kar (1970) is medium sized (34-44 μm) having 3-7 μm thick exine and short colpi. *V. sphaeroides* Pierce (1961) has short colpi extending half of equatorial length. The new species is distinct in being longicolpate and large in size.

Remark—The species is common in the assemblage.

Genus—YEGUAPOLLIS Elsik, 1974

Type species—*Yeguapollis colporatus* Elsik, 1974

Yeguapollis indicus sp. nov.

[Pl. 2.1, 2 (Holotype), 3, 4]

Diagnosis—Tricolporate apiculate pollen grains, exine thicker at poles, sexine columellate, columellae thin, closely placed and vary in size from pole to equator.

Description—Pollen grains radially symmetrical, isopolar, prolate, apiculate, 33-35 x 44-45 μm in size in equatorial view. Tricolporate, apertures indistinct due to dense sculptures; colpi 28 μm long, narrow, tenuimarginate; pore lolongate, elliptical, 5 μm long, 2 μm wide, simple. Exine 2.5-3 μm thick at equator and 4-4.5 μm at poles, tectate; nexine distinct, uniformly 0.5 μm thick; sexine columellate, columellae baculate, slender, closely placed, variable in size, 1.5-2.5 μm long at equator and longer (3-3.5 μm) at poles; tectum thin, distinct at poles. Surface reticulate, reticula at mesocolpia broad; lumina irregular in size and shape, 2-5 μm long, 1-3 μm broad; muri 0.5 μm thick, crooked.

Comparisons—*Yeguapollis colporatus* Elsik (1974) is subprolate with thicker nexine at poles and have finer reticulation. *Y. prolatus* Frederiksen (1994) is comparatively smaller (38 x 24 μm, holotype) with lolongate endoaperture and has clavate columellae.

Remark—This is an infrequent pollen type represented by four specimens.

Affinity—*Yeguapollis indicus* compares closely with pollen of extant genus *Lagerstroemia* of family Lythraceae except lolongate pores.

PLATE 1 →

(Bar on Fig. 2 represents magnification of rest of the photographs)

1. Unidentified spore. Slide No. BSIP13078 (E41/2).
2. *Spinomosulcites achinatus* (Sah & Kar) Singh & Misra, 1991, Slide No. BSIP13072 (V16/3).
3. *Spinomosulcites* sp. Slide No. BSIP13075 (Y33).
4. *Florschuetzia rajpardiensis* Samant & Phadtare, 1997, high and low foci in parts, Slide No. BSIP13075 (N30).
5. *Ovoidites parvus* (Cookson & Dettmann) Nakoman, 1966, Slide No. BSIP13076 (Q36/3).
6. *Schizaeoisporites palanaensis* Sah & Kar, 1974, Slide No. BSIP13074 (P11/4).
7. *Retistephanocolpites ornatus* (Dutta & Sah) Saxena, 1982, Slide No. BSIP13072 (V 9).
8. *Ghosiacolpites globatus* Sah & Kar, 1970, Slide No. BSIP13073 (R 23).
9. *Proteacidites retusus* Anderson, 1960, Slide No. BSIP13074 (K42).
10. *Ctenolophonidites* sp. Slide No. BSIP13072 (S9/1).
11. *Retistephanocolpites flavatus* (Sah & Kar) Saxena, 1979, Slide No. BSIP13072 (T36/4).
12. *Verrustephanocolpites* sp. Slide No. BSIP13072 (W11/2).
13. *Plicatiaperturites retipilatus* Kar, 1985, Slide No. BSIP13079 (G42).
14. Unidentified pollen, Slide No. BSIP13081 (H10/2).
15. *Acanthotricolpites intermedius* Singh & Misra, 1991, Slide No. BSIP13080 (J50/3).
16. *Polybrevicolporites cephalus* Venkatachala & Kar, 1969, Slide No. BSIP13082 (O28/3).
17. *Pseudonothophagidites kutchensis* Venkatachala & Kar, 1969, Slide No. BSIP13074 (K42).
18. *Albertipollenites crassireticulatus* (Dutta & Sah) Mandal & Rao, 2001, Slide No. BSIP13074 (S24/2).
19. *Crototricolpites annemarie* Leidelmeyer, 1966, Slide No. BSIP13080 (S26/1).
20. *Retitrilatiporites kutchensis* (Venkatachala & Kar) Misra *et al.*, 1996, Slide No. BSIP13080 (L30).
21. *Ladakhipollenites pachyexinus* (Couper) Mathur & Jain, 1980, Slide No. BSIP13072 (T43/3).

