Late Middle Eocene (Bartonian) calcareous nannofossils and its bearing on coeval post-trappean transgressive event in Kutch basin, western India*

S.A. Jafar & J. Rai

Birbal Sahni Institute of Palaeobotany, 53 University Road, Lucknow 226007, India

Jafar, S.A. & 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**(1):23-42.

A rich nannofossil assemblage comprising sixty-four species including two species of calcareous dinoflagellates, is described from Harudi Formation exposed at the type locality. The nannofossil assemblage is typical of low latitude, nearshore, shallow marine environment and can be assigned to NP 17: *Discoaster saipanensis* zone, emended herein to include upper part of NP 16: *Discoaster tani-nodifer* zone (Martini, 1971), also matching a part of P13 : *Orbulinoides beckmannii* planktonic foraminifer zone (Blow, 1969) and a part of D11 dinoflagellate zone (Costa & Manum in Vinken, 1988) of Bartonian age.

Critical revaluation of published fossil records including age diagnostic larger- and planktonic foraminifera and field observations of three distinctly recognisable lithounits of supratrappeans : SHALE - MARL - LIMESTONE upto Fulra Limestone Formation, in ascending order, have led us to speculate and propose a single Bartonian transgressive cycle flooding Deccan basalts. This model questions the existence of commonly believed Palaeocene, Lower Eocene and Lutetian marine rocks on inland Kutch basin.

Key-words – Nannofossils, Late Middle Eocene (Bartonian), Kutch basin.

INTRODUCTION

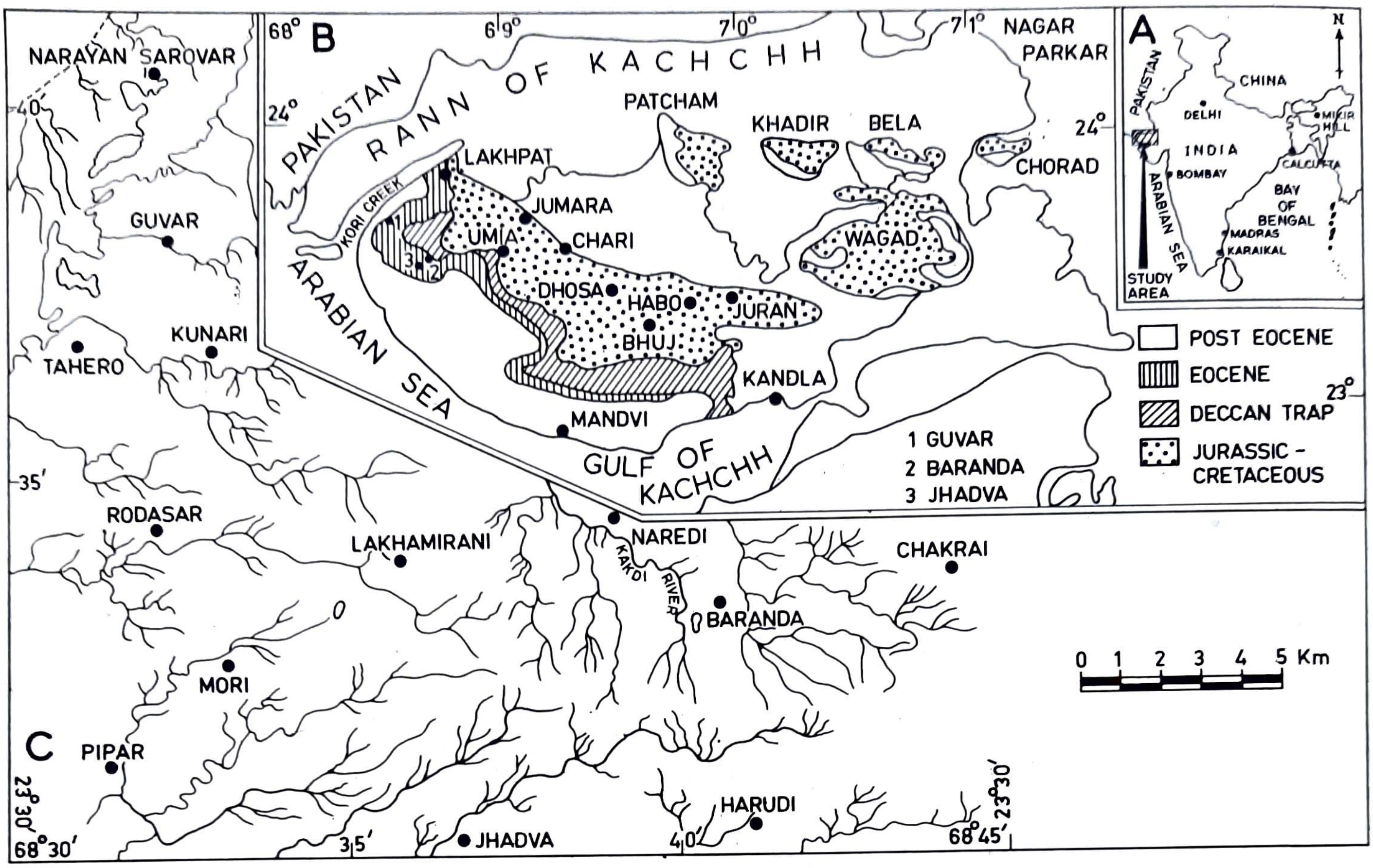
CALCAREOUS nannofossils have proved extremely useful for biostratigraphic and palaeoenvironmental interpretations of shallow marine to deep-sea deposits. The pericratonic basin of Kutch (also spelled as "Cutch" or "Kachchh" in literature) is one of the oldest explored basins in the world (Text-fig. 1A-C), offering excellent fossil-rich exposures of Mesozoic-Tertiary rocks with hydrocarbon potential in offshore areas (Wynne, 1872; Biswas, 1965, 1972, 1982; Biswas & Raju, 1973; Jaikrishna *et al.*, 1983).

Limited nannofossil data is available from Mesozoic rocks of Kutch basin (Jafar, unpublished data 1977; Rai, 1991), except from organic-matter rich green shales of the lower part (Jaikrishna *et al.*, 1983; Jafar & Saxena, 1984) and upper part of the middle Jurassic Jumara Formation (Jafar *et al.* 1983) yielding a rich assemblage suitable for precise dating and palaeoceanographic interpretations. The supratrappean Tertiary rocks (Text-fig. 1B) on the other hand, contain meagre but datable nannofossil assemblage confined to only certain horizons of Maniara Fort and Vinjhan Shale formations (Rai, 1988). However, diversified assemblage comparable to that known from other low- latitude sections of the world, are reported from upper part of Harudi (Pant & Mamgain, 1969; Singh *et al.*, 1980; Jafar & Rai, 1984; Rai, 1988; Singh & Singh, 1987; 1991) and Fulra Limestone formations (Singh, 1978 a, b; 1980a, b; 1988; Singh & Singh, 1986, 1987; Rai, 1988; Singh *et al.*, 1980).

The purpose of this paper is:

1. to present documentation of calcareous nannofossil assemblage from the type section of the Harudi Formation, with brief taxonomic and stratigraphic remarks for each recorded species.
2. to critically discuss published megafossil/ microfossil records from the entire supratrappean rocks terminating at the contact of Fulra Limestone-Maniara Fort Formation, and
3. to propose a plausible palaeoceanographic model to account for the controversial fossil-poor or barren

*Paper presented at the Birbal Sahni Birth Centenary Palaeobotanical Conference, Lucknow, November 20-22, 1991.



Text-figure 1.1A. The study area, 1B. Mesozoic-Tertiary outcrop pattern with key localities of Kutch basin, 1C. Detailed map of northwestern part of Kutch basin, with drainage pattern and important localities exposing type section.

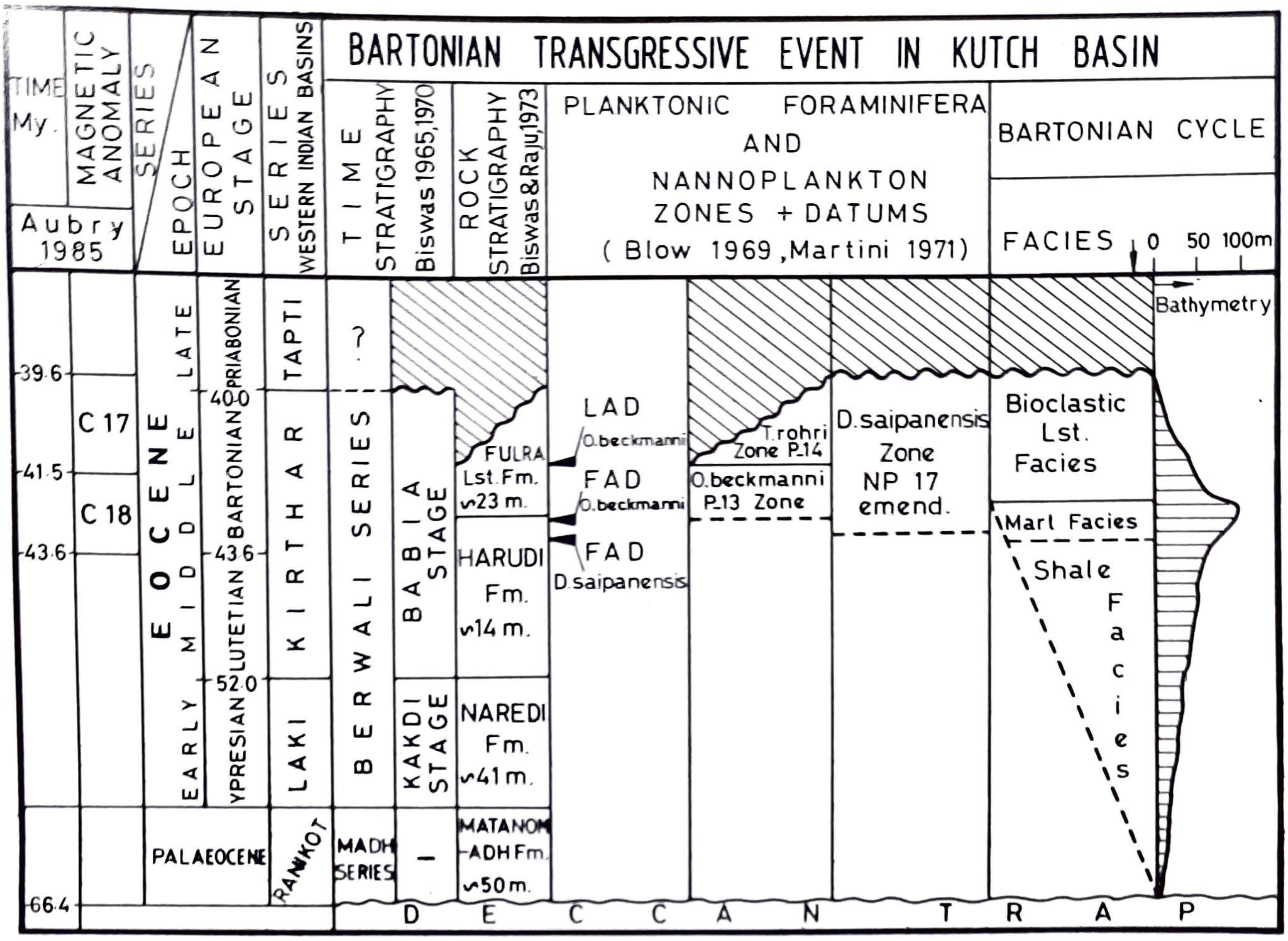
SHALE lithounit overlying the Deccan Trap basement and underlying richly fossiliferous MARL - LIMESTONE lithounits.

GEOLOGIC SETTING

Gently dipping beds with arcuate disposition of outcrops from Lakhpat to Goyela (Text-fig. 1A–C) form conspicuous Tertiary rocks over the Deccan trap basement and encompassing Fulra Limestone (Wynne, 1872), attain thickness of about 80 m. The time- and rock stratigraphic classification proposed by Biswas (1965, 1971, 1972), Biswas and Raju (1973), respectively, formed the basis for later researches in Kutch basin. The marls of the upper part of Harudi Formation and bioclastic Limestone of Fulra Limestone Formation correspond to *Nummulitic Group* of Wynne (1872) by excluding Maniara Fort Formation of Oligocene age. *Nummulitic Group* has yielded one of the richest Late Middle Eocene mega-and microfossils including nannofossil assemblage in Indo-Pacific region, for which the age and environment of deposition suggested by various authors is somewhat unanimous (Text-fig.2). However, the age and environment of deposition of the underlying *Gypseous shale and Sub-Nummulitic Group* (Wynne, 1872) corresponding to Matanomadh, Naredi and Lower Harudi formations (Text-figs 2-4), containing sparse fauna and flora became controversial, specially in view of the researches conducted during the recent years (Ray *et al.*, 1984; Jafar, 1986; Biswas, 1986; Pandey & Ravindran, 1988; Rai, 1988; Biswas, 1990; Jafar & Rai, 1991). For the sake of simplicity and discussions the supra-trappeans of Kutch basin extending upto terminal Fulra Limestone Formation are classified in this paper as three distinct litho-facies in ascending order SHALE-MARL-LIMESTONE (Text-fig.2).

