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DINOFLAGELLATE CYSTS FROM THE NAREDI FORMATION, SOUTHWESTERN KUTCH, INDIA: IMPLICATION ON AGE AND PALAEOENVIRONMENT

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ABSTRACT

The lower part of the early Palaeogene deposits in the Kutch Basin, immediately overlying the Deccan Traps is generally developed as a muddy succession with lignite and rare fossils. Its age has been mostly speculative, based essentially on the age-diagnostic larger foraminiferal fauna in the carbonate horizons present several metres to tens of metres above the base. This muddy succession, named as the Naredi Formation ("Sub-Nummulitic and Gypseous Shale") has been broadly assigned an age of early Eocene or Palaeocene- early Eocene, which has been debated mainly due to the poor record of datable planktic microfossils or lack of age-diagnostic fossils with chronological significance. In the present study, dinoflagellate cyst assemblages including age-diagnostic taxa at several levels from the basal part of the Naredi Formation are recovered. Occurrence of *Muratodinium fimbriatum, Heterolaucacysta granulata, Operculodinium severinii* and *Ginginodinium palaeocenicum* in the basal part indicates an age not older than late Thanetian/Sparnacian (~55 Ma, now early Ypresian). Presence of rich *Kenleyia* complex including LAD of *Kenleyia lophophora* and *K. nuda* just below the *Venericardia* bed indicates Sparnacian/basal Ypresian age (55~54 Ma). Occurrence of *Glaphyrocysta exuberans* above this shell coquina also demonstrates early Ypresian age younger than ~54Ma. *Muratodinium fimbriatum* extends up to the base of *Assilina* Limestone bed in the upper part of the succession. Thus, in terms of traditional European stages, the lower part of the Naredi Formation is assigned the early Ypresian age, broadly corresponding to Ilerdian, representing a time span of ~55-54 Ma.

Keywords: Dinoflagellate cysts, Palaeocene-early Eocene, Naredi Formation, Kutch Basin

INTRODUCTION

The large-scale Deccan volcanism has been related to the globally significant Cretaceous - Tertiary boundary (KTB) event (McLean, 1985; Officer and Drake, 1985; Courtillot *et al.*, 1986, 1988; Keller *et al.*, 2008, 2009a, b; Gertseh *et al.*, 2011). In the Kutch Basin, the Deccan Trap eruption during Late Maastrichtian-Danian was followed by a period of quiescence when Deccan Trap landscape witnessed extensive weathering. It is succeeded by a new episode of deposition which is associated with the early Palaeogene marine transgression producing well developed Palaeogene succession extending all along the marginal areas of Kutch, mainland Gujarat and Rajasthan in western India over the peneplained landscape developed after weathering of the Deccan Traps. These early Palaeogene deposits on the land outcrops exhibit a variety of lithologies, viz. mudstone, siltstone, lignite and carbonaceous shale which mostly do not possess datable fauna. Hence, the age of the oldest post-Deccan Trap sediments and precise timing of early Palaeogene marine transgression has remained highly debatable. The depositional environment of these deposits has also been a controversial topic. The earliest part of this marine succession unconformably overlying the Deccan Traps in the Kutch Basin, is predominantly argillaceous, consisting of carbonaceous shales with lignite bands, grey, chocolate (reddish) and greenish shales with thin shell rich layers in the lower part, followed by minor but prominent Nummulitic limestone and marl bands in the middle part and ferruginous silty shales in the upper part (lower part of "Sub-Nummulitic and Gypseous Shales" of Wynne, 1872; Naredi Formation of Biswas and Raju, 1973). This basal predominantly terrigenous clastic-lignite succession is followed by carbonate deposits, namely Nummulitic carbonates and interbedded marls and shales ("Nummulitic Group" of Wynne,1872) which make the major part of the Palaeogene succession and has been extensively investigated for its rich foraminiferal fauna and is well dated by marine planktons (foraminifera, nannoplankton and dinoflagellate cysts) and larger benthic foraminiferal evidence (Tewari, 1952, 1957; Tandon 1962, 1976; Sengupta, 1964; Mohan and Gupta, 1968; Raju *et al.*, 1979; Samanta, 1970; Raju 1974; Singh 1980a,b, 1988; Jain and Tandon, 1981; Singh and Singh 1986, 1991; Rai, 1997, 2007).

However, age of the post-Trappean and pre-Nummulitic shale succession at the base of the marine Palaeogene succession overlying the Deccan Traps (Naredi Formation of Biswas and Raju, 1973) has long remained shrouded in controversy. Medlicott and Blanford (1879) correlated the "Sub-Nummulitic and Gypseous Shale succession" of Wynne (1872) with the Ranikot series of the Sind-Baluchistan area considered to be lower Eocene. Subsequently, Tewari (1952), Tandon (1962, 1971) and Tandon *et al.* (1980) ascribed Palaeocene-early Eocene age to this lower shaly succession. Raju (1974) and Singh and Singh (1981) also suggested early Eocene age based on larger foraminifera. Some workers however, considered Palaeocene and major part of lower Eocene to be absent in Kutch assigning late Lower Eocene - Middle Eocene (Ray *et al.*, 1984) or late middle Eocene (Bartonian) age to the entire pre-Nummulitic shaly succession (Jafar and Rai, 1994). Absence of datable planktic microfossils or questionable identification of recorded planktic foraminifera (Tandon *et al.*, 1980) and rather long stratigraphic ranges of the larger foraminifera (*Assilina* species) and the bivalves (*Venericardia beaumonti*) have primarily been cited as reasons to reject the direct age derivations of this succession. Instead, these workers support a much younger middle Eocene (Lutetian/Bartonian) age also for the lowest part of the Palaeogene succession which is based on the datable microfossils at stratigraphically much higher levels.

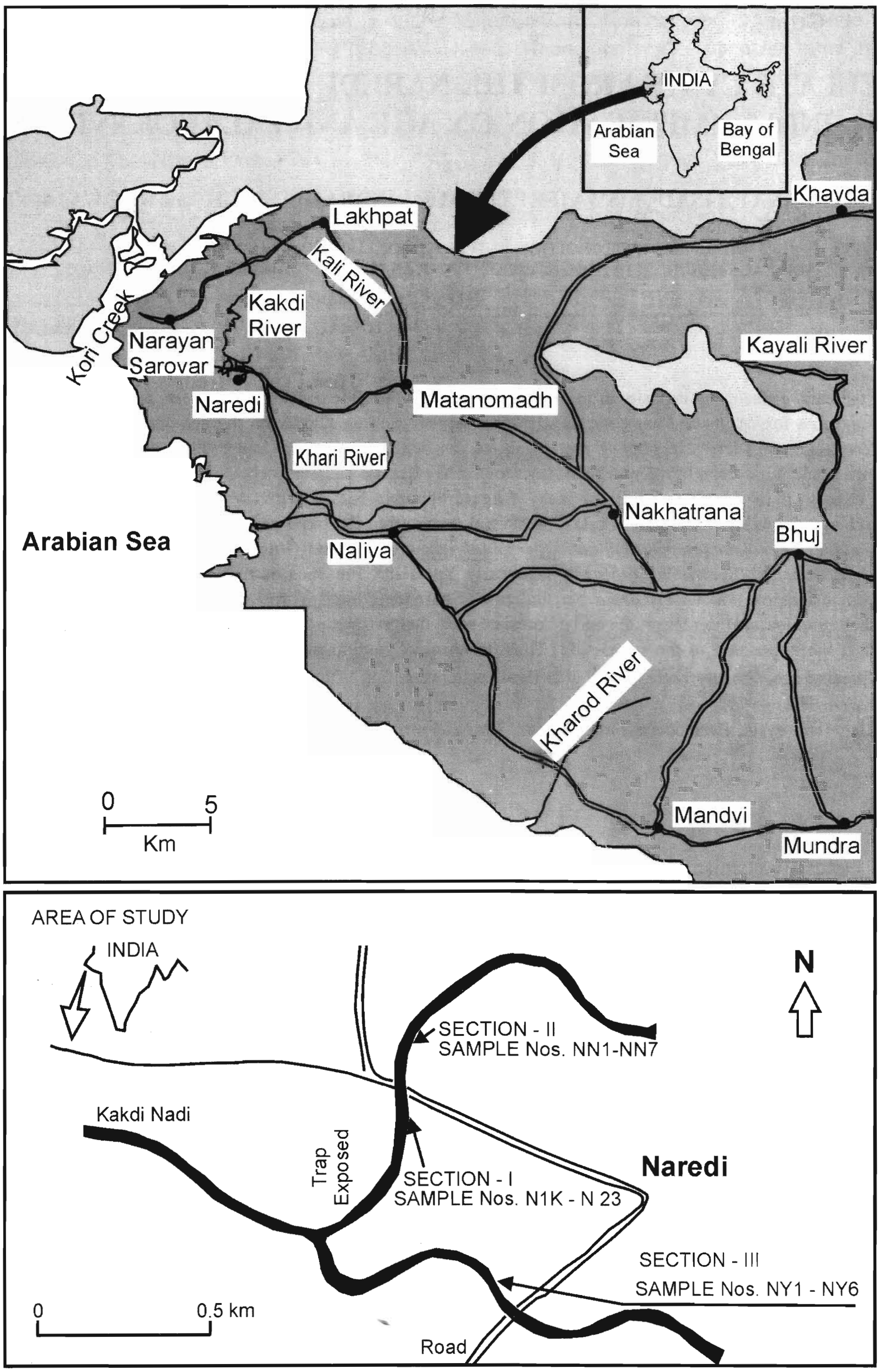

Fig. 1. Location Map of the area of study; a- western Kutch showing location of Naredi village; b- location of studied sections near Naredi village.

Well-preserved and datable dinoflagellate cyst assemblages, including the age-diagnostic species, have been recovered from several levels of the lower muddy part of the Naredi Formation underlying the *Assilina* and *Nummulites* bearing horizons and immediately overlying the Deccan Traps in the type Kakdi River section and other sections in the vicinity of the Naredi village. A preliminary report on the discovery of Palaeocene dinoflagellate cysts from the basal part of the Naredi Formation was earlier made by Garg (1991). In the present paper, dinoflagellate cysts assemblages of latest Palaeocene - early Eocene age (late Thanetian- early Ypresian) are documented which help us date the oldest Palaeogene succession in Kutch and suggest a timing of marine transgression in western India during the early Palaeogene.

STRATIGRAPHIC SET-UP

The pericratonic Kutch Basin is an E-W embayment opening in the west towards the Arabian Sea where a much

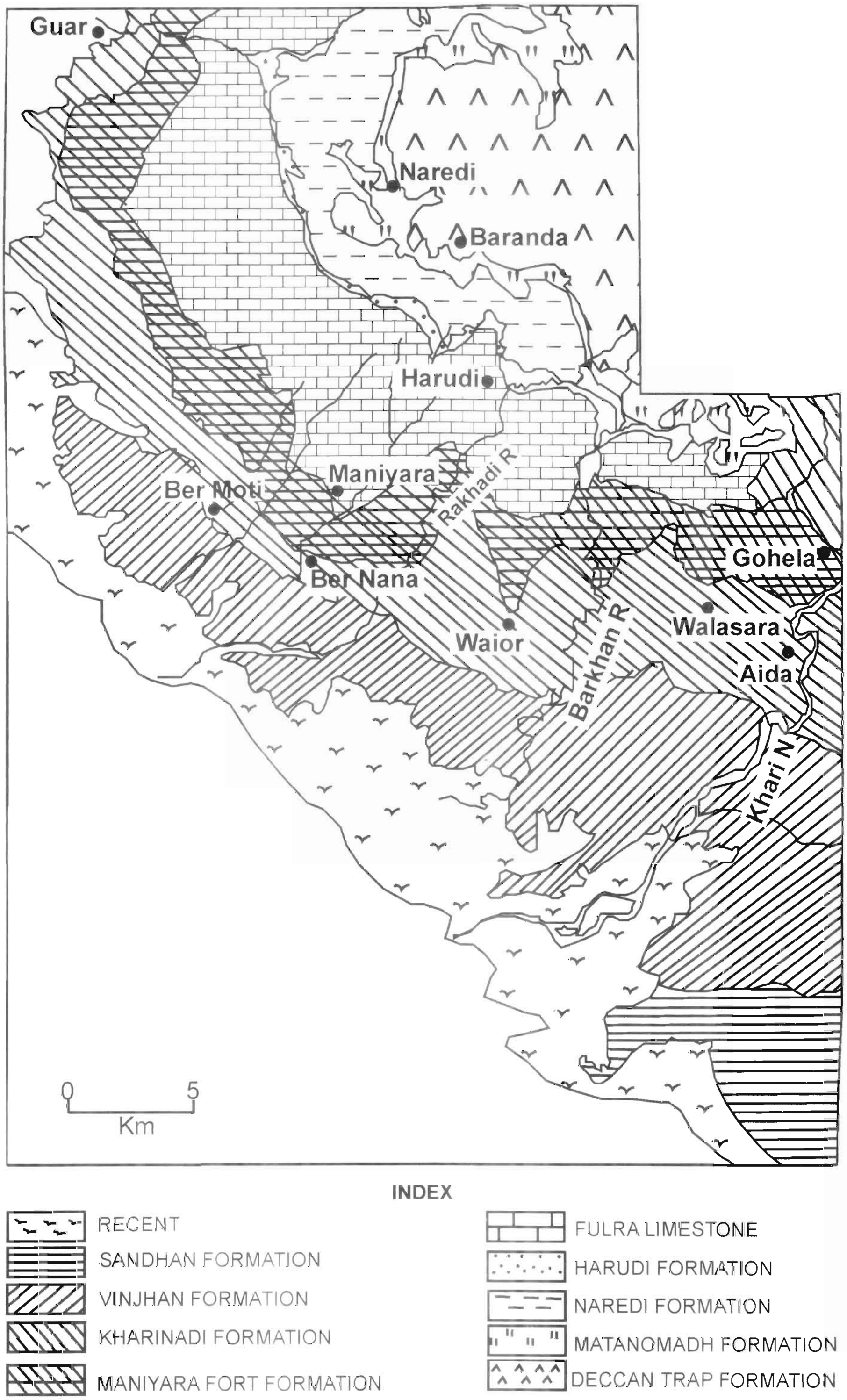

Fig. 2. Geological map of western part of the Kutch Basin (After Biswas and Raju, 1973).

