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AGE-DIAGNOSTIC DINOFLAGELLATE CYSTS FROM THE LIGNITE-BEARING SEDIMENTS OF THE VASTAN LIGNITE MINE, SURAT DISTRICT, GUJARAT, WESTERN INDIA

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ABSTRACT

The lignite-bearing succession (corresponding to Cambay Shale) of the Vastan lignite mine, Gujarat has been extensively studied in the past few years for its rich vertebrate fauna. However, no age-diagnostic fossils with chronological significance are reported. In the present study, several dinoflagellate cysts from different levels in the lignite-bearing sediments (Succession A) of the Vastan lignite mine are identified which are age diagnostic. Occurrence of *Muratodinium fimbriatum*, *Heteraulacacysta granulata* and *Operculodinium severinii* in the lower part indicates an age not older than late Thanetian/Sparnacian (~55 Ma). Presence of rich *Kenleyia* complex including LAD of *Kenleyia lophophora* in the upper half of the succession indicates basal Ypresian age (~54 Ma). Occurrence of *Lanternosphaeridium lanosum* in the upper part suggests an age not younger than middle Ypresian (~52 Ma) for the topmost part of the Vastan succession. Thus, in terms of traditional European stages, the succession ranges from Ilerdian to basal Cuisian (~55-52 Ma) corresponding to upper SBZ7 to basal SBZ10 larger foraminifera zones. Age of the mammal fossil horizons in the lower part of the succession appears to be Sparnacian (~55-54 Ma).

Keywords: Dinoflagellate cysts, Palaeocene-early Eocene, Vastan lignite, early Eocene mammals

INTRODUCTION

The western India witnessed widespread marine transgression during Palaeocene-Eocene on a landscape formed due to weathering of Deccan Traps. Initial deposits of this marine transgression consist of carbonaceous shales, lignite and minor carbonates. Cambay embayment (basin) extending over the mainland Gujarat, eastern margin of Saurashtra Peninsula and Cambay developed muddy sediments with prominent lignite deposits (Fig. 1). These sediments are described as the Cambay Shale. In the Surat region, these muddy sediments often contain lignite deposits. The Vastan lignite mine exposes a thick muddy succession, where the basal part contains lignite horizons.

Recently, a diverse assemblage of terrestrial mammalian fauna has been obtained from the lignite-bearing sediments of the Vastan lignite mine (Bajpai *et al*., 2005 a,b,c, 2006, 2007; Rana *et al*., 2005; Rose *et al*., 2006; Sahni *et al*., 2006; Smith, 2007). In the present paper, we describe the dinoflagellate cyst assemblage, obtained from several levels of the lignite-bearing sediments. Many of these dinocysts are age diagnostic and have helped in determining the age of these sediments.

VASTAN LIGNITE MINE

The Vastan lignite mine (Latitude 21° 25' 27"N, Longitude 73° 07' 30") is located about 30 km northeast of Surat and the succession is often referred to as the Cambay Shale. The mine exposes about 200m thick muddy succession directly overlying the Deccan Traps. The Vastan lignite mine succession can be differentiated into three informal stratigraphic units, namely the Succession A, Succession B, and Succession C. The succession A is about 45m thick consisting of lignite beds, greenish grey shales, carbonaceous shale and shell carbonate. Succession B consists of greenish grey shales with prominent channelling and low angle discordances. Succession C is made up of reddish-brown shales with discordances and mud-filled channels. There are no sand horizons in the Vastan succession.

The Succession A has two thick lignite horizons, one at the base (2nd lignite seam) and the other at the top (1st lignite seam) (Bajpai *et al*., 2005a). The succession between these two lignite seams is made up of cyclic repetition of shell carbonate, carbonaceous shale, greenish grey shale, and lignite. Greenish grey shales in the lower part of the Succession A are devoid of any macrofauna; but in the upper part molluscan macrofauna is common. There are four prominent shell carbonate horizons; where the topmost shell carbonate contains larger foraminifers (*Nummulites*).