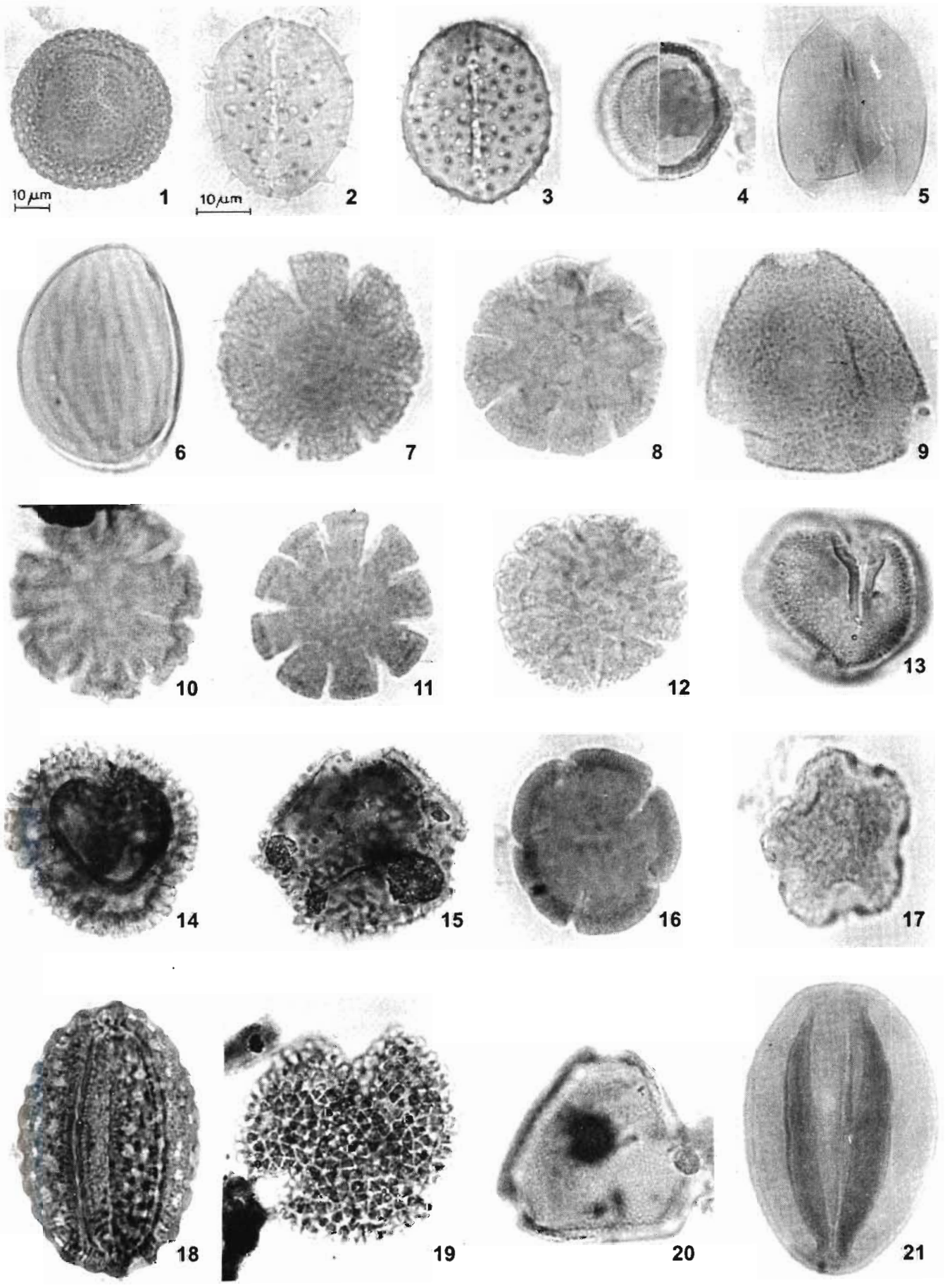

PLATE 1

Genus—VERRUTRICOLPORITES van der Hammen & Wymstra, 1964

Type species—*Verrutricolporites rotundiporis* van der Hammen & Wymstra, 1964

Verrutricolporites cambayensis sp. nov.

[Pl. 2.10 (Holotype), 11]

Diagnosis—Pollen grains tricolporate, colpi long with margo, pores lalongate, costate, surface verrucate.

Description—Pollen grains radially symmetrical, isopolar, spheroidal, 30-38 x 32-41 μm in equatorial view; broadly triangular, 38 x 48 μm in polar view. Tricolporate, colpi long up to 22 μm, margin 2 μm thick; pores distinct to indistinct, lalongate, 7 μm long and 1 μm broad, costate, costae 2 μm thick. Exine 1.5-2 μm thick; nexine-sexine not separable, sexine verrucate, verrucae 1-1.5 μm broad, 1 μm high, closely placed, occasionally fused together. Surface scabrate.

Comparisons—In *Verrutricolporites rotundiporis* van der Hammen and Wymstra (1964) pores are round and simple. *V. kadiensis* Rawat *et al.* (1977) and *V. aveceniales* Rawat *et al.* (1977) have lalongate pores but are smaller in size (19-22 x 25-28 μm and 26 x 35 μm, respectively). In *V. haplites* Garcia Guzmán (1967) apertures are costate but smaller in size (25-35 μm). The new species has thickening around apertures and comparatively larger in size.

Remarks—The species is common. There are variations in surface texture due to differential verrucae size and also length of pores. This variation is considered as developmental stages of grains.

Genus—ECHITRICOLPITES De Silva Pares Regali *et al.*, 1974

Type species—*Echitricolpites communis* De Silva Pares Regali *et al.*, 1974

Echitricolpites communis De Silva Pares Regali *et al.*, 1974

(Pl. 2.19, 20)

Description—Pollen grains radially symmetrical, isopolar, subprolate, 18-20 x 22-25 μm in equatorial view, 24 x 27 μm in polar view, amb broadly triangular. Tricolpate, colpi 15 μm long, close, tenuimarginate. Exine about 1 μm thick, tectate; nexine thin but distinct; columellae layer obscure, tectum thin. Surface echinate, echine small, 1 μm long, 0.5 μm broad at base, tips acute, sparsely distributed all over; inter-echinate area smooth.

PLATE 2 →

(Bar on Fig. 1 represents magnification of rest of the photographs)

1-4. *Yeguapollis indicus* sp. nov., Figs 1, 2 Holotype in two foci, Slide No. BSIP13076 (E22/4), Figs 3, 4, another grain in two foci, Slide No. BSIP13081 (H11).

5, 6. *Striatricolpites* sp. In two foci, Slide No. BSIP13077 (K26/3).

7. *Araliaceoipollenites descretus* Venkatachala & Rawat, 1973, Slide No. BSIP13075 (Q44/3).

8. *Tetraporites* sp. Slide No. BSIP13078 (R20/2).

9. *Paleosantalaceaepites primitiva* Biswas, 1962, Slide No. BSIP13081 (D37/1).

10, 11. *Verrutricolporites cambayensis* sp. nov., Fig.10 Holotype, Slide No. BSIP13077 (L19), Fig. 11, Slide No. BSIP13078 (P32).

12. *Rhoipites anacardioides* Ramanujam, 1987, Slide No. BSIP13080 (F12/4).

13-15. *Intectocolporites baculatus* gen. et sp. nov., Fig. 13, polar view, Slide No. BSIP13074 (W23/4), Figs 14, 15, Holotype in two foci, Slide No. BSIP13077 (T38/4).

16, 21. *Rhoipites pilatus* Sah & Kar, 1974, Fig.16, Slide No. BSIP13076 (Y35/2), Fig. 21, Slide No. BSIP13074 (W35/1).

17, 18. Unidentified pollen in two foci, Slide No. BSIP13075 (Q36).

19, 20. *Echitricolpites communis* De Silva Pares Regali *et al.*, 1974, Fig. 19, Slide No. BSIP13073 (W25/4), Fig. 20, Slide No. BSIP13073 (S31/2).

22. Unidentified pollen, Slide No. BSIP13075 (D36/1).

23. *Minutitricolporites minutus* Kar, 1985, Slide No. BSIP13075 (Q41/2).

24. *Incrotonipollis neyvelii* (Baksi *et al.*) Jansonius & Hills, 1981, Slide No. BSIP13077 (J18).

25, 26. *Verrutricolpites longicolpus* sp. nov., Fig. 25 in polar view, Slide No. BSIP13072 (J25), Fig. 26, Holotype in equatorial view, Slide No. BSIP13072 (G32/3).