MATERIAL AND METHOD

The documented calcareous nannofossils are from a khaki-coloured glauconitic marl sample, collected from the type section of Harudi Formation exposed near Harudi Village (23° 30′ 30″ / 68° 41′ 10″; Text-figs 1 C, 3) in Rato Nala section (also spelled as "Ratchelo" Nala by Late Dr K.K. Tandon of Lucknow University). This corresponds to sample HF-12 (Text-fig.3) dealt in detailed sampling and nannofossil documentation work (Rai, 1988) of the same section, also reported to contain rich dinoflagellate and planktonic foraminifera assemblage. Smear slides were prepared by dispersing of sample in neutral distilled water, and a few drops of turbid suspension were spread and dried on a glass



Text-figure 2. Rock- and time stratigraphy of the early part of supratrappean sedimentaries of Kutch basin tied to magnetic anomaly and absolute time scales; integrated planktonic foraminifera-nannoplankton zones and datums are correlated with major facies developed due to the onset and culmination of proposed Bartonian (Late Middle Eocene) transgressive cycle.

slide by using hot plate and later embedded in Caedax (artificial Canada Balsam) mount.

Nannofossils were photographed under Polarizing Research Microscope (Amplival) by using oil-immersion objective. The slides are deposited in the Museum of the Birbal Sahni Institute of Palaeobotany, Lucknow and bear numbers 10540-10548.

SYSTEMATIC PALAEONTOLOGY

The classification adopted here is after the one proposed for living coccolithophores (Young, 1987). Most species described herein under the open nomenclature are treated as new (Rai, 1988) and would be published elsewhere.

Taxonomic concepts are followed after Perch-Nielsen (1985) and the Families are arranged alphabetically. Frequent thoracosphaerids recorded in this study are considered as calcareous dinoflagellate cysts (Fütterer, 1976; Jafar, 1979). A detailed synonymy of over 100 species of nannofossils from Harudi and Fulra Limestone formations, by employing Light- and Scanning electron microscopy is dealt elsewhere (Rai, 1988). Besides Calyptrosphaeraceae exclusively representing holococcoliths, the other families belong to heterococcoliths.

Kingdom - Protista (Eukaryotic)

Division - Haptophyta

Class - Prymnesiophyceae

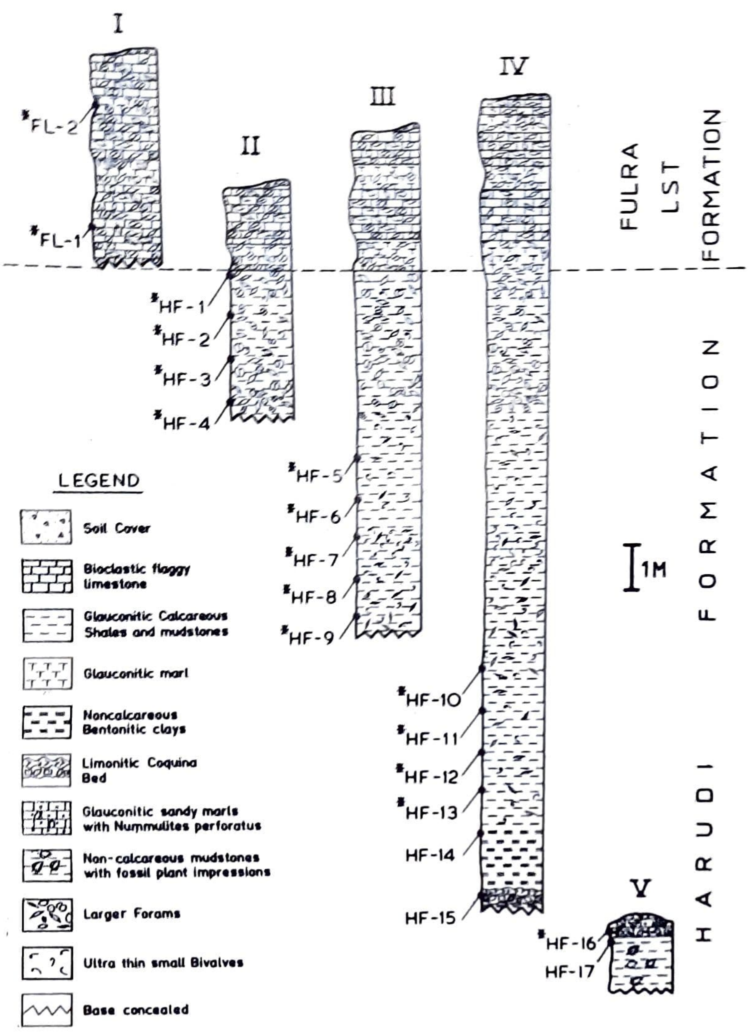
Family - Braarudosphaeraceae

Genus - *Braarudosphaera* Deflandre 1947

Braarudosphaera bigelowii (Graan & Braarud) Deflandre 1947
Pl. 1, fig. 1

Remarks - Originally reported from living plankton of Atlantic Ocean, *B. bigelowii*, the type species, is characterised by five trapezoidal elements forming a regular pentalith. In all 60 such units of 12 regular pentalith-plates enclose space to form a hollow pentagonal dodecahedral cyst. The weak sutures between the adjoining pentaliths show slit-like openings, representing 30 edges of a regular pentagonal dodecahedron comparable to quasicrystal symmetry and matching one of the five known platonic bodies.

This species is reported from Early Cretaceous to Recent, typically associated with shallow, nearshore and warm water sediments. Its rare representation in the studied material suggests some other factors responsible for common occurrence in nearshore deposits else-



Text-figure 3. Measured columnar sections I-V represent sampling profiles, while taking upstream traverse in Rato Nala section, covering lower part of Fulra Limestone Formation (FL) and upper part of Harudi Formation (HF) in the type locality. Solid dots represent sampling points. Sample numbers with asterisk denote calcareous nannoplankton productivity.

where. It is also reported from Cretaceous-Tertiary sediments of other parts of India.

Genus - *Micrantholithus* Deflandre 1950

Micrantholithus aequalis Sullivan 1964
Pl. 1, figs 12 a-b

Remarks- Originally reported from Palaeocene of California. Large star-shaped pentaliths formed by joining of V-shaped segments, the sides of which are of equal length.

Micrantholithus angulosus Stradner 1961
Pl. 1, figs 4-5

Remarks- Pentaliths are large with characteristic angular outline.

Micrantholithus bulbosus Bouche' 1962
Pl. 1, figs 21, 22a-b

Remarks - Pentaliths are nearly pentagonal to circular having elements of triangular outline pierced by distinct marginal pore. Margin of pentaliths is rounded. In overgrown specimens, the constricted part of opening is concealed and the forms look like a species of *Pemma*.

Micrantholithus inaequalis Martini 1961
Pl. 1, figs 10a-b, 11

Remarks- Large star-shaped pentaliths display L-shaped segments. *M. attentuatus* Bramlette & Sullivan (1961) is herein considered as synonym of this species.

Micrantholithus lateralis Sullivan 1965
Pl. 1, fig. 16

Remarks - Pentaliths are small with characteristic shape of triangular segments. It was originally reported from Eocene of California.

Micrantholithus procerus Bukry & Bramlette 1969
Pl. 1, figs 6a-b, 7

Remarks - Pentaliths are of considerable height as clearly seen in side-views. The height being about double the diameter of pentalith as seen in plan-view. It is reported from Palaeocene-Middle Eocene shallow marine sediments of several parts of the world.

Micrantholithus cf. *M. ornatus* Sullivan 1965
Pl. 1, fig.8

Remarks - Pentaliths are moderate-sized with fairly large opening in each segment displaying characteristic margin. It is known from Middle to Late Eocene.

Micrantholithus pinguis Bramlette & Sullivan 1961
Pl. 1, fig.9

Remarks - Small star-shaped pentaliths contain characteristic triangular segments. This species is reported from Palaeocene-Eocene shallow marine sediments of several parts of the world. Earlier it was known from late Middle-Eocene sediments of Kutch basin (Pant & Mamgain 1969).

Micrantholithus sp. 1
Pl. 1, figs 2-3

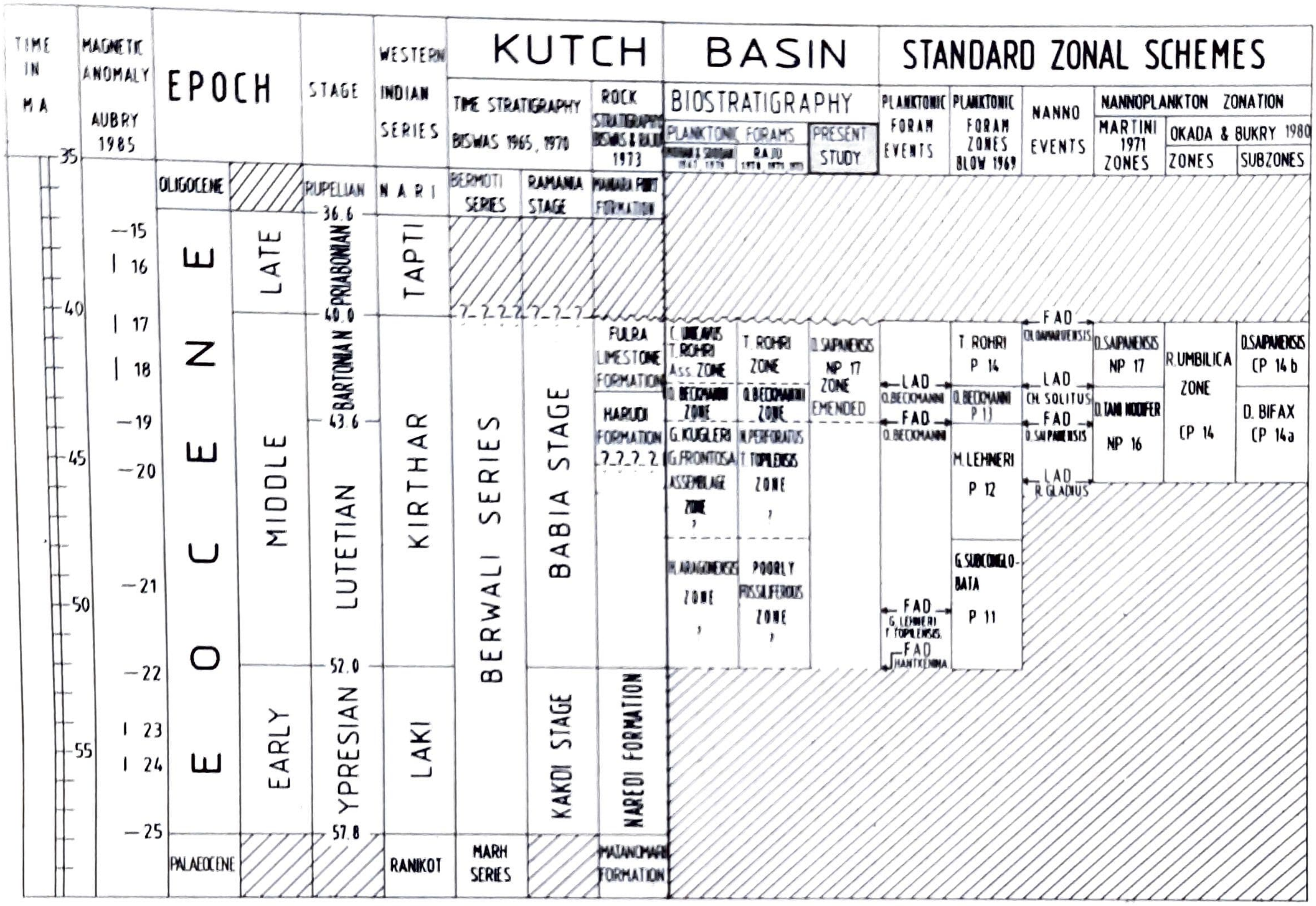
Remarks - The aberrant type of pentaliths are characterised by a pair of larger and similar shaped elements and much reduced other three elements.

Micrantholithus sp. 2
Pl. 1, fig. 15

Remarks - This is also an aberrant form showing a pair of reduced elements and three equal sized pointed elements.

Micrantholithus sp. 3
Pl. 1, figs 18-19

Remarks - Pentaliths are of characteristic triangular



Text-figure 4. Correlation chart showing calcareous nannoplankton and planktonic foraminifera zones and datum markers for the studied sections tied to Time - Rock stratigraphic classifications of Kutch basin, series of western Indian basins and correlated with European Stage/Epoch units, Magnetic events and absolute ages.

outline with rounded margins. A sub-rounded pore pierces each triangular segement. It resembles the form earlier reported from Middle Eocene of Atlantic Ocean (Bukry, 1978).

Genus-*Pemma* Klumpp 1953

Pemma basquensis (Martini) Báldi-Beke 1971
Pl. 1, figs 13a-b, 23-24

Remarks - Moderate-sized pentaliths display pentagonal outline and serrated margin. Variants show protruding elements along radial sutures. Each segment shows small to large opening of rhomboidal outline. It is reported from Middle Eocene-Oligocene shallow marine sediments. In India the same has been recorded from Late Eocene of Assam and late Middle Eocene of Kutch basin (Singh, 1979; Singh *et al.* 1980).