Deposition of the Succession A took place in a shallow marine embayment flanked by prominent coastal marshes. The deposition of different lithofacies of the Succession A took place in open bay, restricted bay, tidal creeks and coastal marshes. Different lithofacies are stacked vertically in response to the fluctuating sea-level in the embayment.

In the following, dinoflagellate cyst assemblages recovered from the Succession A are described.

DISTRIBUTION AND AGE OF DINOFLAGELLATE CYST ASSEMBLAGE

Fifty three samples distributed in different parts of the Succession A have been macerated and studied. Dinoflagellate cysts are recovered from several levels of the Succession A in the Vastan lignite mine (Fig.1). In general, dinocyst recovery is poor to moderate except at a few levels where these palynomorphs occur more abundantly and dominate over the sporomorphs (pollen and spore). The preservation is poor to moderate at best. The illustrated dinocysts (Pls. I and II) are provided with England Finder positions on the respective slides. The slides have been registered (BSIP slide nos 13511-

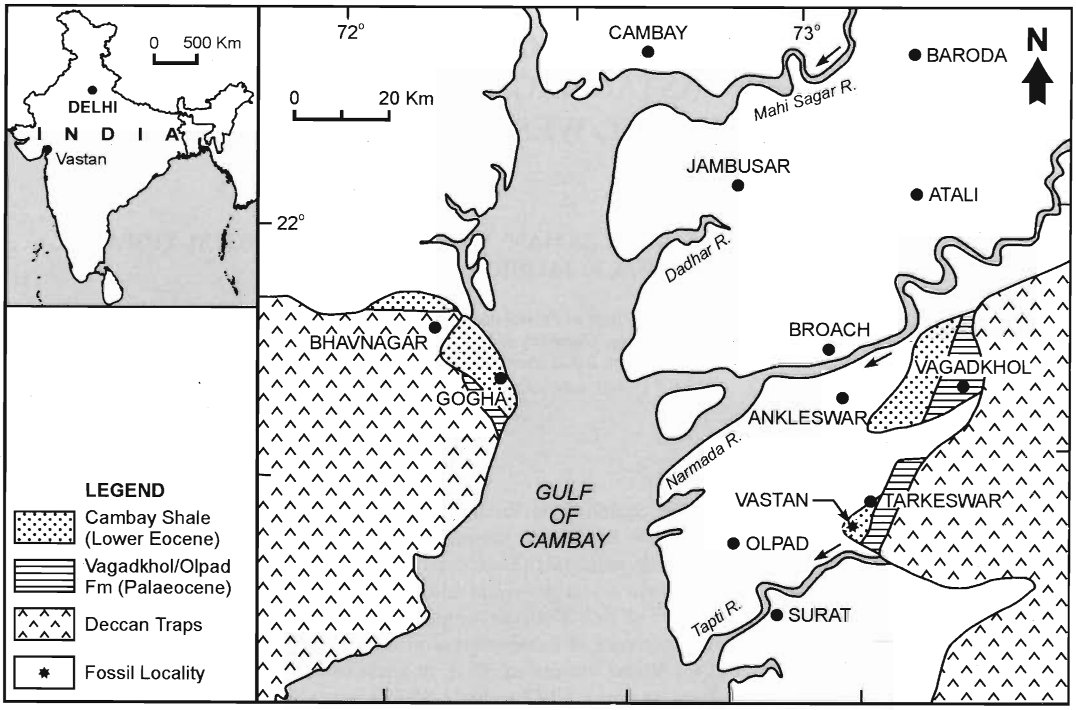

Fig. 1. Schematic geological map of the Cambay embayment showing location of Vastan (Taken from Sahni *et al.*, 2006).

13525) and deposited in the repository of the Museum, Birbal Sahni Institute of Palaeobotany, Lucknow.