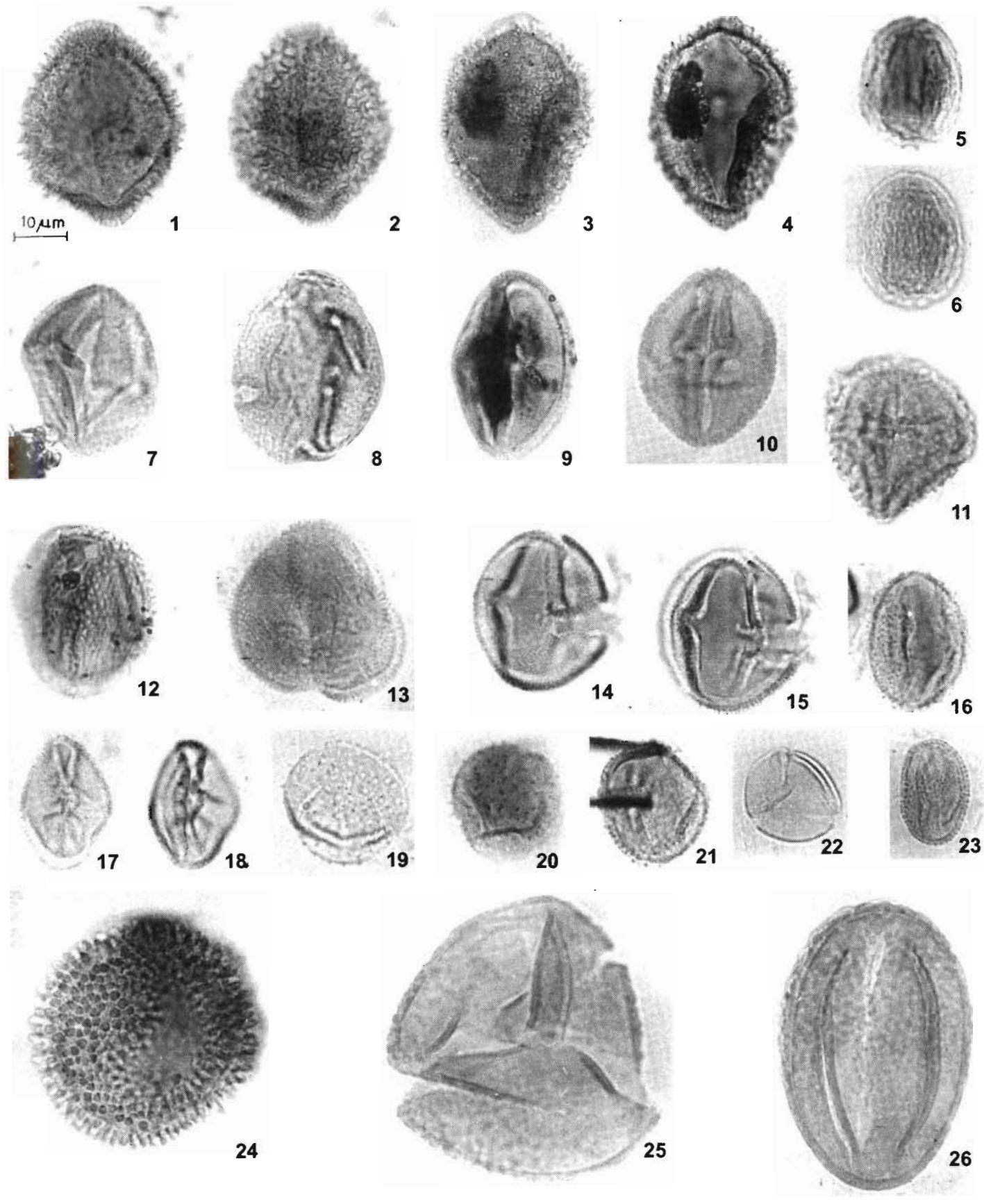

PLATE 2

Remarks—The species is rare in the assemblage (three specimens) and is the first record from India. Koshal and Uniyal (1986) recorded *Echitricolpites* sp. from Cambay Basin but did not provide any description.

Genus—CROTOTRICOLPITES Leidelmeyer, 1966

Type species—*Crototricolpites annemarie* Leidelmeyer, 1966

Crototricolpites annemarie Leidelmeyer, 1966

(Pl. 1.19)

Description—Pollen grains radially symmetrical, isopolar, 42-44 x 45-46 μm in size in polar view, amb subtriangular. Tricolpate, colpi long, gaping (10 μm) at equator and pointed at poles. Exine intectate, 3.5-4 μm thick; nexine 1 μm thick; columellae clavate, compactly arranged, about 3 μm long, 2.5 μm broad at top, appear triangular on top focus. Surface crotonoid, 5-7 clavae arranged in a crotonoid pattern.

Remarks—Crototricolpites densus Salard – Cheboldaeff (1978) recorded by Rao and Ramanujam (1982) from Quilon bed (Miocene) of Kerala is smaller in size (26-35 μm) and is colpate to colporoidate. *C.annemarie* is the first record from India .The species is rare in the assemblage and represented by two specimens.

Affinity—Euphorbiaceae (Rao & Ramanujam, 1982).

Genus—TETRAPORITES Samoilovich, 1965

Type species—*Tetraporites parvus* Samoilovich, 1965

Tetraporites sp.

(Pl. 2.8)

Description—Pollen grain radially symmetrical, isopolar, subprolate, 32 x 40 μm in size. Tetraporate, pores circular, 3 μm in diameter, subequatorial, costate, costae 2 μm wide. Exine 1.5 μm thick, tectate; nexine thin, about 0.5 μm; sexine columellate, columellae baculate, slender, 1 μm apart; tectum smooth, 0.5 μm thick. Surface scabrate to microreticulate.

Remarks—This genus has been rarely recorded in India. *Tetraporites* sp. has been recorded by Koshal and Uniyal (1984) from the Palaeocene-early Eocene subsurface sequence of North Cambay Basin without any description or photograph. Only one specimen has been recorded here and thus no specific name is given.

DISCUSSION

The palynological assemblage recovered from Vastan lignite mine is diverse and rich. The assemblage consists of 71 genera and 82 species of pteridophytic spores, angiosperm and gymnosperm pollen and algal bodies. In addition, fungal remains are also recovered in good number. Moreover, a few spores and pollen grains could not be identified (Pl. 1.1, 14; 2.17, 18). The study recorded one new genus *Intectocolporites* and four new species i.e., *Intectocolporites baculatus, Verrutricolpites longicolpus, Yeguapollis indicus, Verrutricolporites cambayensis* of angiospermous affinity. Angiosperm pollen overwhelmly dominate in the assemblage while pteridophytic spores (5 genera) and gymnosperm pollen (one genus) are poor in both variety and number. Fungal remains are represented by spores, hyphae and microthyraceous fruiting bodies. Dinocysts, *Botryococcus* and some spores like *Psiloschizosporis, Ovoidites* represent algal forms. A list of taxa with their distribution and abundance in each sample is shown in Fig. 4 and some important taxa are illustrated in Plates 1 and 2.

A single sample from seam-I has yielded few spores and pollen. On the other hand, few samples (nos. 2, 5, 7) from seam-II are very rich in palynomorphs while the yield is moderate to poor in other samples. The palynoassemblage shows dominance of genera at different levels of seam-II. Polycolpate genera dominate in sample no. 2 and subdominant forms are *Ladakhipollenites* spp., *Albertipollenites crassireticulatus, Verrutricolpites longicolpus* and *Minutitricolporites minutus*. In samples no. 5 and 6,

Albertipollenites retibaculatus is the dominant taxon and the other important taxa are *Verrucolporites verrucus, Angulocolporites microreticulatus, Plicatiaperturites retipilatus, Florschuetzia rajpardiensis.* Samples no. 7-9 are dominated by *Acanthotricolpites* spp. and *Proxapertites* spp. and subdominant species are *Retipilanopites cenozoicus, Lanagiopollis regularis* and dinoflagellate cysts. A few taxa like *Spinomonosulcites achinatus, Spinomonosulcites* sp., *Retistephacolpites flavatus* occur in good number throughout the seam II. Other taxa show irregular distribution (Fig. 4).

AGE OF VASTAN LIGNITE

The published data on distribution of palynomorphs reveal that a number of taxa exhibit short vertical and wide lateral distribution which helps to determine precise age of an assemblage (Kar, 1985; Samant & Phadtare, 1997; Thanikaimoni *et al.*, 1984; Venkatachala *et al.*, 1989). Vastan assemblage is fairly rich and contains a number of taxa possessing dating potential.