thicker marine Cenozoic succession is encountered in the subsurface. The total estimated thickness of the onland Cenozoic succession in Kutch is about 630 m (Biswas and Deshpande, 1983). The gently southwesterly dipping Palaeogene rocks are exposed in more or less parallel arcuate shaped outcrops in the western part of Kutch along the present day coastline extending from north to south (Figs.1and2). The stratigraphic classification of the Cenozoic succession is dealt with by several workers (Biswas, 1965, 1972, 1992, Biswas and Raju, 1973; Saraswati and Banerjee, 1995). The Palaeogene sedimentary succession has been extensively investigated for both mega - and microfossils by a number of workers since the pioneering work of Wynne (1872). The Palaeogene succession has been classified into five formations, viz. Matanomadh Formation, Naredi Formation, Harudi Formation, Fulra Limestone and Maniyara Fort Formation in ascending order (Biswas and Raju, 1973; Biswas, 1992) (Table 1). The "Gypseous Shale and Sub-Nunmulitic" group of Wynne (1872)

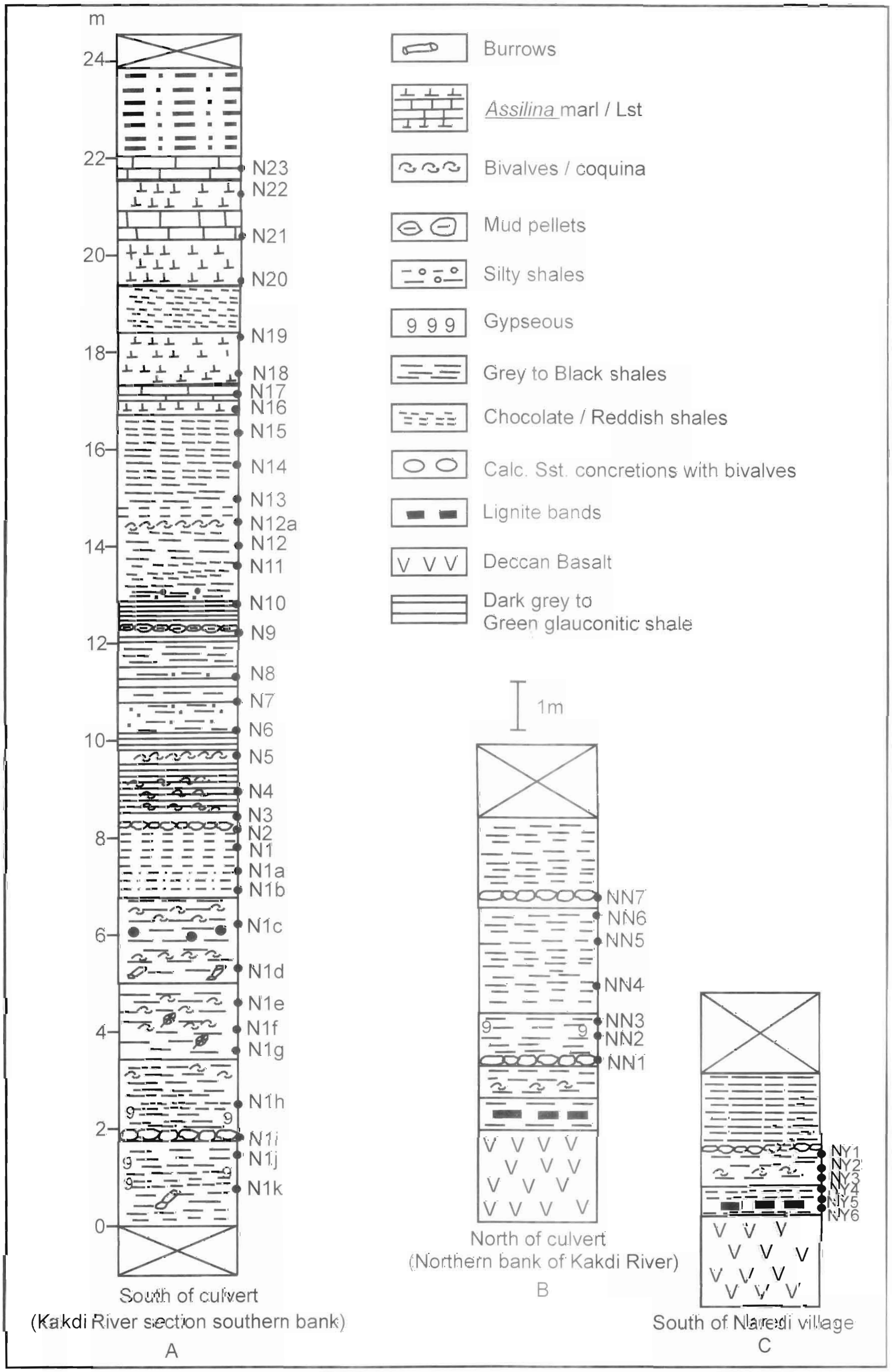

Fig. 3. Lithology of the studied sections near Naredi with stratigraphic position of samples: A- Kakdi River Section (southern bank section exposed south of the culvert. (Type section of the Naredi Formation, Biswas and Raju, 1973); B- section exposed north of the culvert; C- section exposed south of Naredi village.

Table 1: Palaeogene stratigraphy of the Kutch Basin (*after* Biswas and Raju, 1973; Biswas, 1992; along with nomenclature of Wynne, 1872).

Age	Lithounit	Lithology	Wynne, 1872
Oligocene	Maniyara Fort Formation	Foraminiferal and coralline limestone, shale	
	---------Unconformity--------		
Mid- Late Eocene	Fulra Limestone Formation	Foraminiferal limestone	Nummulitic Limestones
	-------Unconformity-------		
Middle Eocene	Harudi Formation	Calcareous shale , siltstone, claystone and fossiliferous marls	
	-------Unconformity-------		
Late Palaeocene-Early Eocene	Naredi Formation	Ferruginous claystone, *Assilina* limestone and marl, glauconitic claystone and gypseous shale along with black shale/lignite (local)	Gypseous Shales
	--------Unconformity--------		
Early Palaeocene	Matanomadh Formation	Variegated clay and shale, sandstone, occasional lignite layers	Sub-Nummulitic
	-------Unconformity-------		
Late Maastrichtian-Early Danian		Deccan Traps	

corresponds to the Matanomadh, Naredi and Harudi formations. The Naredi Formation has been subdivided into three members viz. lower Gypseous Shale Member, predominantly argillaceous containing shales, shell layers and gypsum, the middle *Assilina* Limestone Member containing foraminifera rich carbonate, and the upper Ferruginous Claystone Member made up of silty to ferruginous mud (Biswas and Raju, 1973). In the Kakdi River section, only the lower Gypseous Shale and the middle *Assilina* Limestone members are well exposed. The upper Ferruginous Claystone Member is better exposed in the Guvar River section northwest of the Naredi village. According to Biswas (1992), thick lignite has developed within Naredi Formation towards north between townships of Umarsar and Panandro. The lower part of the Naredi Formation (Gypseous Shale Member) exposed in the Kakdi River section and other sections in the vicinity of Naredi village consists of alternations of grey to dark grey or black to greenish shales, carbonaceous shales and chocolate to red shale facies in the lower part (Figs.1and 3). Occurrence of glauconite in the Naredi Formation has been studied by Singh (1978) and Chattoraj *et al.* (2009). The chocolate to reddish shales of the Gypseous Shale Member in the Kakdi River section are often reported as barren and unfossiliferous (Chattoraj *et al.*, 2009). However, in the present study the entire lower part of the Naredi Formation including the chocolate shales (Gypseous Shale Member) has been found to be productive of dinoflagellate cysts.

In the present study, the succession exposed in the Kakdi River is divided into four informal lithological units. Succession A and B correspond to the Gypseous Shale Member. Succession C corresponds to the *Assilina* Limestone Member, while the Succession D represents the basal part of the Ferruginous Sandstone Member of Biswas and Raju (1973). Lithological details of these lithounits are given in Table 2. The lowermost Succession A begins with a ~ 50 cm thick chocolate to reddish shale with thin lignite partings at the base and shell debris layers, horizontal to oblique tubular burrow horizons and coquina band with *Venericardia beaumonti* at the top. The overlying Succession B also contains a thin shell debris band in the middle. Succession C contains larger foraminifera, namely *Assilina* and *Nummulites*; while Succession D, poorly exposed at the top of the Kakdi River scarp, is unfossiliferous.

MATERIAL AND METHOD

The type section of the Naredi Formation exposed in the Kakdi River near the Naredi Village northwards of Baranda on the Narayan Sarvovar-Naliya road has been investigated and sampled systematically to study dinoflagellate cysts and palynomorphs. In addition to the type section exposed in the river escarpment southwards of the concrete bridge (culvert) on the road, other sections representing the basal shaly part just overlying the Deccan Traps exposed northwards of the culvert and southwest of the Naredi village in a small rivulet have been also systematically sampled (Fig.1). Lithological details are given in Table 2 and the location and lithologs with position of samples indicating dinoflagellate cyst productivity is shown in figs. 3 and 4. For the recovery of dinoflagellate cysts, samples were processed by using standard preparation techniques. After treatment with hydrochloric and hydrofluoric acids, the acid resistant macerate was treated with dilute HNO_3 and washed repeatedly using 15μm sieve. After staining the macerate with safranin, the water free residue was mixed with polyvinyl alcohol and spread evenly on the glass cover slips. Permanent slides were prepared by fixing the oven-dried cover slips on glass slides using Canada Balsam as the mounting medium. Study and photo-documentation of dinoflagellate cysts was carried out under Olympus Vanox-2 microscope with Nomarski Interference Contrast and autophoto attachment. The illustrated specimens are provided with the England Finder position on the respective slides. The slides have been registered and deposited in the repository of the Museum, Birbal Sahni Institute of Palaeobotany, Lucknow.