Pemma papillatum Martini 1959
Pl. 1, figs 1 a-b

Remarks - It is readily recognised by its fairly large size and characteristic club-shaped protuberances along the periphery of each pentalith. Even broken fragments of this species can be readily recognised. It is known to range from Middle to Late Eocene shallow marine sediments.

It was utilized as a zonal marker of Middle Eocene in Alabama. In India, this species is reported from Late Eocene of Assam (Singh, 1979); late Middle Eocene of Kutch basin (Pant & Mamgain, 1969; Singh *et al.*, 1980) and Late Eocene of Surat-Broach (Pant & Mathur, 1973; Jafar *et al.*, 1985).

Pemma sp. 1
Pl. 1, figs 14 a-b

Remarks - It is an aberrant form of pentalith assignable to *Pemma*.

Pemma sp. 2
Pl. 1, figs 25-26

Remarks - Moderate-sized pentaliths possess triangular segments pierced by subrounded pores. Each segment is characterised by a distinct notch at the mid-point of the segment margin.

Family - Calciosoleniaceae

Genus - *Scapholithus* Deflandre in Deflandre & Fert 1954

Scapholithus rhombiformis Hay & Mohler 1967

Pl. 2, figs 6a-b

Remarks - Small nannofossils display characteristic broad rhomboidal outline. It is extremely rare in recorded assemblage.

Family - Calyptrosphaeraceae

Genus - *Dactylethra* Gartner 1969

Dactylethra punctulata Gartner 1969
Pl. 3, figs 23a-b, 24

Remarks - Distinctly helmet-shaped holococcoliths are with concave base. This genus is recorded for the first time from India. It is known to range from Middle to Late Eocene, shallow marine sediments of widely seperated areas.

It resembles modern species of *Homozygosphaera* Kamptner, producing similar holococcoliths.

Dactylethra sp.
Pl. 3, figs 25 a-b

Remarks - Characteristic appearance and semi-circular outline differentiates this from *D. punctulata*, which had so far remained the only species known under *Dactylethra*.

Genus - *Holodiscolithus* Roth 1970

Holodiscolithus macroporus (Deflandre) Roth 1970
Pl. 3, fig. 22

Remarks - It is a small-sized holococcolith. Central area is pierced by a number of pores and appears dark under crossed-nicols. It is very rare constituent of recorded assemblage.

Genus - *Lanternithus* Stradner 1962

Lanternithus minutus Stradner 1962
Pl. 3, figs 26, 27a-b, 28

Remarks - It is readily identified under the light microscope. Detailed morphology of this holococcolith is known. This genus is recorded for the first time from Indian subcontinent and is fairly common in the assemblage.

Lanternithus sp. 1
Pl. 3, figs 29a-b

Remarks - It differs from *L. minutus* in possessing quadrangular outline, thinner elements and large central area as observed under the crossed nicols.

Lanternithus sp. 2
Pl. 3, figs 30a-b, 31a-b

Remarks - Holococcolith consists of six elements (one small and two large pairs) showing, high relief in normal light and strong birefringence under the crossed nicols.

Lanternithus sp.3
Pl. 3, figs 32a-b

Remarks - Holococcolith is hexagonal in outline with a large central area, showing fairly high relief under normal light. A pair each of thick and a thin extinction gyres appear to divide this nannofossil when observed under the crossed nicols.

Genus - *Orthozygus* Bramlette & Wilcoxon 1967

Orthozygus aureus (Stradner) Bramlette & Wilcoxon 1967
Pl. 3, figs 17-18, 19a-b, 20a-b, 21

Remarks - It is readily recognisable holococcolith specially in side views, when observed under the light

---

Plate 1 →

(All photographs x 2000)

nl = normal Light

xn = Crossed nicols

1. *Braarudosphaera bigelowii* (Graan & Braarud) Deflandre 1947; xn.
2-3. *Micrantholithus* sp. 1; xn.
4-5. *Micrantholithus angulosus* Stradner 1961; xn.
6a-b, 7. *Micrantholithus proceus* Bukry & Bramlette 1969; 6a nl; 6b, 7 xn.
8. *Micrantholithus* cf. *M. ornatus* Sullivan 1965; xn.
9. *Micrantholithus pinguis* Bramlette & Sullivan 1961; xn.
10a-b, 11. *Micrantholithus inaequalis* Martini 1961; 10a nl; 10b, 11 xn.
12a-b. *Micrantholithus aequalis* Sullivan 1964; 12a nl; 12b xn.
13a-b. *Pemma basquensis* (Martini) Báldi-Beke 1971; 13a nl; 13b xn.
14a-b. *Pemma* sp. 1; 14a nl; 14b xn.
15. *Micrantholithus* sp. 2; xn.
16. *Micrantholithus lateralis* Sullivan 1965; xn.
17a-b. *Pemma papillatum* Martini 1959; 17a nl; 17b xn.
18-19. *Micrantholithus* sp. 3; xn.
20. *Pemma basquensis* (Martini) Báldi-Beke 1971; xn.
21, 22a-b. *Micrantholithus bulbosus* Bouche' 1962; 21 xn; 22a nl; 22b xn.
23-24. *Pemma basquensis* (Martini) Báldi-Beke 1971; xn.
25-26. *Pemma* sp. 2; xn.
27a-b, 28. *Chiasmolithus titus* Gartner 1970; 27a nl; 27b, 28 xn.
29a-b. Coccosphere of *Chiasmolithus titus* Gartner 1970; 29a nl; 29b xn.
30a-c. *Chiasmolithus consuetus* (Bramlette & Sullivan 1961) Hay & Mohler 1967; 30a nl; 30b, 30c xn.
31a-c. *Bramletteius serraculoides* Gartner 1969; 31a nl; 31b, 31c xn.

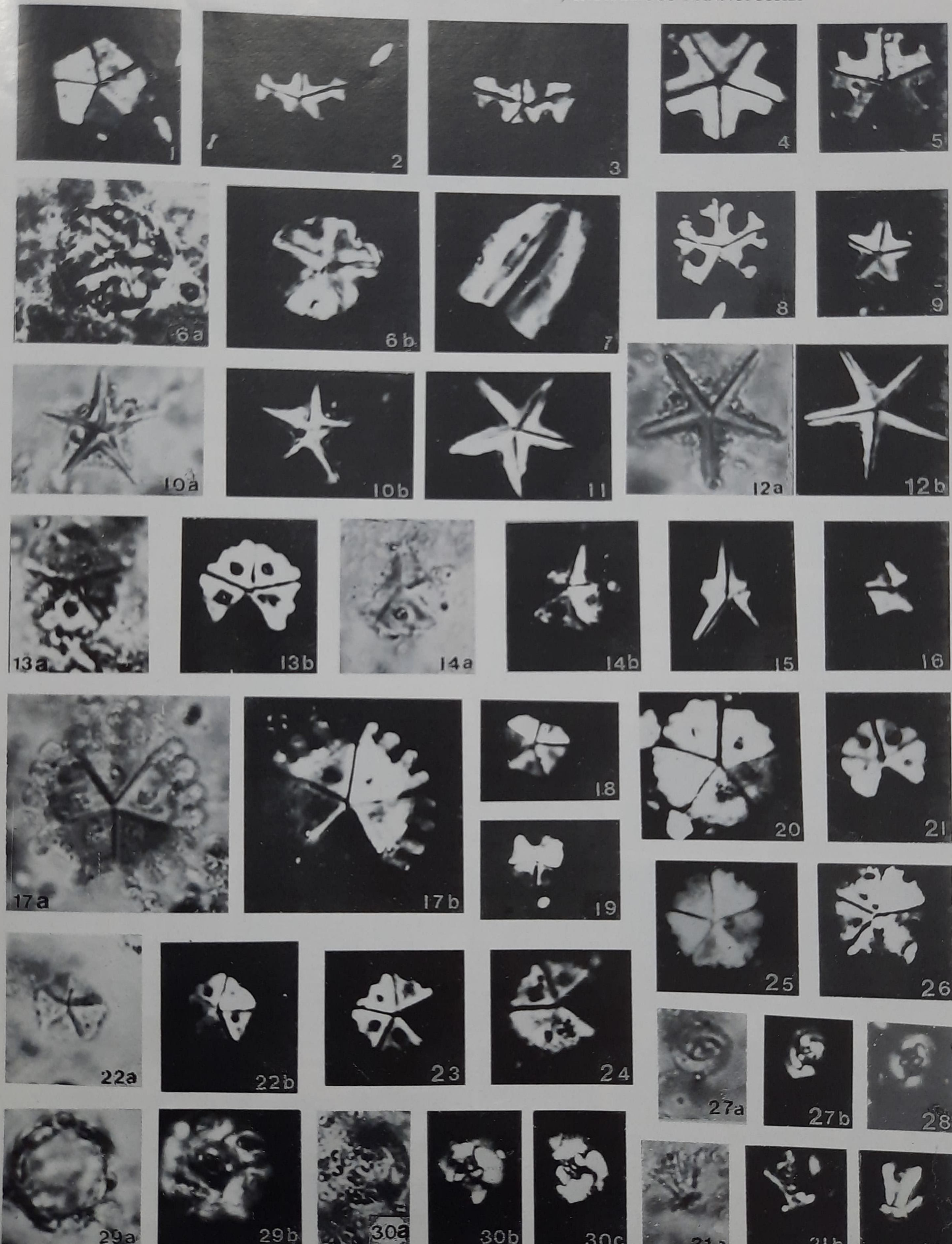

1
2
3
4
5
6a
6b
7
8
9
10a
10b
11
12a
12b
13a
13b
14a
14b
15
16
17a
17b
18
19
20
21
22a
22b
23
24
25
26
27a
27b
28
29a
29b
30a
30b
30c
31a
31b
31c

Plate 1

microscope. The two halves of this small holococcolith show different optical orientation. It is the first record from Indian Tertiary sediments.

Reported from Middle Eocene-Early Oligocene shallow marine deposits of widely separated areas.

Genus - *Zygrhablithus* Deflandre 1959

Zygrhablithus bijugatus (Deflandre) Deflandre 1959
Pl. 3, figs 33, 35, 36a-b, 38a-b, 39a-b, 40, 41a-b

Remarks - It is readily recognisable holococcolith in Palaeogene nannofloral assemblages. Considerable variation occurs in length, breadth and the size of spine of this species as seen in plane and side views. It frequently occurs in Early Eocene-Late Oligocene shallow marine sediments.

Genus - *Clathrolithus* Deflandre in Daflandre & Fert 1954

Clathrolithus ellipticus Deflandre 1954
Pl. 3, fig. 34

Remarks - Moderate-sized holococcolith shows characteristic honey-comb like reticulate pattern. It is very rare in the assemblage.

Family - Coccolithaceae

Genus - *Chiasmolithus* Hay, Mohler & Wade 1966

Chiasmolithus consuetus Hay & Mohler 1967
Pl. 1, figs 30a-c

Remarks - Medium-sized coccolith readily identified by the orientation of the central cross and extinction gyres under the light microscope. It is known to range from Middle Palaeocene to late Eocene and rarely occurs in the present assemblage.

Chiasmolithus titus Gartner 1970
Pl. 1, figs 27a-b, 28, 29a-b

Remarks - It is a small-sized coccolith. Small central area is spanned by a distinct central cross, rather resembling the one found in *Cruciplacolithus*. It is somewhat more frequent chiasmolith in the assemblage, otherwise, such rare occurrences are consistent with the known low-latitude frequency. It is distributed from Middle Eocene to Early Oligocene.

Genus - *Coccolithus* Schwarz 1894

Coccolithus eopelagicus (Bramlette & Riedel) Bramlette & Sullivan 1961
Pl. 2, figs 2a-b

Remarks - It is a fairly large coccolith, often showing two semicircular openings under the lightmicroscope. Under crossed nicols, extinction pattern is characteristic. Commonly present in the assemblage.

This species is well documented from Middle Eocene through Oligocene sediments of several areas. Except for its large size, it is similar to living *Coccolithus pelagicus*. Earlier it was reported from Late Middle Eocene of Kutch basin (Singh *et al.*, 1980; Singh, 1980a; Singh & Singh, 1986).