21 dinoflagellate cyst taxa could be recognized exhibiting low to moderate diversity in the recovered assemblages (Table 1). Most of the dinoflagellate cyst species are rather long ranging, albeit reflecting an overall early Palaeogene aspect. Nevertheless, occurrence of some marker taxa, e.g. *Muratodinium fimbriatum*, *Heteraulacacysta granulata*, *Kenleyia* complex (*K. lophophora*, *K. leptocerata*, and *Kenleyia* spp.), *Lanternosphaeridium lanosum* and *Operculodinium severinii* proved to be of significance for a reasonably precise age determination of the lignite bearing succession. These taxa are known from calcareous plankton and larger foraminifera (SBZ) zone-calibrated late Palaeocene-early Eocene successions from several areas in North Sea, northern Africa, Uzbekistan, New Zealand and elsewhere (Powell *et al.,* 1996; Jan du Chene and Adediran, 1985; Crouch *et al*., 2003; Molina *et al*., 2003; Garg and Khowaja-Ateequzzaman, 2000). Evaluation of FAD/ LAD and restricted occurrences of these taxa in the late Thanetian to early Ypresian allows recognition of some significant dinocyst events (i.e. FAD of *M. fimbriatum*, LAD of *Kenleyia* complex, LAD of *L. lanosum)* and their calibration with global plankton zonations and shallow benthic zones of larger foraminifera (Serra Kiel *et al*., 1998, 2003). General lithology, sample numbers, important dinoflagellate cyst-bearing horizons and ages are given in Fig. 2. *M. fimbriatum* is a cosmopolitan age marker with its FAD (~55 Ma, Stover *et al*., 1996) in the latest Palaeocene (latest Thanetian Aau dinocyst biozone, uppermost NP9 nannoplankton Zone). This species occurs almost throughout the palynologically productive part of the Vastan succession (Succession A), thus indicating an age not older than latest Thanetian (equivalent to P5b and NP9 in part, now Sparnacian) for the lower part. It would correspond to upper part of SBZ6~basal SBZ7 in terms of larger foraminifera biozonation (Serra-Kiel *et al*., 1998).

Kenleyia complex which dominates in the middle part of the Vastan succession (samples V 30-38) is predominantly southern hemisphere taxa. Both *K. lophophora* and *K. leptocerata* have their FADs in the basal Danian (Brinkhuis and Leereveld, 1988; Garg *et al*., 2006). Recent findings from Tunisia

EXPLANATION OF PLATE I

(scale bar equals 10μ in all cases)

1. ***Kenleyia lophophora*** Cookson and Eisenack, 1965; BSIP slide no. 13519; M41/2.
2-3. ***Heteraulacacysta granulata*** Jan du Chêne and Adediran, 1985; 2. BSIP slide no. 13513; E26; 3. BSIP slide no. 13517; O29.
4. ***Operculodinium israelianum*** (Rossignol) Wall, 1967; BSIP slide no. 13520; G36.
5. ***Operculodinium severinii*** (Cookson and Cranwell) Islam, 1983; BSIP slide no. 13511; T44/1.
6. ***Lejeunecysta hyalina*** (Gerlach) Artzner and Dörhöfer, 1978 emend. Kjellström, 1972 emend. Sarjeant, 1984; BSIP slide no. 13513; L25.
7. ***Hystrichkolpoma*** sp.; BSIP slide no. 13517; Q30/4.
8. ***Homotryblium*** cf. H. oceanicum Eaton, 1976; BSIP slide no. 13516; O18/2.
9. ***Homotryblium*** cf. ***H. abbreviatum*** Eaton, 1976; BSIP slide no. 13515; N50/2.
10. ***Selenopemphix nephroides*** Benedek, 1972 emend. Bujak in Bujak *et al.*, 1980 emend. Benedek and Sarjeant, 1981; BSIP slide no. 13522; S35/4.
11-12. ***Selenopemphix*** cf. ***S. armata*** Bujak *in* Bujak *et al.*, 1980; 11. BSIP slide no. 13512; U28/3: 12. BSIP slide no. 13514; N40.