Generally *Proxapertites* spp., *Acanthotricolpites* spp., *Spinomonosulcites achinatus, Ladakhipollenites* spp., *Spinizonocolpites baculatus, Matanomadhiasulcites maximus, Tricolpites reticulatus, Lakiapollis ovatus* are restricted within the late Palaeocene–early Eocene. Although the late Palaeocene–early Eocene palynofloras show close similarity yet the late Palaeocene can be differentiated by the presence of genera like *Droseridites, Kielmeyerapollenites, Lycopodiumsporites, Dandotiaspora* particularly *D. dilata.* Likewise *Tricolporocolumellites, Tricolporopilites, Dermatobrevicolporites* are characteristic forms of the middle Eocene which are absent in the present assemblage. Moreover, association of taxa like *Retitrilatiporites, Cheilanthoidspora, Acanthotricolpites, Ladakhipollenites, Lakiapollis, Dracaenoipollis, Clavaperiporites, Angulocolporites, Minutitricolporites, Sastripollenites, Striacolporites, Pseudonyssapollenites, Pseudonothofagidites, Incrotonipollis, Tricolpites reticulatus* in the assemblage indicate an early Eocene age. Vastan assemblage is closely similar to the early Eocene flora of Kachchh (Kar, 1985), Rajpardi (Kar & Bhattacharya, 1992; Samant & Phadtare, 1997) and Bhavnagar (Samant, 2000).

Thus an early Eocene age has been inferred for the Vastan lignite. A similar age (Ypresian) has been assigned to the lignite sediments of Vastan by Bajpai and Kapur (2004) and Bhandari *et al.* (2005) on the basis of ostracodes, gobiids, molluscs and benthic foraminifera, e.g., *Nummulites burdigalensis.* Bajpai *et al.* (2005) discovered marsupials from this mine and designated middle Ypressian (~ 52 Ma) age.

PALAEOECOLOGY AND PALAEOCLIMATE

For deducing palaeoecology, fossil pollen taxa have been compared with the pollen of extant plants with the assumption that fossil taxa had more or less similar ecological preferences. Several ecological and climatic indicator palynotaxa have been recovered in the assemblage, which are shown in Fig. 5.

The fungal spores, hyphae and microthyraceous fruiting bodies present in the assemblage are commonly found in the mesophytic forests of tropical to subtropical climate where precipitation is high (Selkrik, 1975). Algal elements such as *Psiloschizosporis, Ovoidites* of Zygnemataceae and *Botryococcus* generally reflect fresh water conditions. Pteridophytic spores are represented by Schizaeaceae (*Schizaeoisporites, Lygodiumsporites*), Polypodiaceae (*Polypodiisporites, Laevigatosporites*) and indicate the occurrence of hot and humid conditions.

Angiosperm pollen are represented by at least eighteen families of which monocot belongs to three families (Fig. 5). The pollen grains of Arecaceae (*Spinomonosulcites, Spinizonocolpites, Retitrilatiporites, Acanthotricolpites*), Araceae (*Proxapertites*), Dracaenaceae (*Dracaenoipollis*) indicate tropical climate. The coastal condition is reflected by Rhizophoraceae (*Florschuetzia, Paleosantalaceaepites*) and *Nypa* pollen (*Spinizonocolpites*), a core mangrove element. These mangroves are found in true tropical climate with high precipitation. Equatorial position of India during the early Eocene (Dercourt *et al.*, 1993) also supports the prevalence of tropical climate. Pollen referable to Gunneraceae (*Tricolpites*

Taxa	Sample nos.	1	2	3	4	5	6	7	8	9	10
Cyathidites australis Couper 1953		1	2	1				3			
Lygodiumsporites lakiensis Sah & Kar 1969		2	2			2	1				
Polypodiisporites repandus Takahashi 1964						2					
Laevigatosporites cognatus Sah & Kar 1970		3				2					
Schizaeoisporites palanaensis Sah & Kar 1974 (Pl. 1.6)			2			2	1				
S. eocaenicus (Selling) Potonié 1956			1			2	2				
Cheilanthoidspora enigmata Sah & Kar 1974								2			2
Matanomadhiasulcites maximus (Saxena) Kar 1985			2				2	2			
Palmaepollenites kutchensis Venkatachala & Kar 1969			2				1				
Liliacidites microreticulatus Dutta & Sah 1970			2				2	1			
Arecipites bellus Sah & Kar 1970						2	2	2	2		
Spinomonosulcites achinatus (Sah & Kar) Singh & Misra 1991 (Pl. 1.2)			4			3	2	2	3		
Spinomonosulcites sp. (Pl. 1.3)			3	2		3	2	2			
Spinizonocolpites baculatus Muller 1968								2			
Proxapertites operculatus van der Hammen 1956			2					4	4	2	1
P. crassimurus (Sah & Dutta) Singh 1975								2			
Dracaenoipollis circularis Sah & Kar 1970								2			
Tetraporites sp. (Pl. 2.8)						1					
Ladakhipollenites minutus (Sah & Kar) Mathur & Jain 1980		2	3				2				
L. costatus (Dutta & Sah) Mandal & Rao 2001			2			2	2	3			
L. pachyexinus (Couper) Mathur & Jain 1980 (Pl. 1.21)			2			1		1			
Tricolpites globus Dutta & Sah 1970						2		2			
Tricolpites cf. *T. brevicolpus* Couper 1960			2			1					
T. foxii (Biswas) Ramanujam 1966						2					
T. reticulatus Cookson ex Couper 1953						2	2				
Albertipollenites crassireticulatus (Dutta & Sah) Mandal & Rao 2001 (Pl. 1.18)			3								
A. robustus (Sah & Kar) Mandal & Rao 2001						3					
A. retibaculatus (Saxena) Mandal & Rao 2001						4	2				
Crototricolpites annemarie Leidelmeyer 1966 (Pl. 1.19)								2			
Verrutricolpites longicolpus sp. nov. (Pl. 2.25, 26)			3			1	2				2
Echitricolpites communis De Silva Pares Regali *et al.* 1974 (Pl. 2.19, 20)			2								
Striatricolpites sp. (Pl. 2.5, 6)						1					
Tricolporopollis matanomadhensis (Venkatachala & Kar) Tripathi & Singh 1985						2	1	2			
Retibrevitricolpites foveolatus Venkatachala & Rawat 1972						2					
Tribrevicolporites eocenicus Kar 1985			2			2					
Intectocolporites baculatus gen. et sp. nov. (Pl. 2.13-15)						2	2				
Verrucolporites verrucus Sah & Kar 1970			2	2	1	3					
Verrutricolporites cambayensis sp. nov. (Pl. 2.10, 11)			2	2		2		1			
Lakiapollis ovatus Venkatachala & Kar 1969			2			2		2			
Meliapollis ramanujamii Sah & Kar 1970								2			
Margocolporites venkatachalae Samant & Phadtare 1997			2								
M. sahnii Ramanujam 1966								2			
Rhoipites anacardioides Ramanujam 1987 (Pl. 2.12)			2								
R. psilatus Sah 1967						3		2			
R. pilatus Sah & Kar 1974 (Pl. 2.16, 21)						5	3	3			
Angulocolporites microreticulatus Kar 1985			2			2					