Genus - *Cyclococcolithus* Kamptner 1954

Cyclococcolithus kingi (Roth) Roth *et al.* 1971
Pl. 2, figs 8, 9a-b

Remarks - A fairly large coccolith of circular outline, is readily recognisable under the lightmicroscope. Central area is characteristically dark and wide showing squarish outline under the crossed nicols. *Cycloc-*

Plate 2 →

(All photographs x 2000)

nl = normal Light

xn = Crossed nicols

- 1a-b. *Ericsonia formosa* (Kamptner 1963) Haq 1971; 1a nl; 1b xn.
- 2a-b. *Coccolithus eopelagicus* (Bramlette & Riedel) Bramlette & Sullivan 1961; 2a nl; 2b xn.
- 3. *Cyclicargolithus floridanus* (Roth & Hay) Bukry 1971; xn.
- 4. *Reticulofenestra* cf. *R.minuta* Roth 1970; xn.
- 5. *Discoaster distinctus* Martini 1958; nl.
- 6a-b. *Scapholithus rhombiformis* Hay & Mohler 1967; 6a nl; 6b xn.
- 7a-b. *Ericsonia* sp.; 7a nl; 7b xn.
- 8, 9a-b. *Cyclococcolithus kingi* Roth 1970; 8 xn; 9a xn; 9b nl.
- 10, 11. *Discoaster mirus* Deflandre 1954; nl.
- 12. *Discoaster* sp.; nl.
- 13-18. *Discoaster barbadiensis* Tan Sin Hok 1927; nl.
- 19. *Discoaster saipanensis* Bramlette & Riedel 1954; nl.
- 20. *Discoaster ornatus* Stradner 1958; nl.
- 21. *Discoaster mirus* Deflandre 1954; nl.
- 22-23. *Discoaster barbadiensis* Tan Sin Hok 1927; nl.
- 24-26. *Discoaster binodosus* Martini 1958; nl.
- 27. *Discoaster barbadiensis* Tan Sin Hok 1927; nl. (side-view).
- 28. *Discoaster binodosus* Martini 1958; nl.
- 29. *Discoaster nodifer* (Bramlette & Riedel) Bukry 1973; nl.
- 30. *Discoaster tanii* Bramlette & Riedel 1954; nl.
- 31. *Lithostromation simplex* (Klumpp) Bybell 1975; nl.
- 32a-b. *Helicosphaera* sp.; 32a nl; 32b, xn.
- 33a-c. *Blackites* sp. 1;33a nl; 33b, 33c, xn.
- 34a-b. *Blackites rectus* (Deflandre) Stradner & Edwards 1968; 34a nl; 34b xn.
- 35. *Blackites spinosus* (Deflandre & Fert) Hay & Towe 1962; xn. (plan-view).
- 36. *Blackites* sp. 2; xn.
- 37. *Blackites* sp. 3; xn.
- 38. *Blackites* sp. 4; xn.
- 39. *Rhabdosphaera* cf. *R. gladius* Locker 1967; xn.
- 40-47. *Blackites* sp. 5; xn.

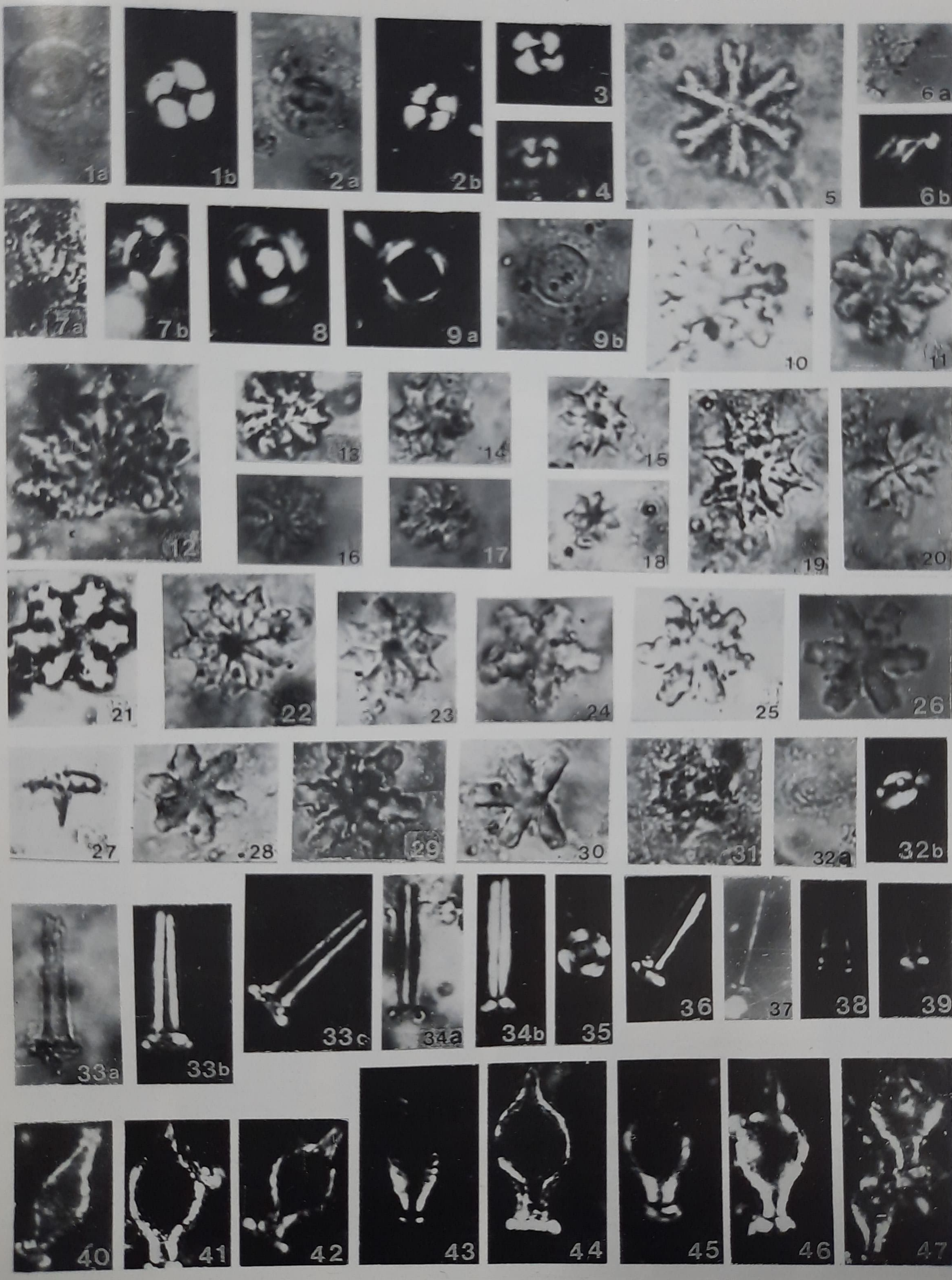

1a
1b
2a
2b
3
4
5
6a
6b
7a
7b
8
9a
9b
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32a
32b
33a
33b
33c
34a
34b
35
36
37
38
39
40
41
42
43
44
45
46
47

Plate 2

colithus protoannulus Gartner (1971) is considered as synonym of this species. It is known from late Middle Eocene of Kutch (Pant & Mamgain, 1969; Singh *et al.* 1980) and Late Eocene of Assam (Singh, 1979).

Genus - *Ericsonia* Black 1964

Ericsonia formosa (Kamptner 1963) Haq 1971
Pl. 2, figs 1a-b

Remarks - This nannofossil is readily recognised both under the light - and scanning electron microscope and is utilized as an important stratigraphic marker. It appears in late Early Eocene and disappears in Early Oligocene. In India, *E. formosa* was earlier reported from several sections of Kutch basin (Singh, 1980a; Singh *et al.*, 1980; Singh & Singh, 1986) and Late Eocene of Surat (Jafar *et al.* 1985).

Ericsonia sp.
Pl.2, figs 7a-b

Remarks - It is a medium-sized species of *Ericsonia* showing several pores in the central area and a thin rim. Under the crossed nicols distinct extinction pattern could be seen.

Genus - *Bramletteius* Gartner 1969

Bramletteius serraculoides Gartner 1969
Pl. 1, figs 31a-c

Remarks - Under the light microscope, this small nannofossil is best recognised in side views. A paddle like process surmounts a double-shield *Cruciplacolithus* like coccolith. It is commonly represented in open ocean assemblage (Bukry *et al.*, 1971). Presence of this nannofossil in the assemblage suggests its occurrence, though rare, in nearshore hemipelagic sediments as well.

Family - Discoasteraceae

Genus - *Discoaster* Tan Sin Hok 1927

Discoaster barbadiensis Tan Sin Hok 1927
Pl.2, figs 13-18, 22-23, 27

Remarks - The rosette-shaped asteroliths, having 7-14 rays, are joined along most of their length displaying pointed to blunt tips. The forms show proximal curvature with a distinct stem, best seen in side views (Pl. 2, fig. 27). Relative abundance of large and small forms could be of value in deciphering open ocean influences affecting coastal areas.

Earlier it was reported from late Middle Eocene of Kutch basin (Pant & Mamgain, 1969; Singh *et al.*, 1980; Singh, 1980a; Singh & Singh 1986) and Late Eocene of Surat (Jafar *et al.*, 1985; Singh, 1979).

Discoaster binodosus Martini 1958
Pl. 2, figs 24-26, 28

Remarks - 5-6 rayed asteroliths show typical features though the ray tips are modified owing to calcite overgrowth. It ranges from Early Eocene to Early Oligocene. Earlier this taxon was reported from late Middle Eocene of Kutch basin (Pant & Mamgain 1969; Singh, 1980b).

Discoaster distinctus Martini 1958
Pl. 2, fig. 5

Remarks - Usually six-rayed asterolith showing characteristic screw-wrench type ray-tips is known to range from Early to Middle Eocene.

Plate 3 →

(All photographs x 2000)
nl = normal Light
xn = Crossed nicols

1a-c. *Blackites* sp. 1; 1a nl; 1b, 1c xn.
2-3. *Blackites spinosus* (Deflandre & Fert) Hay & Towe 1962; xn.
4. *Blackites tenuis* (Bramlette & Sullivan) Bybell 1975; xn.
5a-b. *Wiseorhabdus inversus* (Bukry & Bramlette) Bukry 1981; 5a nl; 5b xn.
6. *Thoracosphaera* cf. *Th. tuberosa* Kamptner 1963; xn.
7. *Thoracosphaera* cf. *Th. saxea* Stradner 1963; xn.
8. *Discolithina* sp. 1; xn.
9. *Discolithina* sp. 2; xn.
10a-b, 11. *Sphenolithus furcatolithoides* Locker 1967; 10a nl; 10b, 11 xn.
12a-b, 13. *Sphenolithus predistentus* Bramlette & Wilcoxon 1967; 12a nl; 12b, 13 xn.
14. *Sphenolithus predistentus* Bramlette & Wilcoxon 1967; xn.
15-16. *Sphenolithus spiniger* Bukry 1971; xn.
17-21. *Orthozygus aureus* (Stradner) Bramlette & Wilcoxon 1967; 17, 18, 19a, 20a nl; 19b, 20b, 21 xn.
22. *Holodiscolithus macroporus* (Deflandre 1954) Roth 1970; nl.
23a-b., 24. *Dactylethra punctulata* Gartner 1969; 23a nl; 23b, 24 xn.
25a-b. *Dactylethra* sp.; 25a nl; 25b xn.
26-28. *Lanternithus minutus* Stradner 1962; 27a nl; 26, 27b, 28 xn.
29a-b. *Lanternithus* sp.1; 29a nl; 29b xn.
30a-b,31a-b. *Lanternithus* sp. 2; 30a, 31a nl; 30b, 31b xn.
32a-b. *Lanternithus* sp. 3; 32a nl; 32b xn.
33. *Zygrhablithus bijugatus* (Deflandre) Deflandre 1959; xn.
34. *Clathrolithus ellipticus* Deflandre 1959; nl.
35-41. *Zygrhablithus bijugatus* (Deflandre) Deflandre 1959; 35 nl; 36a, 37a, 39a, 41a nl; 36b, 37b, 38a-b, 39b, 40, 41b xn.