DISTRIBUTION AND AGE OF DINOFLAGELLATE CYST ASSEMBLAGES

Thirty six samples collected from the type section of the Naredi Formation exposed on the eastern flank of the Kakdi River were analysed for dinoflagellate cysts (dinocysts). Additionally, thirteen samples collected from other sections of the area, just overlying the Deccan Traps outcropping in small rivulets in the vicinity of Naredi village were also analysed. Most of the samples yielded moderate to abundant organic remains (palynodebris) dominated by terrestrially derived

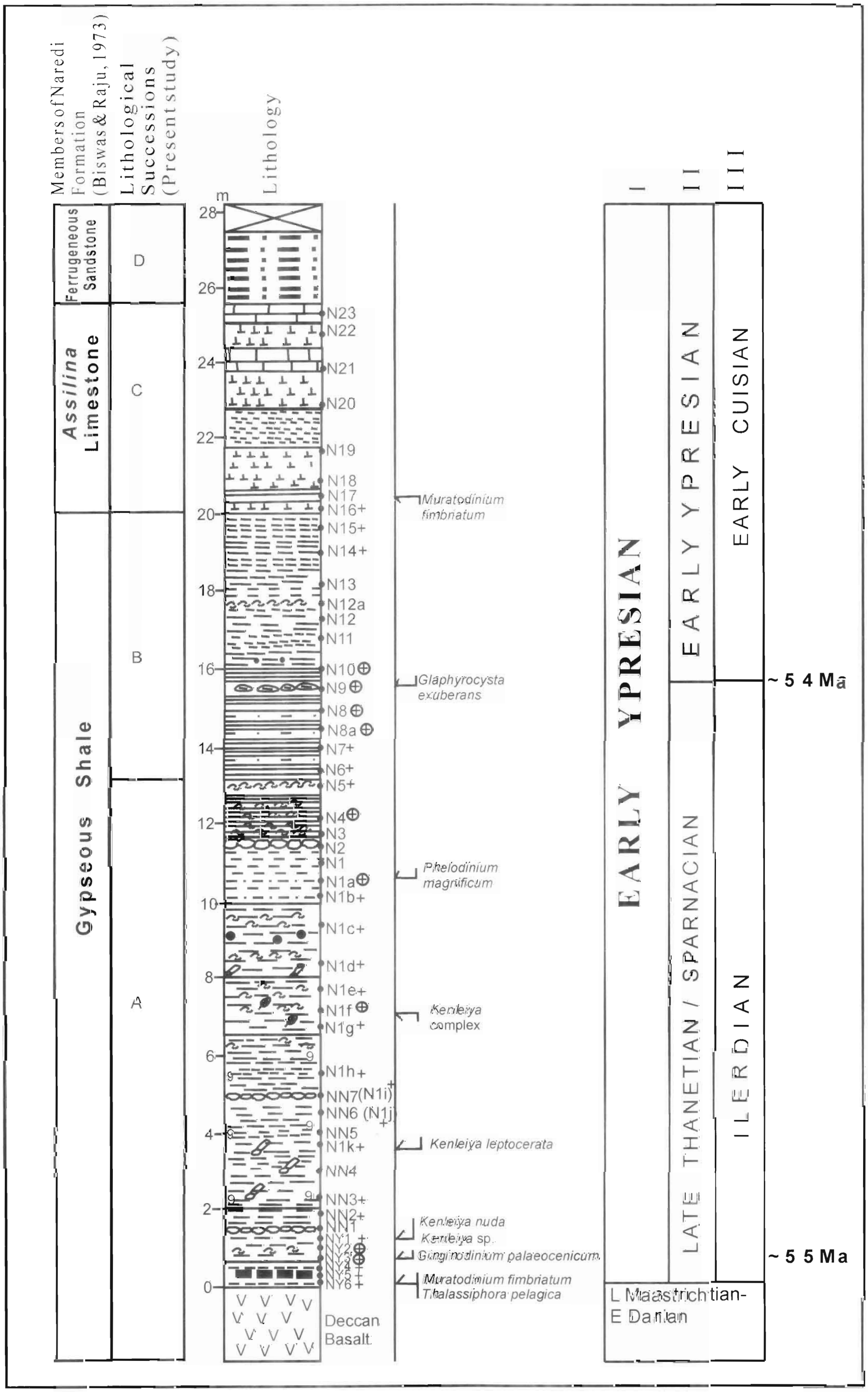

Fig. 4. Composite litholog of the Naredi Formation showing dinoflagellate cyst marker levels along with the age assignment of the studied successions. I Global Stages (Gradstein, 2004), II Global Stages (earlier nomenclature), III Regional European Stages.

Table 2: Lithological succession of the Naredi Formation along the Kakdi River section.

Naredi Formation (Biswas and Raju 1973)	Lithological Succession	Thickness	Description
Ferruginous Claystone Member	**Succession D**	3 m	Yellowish brown sandy to silty shale with ferruginous partings; unfossiliferous
***Assilina* Limestone Member**	**Succession C**	5.5 m	*Assilina* rich yellowish to grey marls with yellowish to dirty white hard carbonate bands containing *Nummulites*
Gypseous Shale Member	**Succession B**	7 m	Dark grey to military green shales with silty layers and a mud pellet band, followed by chocolate to reddish shale and grey to black shale with carbonaceous streaks, silty layers and a thin shell debris band in the middle.
	Succession A	13 m	Alternating chocolate to reddish shale and thinly laminated grey to black carbonaceous shale with layers of thin fragile bivalve shell hash, burrow horizons and hard nodular bands. It is capped by a nodular shell rich coquina band rich in *Venericardia beaumonti*.

organic matter and sporomorphs (pollen, spore). Twenty one samples from the lower shaly succession in the Kakdi River section (Succession A and Succession B) yielded dinocysts. Eight samples from adjoining sections (lower part of Succession A) also proved productive of dinocysts. While sporomorphs occur in moderate to good number almost throughout the Kakdi River section, dinocyst recovery in general is good in Succession A and lower part of Succession B. Dinocysts are scarce to absent in the upper part of the Succession B and Succession C (*Assilina* marl / limestone). Dinocysts or sporomorphs were not recovered from Succession D. The preservation of palynomorphs including dinocysts is generally good facilitating proper identification of age diagnostic taxa; though the number of specimens is often scarce in some samples.

In the recovered assemblages, only thirty dinoflagellate cyst taxa are identified. They generally exhibit a low diversity. Besides, due to low number of dinoflagellate cyst specimens per sample at some levels, quantitative analysis of dinocysts distribution is not feasible. In the basal part of the Succession A, the assemblages are dominated by *Thallasiphora pelagica* along with *Muratodinium fimbriatum*, besides species belonging to the *Kenleyia* complex. In the upper part of Succession A and the overlying Succession B *Polysphaeridium* spp. and *Operculodinium* spp. become more abundant with reduced frequencies of *T. pelagica* and *M. fimbriatum*. Most of the recorded species are long ranging. Nevertheless, a few age-diagnostic taxa are recognized with distribution known from different parts of the world.

Several studies on Palaeocene-Eocene dinocysts from the northern and southern hemispheres have outlined utility of this plankton group in biostratigraphy. These acid-resistant, organic-walled planktons are more useful in age determination of the successions in marginal marine settings where other microfossil groups (planktic foraminifera, nannofossils, larger benthic foraminifera) may be scarce or absent. Stratigraphic ranges of dinocysts are now well established and calibrated with standard plankton zonations and absolute time scale (Williams and Bujak, 1985; Powell, 1992; Williams *et al.*, 1993; Stover *et al.*, 1996; Hardenbol *et al.*, 1998; Williams *et al.*, 2004). Several dinocysts events are now recognized from well calibrated late Palaeocene - early Eocene global sedimentary records (Powell, 1992; Bujak and Mudge, 1994; Powell *et al.*, 1996; Mudge and Bujak, 1996; Bujak and Brinkhuis, 1998; Crouch *et al.*, 2003; Crouch and Brinkhius, 2005). Based on these records, identification of FO (First Occurrence)/LO (Last Occurrence) of the selected taxa in the Kakdi River section and other sections of the area has helped in recognition of several dinocyst events which allowed us to assess a rather precise age of the Naredi Formation (Fig. 3).

FO of *Muratodinium fimbriatum*, *Glaphyrocysta exuberans*, *Adnatosphaeridium multispinosum*, *Phelodinium magnificum* and LO of *Kenleyia* complex allow a reasonably precise age determination of the Naredi Formation. Furthermore, restricted occurrences of some species viz. *Heterolaucysta granulata*, *Operculodinium severinii* and *Ginginodinium palaeocenicum* are also important in age determination. *M. fimbriatum* is a characteristic Late Palaeocene – Early Eocene taxa with its FAD at ~ 55 Ma (Stover *et al.*, 1996) in the latest Palaeocene (late Thanetian; Powel, 1992). *M. fimbriatum* occurs almost throughout the palynologically productive part of the Naredi Formation (Succession A and Succession B), thus indicating an age not older than latest Thanetian (equivalent to P5b and NP9 in part; now Sparnacian/early Ypresian) for the basal part of the Naredi Formation. In terms of the larger foraminiferal biozonation, it would correspond to the upper part of SBZ6 ~ basal SBZ7.

Species belonging to the *Kenleyia* complex, predominantly the southern hemisphere taxa are confined to the lowermost part of the Succession A of the Naredi Formation. *K. nuda*, *K. lophophora* and *K. leptocerata* have their FAD in the basal Danian (Brinkhuis and Zachariasse, 1988; Garg *et al.*, 2006). Recent findings from Tunisia and Uzbekistan (Crouch *et al.*, 2003) indicate last known occurrence of the *Kenleyia* complex in the earliest Eocene (equivalent to lower P6, NP10b ~ NP11 zones), corresponding to larger foraminifera zones SBZ7 and SBZ8 (Serra Kiel *et al.* 1998; 2003; Molina *et al.*, 2003). Moreover, abundance of *Kenleyia* complex is recorded in the earliest Eocene (basal Waipawan: dinocyst zone NZE1a) also at Tawanui, New Zealand (Crouch and Brinkhuis, 2005) and calibrated with NP9b and mid P5 zone at the base of Ypresian above CIE (~ Sparnacian according to Aubry *et al.*, 2003). *Kenleyia* species were originally recorded from Tasmania and SW Victoria (Cookson and Eisenack, 1965a, 1967) in association with *Cerodinium dartmoorium* (LAD in earliest Ypresian, Powell, 1992; Powell *et al.*, 1996). This further supports occurrence of *Kenleyia* species in the early Ypresian and is also significant for assigning early Ypresian age to the Naredi Formation. Taxa belonging to *Kenleyia* complex are often found to be abundant across P-E transition including PETM/IETM interval having preference for warm waters (Crouch *et al.*, 2003; Crouch and Brinkhuis, 2005).

Record of *Ginginodinium palaeocenicum* in the lowermost part of the Succession A just overlying Deccan Traps is noteworthy. Known records of this species from the

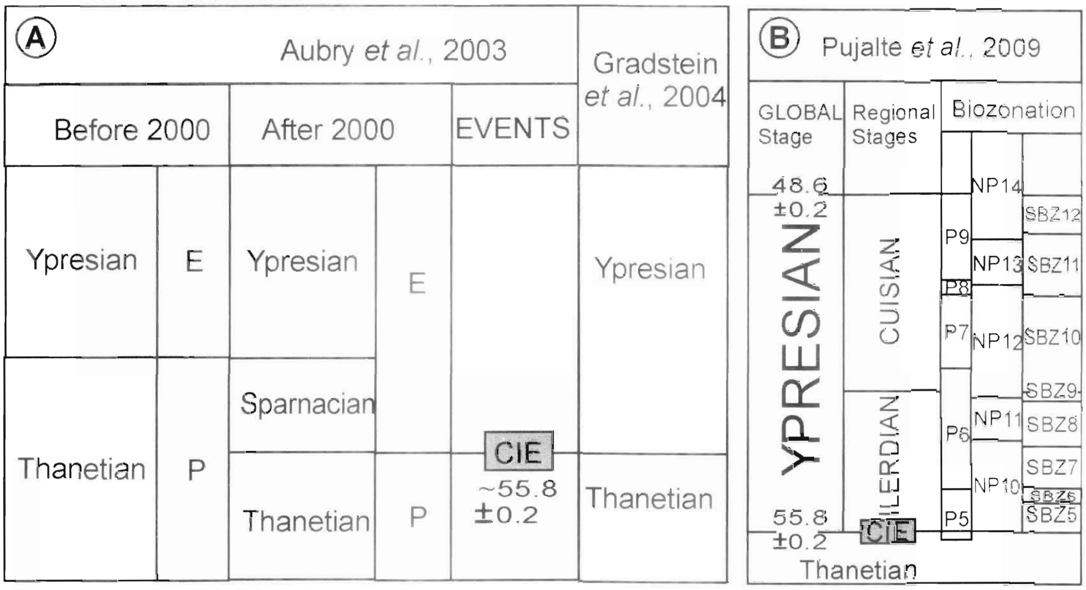

Fig. 5. A- Stage nomenclature across Palaeocene-Eocene Boundary. B- Correlation between global and regional Early Eocene Stages. (Adapted from Aubry *et al.*, 2003, Gradstein *et al.*, 2004, Scheibner and Speijer, 2009 and Pujalte *et al.*, 2009).