Florschuetzia rajpardiensis Samant & Phadtare 1997 (Pl. 1.4)		1			3					
Plicatiaperturites retipilatus Kar 1985 (Pl. 1.13)		1	2		1					
Minutitricolporites minutus Kar 1985 (Pl. 2.23)		3			2	1				
Pseudonyssapollenites kutchensis (Venkatachala & Kar) Kar 1985							2			2
Favitricolporites retipilatus Samant & Phadtare 1997							2			
Paleoaraliaceaepites distinctus Samant & Phadtare 1997					2	2				
Pilatricolporites eocenicus Kar 1985		1			1	2				
Araliaceoipollenites descretus Venkatachala & Rawat 1973 (Pl. 2.7)	1				2					
Paleosantalaceaepites minutus Sah & Kar 1970					2	1				2
P. primitiva Biswas 1962 (Pl. 2.9)					2	1				
Sastripollenites trilobatus Venkatachala & Kar 1969	2						2			2
Lanagiopollis regularis Morley 1982							2			
Tetracolporopollenites brevis Frederiksen 1980						2	2			
Retitrilatiporites kutchensis (Venkatachala & Kar) Misra *et al.* 1996 (Pl. 1.20)							2			
Proteacidites retusus Anderson 1960 (Pl. 1.9)							2			
Clavaperiporites ramanujamii Samant & Phadtare1997						3				
Haloragacidites neyvelii Ramanujam 1966					2	1				
Polygalacidites minutus Samant & Phadtare 1997					1	2				
Triporopollenites minutiformis (Ramanujam) Saxena 1979							2			
Acanthotricolpites kutchensis (Kar & Kumar) Singh & Misra 1991						2	4			2
A. intermedius Singh & Misra 1991 (Pl. 1.15)							2			1
A. bulbospinosus Kar 1985							2			
Pseudonothofagidites kutchensis Venkatachala & Kar 1969 (Pl. 1.17)					2					
Ghosiacolpites globatus Sah & Kar 1970 (Pl. 1.8)		2		2	2					
Ctenolophonidites sp. (Pl. 1.10)		2	1		2					
Retistephanocolpites coromandeliensis Venkatachala & Rawat 1972		4			2	2				
R. flavatus (Sah & Kar) Saxena 1979 (Pl. 1.11)		4	1		2	4	2	2		
R. kutchensis Saxena 1979		4		1	2	2	1			
R. ornatus (Dutta & Sah) Saxena 1982 (Pl. 1.7)		3			2	2				
Granustephanocolpites granulatus (Venkatachala & Kar) Jansonius & Hills 1981		2			2	2				
Verrustephanocolpites sp. (Pl. 1.12)		3			1					
Polybrevicolporites cephalus Venkatachala & Kar 1969 (Pl. 1.16)		2		1		4	2			
Laevigatopolycolpites rotatus Kar & Bhattacharya 1992					2					
Incrotonipollis burdwanensis (Baksi *et al.*) Jansonius & Hills 1981					2	1				
I. neyvelii (Baksi *et al.*) Jansonius & Hills 1981 (Pl. 2.24)			2		2					
Retipilanopites cenozoicus Sah 1967					2			2	2	
Retitetrabrevicolporites sp.		2			2	1				
Striacolporites ovatus Sah & Kar 1970		2	1		1	1				
Yeguapollis indicus sp. nov. (Pl. 2.1-4)				1				2		
Ericipites sp.							1			
Podocarpidites rajpardiensis Samant & Phadtare 1997		2	2		2	1	2			
Psiloschizosporis psilata Kar & Saxena 1981		2			4					
Botryococcus sp.			4							
Psilosphaera plicata Sah & Kar 1972							2	3		
Ovoidites parvus (Cookson & Dettmann) Nakoman 1966 (Pl. 1.5)					2					
Operculodinium centrocarpum (Deflandre & Cookson) Wall 1967							3	2	3	

Fig . 4—List of taxa and their distribution.

reticulatus), Bombacaceae (*Lakiapollis*), Ctenolophonaceae (*Ctenolophonidites*, *Ghosiacolpites*), Polygalaceae (*Polygalacidites*) suggest presence of fresh water swamps. The families like Euphorbiaceae (*Incrotonipollis, Crototricolpites*), Annonaceae (*Matanomadhiasulcites*), Caesalpiniaceae (*Margocolporites*), Lythraceae (*Yeguapollis*), Meliaceae (*Meliapollis*), Linaceae (*Clavaperiporites*), Anacardiaceae (*Rhoipites anacardioides*), Alangiaceae (*Lanagiopollis*) suggest lowland evergreen vegetation.

The occurrence of Araliaceae (*Araliaceoipollenites, Paleoaraliaceaepites*), Proteaceae (*Proteacidites*) and Podocarpaceae (*Podocarpidites*) probably indicate the influence of upland flora from the near by highlands.

DEPOSITIONAL ENVIRONMENT

As mentioned earlier, fungal remains comprising fruiting bodies, hyphae and spores occur in plenty in organic matter rich Vastan sediments, indicating activity of saprophytic fungi. Generally deltaic sediments provide such substrate (Traverse, 1988). Occurrence of dinoflagellate cysts and mangrove taxa *Spinizonocolpites, Paleosantalaceaepites* and *Florschuetzia* in the seam-II indicate marginal marine conditions. *Operculodinium centrocarpum,* the dinocyst taxon, suggests shallow depths in inner neritic zone and low salinity (Harland, 1983; Morzadec–Kerfourn, 1983). Benthic foraminifera, ostracodes and gobiids recorded from the shale horizon above the seam-II (Bajpai & Kapur, 2004; Bhandari *et al.*, 2005) also support prevalence of marine conditions. Moreover, frequent occurrence of lammelibranch shells in the lignite indicating coastal shallow depth deposition throughout the sequence. The lithological evidences of the early Eocene transgression in the Cambay Basin (Bhandari & Raju, 1991) also support this conclusion. Thus it can be concluded that lignite in Vastan was deposited in a delta, which was frequently inundated by seawater incursions.

PALYNOFLORAL COMPARISON

The present palynoassemblage can be compared with the early Eocene assemblages of Gujarat recorded from Rajpardi lignite (Kar & Bhattacharya, 1992; Kumar, 1996; Samant & Phadtare, 1997); Bhavnagar lignite (Samant, 2000); subsurface of Cambay Basin (Koshal, 1991; Venkatachala & Chowdhary, 1977); Kachchh (Kar, 1985; Venkatachala & Kar, 1969); Rajasthan (Jain *et al.,* 1973; Kar & Sharma, 2001; Naskar & Baksi, 1978; Sah & Kar, 1974; Tripathi *et al.,* 2003) and West Bengal (Baksi, 1971; Baksi & Deb, 1980, 1981; Bera & Banerjee, 1995).

All the recorded (early Eocene) assemblages are dominated by angiosperm pollen and show similarity in their compositions. But each assemblage also differs in the presence, absence and frequency of certain important taxa. A brief palynofloral comparison is presented here.

Most distinct of these assemblages are from Rajasthan. In spite of showing general similarity in possessing a number of common taxa such as *Proxapertites, Spinomonosulcites, Spinizonocolpites, Retistephanocolpites, Acanthotricolpites kutchensis*, there are some significant taxa namely *Primofoveomonocolpites excellensus* Kar and Sharma (2001), *Bithnokiapollis striatus* Kar and Sharma (2001), *Spinitetradocolporites spinosus* Kar and Sharma (2001), *Kapurdipollenites gemmatus* Tripathi (1993), *Retiverrumonosulcites barmerensis* Tripathi (1993) which are confined to Barmer and Bikaner basins of Rajasthan.