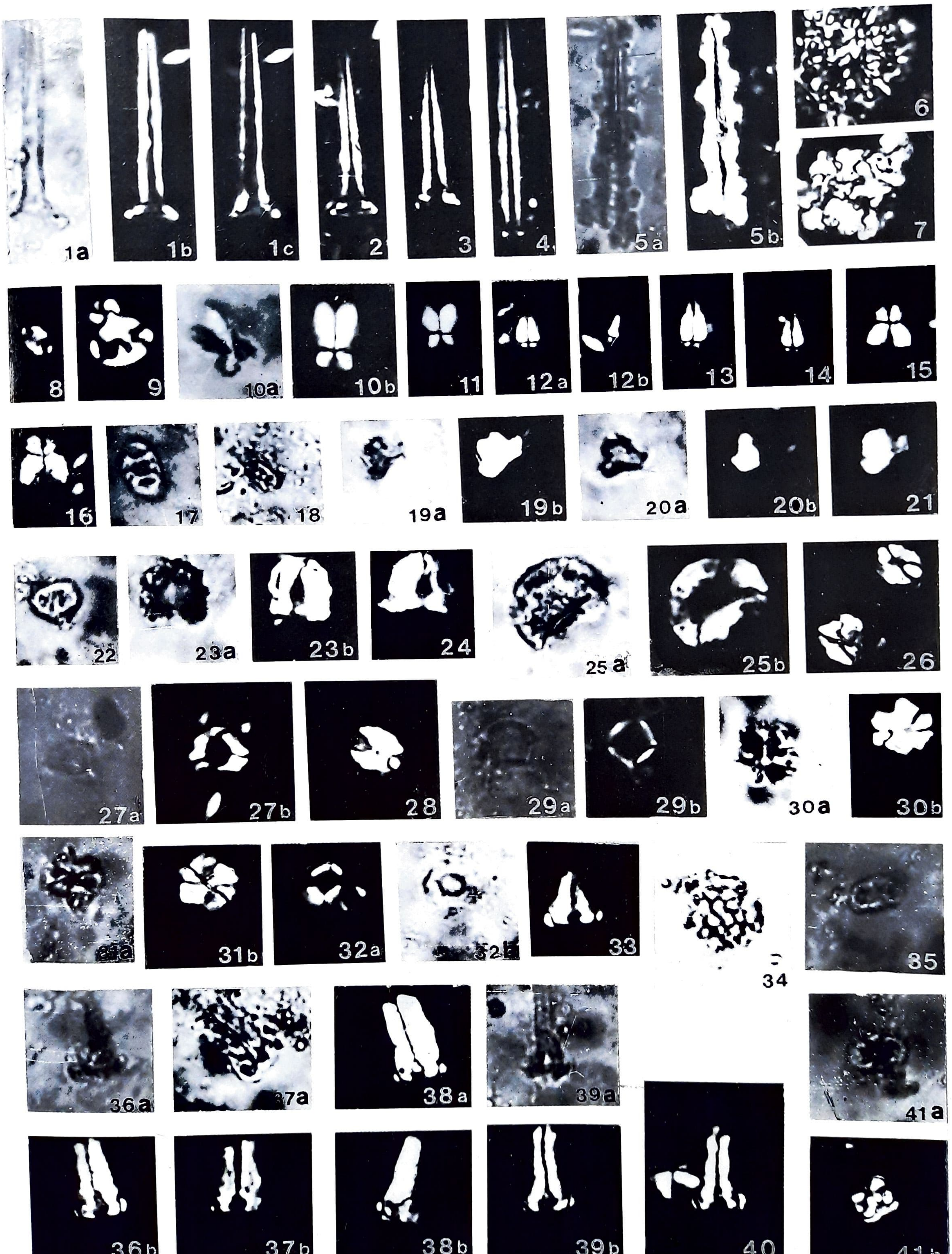

1a
1b
1c
2
3
4
5a
5b
6
7
8
9
10a
10b
11
12a
12b
13
14
15
16
17
18
19a
19b
20a
20b
21
22
23a
23b
24
25a
25b
26
27a
27b
28
29a
29b
30a
30b
31b
32a
33
34
35
36a
37a
38a
39a
41a
36b
37b
38b
39b
40
41b

Plate 3

Discoaster mirus Deflandre 1954
Pl. 2, figs 10-11, 21

Remarks - Asteroliths usually consist of 8 rays, compact with thick arms and notched tips, usually having a pair of knob on each ray. Characteristic suture lines are observed in rather wide central area of some specimens. It is known to range from Early to Middle Eocene.

Discoaster nodifer (Bramlette & Riedel) Bukry 1973
Pl.2, fig. 29

Remarks - Medium to large-sized asteroliths usually display rays of uniform thickness and a notch at the ray-tip with a pair of nodes near small central area.

This species is known to occur from late Middle Eocene to Early Oligocene. In India, it is reported from late Middle Eocene of Kutch basin (Singh, 1980a).

Discoaster ornatus Stradner 1958
Pl. 2, fig. 20

Remarks - 8-rayed asterolith representing four pairs of rhombohedral rays with pointed tips and straight inter-ray sutures. It is the first genuine record of this species from India.

Discoaster saipanensis Bramlette & Riedel 1954
Pl. 2, fig. 19

Remarks - 5-8-rayed asterolith is originally reported from Late Eocene of Saipan Islands. It can be identified by typical abrupt termination of ray tips producing characteristic inter-ray area. A stem is observed on the proximal side of central area.

Size of this species ranges between 9-18 μm. Stratigraphically it is an important species. It appears in the upper part of NP16 as indicated by Martini (1971). Older occurrence reported by Köthe (1986) is misleading. Its extinction together with *D. barbadiensis* defines Eocene/Oligocene boundary. Last appearance of *Rhabdosphaera gladius* and *Chiasmolithus solitus* marks the lower and upper boundary, respectively, of NP 16 (*Discoaster tani-nodifer*) zone of Martini (1971). Since both these markers are absent in Kutch basin, the first appearance of *D. saipanensis* defining the upper part of NP16 (*Discoaster tani-nodifer* zone of Martini 1971) is used to mark the base of herein emended NP 17: *Discoaster saipanensis* zone of Martini 1971 (Text-fig.2). This emendation seems useful for working in low-latitude areas, where the emended definition of NP17 incidently also corresponds to chronostratigraphic boundaries of Bartonian (Aubry, 1985), as discussed later.

D. saipanensis is rarely present in the assemblage. It is also known to occur in Late Eocene of Assam (Singh, 1979) and late Middle Eocene of other sections in Kutch basin (Singh *et al.*, 1980; Singh, 1980a; Pant & Mamgain, 1969).

Discoaster tanii Bramlette & Riedel 1954
Pl.2, fig. 30

Remarks - 5-6 rayed asteroliths are distinguished by uniform ray width terminating abruptly with a small notch at the ray-tip. Small nodes on ray-tips may or may not be present.

It appears roughly at CP 14b/NP17 level and extends upto Early Oligocene.

Discoaster sp.
Pl. 2, fig. 12

Remarks - It is a fairly large asterolith with rays joined along most of its length and having blunt tips. The rays show pitting as seen in *D. elegans*, but poor preservation hampers proper identification.

Family - Helicosphaeraceae

Genus - *Helicosphaera* Kamptner 1954 ex Jafar & Martini 1975

Helicosphaera compacta Bramlette & Wilcoxon 1967

Remarks - Specimens of *H. compacta* are observed in the present material though remain undocumented owing to poor preservation. This species together with other helicosphaerids is well documented and discussed in detail elsewhere (Rai, 1988).

Helicosphaera sp.
Pl. 2, figs 32a-b

Remarks - It is extremely rare and poorly preserved.

Family - Lithostromationaceae

Genus - *Lithostromation* Deflandre 1942

Lithostromation simplex (Klumpp) Bybell 1975
Pl. 2, fig. 31

Remarks - The holococcoliths display hexagonal outline, and are covered by symmetrical depressions.

Family - Pontosphaeraceae

Genus - *Discolithina* Loeblich & Tappan 1963

Discolithina sp. 1
Pl. 3, fig. 8

Remarks - Small nannofossils (3μm) show narrow pores in the center of elliptic plate. Under crossed nicols characteristic extinction pattern is seen. It is rarely observed in the present assemblage.

Discolithina sp. 2
Pl. 3, fig.9

Remarks - Medium-sized (about 6µm) nannofossils show thin rim and basal plate bearing pores. Their bad preservation does not permit specific identification.

Family - Prinsiaceae

Genus - *Cyclicargolithus* Bukry 1971

Cyclicargolithus floridanus (Roth & Hay) Bukry 1971
Pl.2, fig. 3

Remarks - Small to medium-sized placoliths show birefringent distal shield with characteristic extinction gyres. It is known to range from late Middle Eocene to Middle Miocene.

Genus - *Reticulofenestra* Hay, Mohler & Wade 1966

Reticulofenestra cf. *R. minuta* Roth 1970
Pl.2, fig. 4

Remarks - It is small (2 µm) and fairly abundant species in the present assemblage and several other regions of India.

Family - Rhabdosphaeraceae

Genus - *Blackites* Hay & Towe 1962

Blackites rectus (Deflandre) Stradner & Edwards 1968
Pl. 2, figs 34a-b

Remarks - It is distinguished from other species of *Blackites* by the presence of uniform width of the spine. The blunt apical part of spine is nearly as broad as the base. A typical *Blackites* type basal plate underlies the spine.

Blackites spinosus (Deflandre & Fert) Hay & Towe 1962
Pl.2, fig.35; Pl.3, figs 2-3

Remarks - *B. spinosus* is characterised by a spine which is broadest at the base and gradually tapers to a needle-like point and surmounted on a basal plate.

Under crossed polarised light, in plan view, the basal plate shows typical extinction pattern (Pl.2, fig.35). Ultrastructural details as seen under the Electron microscope suggest the assignment of all Palaeogene rhabdosphaerids to *Blackites*.

It is reported from Middle Eocene to Early Oligocene of several regions. In India, earlier record of this nannofossil is from late Middle Eocene of Kutch basin (Pant & Mamgain, 1969).

Blackites tenuis (Bramlette & Sullivan) Bybell 1975
Pl.3, fig.4

Remarks - This species resembles *B. spinosus* in gross features but differs in possessing a narrow constriction just at the base of the spine.

It ranges from Middle Eocene to Middle Oligocene and is already known from late Middle Eocene of Kutch basin (Pant & Mamgain, 1969).

Blackites sp. 1
Pl.2, figs 33a-c; Pl.3, figs 1a-c

Remarks - Medium to large-sized rhabdosphaerids show a wide spine-canal running throughout its length. The spine ends bluntly with the narrowing down of the spine-canal.

Blackites sp. 2
Pl.2, fig. 36

Remarks - It is characterised by a narrow spine of nearly uniform width.

Blackites sp. 3
Pl.2, fig. 37

Remarks - It is an extremely slender form of *Blackites*.

Blackites sp. 4
Pl.2, fig. 38

Remarks - This nannofossil is a small, broad-robust rhabdosphaerid showing a basal plate, surmounted by a thick spine converging and terminating in a point. It resembles *Blackites* sp., earlier described from Middle Eocene of Gulf Coast, Alabama (Bybell, 1975).

Blackites sp. 5
Pl.2, figs 40-47

Remarks - This peculiar rhabdosphaerid is the most common amongst other members recorded in the assemblage. It is characterised by bulbous middle part, a narrow base and rapidly tapering spine. The middle part shows much sculpturing of the wall and the interior of central globular part is usually seen to be filled with dark pyritic material, the organic material having been filtered through narrow spine opening. It is already recorded from late Middle Eocene of Kutch basin (Pant & Mamgain, 1969).

Genus - *Rhabdosphaera* Locker 1967

Rhabdosphaera cf. *R. gladius* Locker 1967
Pl.2, fig.39

Remarks - This small and rare form resembles *R. gladius* in possessing basal constriction of the spine but differs in typical basal plate extinction pattern as observed in side-view.

Family - Sphenolithaceae

Genus - *Sphenolithus* Deflandre in Grasse' 1952

Sphenolithus furcatolithoides Locker 1967
Pl.3, figs 10a-b, 11

Remarks - The sphenolith is medium-sized and readily recognisable under the light microscope employing crossed nicols. Parallel to vibration directions, the proximal elements are observed as two bright dots, surmounted by a spine. The spine bifurcates slightly above and makes an acute angle. Very long and delicate bifurcated-tips reported from other areas, are presumed to have been damaged in the specimens illustrated herein.

The last appearance of *S. furcatolithoides* may be used to define *NP16/NP17* zonal boundary in tropical regions with known stratigraphic range of *NP15-NP16* (Aubry, 1985; Martini, 1971).

Sphenolithus predistentus Bramlette & Wilcoxon 1967
Pl.3, figs 12a-b, 13-14

Remarks - Characterised by having tiny proximal ring elements, surmounted by a spine. The spine is broader at the base, becoming conical and often shows bifurcated tips.

Earlier reported from *NP17 - NP 23* or questionably extending upto NP 24 (Perch-Nielsen, 1985). Its presence in the recorded assemblage suggests older occurrence in the upper part of *NP 16* nannofossil zone (*sensu* Martini, 1971).

Sphenolithus spiniger Bukry 1971
Pl. 3, figs 15-16

Remarks - Shuttle-cock like sphenolith shows characteristic extinction pattern at 0^{o} and 45^{o} position with respect to nicols.

Family - Triquetrorhabdulaceae

Genus - *Wiseorhabdus* (Bukry & Bramlette) Bukry 1981

Wiseorhabdus inversus (Bukry & Bramlette) Bukry 1991
Pl.3, figs 5a-b

Remarks - This nannofossil is originally described from Middle Eocene of Blake Plateau. The rod-like forms bearing multiple blades show serrated margin.

Family - Thoracosphaeraceae

Genus - *Thoracosphaera* Kamptner 1927

Thoracosphaera cf. *Th. saxea* Stradner 1961
Pl.3, fig. 7

Remarks - The fragmentary tests display larger elements than seen in typical *Th. saxea,* but with similar extinction pattern under crossed nicols. It is rarely observed in the assemblage. It was earlier reported from late Middle Eocene of Kutch basin (Pant & Mamgain, 1969).

Thoracosphaera cf. *Th. tuberosa* Kamptner 1963
Pl.3, fig.6

Remarks - Fragmentary pieces of the test under normal light show projecting crystal outlines. Under crossed nicols, display extinction pattern, containing small triangular areas as seen in typical *Th. tuberosa.* It is known to range from Eocene to Recent, but rarely recorded in the present assemblage.

RESULTS AND DISCUSSIONS

The rich and diverse assemblage of calcareous nannofossils described from the type Harudi Formation could be assigned to NP17 : *Discoaster saipanensis* zone of Martini (1971), emended herein to include upper part of NP16 : *Discoaster tani-nodifer* zone of Martini (1971), partly correlatable with CP14 *Reticulofenestra umbilica* zone of Okada and Bukry (1980) and also referable to a part of P13: *Orbulinoides beckmanni* zone of planktonic foraminifera (late Middle Eocene = Bartonian age). Common occurrence of holococcoliths suggests near-shore deposition in inner neritic shelf setting.