Pebble Point Formation, Victoria were dated as middle Palaeocene (Cookson and Eisenack, 1965b). However, the overlying River Nook Member of the Tilwyl Formation in this region has been dated on planktic foraminiferal evidence as older than Cuisian and assigned the upper Palaeocene/Ilerdian age (not older than *M. velascoenesis* zone; see McGowran, 1970). In the Naredi Formation, *G. palaeocenicum* occurs in association with forms referable to early wetzellielloids which are exactly similar to the forms documented just above the CIE and the P/E boundary in the East Khasi Hills, Meghalaya (Garg *et al.*, 2006; Prasad *et al.*, 2006, Pl. 1, Figs. 9-12). Association of these taxa suggests that the basal part of the shale succession of the Naredi Formation (Succession A) may be earliest Ypresian in age (erstwhile latest Thanetian or Sparnacian, now early Eocene).

FO of *Glaphyrocysta exuberans* in the middle part of the Succession B in the Kadki River section (Fig. 4, sample N9) is also significant in the present context as this species has its FAD at the base of Ypresian (~54 Ma, Stover *et al.*, 1996). Additionally, FO of *Phelodinium magnificum* (sample N8) and *Adnatosphaeridinum multispinosum* (sample N9) is equally important as both these taxa are known to have their FOs in the earliest Ypresian (Powell, 1992; Williams *et al.*, 1993; Stover *et al.*, 1996). However, *A. multispinosum* is recorded from the latest Thanetian NP9 nannofossil zone (*D. multiradiatus* Zone) from Gopurapuram, southern India (Jain and Garg, 1986). Occurrence of these taxa helps in placement of Thanetian/Ypresian boundary as per older nomenclature (see discussion below) in the Kakdi River section below sample N8. In addition to above, occurrence of *Heterolaucacysta granulata* and *Operculodinium severinii* in the lower and middle part of Succession B may also be age significant as both these taxa along with *M. fimbriatum* are recorded from the Imo Shale, Nigeria dated as late Palaeocene-early Eocene, equivalent to NP10 – NP11 nannofossil zones (Jan du Chêne and Adediran, 1985). The age of the Succession B is therefore suggested to be as upper part of the early Ypresian.

Thus, on dinoflagellate cysts evidence, the shale succession of the Naredi Formation (Succession A and Succession B) underlying the *Assilina* Limestone Member (Succession C) is dated as early Ypresian (55 – 54 Ma), corresponding to Ilerdian in terms of Tethyan larger foraminiferal biostratigraphy.

It is pertinent to note here, that lately the GSSP designated Palaeocene – Eocene (P/E) boundary is now placed at the base of the syn-CIE interval at Dababiya Quarry Section, Egypt (Aubry *et al.*, 2003; 2007). The CIE was initially identified within the latest Thanetian and thus the GSSP defined P/E boundary is approximately 0.8 my-1.0 m.y. older than the conventional Paleocene/Eocene boundary placed at the base of the Ypresian stage. The (chrono)stratigraphic interval of ~1 m.y. above CIE (uppermost part of late Thanetian) and underlying the traditional Ypresian Stage has been referred to the Sparnacian Stage or preferred to be included within an "extended" Ypresian (see Aubry *et al.*, 2003 for discussion). According to the International Commission on Stratigraphy,

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EXPLANATION OF PLATE I

(Scale bar represents 10 µm; England Finder position of the dinoflagellate cyst specimens is provided in parentheses following the slide numbers)

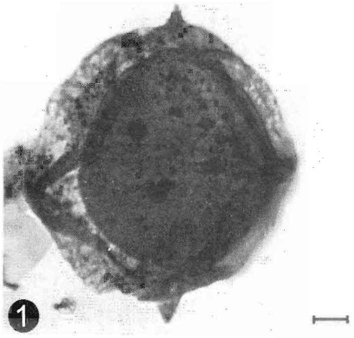
1-3,5. **Thalassiophora pelagica** (Eisenack) Eisenack and Gocht, 1960 emend. Benedek and Gocht, 1981; 1-BSIP Slide no.14420, (T48/2); 2- BSIP Slide no.14420 (P58); 3- BSIP Slide no.14420 (K60/1); 5- BSIP Slide no. 14413 (L28/1).

4,6,7-9. **Muratodinium fimbriatum** (Cookson and Eisenack) Drugg, 1970; 4- BSIP Slide no.14413 (W41.3); 6- BSIP Slide no.14425 (Q48); 7- BSIP Slide no. 14417, apical view (L60); 8-9 BSIP Slide no.14416 (O58), same specimen showing ventral and dorsal side respectively.

10. **Spiniferites** sp.; BSIP Slide no.14415 (R51/4).

11. **Achomosphaera** sp.; BSIP Slide no.14420 (N55/4).

12. **Spiniferites** sp. cf. *S. ramosus* (Ehrenberg, 1838) Loeblich and Loeblich, 1966; BSIP Slide no.14430 (K43/3).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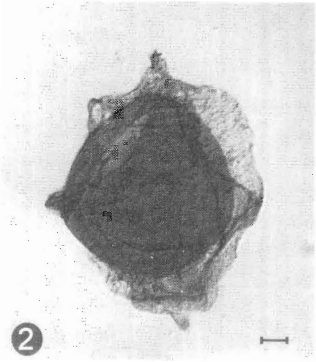
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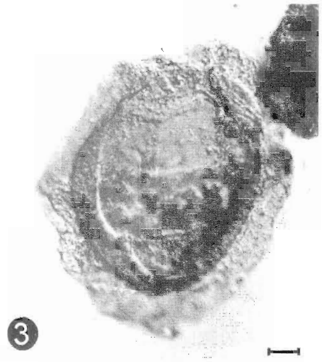
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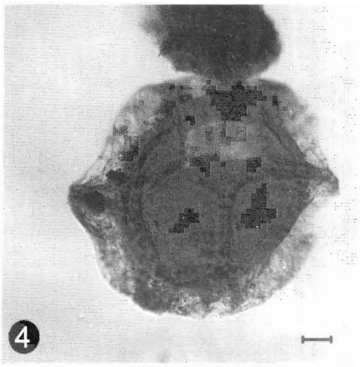
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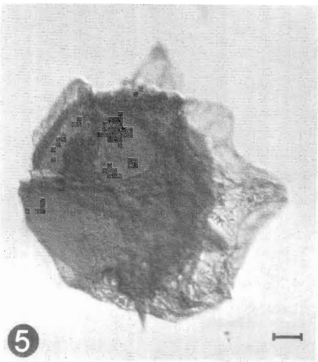
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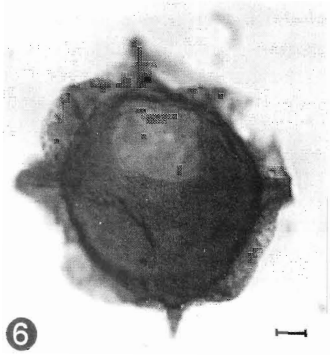
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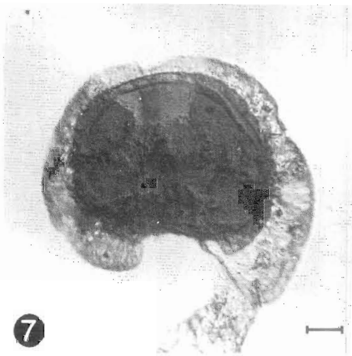
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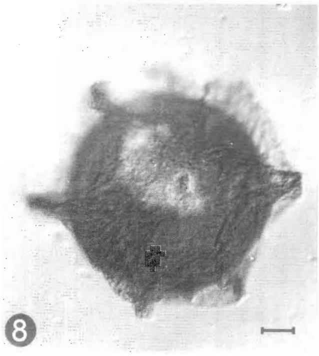
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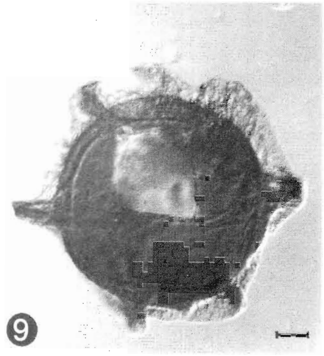
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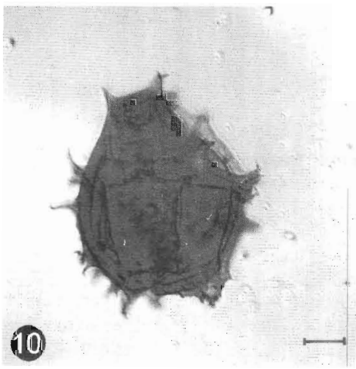
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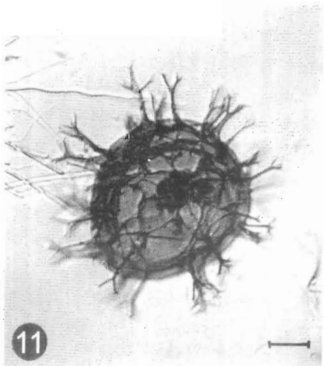
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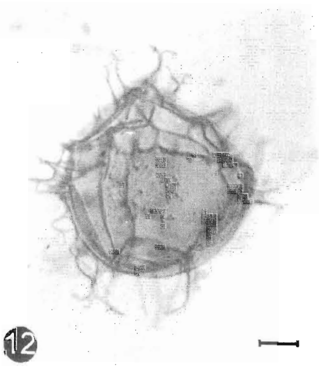
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the base of the global Ypresian Stage is now placed at the base of the CIE interval coinciding with the revised GSSP designated P/E boundary (Gradstein *et al.*, 2004; Steurbaut, 2006). Similarly, the base of the regional Ilerdian Stage has also been redefined and recalibrated in terms of larger benthic foraminiferal SBZ zones and revised early Eocene chronostratigraphic stages (Pujalte *et al.*, 2009; Scheibner *et al.*, 2005; Scheibner and Speijer, 2009). However, as it is beyond the scope of this paper to discuss various alternatives, the correlation between the global and regional early Eocene stages proposed by different workers and followed herein is shown in Fig.5. In this scheme, the time span of the global Ypresian corresponds to the joint time span of the redefined regional Ilerdian Stage plus the Cuisian Stage (Pujalte *et al.*, 2009). Thus, according to Pujalte *et al.* (2009), the bases of both the global Ypresian Stage (as accepted by the International Commission of Stratigraphy) and the redefined regional Ilerdian Stage are considered coeval for all practical purposes so that the Ilerdian Stage becomes directly correlatable to the lower part of the global Ypresian Stage which represents the early Eocene, as defined by the International Commission on Stratigraphy (Gradstein, 2004).

Checklist of Dinoflagellate cysts

Achomosphaera sp.
Adnatosphaeridium multispinosum Williams and Downie, 1966c (Pl.4, Fig. 6)
Adnatosphaeridium vittatum Williams and Downie, 1966c
Cordosphaeridium fibrospinosum Davey and Williams, 1966b
Cordosphaeridium sp. (Pl.4, Fig. 1)
Cribroperidinium pyrum Drugg, 1970 (Stover and Evitt, 1978) (Pl.3, Fig.12)
Diphyes colligerum (Deflandre and Cookson, 1955) Cookson, 1965a emend. Cookson, 1965a emend. Goodman and Witmer, 1985 (Pl.2, Figs. 8-9)
Diphyes spinula (Durgg, 1970) Stover and Evitt 1978 (Pl.2, Fig. 12)
Gen. et sp. indet (early wetzellielloid) (Pl.3, Fig. 1)
Ginginodinium palaeocenicum (Cookson and Eisenack 1965) Stover and Evitt, 1978 (Pl.3, Figs. 2-6)
Glaphyrocysta exuberans (Deflandre and Cookson, 1955) Stover and Evitt 1978 emend. Sarjeant, 1986 (Pl.4, Figs. 8-9)
Glaphyrocysta cf. *G. exuberans* (Deflandre and Cookson, 1955) Stover and Evitt 1978 emend. Sarjeant, 1986 (Pl.4, Figs. 11-12)
Heterolaucysta granulata Jan du Chêne and Adediran, 1985 (Pl.4, Figs. 10)
Hystrichokolpoma rigaudae Deflandre and Cookson, 1955 (Pl.2, Figs. 10-11)
Hystrichokolpoma sp. (Pl.2, Fig. 7)
Impagidinium sp. cf *I. ovum* (Sah et al., 1970) Stover and Evitt, 1978 (Pl.4, Figs. 2)
Kenleyia leptocerata Cookson and Eisenack, 1965 (Pl.2, Fig. 3)
Kenleyia lopophora Cookson and Eisenack, 1965 (Pl.2, Figs. 1-2)
Kenleyia nuda Cookson and Eisenack, 1965 (Pl.2, Figs. 4-5)
Kenleyia sp. (Pl.2, Fig. 6)
Lejeunecysta hyalina (Gerlach) Artzner and Dörhöfer, 1978 emend. Kjellström, 1972 emend. Sarjeant, 1984 (Pl.3, Fig. 9)
Lejeunecysta globosa Biffi and Grignani, 1983 (Pl.3, Figs. 10-11)
Muratodinium fimbriatum (Cookson and Eisenack) Drugg, 1970 (Pl.1, Figs. 4-6,7,9)
Operculodinium centrocarpum (Deflandre and Cookson) Wall, 1967 (Pl.4, Fig. 5)
Operculodinium severinii (Cookson and Cranwell) Islam, 1983 (Pl.4, Fig. 7)
Phelodinium magnificum (Stanley, 1965) Stover and Evitt, 1978 (Pl.3, Fig. 8)
Polysphaeridium subtile Davey and Williams, 1966 emend. Bujak *et al.*, 1980 (Pl.4, Figs. 3-4)
Spiniferites sp. cf. *S. ramosus* (Ehrenberg, 1838) Loeblich and Loeblich, 1966 (Pl.1, Fig. 12)
Spiniferites sp. (Pl.1, Fig. 10)
Thalassiphora pelagica (Eisenack) Eisenack and Gocht, 1960 emend. Benedek and Gocht, 1981 (Pl.1, Figs.1-3,5)