The common taxa with Bengal Basin are *Proxapertites, Spinizonocolpites, Incrotonipollis, Spinomonosulcites, Acanthotricolpites, Paleosantalaceaepites, Tricolpites reticulatus* and abundance of polycolpate forms. However, diporate pollen, one of the major elements of Bengal flora (Bera & Banerjee, 1995) is totally absent here. Both quantitatively and qualitatively Vastan assemblage is richer than the Bengal palynoflora.

The present assemblage also shows close similarity with Kachchh flora. The early Eocene flora of Kachchh consists of 78 genera and 116 species of which 37 genera and 32 species are in common to Vastan flora.

Fossil taxa	Affinity	Geographical distribution	Habitat
Lygodiumsporites lakiensis	Schizaeaceae (*Lygodium*)	Tropics-subtropics	Climbing fern in thick forest
Schizaeoisporites eocaenicus	Schizaeaceae (*Lygodium*)	Commonly in tropics-subtropics	Member of thick forest
Polypodiisporites repandus	Polypodiaceae	Cosmopolitan, specially tropics	Moist forest
Laevigatosporites cognatus	Polypodiaceae	Cosmopolitan, specially tropics	Moist forest
Retitrilatiporites kutchensis	Arecaceae (*Sclerosperma*)	Tropical west Africa	Undergrowth in primary forest
Spinizonocolpites baculatus	Arecaceae (*Nypa*)	Tropics	Core mangrove
Spinomonosulcites achinatus	Arecaceae	Tropics	–
Acanthotricolpites spp.	Arecaceae	Tropics	–
Proxapertites spp.	Araceae (*Rhapidophora*)	Tropics, mostly Indo-Malaya	Climber in evergreen forest
Dracaenoipollis circularis	Dracaenaceae (*Dracaena*)	Tropics	Shrubs & trees in evergreen forest
Tricolpites reticulatus	Gunneraceae (*Gunnera*)	Tropics front Malaysia, South Africa	Perennial herbs on marshy places
Lakiapollis ovatus	Bombacaceae (*Durio*)	Tropics of Indo-Malaya	Trees of swampy evergreen forest
Margocolporites spp.	Caesalpiniaceae (*Caesalpinia*)	Tropics-subtropics	Woody climber in thick forest
Rhoipites anacardioides	Anacardiaceae (*Melanorrhoea/Gluta*)	Tropics of Asia to Madagaskar	Tree of tropical vegetation
Florschuetzia rajpardiensis	Sonneratiaceae	Tropics	Core mangrove
Minutitricolporites minutus	Euphorbiaceae (*Alchornea*)	Tropics	Open forest
Paleoaraliaceaepites distincticus	Araliaceae	Primarily tropics	Montane evergreen vegetation
Araliaceoipollenites descretus	Araliaceae	Primarily tropics	Montane evergreen vegetation
Paleosantalaceaepites minutus	Rhizophoraceae	Tropics	Core mangrove
Lanagiopollis regularis	Alangiaceae	Tropics-subtropics	Woody trees in lowland forest
Tetracolporopollenites brevis	Sapotaceae	Tropics	Evergreen vegetation
Clavaperiporites ramanujamii	Thymelaeaceae	Tropical Africa	Montane herb
Haloragacidites neyvelii	Haloragidaceae (*Myriophyllum*)	Cosmopolitan	Submerged aquatic herb
Polygalacidites minutus	Polygalaceae	Cosmopolitan	Commonly creeping herb around wet area
Ghosiacolpites globatus	Ctenolophonaceae	Tropics	Fresh water swamp
Incrotonipollis burdwanensis	Euphorbiaceae (*Jatropha*)	Tropics	Perennial shrubs in open forest
Matanomadhiasulcites maximus	Annonaceae (*Annona*)	Tropics	Evergreen vegetation
Proteacidites retusus	Proteaceae	Tropics to subtropics of southern hemisphere	Trees and shrubs in evergreen rain forest
Meliapollis ramanujamii	Meliaceae	Tropics-subtropics	Moist deciduous forest
Yeguapollis indicus	Lythraceae (*Lagerstroemia*)	Tropics	Open forest often near water shed
Podocarpidites rajpardiensis	Podocarpaceae (*Podocarpus*)	Tropics-subtropics in southern hemisphere	Tropical wet to temperate evergreen forest

(Data source – Baksi *et al.*, 1979; Kar, 1985; Mabberley, 1997; Ramanujam, 1966; Samant & Phadtare, 1997; Thanikaimoni *et al.*, 1984; Venkatachala *et al.*, 1989)

Fig. 5—Distribution and habitat of comparable modern analogue of fossil spores and pollen.

The present assemblage can, however, be differentiated having meagre pteridophytic spores and abundance of polycolpate pollen. Moreover, several significant taxa of Kachchh assemblage like *Marginipollis, Umbelliferoipollenites, Pellicieroipollis, Sonneratioipollis, Liguliflorae dites, Spinulotetradites, Tripilaorites, Intrareticulites* are absent here.

The Cambay Basin flora from subsurface also has some genera common with the present one but the important taxa of Cambay assemblages like *Cicatricosisporites, Osmundacidites, Annutriporites, Myricipites* are absent in the Vastan assemblage.

The Bhavnagar lignite flora consists of 66 genera and 85 species of which 21 genera are common to Vastan. The important constituents of Bhavnagar flora like *Pellicieroipollis, Umbelliferoipollenites, Triangulorites, Quilonipollenites, Bombacacidites, Marginipollis* are absent in the present assemblage.

The Rajpardi (Bharuch District) palynoflora is fairly rich consisting of 84 genera and 138 species. Of these, 30 genera and 23 species of spores and pollen grains are common to Vastan flora. In spite of a lot of similarity, the present assemblage contains some significant taxa such as *Intectocolporites baculatus, Verrutricolpites longicolpus, Verrutricolporites cambayensis, Yeguapollis indicus, Crototricolpites annemarie, Echitricolpites communis, Angulocolporites, Sastripollenites* which are absent in Rajpardi flora. It is evident from the above comparison that the present assemblage shows close relationship with Kachchh, Rajpardi and Bhavnagar palynofloras and the observed differences probably reflect variations in local vegetation.

CONCLUSIONS

The following inferences can be made from the study of rich Vastan assemblage:

1. Vastan palynoflora indicates an early Eocene age.
2. The flora shows close similarity with Rajpardi, Bhavnagar and Kachchh assemblages compared to other known floras.
3. Lignite was deposited in a coastal deltaic environment under marine influence.
4. The palynoassemblage indicates existence of tropical climate at the time of lignite deposition.

Acknowledgements—*The authors are thankful to Dr Samir Sarkar for identification and interpretation of dinocysts.*

REFERENCES

Alimohammadian H, Sahni A, Patnaik R, Rana RS & Singh H 2005. First record of an exceptionally diverse and well preserved amber-embedded biota from Lower Eocene (~52 Ma) lignites, Vastan, Gujarat. Current Science 89 : 1328-1330.

Anderson RY 1960. Cretaceous-Tertiary palynology, eastern side of the San Juan Basin, New Mexico. New Mexico Bureau of Geology and Mineral Resources, Memoir 6: 1-58.