The Bartonian concept and zonal assignment

The threefold chronostratigraphic subdivision of Eocene having stratotypes in classic areas of western Europe, viz., Ypresian (Early Eocene), Lutetian and Bartonian (Middle Eocene) and Priabonian (Late Eocene) is currently in use (Harland *et al.*, 1982; Hardenbol & Berggren, 1978). Lutetian corresponds to planktonic foraminifer zones P10, P11 and P12 referable to nannofossil zones NP14, NP15 and Lower NP16, respectively. Bartonian corresponds to planktonic foraminifer zones P13 and P14 referable to nannofossil zones upper NP16 and NP17 (Text-fig. 2). It must be emphasized that the workers attempting to establish FAD (First appearance datum) and LAD (Last appearance datum) of two important groups of calcareous plankton, viz., nannofossils and planktonic foraminifera, in coastal marine set up of Kutch supratrappeans and elsewhere, must not overlook the role of terrigenous influx, rapid changes in coastal geomorphology. These seriously influence the disappearance or appearance of species, which are in turn controlled by factors of salinity and the capacity of open ocean currents to exchange plankton crop from restricted environments of the coastal region. As such the recorded FADs and LADs specially of index planktonic foraminifers may not be real and several small to big plankton-barren horizons could be expected.

A brief definition of nannofossil zones NP16 and NP17 seems warranted for justifying the emendation of the latter zone and for discussions related to the detailed nannofossil assemblages earlier recorded from Harudi and Fulra Limestone formations (Rai, 1988).

NP16 : *Discoaster tani-nodifer zone*

Definition - Interval from LAD of *Rhabdolithus gladius* Locker to LAD of *Chiasmolithus solitus* (Bramlette & Sullivan)

Author - Hay 1967; emend. Martini 1970.

Last occurrence of *Discoaster distinctus* and first occurrence of *Discoaster saipanensis* was indicated in the upper part of NP16.

NP17: *Discoaster saipanensis zone*

Definition - Interval from LAD of *Chiasmolithus solitus* (Bramlette & Sullivan) to the FAD of *Chiasmolithus oamaruensis* (Deflandre)

Author - Martini 1970

Martini (1971) indicated LAD of *Sphenolithus furcatolithoides* Locker and FAD of *Helicosphaera compacta* (Bramlette & Wilcoxon) in the lower part of NP17.

While attempting a detailed nannofossil biostratigraphy of Harudi and Fulra Limestone formations of Kutch basin (Rai, 1988), it was realised that zonal markers; *Rhabdolithus gladius, Chiasmolithus solitus, Chiasmolithus oamaruensis* being exceedingly rare elsewhere, and absent in Indian basins, could not be used, specially for demarcating NP16/NP17 nannofossil boundary (Jafar & Rai unpublished data). The NP17: *D. saipanensis* zone was thus emended to include upper part of NP16: *D. tani-nodifer* zone for practical reasons. Although total range of distinctive *D. saipanensis* is well established (upper NP16 to NP20 nannofossil zones), Perch-Nielsen (1985) plotted doubtful range down into NP15 without assigning any reason or illustrations of the species from older levels. *D. saipanensis* illustrated from NP13/NP14 zonal levels of borewell material from northern Germany (Köthe, 1986) is due to misidentifications, hence not reliable. *D. saipanensis* is commonly found in Indian basins, hence the FAD of this species is used to define the base of emended zone NP17, so that shallow marine sediments lacking traditional markers, including chiasmoliths in low- latitude sites, could be dated. Müller (1974) also used *D. saipanensis* as substitute marker to roughly coincide with extremely rare LAD of *Chiasmolithus solitus* in Arabian sea DSDP material.

Emended NP 17: *Discoaster saipanensis zone*

Definition - FAD of *D. saipanensis* to FAD of *Chiasmolithus oamaruensis*.

Author - Martini 1970, 1971; emended.

The emended definition encompasses upper part of NP16 and entire NP17 in nannofossil zonation of Martini (1971). The emended definition of NP17 incidently corresponds to the chronostratigraphic boundaries of Bartonian (Aubry, 1985; Text-fig. 2) and would contain both P13 : *O. beckmanni* and P14: *T. rohri* planktonic foraminifer zones, further matching D11 : dinoflagellate zone of Costa and Manum in Vinken (1988). The emended NP17 nannofossil zone thus partly corresponds to CP14 : *R. umbilica* zone of Okada and Bukry (1980). Frequent occurrence of *Cribrocentrum reticulatum* (*Reticulofenestra reticulata*) in basal samples of Harudi Formation, and a marker nannofossil for recognising Lutetian/Bartonian boundary (Aubry, 1985), suggests Bartonian age. The detailed work on Harudi and Fulra Limestone formations, has demonstrated (Rai, 1988), that LAD of *Sphenolithus furcatolithoides, Discoaster distinctus* and the presence of *Discoaster bifax* and *Cribrocentrum reticulatum*, supports assignment of Harudi Formation to upper part of NP16 nannofossil zone, as defined by Martini (1971). The FAD of *Helicosphaera bramlettei* and presence of *Helicosphaera compacta* further supports this. The FAD of *Helicosphaera reticulata* in the overlying Fulra Limestone favours its assignment to NP17 nannofossils zone of Martini (1971), implying that by older definition of Martini (*op.cit.*), the zonal boundary NP16/NP17 roughly corresponds to lithoboundary of Harudi/Fulra Limestone Formation exposed in Rato Nala section of Kutch basin (Rai,1988).

Correlations with planktonic foraminifera zones

Planktonic foraminiferal scheme valid for low latitude Middle Eocene is followed herein (Blow, 1969; Tourmakine & Luterbacher, 1985). The marls of the upper part of Harudi Formation and the bioclastic Fulra Limestone Formation (Text-fig. 2) has yielded a rich assemblage of calcareous nannofossils (Rai, 1988) and planktonic foraminifera from widely separated exposures in Kutch basin. It must be emphasized that such a rich biotope of planktonic fossils are neither found in the underlying nor overlying levels of upper Harudi-Fulra Limestone marine supratrappeans of Kutch basin. It suggests the deposition of upper Harudi-Fulra Limestone in increased bathymetric setting with open ocean currents freely entering the coastal embayments. Analysis of samples from Harudi and Fulra Limestone formations of Rato Nala, shows that the samples otherwise containing rich calcareous nannofossils were barren or contained rare planktonic foraminifera, which need much higher power of the currents to exchange the crop with the open oceanic plankton.

Improved frequency of planktonic foraminifera comprising : *O. beckmanni, T. rohri, T. topilensis, G. kugleri* and *M. lehneri* were, however, observed near the Harudi/Fulra Limestone Formation contact (Text-fig. 2-4), thus favouring the assignment of upper Harudi Formation and a part of Fulra Limestone Formation to P13 : *O. beckmanni* zone (Rai, 1988). Presence of *T. rohri* zone recognised by the disappearance of marker *O.*

Figure 1 Section in type Rato Nala exposing maximum thickness of Harudi Formation overlain by thinly bedded Fulra Limestone Formation. Finely laminated glauconitic marls and mudstones contain sparse larger foraminifera, ultrathin small bivalves and abundant calcareous nannofossils documented in this paper. Section IV in Text-fig. 3 corresponds to this exposure.

Figure 2. A section near Maniara Fort exposing the sharp contact (marked by an arrow) of cream coloured bioclastic Limestone of Fulra Limestone Formation overlain by glauconitic marls of Maniara Fort Formation containing abundant *Nummulites fichteli* of Rupelian age. The contact represents submarine hiatus involving considerable time (*partim* Bartonian, Priabonian, *partim* Rupelian).

Mohan & Soodan, 1970; Samanta, 1970, 1978, 1981; Raju, 1971). The Vinjhan-Miani area however does not reveal the presence of P14: *T. rohri* zone, presumably owing to the local erosion there of the upper part of Fulra Limestone Formation (Jauhari, 1981).

Incidently the P13 : *O. beckmanni* and P14 : *T. rohri* zones correspond to chronostratigraphic boundaries of Bartonian (Harland *et al.*, 1982: Aubry, 1985; Text-figs 2,4), matching upper part of NP16 : *D. tani-nodifer* and NP17: *D. saipanensis* zones as per the definitions of Martini (1971). These zones have been recognised in several parts of Kutch basin and the Late Eocene hiatus (Priabonian) is supported by several workers including our own observations made at Fulra Limestone/ Maniara Fort Formation contact near Maniara Fort (Jafar & Rai, unpublished data; Figs 1-2). Based on published data, the P13/P14 planktonic foraminifer zonal boundary lies within Fulra Limestone Formation and NP16/NP17 nannofossil boundary falls within P13 : *Orbulinoides beckmanni* zone in low latitude assemblages including Kutch basin. Nannofossil assemlage older than upper part of NP16 - *partim* Bartonian, has neither been recorded in basalmost productive sample of Harudi Formation nor in any other section of Kutch basin (Rai, 1988). However, well documented account of planktonic foraminifera from several widely separated sections referable to a part of P13 and P14 zones, suggest undisputed presence of Bartonian age sediments in Kutch basin.

beckmanni has been published by several workers from different sections of Kutch basin (Sen-Gupta, 1964;

The Bartonian transgressive event

The arguments for including the entire SHALE sequence encompassing Matanomadh, Naredi and Lower Harudi formations (Text-figs 1-4), as a part of Bartonian transgressive cycle, otherwise lacking age diagnostic planktonic elements, are supported by critical field observations and evaluation of published mega- and microfossil records (Rai, 1988). Herein we present a brief critical account of the basin evolution favouring the proposed model.

In response to activation of basinal faults, a shallow epeiric sea invaded Kutch basin during late Middle Eocene (Bartonian) time. The Deccan trap basement rock contained thick laterite cover and lacustrine intertrappean beds with typical palynoflora straddling K/T transition (Courtillot *et al.*, 1986; Ghevariya, 1988). The beach was largely muddy owing to increased flux of terrigenous clay emanating from weathered terrain, supporting sparse megafossils, which are not age diagnostic, viz., *Venericardia* horizons, sponges etc. (Tewari 1952; Tandon 1962, 1971; Tandon *et al.* 1980). System of shallow lagoons and embayments with subdued salinity girdled the coast during the deposition of Matanomadh Formation, which were not efficiently connected to the open sea currents and periodically supported "dwarf" planktonic foraminifera crop (Samanta, 1974; Tandon *et al.*, 1980; Singh & Singh, 1981; Biswas 1986, 1990; Jafar, 1986; Jafar & Rai, 1991) not fit for age determinations.

Low energy clastics, displaying variegated colours of Matanomadh Formation contained plenty of trap derivatives, show rapid lateral facies variations, being well developed in northwestern part of the basin and pinching out completely in several sections such as in Rato Nala section. Bituminous, pyritiferous and resiniferous rich shales contain reworked trap debris including typical palynoflora derived from Early Cretaceous infratrappean and Palaeocene intertrappean sediments during Bartonian transgression (SenGupta, 1964; Biswas, 1965, 1990; Mathur, 1966; Saxena, 1977a, 1977b, 1979, 1980, 1981; Pandey & Ravindran, 1988; Singh & Singh 1981). Reduced salinity inhibited the growth of mineral glauconite, except locally (Singh 1978). The land supported luxuriant tropical humid deciduous-vegetation as evidenced by the plant fossils preserved in lignites (Lakhanpal & Guleria, 1981). The mineral gypsum occurs as secondary throughout Kutch basin and has no palaeoenvironmental significance (Saraswati & Banerji, 1984).

Increased bathymetry and the resultant decreased supply of terrigenous clay debris coupled with improved salinity resulted in deposition of "gypseous clays" of Naredi and lower part of Harudi Formation with glauconite (Text-figs 2,4). The change in the geometry of coastline permitted restricted access to open-sea currents, inducing local growth of larger-planktonic foraminifera biotope, though much reduced in size and diversity. Black shales developed in pockets, occasional bioturbated horizons were erroneously interpreted as laterite and do not signify hiatus. It is rather interesting that most micropalaeontologic work on Naredi Formation was based on a solitary Naredi section (Text-fig. 1B, 23° 34′30″/68° 39′00″) on Baranda-Narayan Sarovar road on either sides of a small concrete bridge exposing Deccan trap basement (Biswas & Raju, 1973; Tandon, 1962; Singh & Singh, 1981, 1991; Biswas, 1990). Laminated shales with conspicuous nodule horizons contain a variety of terrestrial and marine fossils (Wynne, 1872) and were erroneously correlated with early Eocene Laki Series of Sind area. Traditional larger foraminifera species *Assilina granulosa, Assilina daviesi, Asslina spinosa, Nummulites burdigalensis* were cited for Early Eocene age assignments, but in view of strong facies control and provinciality, the age diagnostic value of these species cannot be relied upon (Tewari 1952, 1957; Tandon, 1962; SenGupta, 1964; Mohan & Gupta, 1968; Raju *et al.*, 1970; Samanta, 1970; Singh & Singh 1981, 1991; Samanta *et al.*, 1990; Pandey & Shukla, 1991). Besides Naredi, these species have not been recorded from several other sections of Kutch basin (Jafar & Rai, 1991). Rich palynofloral assemblage comprised species which are not age diagnostic and extend higher up in Eocene (Mathur, 1963, 1966; Sah & Kar, 1969, 1970, 1972; Venkatachala & Kar, 1969a, 1969b; Venkatachala *et al.*, 1988).