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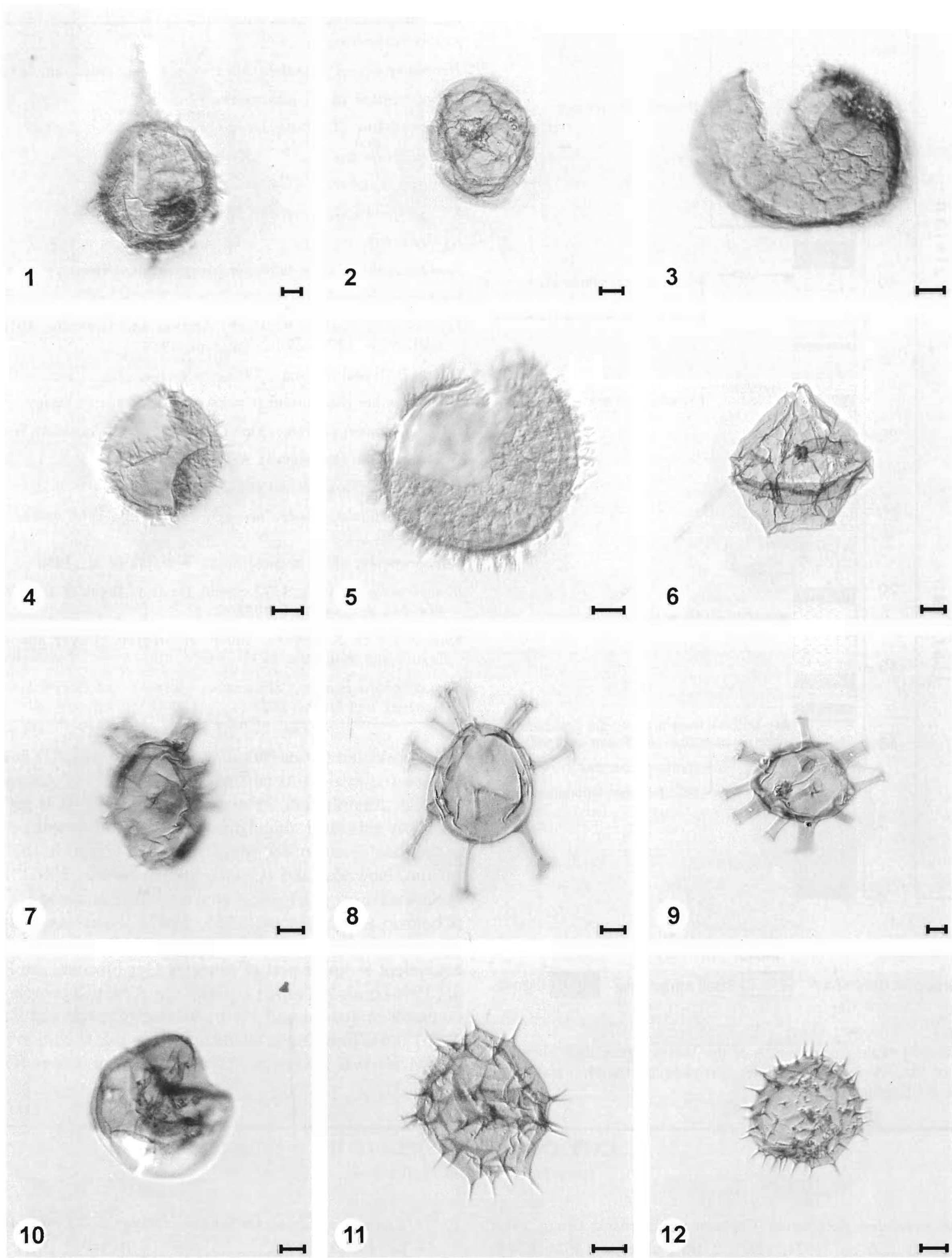
Plate I