Bajpai S & Kapur VV 2004. Oldest known gobiids from Vastan Lignite Mine (early Eocene), Surat District, Gujarat. Current Science 87: 433-435.

Bajpai S, Kapur VV, Thewissen JGM, Tiwari BN & Das DP 2005. First fossil marsupials from India: early Eocene *Indodelphis* n. gen. and *Jaegeria* n. gen. from Vastan lignite mine, District Surat, Gujarat. Journal of the Palaeontological Society of India 50: 147-151.

Baksi SK 1971. On the palynological biostratigraphy of Bengal Basin. *In*: Ghosh AK *et al.* (Editors)—Proceedings of the Seminar on Paleopalynology and Indian Stratigraphy : 188-206. Botany Department, Calcutta University.

Baksi SK & Deb U 1980. Palynostratigraphic zonation of the Upper Cretaceous-Paleogene sequence of Bengal Basin. Geophytology 10: 199-224.

Baksi SK & Deb U 1981. Palynology of the Upper Cretaceous of the Bengal Basin, India. Review of Palaeobotany & Palynology 31: 335-365.

Baksi SK, Deb U & Siddhanta BK 1979. On *Crotonipollis*—a new genus from the Paleocene-Eocene of India. Indian Journal of Earth Sciences 6: 232-236.

Bera S & Banerjee M 1995. Eocene palynoassemblage from lignite deposits of West Bengal, India with remarks on environment of deposition. Indian Journal of Earth Sciences 22: 149-152.

Bhandari A & Raju DSN 1991. Tertiary sea level changes and Transgression/Regression cycles in Cambay, Kutch and Rajasthan basins. A review. *In*: Pandey J & Banerji V (Editors)—Proceedings of Conference on Integrated and Exploratory Research. Achievements and Perspectives : 169-177. Dehra Dun.

Bhandari A, Singh H & Rana RS 2005. A note on occurrence of ostracodes from the Vastan lignite mine, Gujarat. Journal of the Palaeontological Society of India 50: 141-146.

Biswas B 1962. Stratigraphy of the Mahadeo, Langpar, Cherra and Tura formations, Assam, India. Bulletin of the Geological, Mining and Metallurgical Society of India 25: 1-48.

Chandra PK & Chowdhary LR 1969. Stratigraphy of the Cambay Basin. Bulletin of ONGC 6: 37-50.

Couper RA 1953. Upper Mesozoic and Cainozoic spores and pollen grains from New Zealand. New Zealand Geological Survey Palaeontological Bulletin 22: 1-77.

Couper RA 1960. New Zealand Mesozoic and Cenozoic plant microfossils No. 2. New Zealand Geological Survey Palaeontological Bulletin 32: 1-87.

Dercourt J, Ricou LE & Vrielynck B (Eds.) 1993. Atlas Tethys palaeoenvironmental Maps. BEICIP-FRANLAB, Rueil-Malmaison.

De Silva Pares Regali PM, Uesugui, I & De Silva Santos A 1974. Palinologia dos sedimentos Meso-Cenozoicas do Brail (II). Boln. Tecn. Petrobras. 17: 263-301.

Dutta SK & Sah SCD 1970. Palynostratigraphy of the Tertiary sedimentary formations of Assam: 5. Stratigraphy and palynology of South Shillong Plateau. Palaeontographica B131: 1-72.

Elsik WC 1974. Characteristic Eocene palynomorphs in the Gulf Coast, U.S.A. Palaeontographica B149: 90-111.

Frederiksen NO 1980. Sporomorphs from the Jackson group (Upper Eocene) and adjacent strata of Mississippi and Western Alabama. United States Geological Survey Professional Papers 1084: 1-75.

Frederiksen NO 1994. Middle and Late Paleocene angiosperm pollen from Pakistan. Palynology 18: 91-137.

Garciá Guzmán AE 1967. A palynological study on the Upper Los Cuervos and Mirador formations (Lower and Middle Eocene, Tibu area, Colombia). Akademisch Proefschrift, Leiden, E.J. Brill : 1-68.

Harland R 1983. Distribution maps of Recent dinoflagellate cysts in bottom sediments from the north Atlantic ocean and adjacent seas. Palaeontology 26: 321-387.

Jain KP, Kar RK & Sah SCD 1973. A palynological assemblage from Barmer, Rajasthan. Geophytology 3: 150-165.

Jansonius J & Hills LV 1981. Genera file of fossil spores. Special Publication, Department of Geology, University of Calgary, Canada : 3801-3932.

Kar RK 1985. The fossil floras of Kachchh – IV. Tertiary palynostratigraphy. Palaeobotanist 34: 1-280.

Kar RK & Bhattacharya M 1992. Palynology of Rajpardi lignite, Cambay Basin and Gujra Dam and Akri lignite, Kutch Basin. Palaeobotanist 39: 250-263.

Kar RK & Saxena RK 1981. Palynological investigation of a bore core near Rataria, southern Kutch, Gujarat. Geophytology 11: 103-124.

Kar RK & Sharma P 2001. Palynostratigraphy of Late Palaeocene and Early Eocene sediments of Rajasthan, India. Palaeontographica B256: 123-157.

Koshal VN 1991. Important palynofossils and palaeo-environment in Jaksana well, North Cambay Basin, West India. *In*: Pandey J & Banerji V (Editors)—Proceedings of Conference on Integrated and Exploratory Research Achievements and Perspectives: 203-206. Dehra Dun.

Koshal VN & Uniyal SN 1984. Palaeocene-Early Eocene palynofossils in the subsurface of North Cambay Basin, Gujarat (western India). *In* : Badve RM *et al.* (Editors)—Proceedings of 10th Colloquium on Indian Micropalaeontology and Stratigraphy (1982) : 233-243. Pune.

Koshal VN & Uniyal SN 1986. Palynostratigraphy of the Cenozoic succession of Cambay Basin, Gujarat. Bulletin of the Geological, Mining and Metallurgical Society of India 54: 208-226.

Kumar M 1996. Palynostratigraphy and palaeoecology of Early Eocene palynoflora of Rajpardi lignite, Bharuch District, Gujarat. Palaeobotanist 43: 110-121.

Leidelmeyer P 1966. The Paleocene and Lower Eocene pollen flora of Guyana. Leidsche geologische mededelingen 36: 49-70.

Mabberley DJ 1997. The Plant-Book. Cambridge University Press, 858 pp.

Mandal J & Rao MR 2001. Taxonomic revision of tricolpate pollen from Indian Tertiary. Palaeobotanist 50: 341-368.

Mathur YK & Jain AK 1980. Palynology and age of the Dras Volcanics near Shergol, Ladakh, Jammu and Kashmir, India. Geoscience Journal 1: 55-74.

Misra BK, Singh A & Ramanujam CGK 1996. Trilatiporate pollen from Indian Palaeogene and Neogene sequences: evolution, migration and continental drift. Review of Palaeobotany & Palynology 91: 331-352.

Morlay RJ 1982. Fossil pollen attributable to *Alangium* Lamarck (Alangiaceae) from the Tertiary of Malaysia. Review of Palaeobotany & Palynology 36: 65-94.

Morzadec–Kerfourn M-T 1983. In téret des kystes de dinoflagellés pour l'etablissement de reconstitution Paléogeographique: example du Golfe de Gabés (Tunisie). Cahiers de Micropaléontologie 1983-4: 15-22.