Outstanding planktonic foraminifera records supporting "Early Eocene" dating of Naredi Formation (Tandon *et al.*, 1980; Mohan & Gupta, 1968; Bhatt, 1968), has earlier been doubted by SenGupta (1964) and Samanta (1970). Much quoted work of Bhatt (1968) on planktonic foraminifera supporting Early Eocene age after critical assessment seems doubtful on following grounds:

a. about a dozen species of *Globigerina* and *Globorotalia* including Early Eocene marker "*Globorotalia wilcoxensis*" are based on just 1-3 specimens without details of dorsal, ventral and axial views for precise specific determinations. Moreover, all specimens are "dwarfed" at least by a factor of three.

b. abundant specimens of *Assilina granulosa* are reported to be associated with these planktonic foraminifera species (Raju *et al.*, 1970; Singh & Singh, 1981, 1991; Ray *et al.*, 1984; Biswas, 1986; Pandey & Shukla, 1991; Jafar & Singh, 1992). However the status of *A. granulosa* as Early Eocene marker has yet to be established.

c. specimens recovered from a thin marlite layer lying within a 40m thick gypseous and ferrugenous clays of Berwali stream section, are not known from other sections.

Further increase in the bathymetry resulted in the free incursions of the open sea current system into the coastal embayments and lagoons. Far better growth of invertebrate fauna with establishment of dinoflagellate and nannoplankton crops occurred during deposition of the upper part of Harudi Formation; while larger - and benthic foraminifera flourished, planktonic foraminifera were rare and stunted at this level (Text-figs 2-4), till the initiation of the sea regression near the Marl-Bioclastic limestone facies transition, so well displayed in Rato Nala section (Text-fig.3). Shallowing of the basin resulted in the development of foraminiferal banks, supplying larger foraminifera which were subjected to *in situ* winnowing and reworking under high energy conditions to deposit Fulra Limestone, making impressive present day scarps. Further shallowing trend resulted in submarine hiatus involving considerable time (partim *Bartonian*, *Priabonian*, partim *Rupelian*). Renewed transgression during Early Oligocene deposited Maniara Fort Formation, which has sharp contact with the underlying Fulra Limestone Formation, so well exposed in a section near Maniara Fort (Fig.2) and readily recognised by the influx of glauconitic marl containing abundant and typical *Nummulites fichteli*.

There is however, a widespread consensus on the age and depositional milieu of Nummulitic group of rocks (Harudi and Fulra Limestone Formations excluding Maniara Fort Formation *sensu* Biswas & Raju, 1973). These contain one of the richest mega- and microfossils notably larger foraminifera (SenGupta, 1964; Samanta 1970, 1981; Tandon, 1976; Samanta *et al*., 1984, 1990; Samanta & Lahiri, 1984), including planktonic foraminifera (SenGupta, 1964; Mohan & Soodan, 1970; Jauhari & Vimal, 1976; Jauhari, 1981; Samanta *et al*. 1990), dinoflagellate (Jain & Tandon, 1981), nannofossils (See Rai 1988, Singh & Sigh 1991) and palynofossils (Kar, 1978).

Based on critical field observations and revaluation of published records, some questions were raised about the existence of complete Palaeocene-Eocene marine record in Kutch basin (Ray *et al*., 1984; Jafar 1986; Biswas, 1986; Rai, 1988). More comprehensive debate followed in subsequent years (Pandey & Ravindran, 1988; Pandey & Shukla, 1991; Singh & Singh 1991; Jafar & Rai, 1991). The model proposed in this paper demands critical reappraisal of published fossil record and facies development in the outcrop sections of the Eocene rocks of Kutch basin. The time - and rock stratigraphic classification would need revision, if further supported by geomagnetic and radiometric data of fossil-poor or barren horizons.

CONCLUSIONS

1. The SHALE-MARL-LIMESTONE sequence of supratrappean marine sediments upto Fulra Limestone (ca. 80m) were deposited during a late Middle Eocene (Bartonian) transgressive event in pericratonic Kutch basin.
2. A rich low-latitude shallow marine assemblage of calcareous nannofossils is documented and discussed from Upper Harudi and Fulra Limestone formations, assignable to NP17: *Discoaster saipanensis* zone emended, further correlated with D11 dinoflagellate zone and a part of *O. beckmanni* and *T. rohri* planktonic foraminifera zones of late Middle Eocene (Bartonian) age.
3. The controversial SHALE sequence overlying the Deccan trap and encompasssing Matanomadh, Naredi and Lower Harudi Formations, contain mega-and microfossils, which are not age diagnostic as they are invariably stunted owing to constraints imposed by shallow marine coastal setup.
4. Indepth facies analysis, critical reappraisal of fossils supplemented by geomagnetic-radiometric studies is warranted for understanding the early part of supratrappeans in Kutch basin.

ACKNOWLEDGEMENTS

Gratitude is expressed to Dr R.S. Tiwari, Director Birbal Sahni Institute of Palaeobotany, Lucknow for the encouragements and to Prof. Ashok Sahni, Punjab University, Chandigarh and Prof. I.B. Singh, Lucknow University, Lucknow for kindly going through the manuscript. For useful suggestions and discussions thanks are due to Drs N. Awasthi and R.K. Kar, Birbal Sahni Institute of Palaeobotany, Lucknow.

REFERENCES

Aubry, M.P. 1985. Northwestern European Palaeogene magnetostratigraphy, biostratigraphy, and palaeogeography : calcareous nannofossil evidence. *Geology* **13**: 198-202.

Bhatt, D.K. 1968. Planktonic foraminifera from lower Eocene sediments of Kutch. *Bull. Oil nat. Gas Comm. Dehradun* **4** (2) : 13-17.

Biswas, S.K. 1965. A new classification of the Tertiary rocks of Kutch, western India. *Bull. geol. Min. metall. Soc. India* **35** : 1-6.

Biswas, S.K. 1971. Note on the geology of Kutch. *Q.Jl. geol. Min. metall. Soc. India* **43** (4) : 223-235.

Biswas, S.K. 1972. The Time stratigraphic classification of the Tertiary rocks of Kutch-Revision and Amendments. *Q.Jl. Min. metall. Soc. India* **44** (3) : 221-224.

Biswas, S.K. 1982. Rift basins in western margin of India and their hydrocarbon prospects with special reference to Kutch basin. *Bull. Amer. Assoc. Pet. Geol.* **66** (10) : 1497- 1513.

Biswas, S.K. 1986. Palaeogene of Kutch - A rejoinder. *Indian J. Earth Sci.* **13** : 343-360.

Biswas, S.K. 1990. A review of Tertiary stratigraphy of Kutch, western India. *8th M.R. Sahni Mem. Lecture*, Deptt. Geology, Lucknow University, 1990; unpublished Rep., 40 pp.

Biswas, S.K. & Raju, D.S.N. 1973. The rock stratigraphic classification of the Tertiary sediments of Kutch. *Bull. Oil nat. Gas Comm. Dehradun* **10** (1-2) : 37-45.

Blow, W.H. 1969. Late Middle Eocene to Recent planktonic foraminiferal biostratigraphy. *In* : Brill, E.J. (ed)- *Proc. First Internat. Conf. Planktonic Microfossils, Geneva* 1967, **1** : 199-422.

Bukry, D. 1978. Cenozoic coccolith, silicoflagellate, and diatom stratigraphy, Deep Sea Drilling Project Leg 44. *In* : Benson, W.E., Sheridan, R.E. *et al.* (eds) - *Initial Rep. Deep Sea Drilling Project, U.S. Government Printing Office, Washington* **44** : 807-863.

Costa, L. & Manum, S.B. 1988. The description of the interregional zonation of the Palaeogene (D1-D15) and the Miocene (D16-D20) - *In* : Vinken, R. (ed.) - A **100** : 321-330, Hannover.

Courtillot, V., Besse, J., Vandamme, D., Montigug, R., Jaeger, J. & Cappetta, H. 1986. Deccan Flood Basalt at the Cretaceous- Tertiary boundary? *Earth Planet Sci. Lett.* **80** : 361-374.

Fütterer, D. 1976. Kalkige Dinoflagellaten (calciodinelloideae) und die systematische Stellung der Thoracosphaerideae. *N.Jb. Geol. palaeontol. Abh.* **151** (2) : 119-141.

Ghevariya, Z.G. 1988. Intertrappean dinosaurian fossils from Anjar area, Kachchh District, Gujarat. *Curr. Sci.* **57** (5) : 248-251.

Hardenbol. J. & Berggren, W.A. 1978. A new Palaeogene numerical time scale. *In*: Cohee, G.V. *et al.* (eds) - Contributions to the Geologic Time Scale, *Stud. Geol., Amer. Assoc. Pet. Geol., Tulsa, Oklahoma, U.S.A.* : 213-234.

Harland, W.B., Cox, A.V., Llewellyn, P.G., Pickton, C.A., Smith, A.G. & Walters, R. 1982. A geologic time scale, Cambridge Earth Science series. *In*: Hughes, N.F. *et al.* (eds), Cambridge University Press, Cambridge : 1-131.

Jafar, S.A. 1979. Taxonomy, stratigraphy and affinities of calcareous nannoplankton genus *Thoracosphaera* Kamptner. *Proc. IVth Int. Palyn. Conf., Lucknow* (1976/1977) **2** : 1-21.

Jafar, S.A. 1986. Fallacious status of Palaeocene in Kutch basin. *Symp. Palaeocene India - Limits and subdivisions, Indian Assoc. Palynostratigrapers, Lucknow.* **8** : 8-10 (Abstract).

Jafar, S.A. & Rai, J. 1984. Late Middle Eocene calcareous nannoplankton from Kachchh, western India. *Bull. geol. Min. metall. Soc. India.* **51** *XIth Ind. Colloq. Micropalaeont. Strati. Calcutta.* : **41** (Abstract).

Jafar, S.A. & Rai J. 1991. Late Middle Eocene (Bartonian) calcareous nannofossils and its bearing on coeval post-trappean transgressive event in Kutch basin, western India. Birbal Sahni Centenary Palaeobotanical Conf., Lucknow. : 52 (Abstract).

Jafar, S.A., Rai, J. & Vimal, R. 1985. Integrated nannoplankton - larger foram biostratigraphy and facies of Late Eocene rocks exposed around Tarakeshwar town, Surat, Gujarat. *5th Conv. Indian Assoc. Sedimentol, Hyderabad* : 46-48 (Abstract).

Jafar, S.A. & Saxena, R.K. 1984. Late Bathonian calcareous nannoplankton from basal part of Jumara Formation Kachchh, western India. *Bull. geol. Min. metall. Soc. India* **51** : 76-77 (Abstract).

Jafar, S.A. & Singh, O.P. 1992. K/T boundary species with Early Eocene nannofossils discovered from Subathu Formation, Shimla Himalaya, India. *Curr. Sci.* **62** (5) : 409-413.

Jafar, S.A., Singh, I.B. & Howard, J.D. 1983. Palaeoecology of calcareous nannoplankton in Late Jurassic shallow marine sequence of Ler section, Kachchh, western India : Meaning of Productive and barren horizons. *1st Int. Conf. Palaeoceanography, Zürich* : 30 (Abstract).

Jaikrishna, Singh, I.B., Howard, J.D., Jafar, S.A. 1983. Implication of new data on Mesozoic rocks of Kachchh, western India. *Nature* **305** (5937) : 790-792.

Jain, K.P. & Tandon, K.K. 1981. Dinoflagellate and acritarch biostratigraphy of the middle Eocene rocks of a part of southwestern Kutch, India. *J. palaeont. Soc. India* **26** : 6-21.

Jauhari, A. K. 1981. Observations on morphotypes, taxonomy and biostratigraphic correlation of the Middle Eocene planktonic foraminifera from the Vinjhan-Miani area of Kutch, western India. *Geosci. J.* **2** (2) : 177-212.

Jauhari, A. K. & Vimal, K.P. 1976. Lutetian planktonic foraminifera from Vinjhan-Miani area, South-Western Kutch, Gujarat, India. *J. palaeont. Soc. India* **19** : 20-23.

Jauhari, A.K. & Vimal, K.P. 1978. Some observations on the foraminifera from the Tertiary rocks of the Vinjhan-Miani area, Kutch. *J. geol. Soc. India* **19**(4) : 154-159.

Köthe, A. 1986. Kalkiges Nannoplankton aus dem Palaeogen Nordwestdeutschlands. *Geol. Jb. Reihe A., Heft* **89** : 3-114.

Kar, R.K. 1978. Palynostratigraphy of the Naredi (Lower Eocene) and the Harudi (Middle Eocene) Formations in the District of Kutch, India. *Palaeobotanist* **25** : 161- 178.

