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SCANNING-ELECTRON MICROSCOPIC STUDIES OF THE LATE MIDDLE EOCENE (BARTONIAN) CALCAREOUS NANNOFOSSILS FROM THE KUTCH BASIN, WESTERN INDIA

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ABSTRCT

This is the first detailed documentation of nannofloral taxa under scanning electron microscope from the Kutch basin. Over a hundred taxa are recorded from the Harudi Formation in the type area and from the Fulra Limestone Formation both under LM and SEM (Rai, 1988). The assemblage belongs to the NP 17 *Discoaster saipanensis* zone of Martini, 1971 emended Rai, 1988 to incorporate Upper part of NP 16 *Discoaster tani nodifer* zone with FAD of cosmopolitan *D. saipanensis* denoting its lower boundary, in the absence of marker chiasmoliths. It is also correlatable partly with the CP 14 *Reticulofenestra umbilica* zone of Okada and Bukry 1980 and contains part of both P 13 *Orbulinoides beckmanni* and P 14 *Truncorotaloides rohri* planktic foraminiferal zones. The assemblage which does not show reworking, is typical of the nearshore, shallow marine and warm water environment. The forms appearing extremely well preserved under lightmicroscope, show heavy calcitic secondary overgrowth under scanning electron microscope due to tropical arid climate.

Based on field observations and critical survey of the existing literature on the Kutch Tertiaries overlying the Deccan Traps, a Bartonian transgressive event is postulated to account for about 80 meter ±10 meter sequence comprising *Shale, Marl* and *Bioclastic Limestone* sequence in ascending order up to the Fulra Limestone Formation in the Kutch basin. The controversial *Shale* and lower part of *Marl* unit lacking suitable biotope of the datable fossils for dating on international scale requires radiometeric dating. The geomorphological details and evidence of marine cycles support ca. 3.6 million year time span, sufficient to deposit the entire sequence.

Three new nannofossil species viz., *Rhabdolithus ? pseudoliasicus, Neococcolithes ? erraticus* and *Naninfula ? hexaporus* are proposed. Besides this, two new combinations viz., *Cyclococco lithus protoannulus* (Gartner, 1971) n. comb. and *Citrocalculus procerus* (Bukry & Bramletle, 1969) n. comb. are proposed.

INTRODUCTION

The present study is a first detailed account of nannofloral assemblage from the late Middle Eocene of the Kutch basin. The Kutch basin is a pericratonic basin (also spelled as Cutch or Kachchh) which is graben bounded and lies in the western part of India. It was one of the earliest geologically explored areas in the world (Wynne, 1872). The area is characterised by marine clastic sediments of great hydrocarbon potential (Biswas, 1982) overlying the Deccan Traps and marine Mesozoics. The Kutch Tertiaries dip gently towards the South-West. Exposures extend from Lakhpat in the NW to Goyela in the SW part in an arcuate pattern merging with the present day coast line.

Geological and Tectonic maps were provided by Biswas and Deshpande (1970) and Biswas and Raju (1973). A modified version of the latter is given in fig.1. Chrono- and Litho-Stratigraphic classification of Tertiaries of Kutch are given by Biswas (1965, 1972), Biswas and Raju (1973), Biswas (1992). About 80m of thick shallow marine sediments overlying Deccan Trap and terminating at the top of Fulra Limestone can be divided into three discrete lithounits, in ascending order: *Shale-Marl- Bioclastic Limestone* sequences, corresponding to Marh Series (=Matanomarh Formation),Berwali Series (Lower: Kakdi Stage=Nareda Formation; Upper:Babia Stage=Harudi and Fulra Limestone Formations of Biswas and Raju (1973) or to Sub-Nummulitic, Gypseous Shales and Nummulitic group (in part) of Wynne 1872. Tandon (1976) gave biostratigraphic classification of middle Eocene rocks of south-western Kutch.

The Marl-Bioclastic Limestone sequence representing the Nummulitic group of Wynne, 1872 (except Oligocene part) has yielded one of the richest mega and microfossil faunas of Middle Eocene age in the Kutch basin. However, there is difference of opinion among workers on the age and environment of deposition of the Sub Nummulitic and Gypseous Shales of Shale Sequence due to absence or scarcity of marine, datable elements especially plankton. The Shale sequence is characterised by rapid lateral facies variation and patchy outcrops. Its age and environment has been debated in recent years by Ray *et al.* (1984), Jafar (1986), Biswas (1986), Biswas (1990), Rai (1988), Jafar and Rai (1994).

The present study which is part of the author's Ph.D. thesis (Rai, 1988) was carried out with a view to solving this problem through detailed field work and critical examination of the entire sequence for nannofloral productivity and survey of the published field and fossil data. A palaeo-oceanographic model is suggested to explain confinement of extremely scarce dwarf planktonics in thin horizons of the shale sequence, and an uninterrupted Bartonian marine trangressive event is postulated to account for the Shale-Marl and Bioclastic Limestone sequence in the Kutch Basin.