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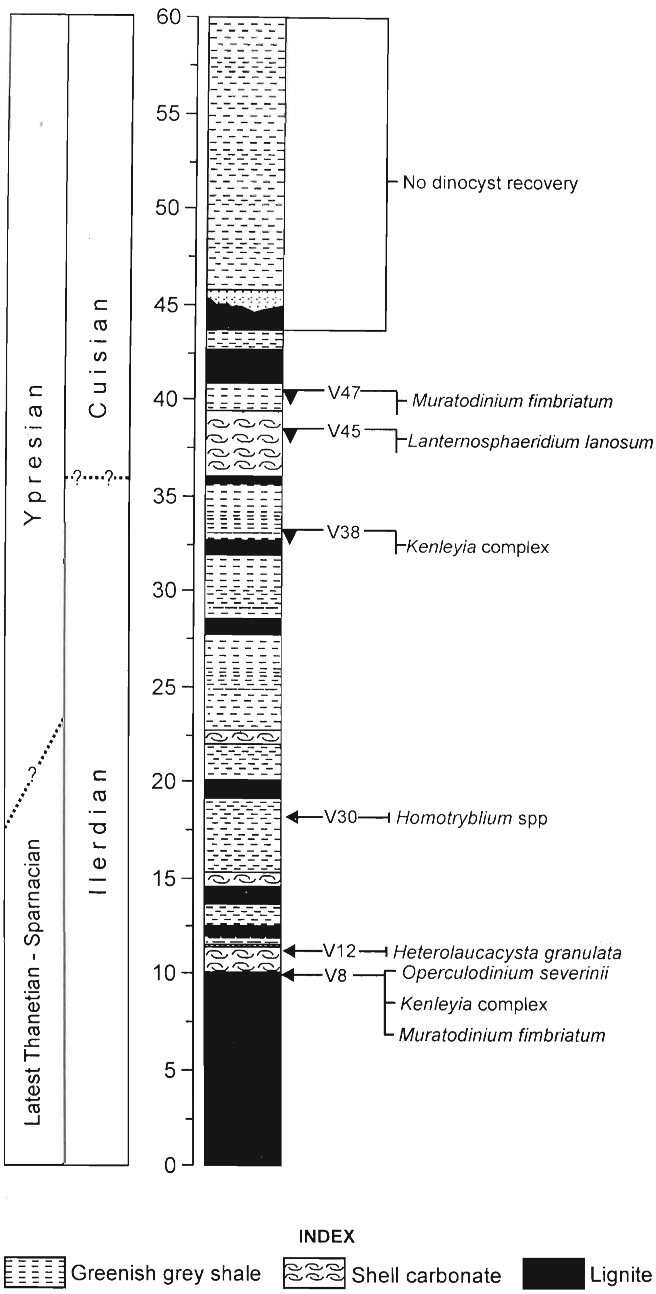


Fig. 2. Litholog of the Succession A of the Vastan lignite mine showing position of important dinoflagellate cyst-yielding samples and age-diagnostic dinoflagellates.

Table 1: Dinoflagellate cyst taxa recovered from the Vastan lignite mine.