SPOROMORPHS

The palynological assemblage predominantly consists of pollen grains and is dominated by tropical rain forest elements represented by *Lakiapollis ovatus*, *Retimonocolpites thanikaimonii*, *Meliapollis navelii*, *Matanomadiasulcites maximus*, *Retitribrevicolporities* spp., *Tetracolporopollenites brevis*, *Tripilaporites* spp., *Tricolpites reticulates*, *Albertipollenites* spp., *Pellicieroipollis langenheimii*, *Spinizonocolpites bulbospinosus*, *Spinizonocolpites echinatus*, *Spinizonocolpites prominatus* and large quantity of pteridophytiic spores. Some pollen (*Spinizonocolpites*) show strong affinity with the back mangrove plant *Nypa*. The palynoflora indicates fresh-brackish swamp like environment with luxuriant growth of riparian vegetation in vicinity of the depositional area under the influence of excessive warm and humid climatic conditions. This assemblage shows similarity with the other contemporaneous assemblages of late Paleocene-early Eocene successions of western India (Samant *et al.*, 1997; Tripathi *et al.*, 2000, 2009; Morley, 2000).

PALAEOENVIRONMENT

Palaeoenvironmental significance of Dinoflagellate cyst assemblages

The lower part (Succession A) of the Gypseous Shale Member of the Naredi Formation consists of finely laminated organic matter rich sediments with lignite partings, with only scarce macrobenthic elements, indicating a low-oxygen

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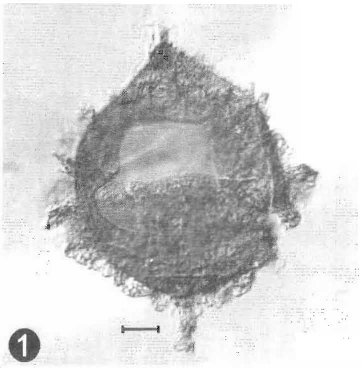
EXPLANATION OF PLATE II

(Scale bar represents 10 μm; England Finder position of the dinoflagellate cyst specimens is provided in parentheses following the slide numbers)

1-2. ***Kenleyia lophophora*** Cookson and Eisenack, 1965; 1-BSIP Slide no.14423 (S43/4); 2- BSIP Slide no.14422 (P44/3).
3. ***Kenleyia leptocerata*** Cookson and Eisenack, 1965; BSIP Slide no.14422(N47).
4-5. ***Kenleyia nuda*** Cookson and Eisenack, 1965; 4- BSIP Slide no.14424 (G38/1); 5- BSIP Slide no.14413 (W54).
6. ***Kenleyia*** sp. BSIP Slide no.14432 (J46).
7. ***Hystrichokolpomu*** sp.; BSIP Slide no.14429 (W65/1).
8-9. ***Diphyes colligerum*** (Deflandre and Cookson, 1955) Cookson, 1965a emend. Cookson, 1965a emend.Goodman and Witmer, 1985; 8- BSIP Slide no.14421 (T62); 9- BSIP Slide no.14427 (R48).
10-11. ***Hystrichokolpoma rigaudae*** Deflandre and Cookson, 1955; BSIP Slide no.14431 (J48/3), same specimen in different foci.
12. ***Diphyes spinula*** (Drugg, 1970) Stover and Evitt 1978; BSIP Slide no.14426 (G57).

Plate II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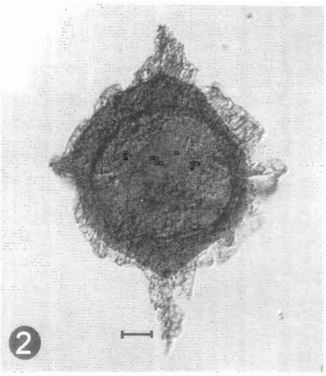
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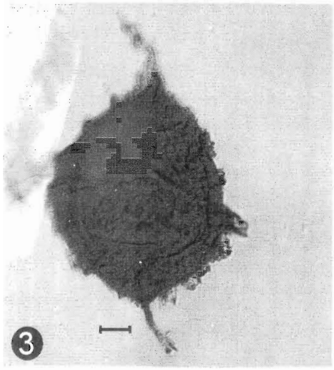
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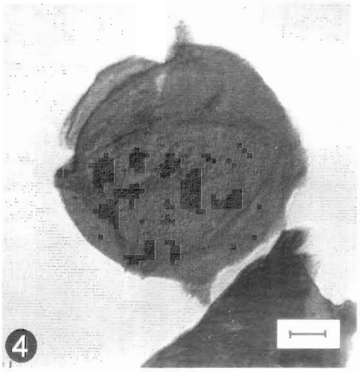
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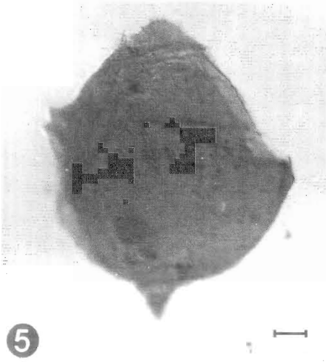
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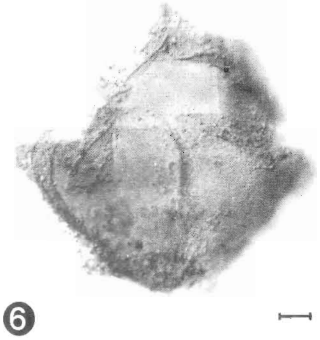
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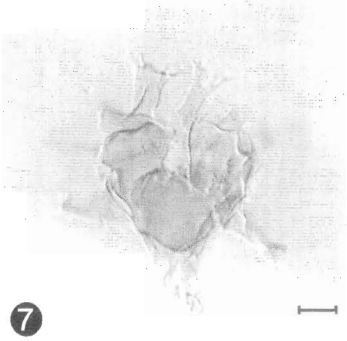
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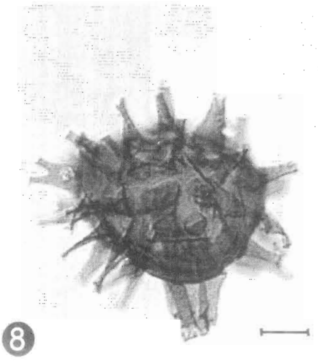
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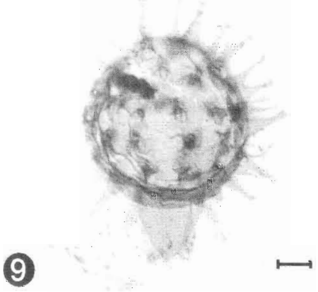
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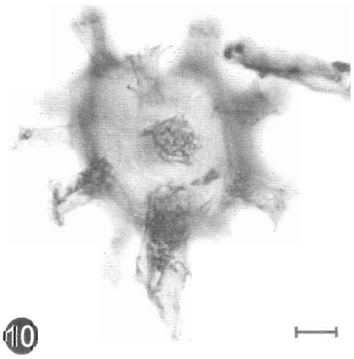
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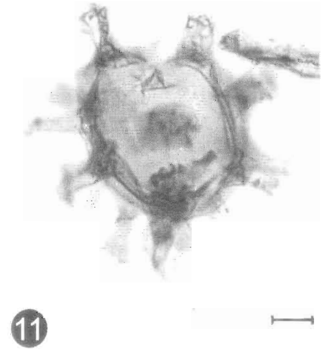
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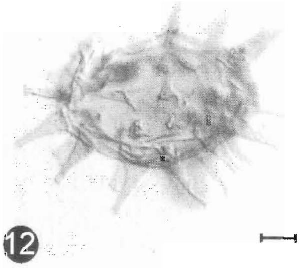
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environment. However, occurrence of foraminifer test linings and thin layers with abundant fragile bivalve shells in specific layers suggests sufficient oxygen availability. Apparently, bottom-water oxygenation fluctuated periodically and ranged from aerobic to weakly anaerobic conditions. Evidence for varying paleo-oxygenation is provided by the distribution of dinoflagellate cyst assemblages. *Thallasiphora pelagica* which predominates in the Succession A is a globally widely distributed dinocyst (see Pross, 2001) whose mass occurrence has repeatedly been reported from low-oxygen depositional environments (Gocht, 1968; Köthe, 1990; Pross, 1997, 2001). Pollen data of the Succession A suggests high precipitation under warm and humid climatic conditions in the hinterland in vicinity of the depositional site. This inference is supported by the abundance of terrestrial organic matter in this part of the succession indicating large freshwater discharge into the depositional basin. Probably, the reduced salinity in surface waters, induced by freshwater influx caused periodic stratification with restricted vertical mixing; high influx of terrestrial plant debris caused oxygen depletion in the lower water column and sediment water interface which restricted the growth of macrobenthic biota. The succession B consists of brown shale with poorly preserved organic matter. The dinocyst assemblages in the Succession B are significantly different with drastically reduced populations of *T. pelagica* and increased frequency of *Operculodinium, Polysphaeridium, Impagidinium* and *Glaphyrocysta,* indicating well oxygenated marine waters in coastal to neritic environment.

Depositional Environment

The Succession A consists mostly of greenish grey shales with dispersed shell debris. There are horizons of brown shales, which become more prominent in the upper part. Deposition of Ssuccession A took place in a low-energy shallow embayment under conditions similar to inner neritic zone. The unfossiliferous brown shales were most probably deposited in the low-energy peritidal zone with oxidizing conditions. The top of the succession A is a nodular carbonate band with *Venericardia beaumontii*. This succession represents deposition in the initial phase of a transgressive systems tract with minor cycles of shallowing and deepening.

The Succession B is predominantly made up of brown shales without visible shell debris. It contains a prominent horizon of green shales (glauconitic). Deposition took place essentially in peritidal zone of embayment with a distinct event of short-lived transgression.

The Succession C is made up of foraminiferal shale, foraminiferal carbonate and brown shale. Within the hard bands of foraminiferal limestone, there are 10-30 cm thick marl bands poor in forams; however they show dense bioturbation with well-developed *Thalassinoides* burrows. Deposition took place in upper neritic conditions with reduced supply of terrigenous clastic sediments from land, leading to development of foraminiferal banks in the shallow embayment. There are two shallowing upward cycles (foraminiferal shale - foraminiferal carbonate). Partly, deposition took place near wave base, leading to winnowing of fine-grained sediments and concentration of larger foraminifers. Deposition took place in transgressive systems tract and highstand systems tract. This succession represents peak of the early Eocene transgression in the shallow embayment where sediments of the Naredi Formation were deposited.

Thus, the Naredi Formation (Succession A to Succession C) represents deposition during early Eocene transgressive systems tract and is punctuated by small cycles within it due to changes in eustatic sea-level, local tectonics, and supply of terrigenous clastic sediments. We do not agree with the palaeobathymetry and depth fluctuations suggested by Chattoraj *et al.* (2009) during deposition of Succession A to Succession C, as red shales (brown shales) also contain marine dinoflagellates, and there are evidences of current and wave action. We would like to argue that deposition took place in a coastal embayment in water depths of 2 m to about 10 m. More detailed facies analysis of the Naredi Formation is required to interpret palaeobathymetry and cyclicity of the lithofacies.