Lakhanpal, R.N. & Guleria, J.S. 1981. Leaf impressions from the Eocene of Kachchh, western India. *Palaeobotanist* **28- 29** : 353-374.

Martini, E. 1970. Standard Palaeogene calcareous nannoplankton zonation. *Nature* **226** : 560-561.

Martini, E. 1971. Standard Tertiary and Quaternary calcareous nannoplankton zonation, *In* : Farinacci, A. (Ed.) - *Proc. IInd. Int. Plankt. Conf. Roma 1970, Technoscienza* **2** : 739-785.

Mathur, Y.K. 1963. Studies in the fossil microflora of Kutch, India.1. On the microflora and the hystrichosphaerids in the gypseous shales (Eocene) of western Kutch, India. *Proc. nat. Inst. Sci. India.* B **29**(3) : 356-371.

Mathur, Y.K. 1966. On the microflora in the Supra-Trappeans of western Kutch, India. *Q.Jl. geol. Min. metall. Soc. India* **38** : 33-51.

Medlicott, M.B. & Blanford, W.T. 1879. Manual of Geology of India, chiefly compiled from the observations of the Geological Survey. **1** : 342-348.

Mohan, M. & Gupta, S.C. 1968. The microfauna and age of the gypseous shales, western Kutch, India. *Cushman Found. Foram. Res. Contr.* **19**(1) : 21-26.

Mohan, M. & Soodan, K.S. 1970. Middle Eocene planktonic foraminiferal zonation of Kutch, India. *Micropalaeontology* **16**(1) : 37-47.

Müller, C. 1974. Calcareous nannoplankton, Leg 25 (western Indian Ocean). *In* : Simpson, E.S.W. & Schlich, R. *et al.* (eds.)- *Initial Reports of the Deep Sea Drilling Project, U.S. Government Printing Office, Washington.* **25** : 579-633.

Okada, H. & Bukry, D. 1980. Supplementary modification and introduction of code numbers to the low-latitude coccolith, biostratigraphic zonation (Bukry, 1973; 1975). *Marine Micropaleont.* **5** : 321-325.

Pandey, J., Ravindran, C.N. 1988. Foraminiferal controls in the Indian Palaeocene. *In* : Maheshwari, H.K. (ed.)- Palaeocene of India. *Proc. Symp. Palaeocene of India : Limits and Subdivisions.* Lucknow : 124-184.

Pandey, J. & Shukla, S. 1991. Larger foraminiferal indices of the Indian Palaeogene. *Indian Geologists Association, Short Course Notes : Techniques in Micropalaeontology : Application of Electron Microscopy, Feb. 5-11, 1991, CAS in Geology, Panjab Univ., Chandigarh* : 207-239.

Pant, S.C. & Mamgain, V.D. 1969. Fossil Nannoplankton from the Indian subcontinent. *Rec. geol. Surv. India* **97**(2) : 108-128.

Pant, S.C. & Mathur, U.B. 1973. Fossil nannoplankton from Eocene of Broach, Gujarat, India. *Rec. geol. Surv. India* **105**(2) : 209-216.

Perch-Nielsen, K. 1985. Cenozoic calcareous nannofossils, In : Bolli, H.M., Saunders, J.B. & Perch-Nielsen K. (eds) - *Plankton Stratigraphy. Cambridge University Press* : 427- 554.

Rai, J. 1988. *Calcareous nannoplankton from Eocene of Kutch, western India.* Ph.D. Thesis, Lucknow University, Lucknow, pp. 1-316.

Rai, J. 1991. Nannoplankton, In : *A Catalogue of Fossil Plants*, Birbal Sahni Institute of Palaeobotany, Lucknow: 1-29.

Raju, D.S.N. 1971. Observations on the Eocene, Oligocene and Miocene foraminiferal biostratigraphy of Kutch, western India. *Pub. Centre Adv. Stud. Geol., Punjab University, Chandigarh* **10** : 136-155.

Raju, D.S.N., Guha, D.K., Bedi, T.S., Kumar, P. & Bhatt, D.K. 1970. Microfauna, Biostratigraphy and Palaeoecology of the Middle Eocene sediments in western India. *Pub. Centre Adv. Stud. Geol., Punjab Univ., Chandigarh* **7** : 155-178.

Ray, A.K., Ghosh, C.C., Sen, P., Gosh, A., Nag, S., Saha, D. & Chowdhury, A. 1984. Palaeogene of Kutch - An alternative view on the initial part of the sequence. *Ind. J. Earth Sci.* **11**(3-4) : 207-224.

Sah, S.C.D. & Kar, R.K. 1969. Pteridophytic spores from the Laki Series of Kutch, Gujarat, India. In : Santapau, H. *et al.* (eds). *J. Sen Mem. Vol.*, Bot. Soc. Bengal : 109- 122.

Sah, S.C.D. & Kar, R.K. 1970. Palynology of the Laki sediments in Kutch. 3. Pollen from the boreholes around Jhulari, Baranda and Panandhro. *Palaeobotanist* **18** (2) : 127-142.

Sah, S.C.D. & Kar, R.K. 1972. Palynostratigraphic evaluation of Lower Eocene sediments of India. *Proc. Sem. Palaeopalynol. Indian Strat. Calcutta*, 1971 : 255-265.

Samanta, B.K. 1970. Middle Eocene Planktonic foraminifera from Lakhpat, Kutch, western India. *Micropaleontology* **16** (2) : 185-215.

Samanta, B.K. 1974. The limits and subdivision of the Palaeocene with remarks on the marine occurrences recorded in the India-Pakistan region. *Q. Jl. geol. Min. metall. Soc. India, Golden Jub.* **46** : 183-205.

Samanta, B.K. 1978. The Middle-Upper Eocene boundary in the Indian region. *Q. Jl. geol. Min. metall. Soc. India* **50** : 137-148.

Samanta, B.K. 1981. Morphology and stratigraphic distribution of *Nummulites maculatus* NUTTAL with observation on the extinction of *Nummulites* near the Middle/Upper Eocene boundary *Q. Jl. geol. Min. metall. Soc. India* **52** (1-2) : 14-35.

Samanta, B.K. & Lahiri, A. 1984. The occurrence of *Discocyclina* Gümbel in the middle Eocene Fulra Limestone of Cutch, western India, with notes on the phylogeny of the Indian Discocycline. *XIth Ind. Colloq. Micropalaeont. Strat. 1984, Bull. geol. Min. metall. Soc. India* **51** : 21-22.

Samanta, B.K., Bandopadhyay, K.P. & Lahri, A. 1990. The occurrence of *Nummulites* Lamarck (Foraminiferida) in the Middle Eocene Harudi Formation and Fulra Limestone of Kutch, Gujarat, western India. *Bull. geol. Min. metall. Soc. India* **55** : 1-66.

Samanta, B.K., Lahiri, A. & Das, S.K. 1984. A revision of the Middle Eocene *Nummulites* of Kutch, Gujarat, western India, *XIth Ind. Colloq. Micropalaeont. Strat. 1984, Bull, geol. Min. metall. Soc. India* **51** : 22-23.

Saraswati, P. & Banerji, R.K. 1984. Post-trappean sedimentation history of the north-western Kutch. *Proc. Xth Ind. Colloq. Micropalaeontology and stratigraphy Pune* : 377-390.

Saxena, R.K. 1977a. Lithostratigraphy of the Matanomarh Formation, Kutch, India. *Palaeobotanist* **24** (3) : 167-174.

Saxena, R. K. 1977b. On the stratigraphic status of the Matanomarh Formation, Kutch, India. *Palaeobotanist* **24** (3) : 211-214.

Saxena, R. K. 1979. Reworked Cretaceous spores and pollen grains from the Matanomarh Formation (Palaeocene), Kutch, India. *Palaeobotanist* **26** (2) : 167-174.

Saxena, R.K. 1980. Palynology of the Matanomarh Formation in type area, North-western Kutch, India (Part 3). - Discussion. *Palaeobotanist* **26** (3) : 279-296.

Saxena, R.K. 1981. Stratigraphy of the area around Matanomarh in North-western Kutch with special reference to the Matanomarh Formation. *Palaeobotanist* **27** (3) : 300-313.

SenGupta, B.K. 1964. Tertiary biostratigraphy of a part of north-western Kutch. *J. geol. Soc. India* **5** : 138-158.

Singh, I.B. 1978. Microfacies, petrography and mineralogy of the Tertiary rocks of Guar Nala near Narain Sarovar, Kutch, India and their palaeoecological significance. *J. palaeont. Soc. India* **21-22** : 78-95.

Singh, M.P. & Singh, P. 1987. A note on the geology and micropalaeontology of the Rato Nadi section, Kutch, Gujarat State, India. *Geosci. J.* **8** (1-2) : 201-204.

Singh, P. 1977. Late Jurassic nannoplankton from the Jurassic sequence in the subsurface of the Banni Rann, Kutch. *J. palaeont. Soc. India* **20** : 331-332.

Singh, P. 1978a. A note on the late Middle Eocene nannofossils from Lakhpat, Kutch. *Curr. Sci.* **47** (3) : 87-88.

Singh, P. 1978b. A note on the late Middle Eocene Nannofossils from the Vinjhan-Miani area, Kutch. *Curr. Sci.* **47** (2) : 53-54.

Singh, P. 1979. Calcareous Nannoplankton from the Kopili Formation of Mikir Hills, Samkherjan area, Assam. *Bull. Oil nat. Gas Comm. Dehradun* **16** (2) : 1-11.

Singh, P. 1980a. Late Middle Eocene calcareous nannoplankton from Lakhpat, Kutch, western India. *Geosci. J.* **1** (1) : 1- 14.

Singh, P. 1980b. Late Middle Eocene calcareous Nannoplankton and palaeogeographic remarks on Vinjhan-Miani area, Kutch, Gujarat. *Geosci. J.* **1** (1) : 15-29.

Singh, P. 1988. Late Middle Eocene calcareous nannoplankton from Berwali River section, Kachchh, India. *Geosci. J.* **9** (2) : 145-156.

Singh, P. & Singh, M.P. 1986. Late Middle Eocene calcareous nannoplankton from Babia Hill, Kutch, Gujarat, India. *Geosci. J.* **7** (2) : 145-162.

Singh, P. & Singh, M.P. 1981. Larger foraminiferal zonation of Naredi formation, Naredi, Kutch, India. *Geosci. J.* **2** (2) : 145-156.

Singh, P. & Singh, M.P. 1991. Nannofloral biostratigraphy of Late Middle Eocene strata of Kachchh region Gujarat State, India. *Geosci. J.* **12** (1) : 17-52.

Singh, P., Singh, M.P., Mathur, D. N. & Srivastava, R. N. 1980. Late Middle Eocene calcareous nannoplankton from Rakhadi River Section, Harudi, Kutch. *Curr. Sci.* **49** (5) : 172-176.

Tandon, K.K. 1962. Fossiliferous Laki beds from Kutch, India. *Curr. Sci.* **31** : 65-66.

Tandon, K.K. 1971. Occurrence of *Venericardia beaumonti* d' Archaic Haime from Nareda, S.W. Kutch, India. *Geophytology* **1** (1) : 70-74.

Tandon, K.K. 1976. Biostratigraphic classification of the Middle Eocene rocks of a part of South-western Kutch, India. *J. palaeont. Soc. India* **19** : 71-88.

Tandon, K.K. & Saxena, R.K. & Mathur, Y.K. 1980. Palaeocene-Early Eocene biostratigraphy in Nareda, southwestern Kutch, western India. *J. palaeont. Soc. India* **23-24** : 86-91.

Tewari, B.S. 1952. The Tertiary beds of Vinjhan-Miani area South-western Cutch, India. *Curr. Sci.* **21** : 217-218.

Tewari, B.S. 1957. Geology and stratigraphy of the area between Waghopadar and Cheropadi, Kutch, western India. *J. palaeont. Soc. India* **2**: 136-148.

Tourmakine, M. & Luterbacher, H. 1985. Palaeocene and Eocene planktic foraminifera. *In* : Bolli, H.M., Saunders, J.B. & Perch-Nielsen, K. (eds). Cambridge University Press, Cambridge : 87-154.

Venkatachala, B.S. & Kar, R.K. 1969a. Palynology of the Tertiary sediments of Kutch 1. Spores and pollen from borehole no. 14. *Palaeobotanist* **17** (2): 157-178.

Venkatachala, B.S. & Kar, R.K. 1969b. Palynology of the Tertiary sediments in Kutch-2. Epiphyllous fungal remains from the bore hole no. 14. *Palaeobotanist* **17** (2): 179-183.

Venkatachala, B.S., Caratini, C., Tissot, C. & Kar, R.K. 1988. Palaeocene-Eocene marker pollen from India and tropical Africa. *Palaeobotanist* **37** (1): 1-25

Wynne, A.B. 1872. Memoir on the geology of Kutch accompanied by the map compiled by A.B. Wynne & F.Fedden. *Mem. geol. Surv. India* **9**(1) : 1-293.

Young, J.C. 1987. Higher classification of Coccolithophores, *INA Newsletter* **9**: 36-38.