Achomosphaera sp.
Heteraulacacysta granulata Jan du Chêne and Adediran, 1985
Homotryblium cf. *H. abbreviatum* Eaton, 1976
Homotryblium cf. *H. oceanicum* Eaton, 1976
Hystrichkolpoma sp.
Kenleyia leptocerata Cookson and Eisenack, 1965
K. lophophora Cookson and Eisenack, 1965
Kenleyia spp.
Lanternosphaeridium lanosum Morgenroth, 1966
Lanternosphaeridium sp.
Lejeunecysta hyalina (Gerlach) Artzner and Dörhöfer, 1978 emend. Kjellström, 1972 emend. Sarjeant, 1984
L. lata Biffi and Grignani, 1983
Muratodinium fimbriatum (Cookson and Eisenack) Drugg, 1970
Operculodinium centrocarpum (Deflandre and Cookson) Wall, 1967
O. israelianum (Rossignol) Wall, 1967
O. severinii (Cookson and Cranwell) Islam, 1983
Polysphaeridium subtile Davey and Williams, 1966 emend. Bujak *et al.*, 1980
Selenopemphix cf. *S. armata* Bujak *in* Bujak *et al.*, 1980
S. nephroides Benedek, 1972 emend. Bujak in Bujak *et al.*, 1980 emend. Benedek and Sarjeant, 1981
Spiniferites cf. *S. ramosus* subsp. *multibrevis* (Davey and Williams) Lentin and Williams, 1973
Thalassiphora pelagica (Eisenack) Eisenack and Gocht, 1960 emend. Benedek and Gocht, 1981

and Uzbekistan (Crouch *et al.*, 2003) show its LAD in the early Eocene (equivalent to early P6; NP10b~NP11), corresponding to larger foraminifera zones SBZ7 and SBZ8. It is pertinent to note that enhanced abundances of *Kenleyia* complex are noted in the basalmost Eocene (dinocyst zone NZE1a) in the Tawanui section, New Zealand (Crouch and Brinkhuis, 2005). *Kenleyia* species were originally recovered from Tasmania and SW Victoria (Cookson and Eisenack, 1965, 1967). Their association with *Cerodinium dartmoorium* in Victoria (LAD in earliest Ypresian; equivalent to lower part of dinocyst Gor biozone, see Powell *et al.*, 1996) is also of much significance. *Kenleyia* complex is most common in coastal and neritic setting (Crouch and Brinkhuis, 2005) and is found to be abundant across P-E transition including PETM interval having preference for warm waters (Crouch *et al.*, 2003).

EXPLANATION OF PLATE II

(scale bar equals 10μ in all cases)

1-2, 4. ***Muratodinium fimbriatum*** (Cookson and Eisenack) Drugg, 1970; 1. BSIP slide no. 13524; Y28/1; 2. BSIP slide no. 13524; R21/1; 4. BSIP slide no. 13515; U49/4.

3. ***Polysphaeridium subtile*** Davey and Williams, 1966 emend. Bujak *et al.*, 1980; BSIP slide no. 13518; F34/1.

5-6. ***Thalassiphora pelagica*** (Eisenack) Eisenack and Gocht, 1960 emend. Benedek and Gocht, 1981; 5. BSIP slide no. 13525; Y17/4; 6. BSIP slide no. 13524; Y28/1.

7. ***Lanternosphaeridium lanosum*** Morgenroth, 1966; BSIP slide no. 13522; E30/4.