Muller J 1968. Palynology of the Pedawn and Plateau Sandstone formations (Cretaceous-Eocene) in Sarawak, Malaysia. Micropaleontology 14: 1-37.

Nakoman E 1966. Contribution a l'etude palynologique des formations Tertiaires du Bassin de Thrace.I. Etude qualitative. Annales de la Societe Geologique du Nord 86: 65-107.

Naskar P & Baksi SK 1978. Palynological investigation of Akli lignite, Rajasthan, India. Palaeobotanist 25: 314-329.

Pierce RL 1961. Lower-Upper Cretaceous plant microfossils from Minnesota. Minnesota Geological Survey Bulletin 42: 1-86.

Potonié R 1956. Synopsis der Gattungen der Sporae dispersae 1. Teil: Sporites. Beihefte zum Geologischen Jahrbuch 23: 1-103.

Ramanujam CGK 1966. Palynology of the Miocene lignite from South Arcot District, Madras, India. Pollen et spores 8: 149-203.

Ramanujam CGK 1987. Palynology of the Neogene Warkalli beds of Kerala State in south India. Journal of the Palaeontological Society of India 32: 26-46.

Rao KP & Ramanujam CGK 1982. Palynology of the Quilon beds of Kerala State in south India II—pollen of dicotyledons and discussion. Palaeobotanist 30: 68-100.

Rawat MS, Mukherjee JS & Venkatachala BS 1977. Palynology of the Kadi Formation, Cambay Basin, India. *In*: Venkatachala BS & Sastri VV (Editors)—Proceedings of 4th Colloquium on Indian Micropalaeontology and Stratigraphy (1974-75) : 179-192. Dehradun.

Sah SCD 1967. Palynology of an Upper Neogene profile from Rusizi Valley (Burundi) Museé Royal de L'Afrique Centrale Tervuren Belgique Annales Serie in-8 Sciences Geologiques 57: 1-173.

Sah SCD & Kar RK 1969. Pteridophytic spores from the Laki Series of Kutch, Gujarat, India. J. Sen Memorial Volume, Calcutta: 109-122.

Sah SCD & Kar RK 1970. Palynology of the Laki sediments in Kutch-3. Pollen from the boreholes around Jhulrai, Baranda and Panandhro. Palaeobotanist 18: 127-141.

Sah SCD & Kar RK 1972. Palynostratigraphic evaluation of the Lower sediments of India. *In:* Ghosh AK *et al.* (Editors) —Proceeding of the Seminar Palaeopalynology and Indian Stratigraphy : 255-265. Calcutta.

Sah SCD & Kar RK 1974. Palynology of Tertiary sediments of Palana, Rajasthan. Palaeobotanist 21: 163-188.

Salard-Cheboldaeff M 1978. Sur la palynoflore Maestrichtienne et Tertiaire du basin sédimentaire littoral du Cameron. Pollen et Spores 20: 215-260.

Samant B 2000. Palynostratigraphy and age of the Bhavnagar Lignite, Gujarat, India. Palaeobotanist 49: 101-118.

Samant B & Phadtare NR 1997. Stratigraphic palynoflora of the Early Eocene Rajpardi lignite, Gujarat and the lower age limit of the Tarkeswar Formation of South Cambay Basin, India. Palaeontographica B245: 1-108.

Samoilovich SR 1965. Pollen and new species of Upper Cretaceous angiosperm plant of Yakutia. Paleofitolog. Sbornik; Trudy VNIGRI; vyp 239:121-142 (in Russian).

Saxena RK 1979. Palynology of the Matanomadh Formation in type area, northwestern Kutch, India (Part-2). Systematic description of gymnospermous and angiospermous pollen grains. Palaeobotanist 26: 130-143.

Saxena RK 1982. Taxonomic study of the polycolpate pollen grains from the Indian Tertiary sediments with special reference to nomenclature. Review of Palaeobotany & Palynology 37: 283-315.

Selkirk DR 1975. Tertiary fossil fungi from Kiandra, New South Wales. Proceedings Linnean Society of New South Wales 100: 70-94.

Singh A & Misra BK 1991. A new spinose monosulcate genus *Spinomonosulcites* and emendation of spinose porate *Acanthotricolpites*. Review of Palaeobotany & Palynology 67: 217-227.

Singh RY 1975. Morphological study of the *Retialetes* complex from Indian Tertiaries. Geophytology 5: 98-104.

Takahashi K 1964. Sporen und pollen der oberkretazeischen Hakobouchi – Schichtengruppe, Hokkaido. Memoirs of the Faculty of Science, Kyushu University Series 14: 159-271.

Thanikaimoni G, Caratini C, Venkatachala BS, Ramanujam CGK & Kar RK 1984. Selected Tertiary angiosperm pollen from India and their relationship with African Tertiary pollen. Travaux de la Section Scientifique et Technique Tome/Séries 19: 1-92. Institut Français de Pondichéry.

Traverse A 1988. Paleopalynology. UNWIN HYMAN, Boston pp. 600.

Tripathi SKM 1993. New angiosperm pollen from subsurface Early Palaeogene sediments of Barmer District, Rajasthan, India. Palaeobotanist 42: 61-65.

Tripathi SKM & Singh HP 1985. Palynology of the Jaintia Group (Palaeocene-Eocene) exposed along Jowai-Sonapur Road, Meghalaya, India—Part I. Systematic palynology. Geophytology 15: 164-187.

Tripathi SKM, Singh UK & Sisodia MS 2003. Palynological investigation and environmental interpretation on Akli Formation (Late Palaeocene) from Barmer Basin, Western Rajasthan, India. Palaeobotanist 52: 87-95.

van der Hammen T 1956. A palynological systematic nomenclature. Boletin Geológico Bogota 4: 63-101.

van der Hammen T & Wymstra TH 1964. A palynological study of the Tertiary and Upper Cretaceous of British Guiana. Leidse Geologische Mededelingen 30: 183-241.

Venkatachala BS & Chowdhary LR 1977. Palaeoecology of the Kadi Formation, Cambay Basin, India. *In* : Venkatachala BS & Sastri VV (Editors)—Proceeding of 4th Colloquium on Indian Micropalaeontology and Stratigraphy (1974-75) : 259-277. Dehradun.

Venkatachala BS & Kar RK 1969. Palynology of the Tertiary sediments of Kutch—1. Spores and pollen from Bore-hole no. 14. Palaeobotanist 17: 157-178.

Venkatachala BS & Rawat MS 1972. Palynology of the Tertiary sediments in the Cauvery Basin I. Palaeocene-Eocene palynoflora from the sub-surface. *In:* Ghosh AK *et al.* (Editors)—Proceeding of the Seminar on Paleopalynology and Indian Stratigraphy: 292-335. Calcutta.

Venkatachala BS & Rawat MS 1973. Palynology of the Cauvery Basin—II. Oligocene-Miocene palynoflora from the subsurface. Palaeobotanist 20: 238-263.

Venkatachala BS, Caratini C, Tissot C & Kar RK 1989. Palaeocene-Eocene marker pollen from India and tropical Africa. Palaeobotanist 37: 1-25.

Wall D 1967. Fossil microplankton in deep-sea cores from the Carribean Sea. Palaeontology 10: 95-123.