The Succession-D making top of the Naredi Formation is made up of ferrugenous shales, probably deposited under supratidal conditions. The probable unconformity between the Naredi and the Harudi formations (Biswas, 1992) may represent a sequence boundary. Systematic sedimentological studies are required to reconstruct sequence stratigraphic framework.

DISCUSSION

The early Eocene age assignment of the Naredi Formation by previous investigators has been based primarily on larger foraminifera (*Assilina spinosa, A. daviesi, Nummulites burdigalensis, N. globulus*) from the *Assilina* Limestone Member in the middle part of the Naredi Formation, overlying the Gypseous Shale Member exposed in Kakdi River and elsewhere (Tewari, 1952; Tandon, 1962; Mohan and Gupta, 1968; Raju, 1971; Biswas and Raju, 1973; Singh and Singh, 1981, Shukla, 2008). However, Tandon (1971) assigned Palaeocene age to the lower part of the gypseous shale based on his record of *Venericardia beaumonti* and *Venericardia* cf *V. vrendenburgi* in the shell-rich nodular clay and shale overlying the Deccan Traps. Although planktic foraminifera

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EXPLANATION OF PLATE III

(Scale bar represents 10 μm; England Finder position of the dinoflagellate cyst specimens is provided in parentheses following the slide numbers)

1. Gen et sp. indet. (early wetzellielloid); BSIP Slide no.14418 (S66).

2-6. ***Ginginodinium palaeocenicum*** (Cookson and Eisenack 1965) Stover and Evitt, 1978; 2- BSIP Slide no.14418 (Q51/2); 3- BSIP Slide no.14419 (Q62/1);4- BSIP Slide no.14418 (G41/3); 5- BSIP Slide no.14419 (H36); 6- BSIP Slide no.14419 (M33/1).

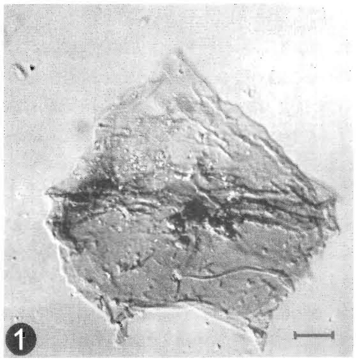
7. **Acritarch**; BSIP Slide no.14428 (Q64/2).

8. ***Phelodinium magnificum*** (Stanley, 1965) Stover and Evitt, 1978; BSIP Slide no.14431 (G40/3).

9. ***Lejeunecysta hyalina*** (Gerlach) Artzner and Dörhöfer, 1978 emend. Kjellström, 1972 emend. Sarjeant, 1984; BSIP Slide no.14418 (T52/2).

10-11. ***Lejeunecysta globosa*** Biffi and Grignani, 1983; 10- BSIP Slide no.13511 (E59); 11- BSIP Slide no.14413 (N36/3).

12. ***Cribroperidinium pyrum*** Drugg, 1970 (Stover and Evitt, 1978); BSIP Slide no.14420 (S46/4).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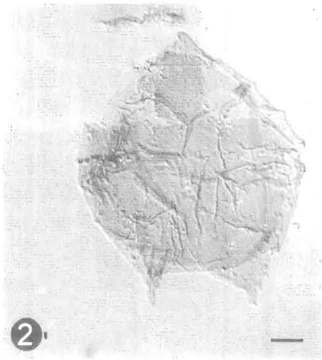
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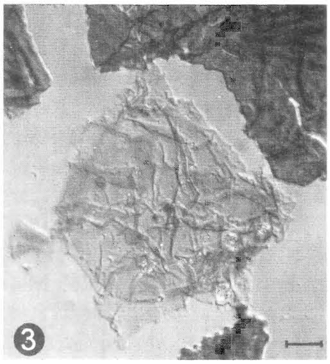
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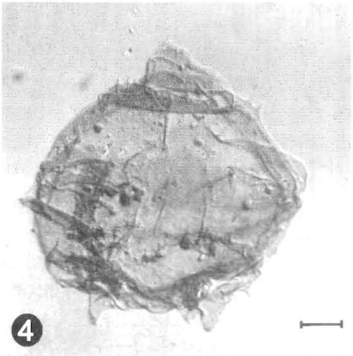
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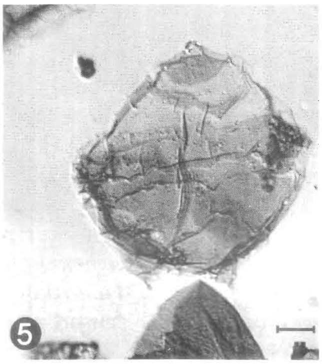
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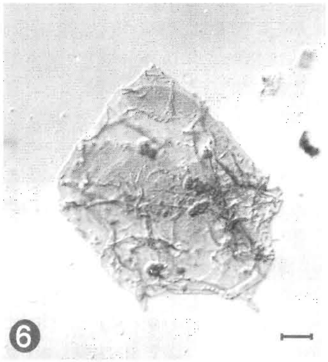
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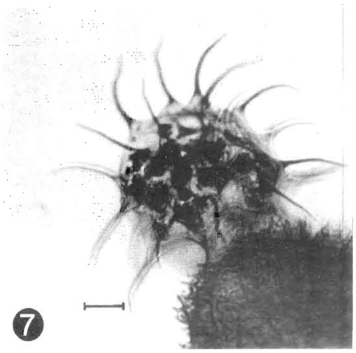
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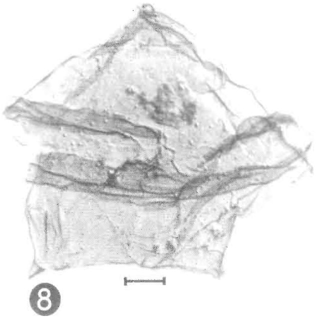
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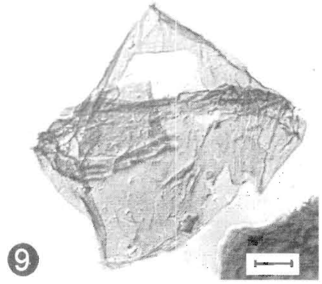
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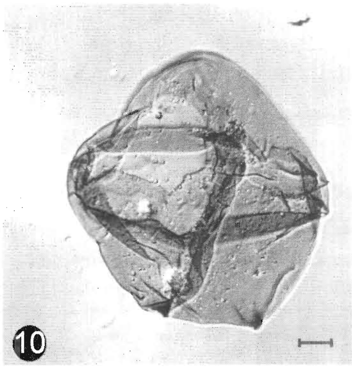
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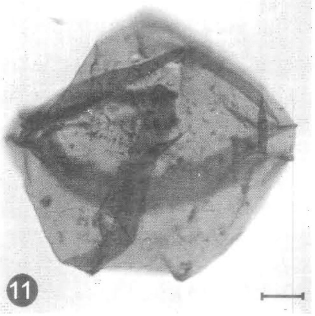
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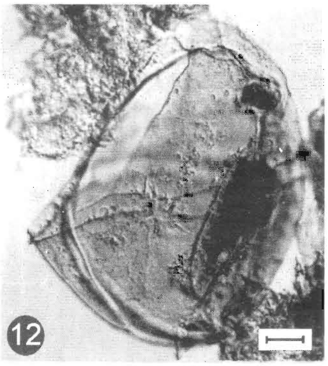
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GARG, PRASAD, THAKUR, SINGH AND ATEEQUZZAMAN (globigerines and globorotalids) were subsequently reported (Tandon *et al.*, 1980) and used to suggest Palaeocene (late Danian-Landenian) age, these evidences were not accepted by later workers due to very small nature of the foraminiferal tests and poor preservation and illustrations of the foraminifer specimens (Ray *et al.*, 1984; Jafar and Rai, 1994). Occurrence of late Palaeocene planktic foraminifera characterising upper P4 and P5- P6 zones in association with larger foraminifera is reported in the subsurface succession overlying the Deccan Traps from the offshore Kutch region and have been correlated with the Naredi Formation in the Kutch Mainland based on the similar larger foraminiferal assemblages (Pandey and Ravindran, 1988). More recently, *Gumbelitria*, *Cheilogumbelina* and *Nummulites* besides juvenile globigerines and globorotalids have been reported from the Gypseous Shale Member underlying the *Assilina* Limestone Member, but these have not been used for any age determination and late Palaeocene-early Eocene age has been broadly assigned to the Naredi Formation (Chattoraj *et al.*, 2009). Thus, datable larger foraminifera from the *Assilina* Limestone Member provided age only to the middle part of the Naredi Formation (*N. burdigalensis cantabricus*, SBZ11, middle Cuisian; Punekar and Saraswati 2010), while age of the Gypseous Shale Member still remained questionable due to the absence of any direct evidence. The dinocysts assemblages in the present study recorded from several levels of the Gypseous Shale Member (Succession A and Succession B) of the Naredi Formation, including its basalmost part suggest an early Ypresian age (~55 Ma to ~54 Ma; corresponding to erstwhile latest Thanetian or Sparnacian).

In the mainland Gujarat also, deposits of early Palaeogene transgression are present. These deposits are represented by carbonaceous shale, shale and lignite, which directly overlie the Deccan Traps. In the Vastan lignite mine near Surat, this lignite bearing succession has been studied and dinoflagellate cyst assemblages have been recorded. The lignite-bearing succession of Vastan is assigned the age of latest Thanetian or Sparnacian (~55 Ma) to middle Ypresian (~52Ma), correlated with Ilerdian-early Cuisian based on dinoflagellate cysts (Garg *et al.*, 2008). This age assignment can be redesignated as early to middle Ypresian corresponding to Ilerdian-early Cuisian as per the early Eocene chronostratigraphic terminology followed by International Commission of Stratigraphy (see Fig. 5). The dinocyst assemblages of the Naredi Formation and the Vastan Lignite mine show many similarities and have several common age marker taxa. Recently, Punekar and Saraswati (2010) have reiterated basal Cuisian age (lower part of SBZ 10) for the entire sedimentary succession of Vastan and have ruled out presence of latest Palaeocene-earliest Eocene or Ilerdian strata in the Vastan mine. It may be pointed out that age proposed by Punekar and Saraswati (2010) is based on the datable fossils occurring almost 35m above the base of the Palaeogene sedimentary succession exposed in the Vastan mine; they have not recorded any age-diagnostic fossil from the entire ~35m thick lower succession. The age proposed by Punekar and Saraswati (2010), thus, cannot be considered valid for the lower part of the Vastan succession which contains diagnostic dinoflagellate cysts indicating early-middle Ypresian (Ilerdian-early Cuisian) age.

In the Vastan Lignite succession and also in the Naredi Formation, *Apectodinium* species (including the late Thanetian index marker *A. augustum*) are not recorded. *Apectodinium* dominated dinocyst assemblages occur commonly in the coal-bearing Lakadong Sandstone straddling the Palaeocene-Eocene boundary in the Khasi Hills, Meghalaya, northeastern India (Garg and Khowaja- Ateequzzaman, 2000; Garg *et al.*, 2006; Prasad *et al.*, 2006). The abundance of *Apectodinium* and related dinocysts in the coal bearing successions in the Khasi Hills are associated with the PETM/IETM event (Prasad *et al.*, 2006; 2009). In the north-western part of the Kutch Basin, a rich suite of *Apectodinium* species (*A. paniculatum*, *A. hyperacanthum*, *A. quinquelatum*, *A. parvum*, *A homomorphum*, *Apectodinium* cf. *A. augustum*) indicating late Thanetian-early Ypresian age has been recorded from the subsurface Lakhpat Bore Hole-1 between 204-207 m and 222-225 m depth (R. Garg, *personal observation*, *unpublished*). Scarce dinoflagellate cyst assemblage with *Apectodinium* is observed in lignite-bearing succession at Panandhro (R. Garg, *personal observation*, *unpublished*) which is considered to be equivalent to the Naredi Formation by Biswas (1992). In the adjoining area, occurrence of dinoflagellate cysts with *Apectodinium* spp. has been noted in lignite-bearing successions of Akli in Bikaner, Rajasthan (Sahni *et al.*, 2004), indicating late Thanetian/ Sparnacian to early Ypresian (now early Ypresian) age similar to that of the Naredi Formation.