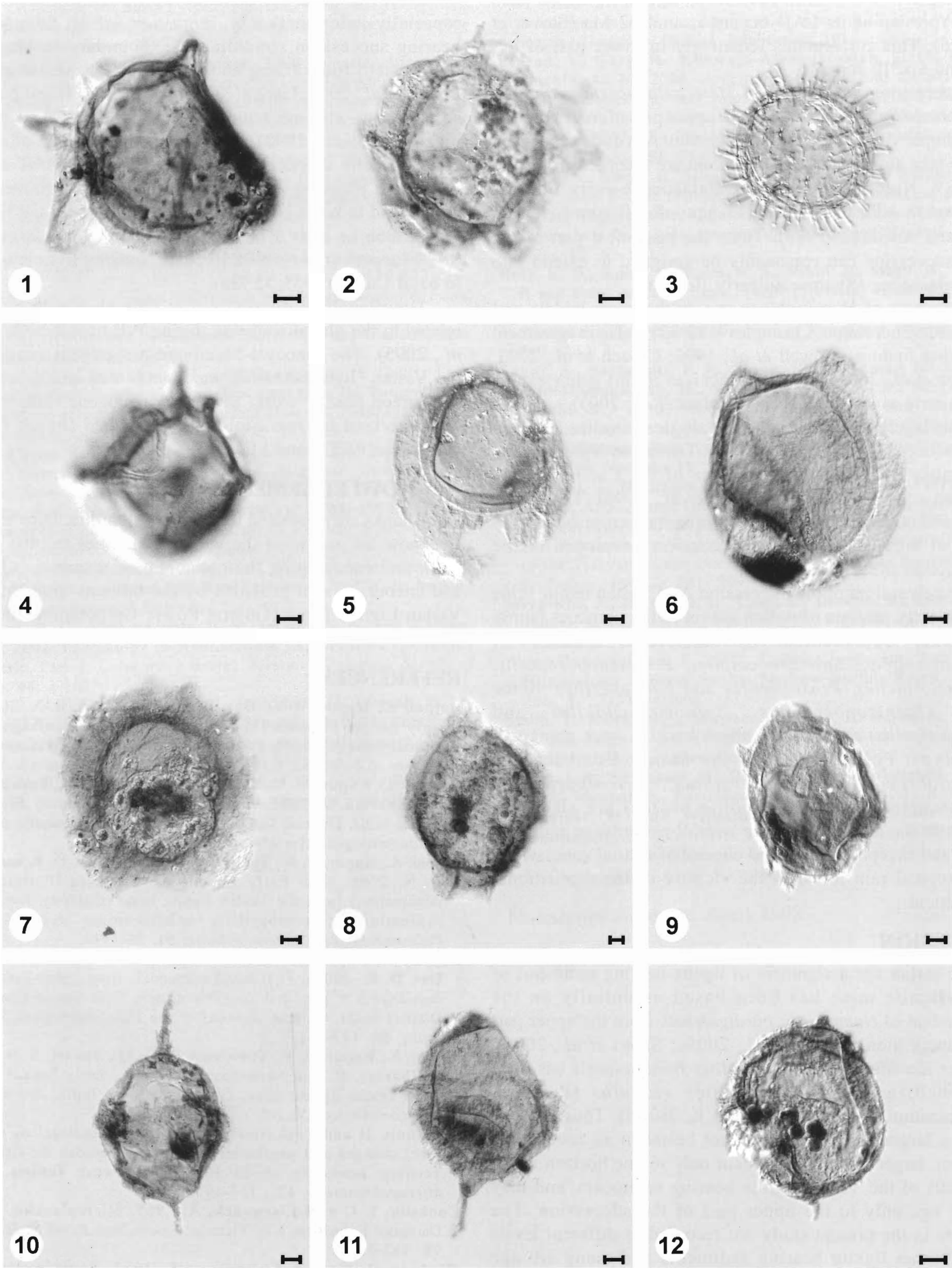
8. ***Lanternosphaeridium*** sp.; BSIP slide no. 13523; Q44/3.

9-10. ***Kenleyia*** spp.; 9. BSIP slide no. 13515; D41/3; 10. BSIP slide no. 13521; O14/3.

11. ***Kenleyia leptocerata*** Cookson and Eisenack, 1965; BSIP slide no. 13519; V33/3.

12. ***Kenleyia lophophora*** Cookson and Eisenack, 1965; BSIP slide no. 13519; G36/3.

Plate II



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Presence of *Lanternosphaeridium lanosum* in the upper part (sample V 44) is indicative of an age not younger than middle Ypresian as its LAD occurs around 52 Ma (Stover *et al.*, 1996). This corresponds tentatively to lower part of P7, NP12 and SBZ10 zones.

Furthermore, occurrence of *Heteraulacacysta granulata* and *Operculodinium severinii* in the upper part of lowest lignite seam (sample V 8) in the Vastan Succession A is quite significant as these taxa along with *M. fimbriatum* are recorded from Imo shale, SW Nigeria dated as late Palaeocene-early Eocene, equivalent to NP9 to NP10-NP11 nannofossil zones (Jan du Chêne and Adediran, 1985). Thus, the basalmost part of the Vastan succession can reasonably be assigned to extend into latest Palaeocene (Sparnacian/early Ilerdian).