The dinoflagellate cyst evidences from various parts of northwestern India suggest that early Palaeogene marine transgressive event post-dating the Deccan Trap activity is most probably the earliest Ypresian (~55 Ma) in age (latest Thanetian-Sparnacian in older terminology). Significantly, the dinoflagellate cyst assemblages reported from coeval successions in Salt Range, Pakistan (Edwards, 1993) have in addition to *Apectodinium*, several taxa common to the Naredi and the Vastan successions. It can, therefore, be argued that the late Palaeocene-early Eocene deposits exposed along northwestern margin of the Indian Subcontinent have

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EXPLANATION OF PLATE IV

(Scale bar represents 10 µm; England Finder position of the dinoflagellate cyst specimens is provided in parentheses following the slide numbers)

1. ***Cordosphaeridium*** sp.; BSIP Slide no.14428 (K36).
2. ***Impagidinium*** sp. cf ***I. ovum*** (Sah *et al.*, 1970) Stover and Evitt, 1978; BSIP Slide no.14420 (G40/4).

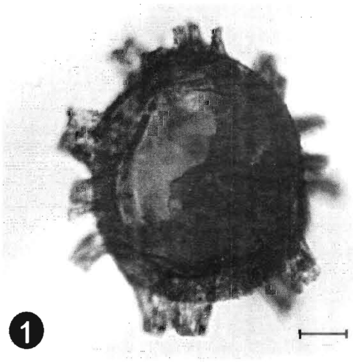
3-4. ***Polysphaeridium subtile*** Davey and Williams, 1966 emend. Bujak *et al.*, 1980;3-BSIP Slide no.14420 (R55/2); 4- BSIP Slide no.14418 (G52/2).

5. ***Operculodinium centrocarpum*** (Deflandre and Cookson) Wall, 1967; BSIP Slide no.14427 (P48/1).
6. ***Adnatosphaeridium multispinosum*** Williams and Downie, 1966c; BSIP Slide no.14430 (D54).
7. ***Operculodinium severinii*** (Cookson and Cranwell) Islam, 1983; BSIP Slide no.14428 (E63/1).

8-9. ***Glaphyrocysta exuberans*** (Deflandre and Cookson, 1955) Stover and Evitt 1978 emend. Sarjeant, 1986; BSIP Slide no.14431 (K46), same specimen in different foci.

10. ***Heterotaucysta granulata*** Jan du Chêne and Adediran, 1985; BSIP Slide no.14430 (S52/2).

11-12. ***Glaphyrocysta*** cf. ***G. exuberans*** (Deflandre and Cookson, 1955) Stover and Evitt 1978 emend. Sarjeant, 1986; BSIP Slide no.14431 (P44), same specimen in different foci.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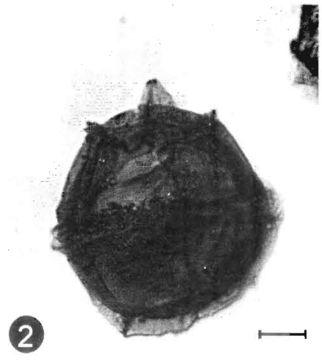
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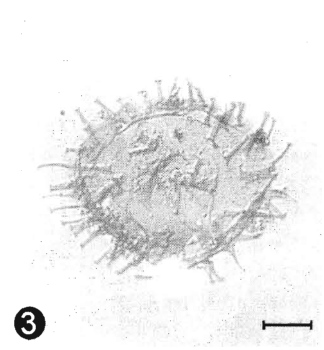
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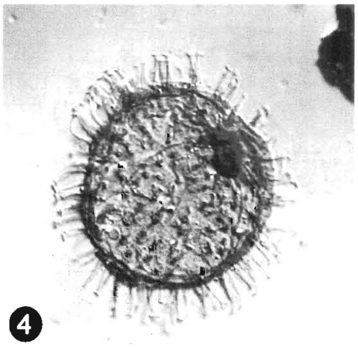
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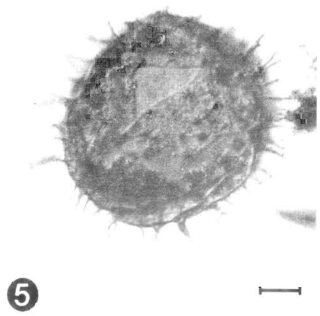
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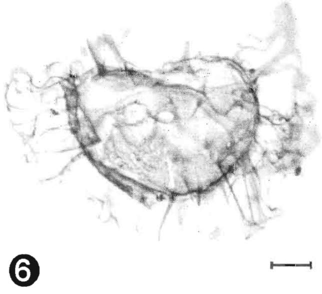
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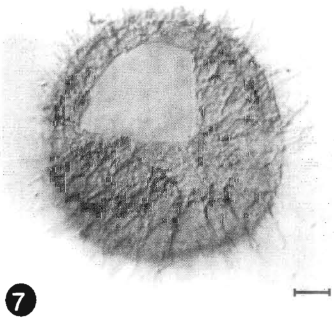
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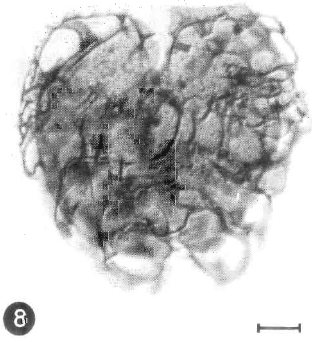
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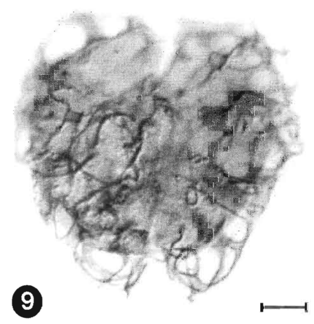
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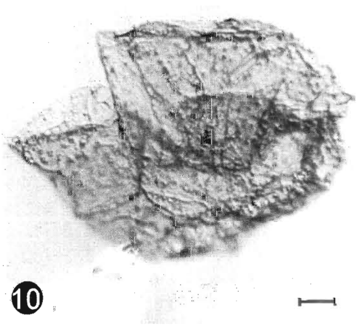
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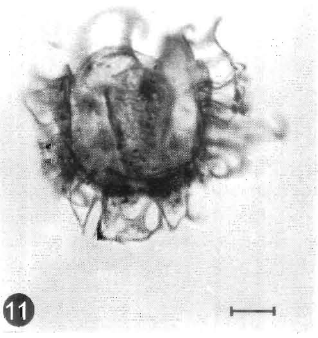
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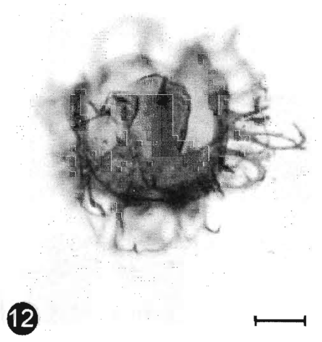
12

essentially similar dinoflagellate cyst assemblages, albeit showing some variations in diversity, vertical distribution and abundance related to variation in coastal depositional environments. It supports the viewpoint that the marine Naredi Formation and widespread lignite-bearing successions at the base of the early Palaeogene succession in Kutch, Cambay and western Rajasthan in the western region of the Indian Subcontinent are in part coeval and broadly of the same age (Sahni *et al.*, 2004).

During early Palaeogene times, the widespread peat accumulation occurred in the epicontinental seaways fringing the northeastern and western margins of the Indian subcontinent lying within the equatorial zone. On the western margin of India (Barmer, Jaisalmer, Bikaner, Kutch, Gujarat), the sedimentary successions contain thick lignite deposits, whereas in the north (Jammu, Himachal Pradesh) and the northeastern region (Garo-Khasi-Jaintia Hills in Meghalaya) the successions are interspersed with thin, discontinuous coal seams. The lignite-bearing successions in the western margins are characteristically followed by larger foraminifera rich carbonate horizons (limestone and marls). In most of the sections in western India, the age based on larger foraminifera of these carbonate horizons has generally been used to assign age to the underlying lignite-bearing muddy succession also. The recovery of rich dinoflagellate cyst assemblages from the lignite bearing muddy sediments straddling the Palaeocene-Eocene boundary in different parts of the Indian Subcontinent has provided a considerable refinement to the age of these successions. Earlier, the age of these deposits was based indirectly on larger foraminiferal evidence which occurs at stratigraphically higher level much younger in age. Dinoflagellate cyst distribution is now known to be closely related to the global warming during P-E transition (Bujak and Brinkhuis, 1998; Crouch *et al.*, 2001, 2003; Iakovleva *et al.*, 2001). The dinocyst-based age assignment suggests that the lignite-bearing successions in western India are related to the marine transgressive event with frequent sea level fluctuations during the "green house" world of the early Palaeogene times during or immediately after the PETM global warming event and during other early Eocene hyperthermal events.

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REFERENCES

Aubry, M.-P., Berggren, W.A., Van Couvering, J.A., Ali, J., Brinkhuis, H., Cramer, B., Kent, D.V., Swisher, C.C. III, Gingerich, P.R., Heilmann-Clausen, C., Knox, R.W.O'B., Laga, P., Steurbaut, E., Stott, L.D. and Thiry, M. 2003. Chronostratigraphic Terminology at the Palaeocene –Eocene Boundary, p. 551-566. In: *Causes and consequences of Globally Warm Climates in the Early Palaeogene* (Eds. Wing, S.L., Gingerich, P.R., Schmitz B., and Thomas E.), Geological Society of America (GSA) Special Paper, **369**.

Aubry, M.-P., Ouda, K., Dupuis, C., Berggren, W. A.,Van Couvering, J. A. and the Members of the Working Group on the Paleocene/Eocene boundary, 2007. The Global Standard Stratotype-section and Point (GSSP) for the base of the Eocene Series in the Dababiya section (Egypt). *Episodes*, **30**(4): 271-286.

Biswas, S.K. 1965. A new classification of the Tertiary rocks of Kutch, western India. *Bulletin of Geological, Mining and Metallurgical Society of India*, **35**: 1-6.

Biswas, S.K. 1972. Time stratigraphic classification of the Tertiary rocks of Kutch- Revision and Amendments. *Quarterly Journal of Geological, Mining and Metallurgical Society of India*, **44** (3): 221-224.

Biswas, S.K. 1992. Tertiary Stratigraphy of Kutch. *Journal of the Palaeontological Society of India*, **37**: 1-29.

Biswas, S.K. and Raju D.S.N. 1973. The rock-stratigraphic classification of the Tertiary sediments of Kutch. *Bulletin Oil & Natural Gas Commission*, **10**(1-2): 37-45.

Brinkhuis, H. and Zachariasse, W. J. 1988. Dinoflagellate cysts, sea level changes and planktonic foraminifera across the Cretaceous-Tertiary boundary at El Haria, northwest Tunisia. *Marine Micropaleontology*, **13**: 153-191.

Bujak, J. P. and Brinkhuis, H. 1998. Global warming and dinocyst changes across the Paleocene/Eocene boundary, p. 277-295. In: *Late Paleocene-Early Eocene Climatic and Biotic Events in the Marine and Terrestrial Records* (Eds. Aubry, M. P., Lucas, S. and Berggren, W.), New York (Columbia University Press).

Bujak, J. P. and Mudge, D.C. 1994. A high-resolution Eocene dinocyst zonation. *Journal Geological Society*, *London, U.K.*, **151**: 449-462.

Chattoraj, S. L., Banerjee, S. and Saraswati P.K. 2009. Glauconites from the Late Palaeocene - Early Eocene Naredi Formation, western Kutch and their genetic implications. *Journal of the Geological Society of India*, **73**: 567-574.

Cookson, I. C. and Eisennack, A. 1965a. Microplankton from the Dartmoor Formation, SW Victoria. *Proceedings Royal Society Victoria*, **79**: 133-137.

Cookson, I. C. and Eisennack, A. 1965b. Microplankton from the Pebble Point Formation, south-western Victoria. *Proceedings Royal Society Victoria*, **79**: 139-146.

Cookson, I. C. and Eisennack, A. 1967. Some early Tertiary microplankton and pollen grains from a deposit near Strahan, Western Tasmania. *Proceedings Royal Society Victoria*, **80:** 131-140.

Courtillot, V., Besse, J., Vandamme, D., Montigny, R., Jaeger, J.-J., and Cappetta, H., 1986. Deccan flood basalts at the Cretaceous/Tertiary boundary? *Earth and Planetary Science Letters*, **80:** 361-374

Courtillot, V., Feraud, G., Maluski, H., Vandamme, D., Moreau, M.G., and Besse, J., 1988. Deccan flood basalts and the Cretaceous/Tertiary boundary. *Nature*, **333:** 843-846.

Crouch, E. M and Brinkhuis, H. 2005. Environmental change across the Paleocene-Eocene transition from eastern New Zealand: A marine palynological approach. *Marine Micropaleontology*, **56**: 138-160.

Crouch, E.M., Brinkhuis, H., Visscher, H., Adatte T. and Bolle, M. P. 2003. Late Palaeocene-Early Eocene dinoflagellate cysts records from the Tethys: further observations on the global distribution of *Apectodinium*, p. 113-131. In: *Causes and consequences of Globally Warm Climates in the Early Palaeogene* (Eds. Wing, S.L., Gingerich, P.R., Schmitz, B. and Thomas, E.), *Geological Society of America (GSA)*. *Special. Paper*, **369**.

Crouch, E.M., Heilman-Clausen,C., Brinkhuis, H., Morgans, H.E.G., Rogers, K.M., Egger, H. and Schmitz, B. 2001. Global dinoflagellate cyst event associated with the late Paleocene thermal maximum. *Geology*, **29**(4): 315-318.

Edwards, L.E. 1993. Paleocene and Eocene Dinocysts from the Salt Range, Punjab, Northern Pakistan. p.1-20. In: *Regional Studies of the Potwar Plateau Area, Northern Pakistan. Chapter C* (Eds. Peter D. Warwick and Bruce R. Wardlaw). U.S. Geological Survey Bulletin 2078–C.

Garg, R. 1991. Palaeocene dinoflagellate cysts from Kutch. *Birbal Sahni Birth Centenary Conference*, **BSIP, Lucknow, Abstracts**: 37.

Garg, R. and Khowaja-Ateequzzaman. 2000. Dinoflagellate cysts from the Lakadong Sandstone, Cherrapunji area: biostratigraphical and palaeoenvironmental significance and relevance to sea level changes in the Upper Palaeocene of the Khasi Hills, South Shillong Plateau, India. *Palaeobotanist*, **49**: 461-484.

Garg, R., Khowaja-Ateequzzaman, and Prasad, V. 2006. Significant dinoflagellate cyst biohorizons in the Upper Cretaceous-Palaeocene succession of the Khasi Hills, Meghalaya, northeastern India. *Journal of the Geological Society of India*, **67**: 737-747.

Garg, R. Khowaja-Ateequzzaman, Prasad V., Tripathi S.K.M., Singh, I.B., Jauhri, A.K and Bajpai, S. 2008. Age diagnostic dinoflagellate cysts from the lignite-bearing sediments of the Vastan

Lignite mine, Surat district Gujarat, western India. *Journal of the Palaeontological Society of India*, **53**: 99-105.

Gertsch, B., Keller, G., Adatte, T., Garg, R. Prasad, V., Fleitmann, D. and Berner, Z. 2011. Environmental effects of Deccan volcanism across the Cretaceous-Tertiary transition in Meghalaya, India. *Earth and Planetary Science Letters*, **310**: 272-285.

Gocht, H., 1968. Zur Morphologie und Ontogenie von *Thalassiphora* (Dinoflagellata). *Palaeontographica B*. **129**: 149-156.

Gradstein, F.M., Ogg, J.G., Smith, A.G., Bleeker, W. and Lourens, L.J. 2004. A new geologic time scale with special reference to the Precambrian and Neogene. *Episodes*. **27**: 83-100.

Hardenbol, J., Thierry, J., Farley, M.B., Jacquin, T., De Graciansky, P. C. and **Vail, P.** 1998 Mesozoic and Cenozoic sequence chronostratigraphic framework of European basins, p. 3-13, p. 763-781. In: *Mesozoic and Cenozoic Sequence Stratigraphy of the European Basins* (Eds. Graciansky, P.C. de, Hardenbol, J., Jacquin, T., and Vail, P.), *Society of Economic Palaeontologist and Mineralogist Special Publication*, **60**.

Iakovleva, A. I., Brinkhuis, H. and Cavagnetto, C. 2001. Late Palaeocene-Early Eocene dinoflagellate cysts from the Turgay Strait, Kazakhstan; correlations across ancient seaways. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **172**: 243-268.

Jafar, S.A. and Rai, J. 1994. Late Middle Eocene (Bartonian) calcareous nannofossils and its bearing on coeval post-trappean transgressive event in Kutch Basin, western India. *Geophytology*, **24**: 23-42.

Jain, K.P. and Garg, R. 1986. Upper Palaeocene Dinoflagellate cysts and Acritarchs from Vriddhachalam, Cauvery Basin, Southern India. *Palaeontographica* **B**, **198**: 101-132

Jain, K.P. and Tandon, K.K. 1981. Dinoflagellate and acritarch biostratigraphy of the Middle Eocene rocks of a part of south-western Kachchh. India. *Journal of the Palaeontological Society of India*. **26**: 6-21.

Jan du Chêne, R. E. and Adediran, S. A. 1985. Late Palaeocene to early Eocene dinoflagellates from Nigeria. *Cahiers de Micropaléontologie*. **3**: 1-38.

Keller, G., Adatte T., Gardin, S., Bartolini, A., Bajpai, S., 2008. Main Deccan volcanism phase ends near the K-T boundary: Evidence from the Krishna- Godavari Basin, SE India. *Earth and Planetary Science Letters*. **268**: 293-313.

Keller, G., Sahni, A., and Bajpai, S. 2009. Deccan volcanism, the K-T mass extinction and dinosaurs. *Journal of Biosciences*, **34:** 709-728.

Keller, G., Reddy, A.N., Jaiprakash, B.C., Adatte, T., Gertsch, B., Bajpai S., Garg, R., Prasad, V., Upadhyay, H. and Bhowmick, P.K. 2009. Deccan Volcanism likely cause for K-T Mass Extinction. *Geophysical Research Abstracts*, **11**, EGU2009-2557.

Köthe, A. 1990. Paleogene dinoflagellates from Northwest Germany - biostratigraphy and paleoenvironment. *Geologisches Jahrbuch A*, **118**: 3-111.

McLean, D. 1985. Deccan Traps Mantle Degassing in the Terminal Cretaceous Marine Extinctions. *Cretaceous Research*, **6:** 235-259.

McGowran, B. 1970. Late Palaeocene in the Otway Basin: biostratigraphy and age of key microfaunas. *Transactions Royal Society of Southern Australia*. **94**: 1-13.

Medlicott, H.B. and Blanford, W.T. 1879. *A manual of the geology of India*. **1**.

Mohan Madan and **Gupta, S.C.** 1968. The microfauna and the age of the "Gypseous shales", Western Kutch, India. *Contributions Cushman Foundation for Foraminiferal Research*. **19**(1): 21-26.

Molina, E., Angori, E., Arenillas, I., Brinkhuis, H., Crouch, E. M., Luterbacher, H., Monechi, S. and Schmitz, B. 2003. Correlation between the Paleocene/Eocene boundary and the Ilerdian at Campo, Spain. *Revue de Micropaleontology*, **46**: 95-109.

Morley, R J. 2000. *Origin and evolution of tropical rainforests*. John Wiley.

Mudge, D.C. and Bujak, J. P. 1996. Palaeocene biostratigraphy of and sequence stratigraphy of the UK central North Sea. *Marine and Petroleum Geology*. **13**:195-312.

Officer, C.B. and Drake, C.L. 1985. Terminal Cretaceous Environmental Events. *Science*, **227**: 1161-1167.

Pandey, J. and Ravindran, C.N. 1988. Foraminiferal controls in the Indian Palaeocene. p. 124-184. In: *Proceedings Symposium on Palaeocene of India : Limits and Subdivisions* (Ed. Maheshwari, H.K.), Lucknow.

Powell, A. J. 1992. Dinoflagellate cysts of the Tertiary System, p. 155-252. In: *A Stratigraphic Index of dinoflagellate cysts* (Ed. Powell, A.J.), Chapman and Hall, London.

Powell, A. J., Brinkhuis, H., and Bujak, J. P. 1996. Upper Palaeocene-lower Eocene dinoflagellate cyst sequence biostratigraphy of south-east England. p. 145-183. In: *Correlation of the early Palaeogene in northwest Europe* (Eds. Knox, R.W. O'B, Corfield, R.M. and Dunay, R.E.), Geological Society (London), Special Publication, **101**.

Prasad, V., Farooqui, A, Tripathi, S.K.M., Garg, R. and Thakur, B. 2009. Evidence of Late Paleocene-Early Eocene equatorial rain forest refugia in southern Western Ghats, India. *Journal of Biosciences*, **34**: 771-979.

Prasad, V., Garg, R., Khowaja-Ateequzzaman, Singh, I. B. and Joachimski, M. 2006. *Apectodinium* acme and the palynofacies characteristics in the latest Palaeocene-earliest Eocene of northeastern India: Biotic response to the Palaeocene-Eocene Thermal Maxima (PETM) in low latitude. *Journal of the Palaeontological Society of India*, **51**: 75-91.

Pross, J. 1997. Aquatische Palynomorphe im Rupel des Mainzer Beckens (Oligozän Südwestdeutschland): Paläoökologie, Biostratigraphie und Taxonomie. *Tübinger Mikropaläontologische Mitteilungen*, **15**: 1-200.

Pross, J. 2001. Palaeo-oxygenation in Tertiary epieric seas: evidence from dinoflagellate cysts. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **166**:369-381.

Pujalte ,V., Baceta J.I., Schmitz, B., Orue-etxebarria, X., Payros, A., Bernaola, G., Apellaniz, E., Caballero, F., Robador, A. Serra-Kiel, J. and Tosquella, J. 2009. Redefinition of the Ilerdian Stage (early Eocene). *Geologica Acta*, **7**: 177-194.

Punekar, J. and Saraswati, P.K. 2010. Age of the Vastan Lignite in Context of Some Oldest Cenozoic Fossil Mammals from India. *Journal of the Geological Society of India*. **76** (1): 63-68.

Rai, J. 1997. Scanning electron microscopic studies of the late Middle Eocene (Bartonian) calcareous nannofossils from the Kutch Basin, western India. *Journal of the Palaeontological Society of India*. **42**: 147-167

Rai, J. 2007. Middle Eocene calcareous nannofossil biostratigraphy and taxonomy of onland Kutch Basin, western India. *The Palaeobotanist*, **56**: 29-116.

Raju, D.S.N. 1974. Observation on the Eocene, Oligocene and Miocene foraminiferal biostratigraphy of Kutch, Western India. *Publications Centre of Advance Study in Geology*, Panjab University, Chandigarh. **10**: 136-155.

Raju, D.S.N., Guha, D.K., Bedi, T.S., Kumar, P. and Bhatt, D.K. 1979. Microfauna, biostratigraphy and palaeoecology of the Middle Eocene to Oligocene and Miocene sediments in Western India. *Publications Centre of Advance Study in Geology*, Panjab University, Chandigarh. **7**: 155-178

Ray, A.K., Ghosh, C.C., Sen, P., Ghosh, A., Nag. S., Saha, D. and Chowdhury, A. 1984. Palaeogene of Kutch – An Alternative View on the Initial Part of the Sequence. *Indian Journal of Earth Sciences*, **11**:207-224.

Sahni, A., Rana, R.S., Loyal,R.S., Saraswati, P.K., Mathur, S.K., Rose, K.D., Tripathi, S. K. M., and Garg, R. 2004. Western margin Palaeocene-Lower Eocene Lignites: Biostratigraphic and palaeoecological constraints. *2nd Association of Petroleum Geologist Conference*. Khajuraho, India: 1-18.

Samant, B. and **Phadtre, N. R.** 1997. Stratigraphic palynoflora of the early Eocene Rajpardi lignite, Gujarat and the lower age limit of the Tarkeshwar Formation of South Cambay Basin, India. *Palaeontographica*, **B 245:** 1–108.

Samanta, B.K. 1970. Middle Eocene planktic foraminifera from Lakhpat, Kutch, Western India. *Micropaleontology*, **16**:185-215.

Saraswati, P.K. and Banerjee, R.K. 1995. Post-Trappean sedimentation history of the north western Kutch. *Proceedings X Indian Colloquium Micropalaeontology and Stratigraphy*, pp.377-390.

Scheibner, C. and Speijer, R.P., 2009: Recalibration of the Tethyan shallow-benthic zonation across the Paleocene-Eocene boundary: the Egyptian record. *Geologica Acta*, 7(1-2): 195-214.

Scheibner, C., Speijer, R.P., Marzouk, A., 2005. Larger foraminiferal turnover during the Paleocene/ Eocene thermal maximum and paleoclimatic control on the evolution of platform ecosystems. *Geology*, **33**: 493-496.

Sengupta, B.K. 1964. Tertiary biostratigraphy of a part of north-western Kutch. *Journal of the Geological Society of India* **5**:138-158.