Occurrence of *Homotryblium* spp. in the lower-middle part of the Vastan Succession A (samples V 12-33) is also in agreement with earlier findings (Powell *et al.*, 1996; Crouch *et al.*, 2003; Iakovleva *et al.*, 2001) that representatives of this genus extend up to as early as late Palaeocene (Molina *et al.*, 2003).

Dinoflagellate cysts and palynological studies indicate late Palaeocene to early Eocene age (Danian to Ypresian) for the Cambay Shale in the subsurface of the Cambay Basin (Mehrotra *et al.*, 1996, 2002; Gupta *et al.*, 1996). The lignite bearing sediments of Vastan lignite mine may correspond only to part of the Cambay Shale succession developed in the subsurface of the Cambay Basin.

The palynoflora of the Succession A of Vastan lignite mine predominantly consists of pollen grains of the monocot family Arecaceae, represented by different species of *Acanthotricolpites, Spinizonocolpites, Echimonoporopollis, Spinomonosulcites, Proxapertites* and *Longapertites*. Some pollen (*Spinizonocolpites, Spinomonosulcites* and *Neocouperipollis*) show strong affinity with a back mangrove plant Nypa. Pollen grains of the family Bombacaceae (*Dermatobrevicolporites dermatus, Tricolporopollis matanomadhensis* and *Lakiapollis ovatus*) are also very frequent in the assemblage. The overall assemblage indicates a warm and exceptionally humid climate of coastal zone, with a dense tropical rain forest in the vicinity of the depositional environment.

DISCUSSION

The earlier age assignment of lignite-bearing sediments of Vastan lignite mine has been based essentially on the identification of *Nummulites burdigalensis* from the upper part of the succession (Bajpai *et al.*, 2005c; Sahni *et al.*, 2006). However identification of *Nummulites burdigalensis* has been questioned; and it is *Nummulites globulus* (Personal communication, K. Matsumaru to A.K. Jauhri). Thus, the age based on larger foraminifera cannot be taken as conclusive. Moreover, larger foraminifera occur only in one horizon in the upper part of the Vastan lignite bearing sediments, and may provide age only to the upper part of the succession. The dinocysts in the present study are recorded at different levels of the Vastan lignite bearing sediments and many are age diagnostic. An age ranging from latest Thanetian or Sparnacian (~55 Ma) to middle Ypresian (~52 Ma) is assigned to lignite bearing Vastan succession (Succession A).

The mammalian fauna rich horizon (Bajpai *et al.*, 2005c) of Vastan Succession A is only few meters above the sediments containing *Muratodinium fimbriatum* and associated dinocysts (age ~55 Ma). Thus, the age of mammalian fauna rich horizon may be ~55-54 Ma.

Despite apparent absence of *Apectodinium* species, especially index marker *A. augustum*, which dominate coal bearing succession straddling P-E boundary in Meghalaya, northeastern India (Garg and Khowaja Ateequzzaman, 2000; Prasad *et al.*, 2006; Garg *et al.*, 2006), the lowermost part of the section may still be tentatively assigned to Aau dinocyst biozone (Powell, 1992), more so in the absence of any true basal Eocene marker dinocyst taxa. In terms of standard calcareous plankton zonations, such an age assignment would correspond to latest NP9- NP10 to NP12 (lower) and latest P5-P6a to P6b or early P7 zones correlatable with larger foram SBZ7 (upper) to lower SBZ10 zones, ranging from late Ilerdian to basal Cuisian (~55-52 Ma).

Dinoflagellate distribution is now known to be closely related to the global warming during P-E transition (Crouch *et al.*, 2005). The dinocyst-based age assignment suggests that the Vastan lignite-bearing succession was laid down during the "green house" world of early Palaeogene times which is characterized by two globally recognized 'hyper thermal' events, i.e. PETM and EECO.

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