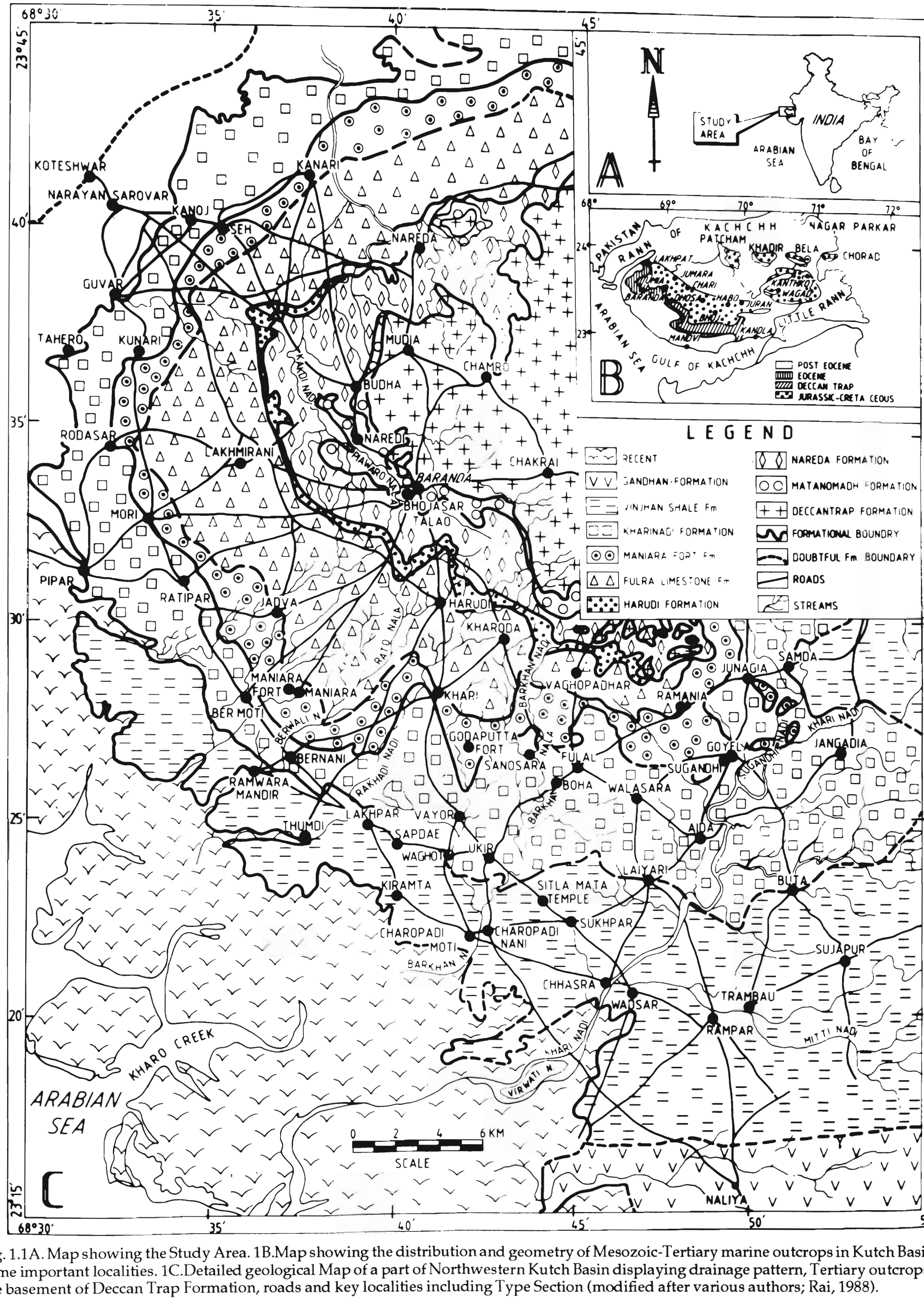
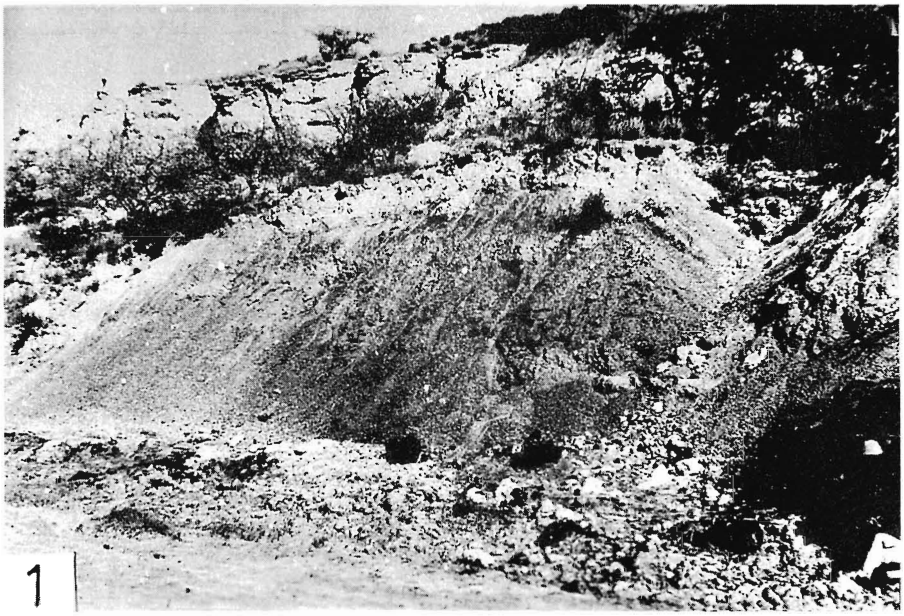


Fig. 1.1A. Map showing the Study Area. 1B.Map showing the distribution and geometry of Mesozoic-Tertiary marine outcrops in Kutch Basin and some important localities. 1C.Detailed geological Map of a part of Northwestern Kutch Basin displaying drainage pattern, Tertiary outcrops over the basement of Deccan Trap Formation, roads and key localities including Type Section (modified after various authors; Rai, 1988).



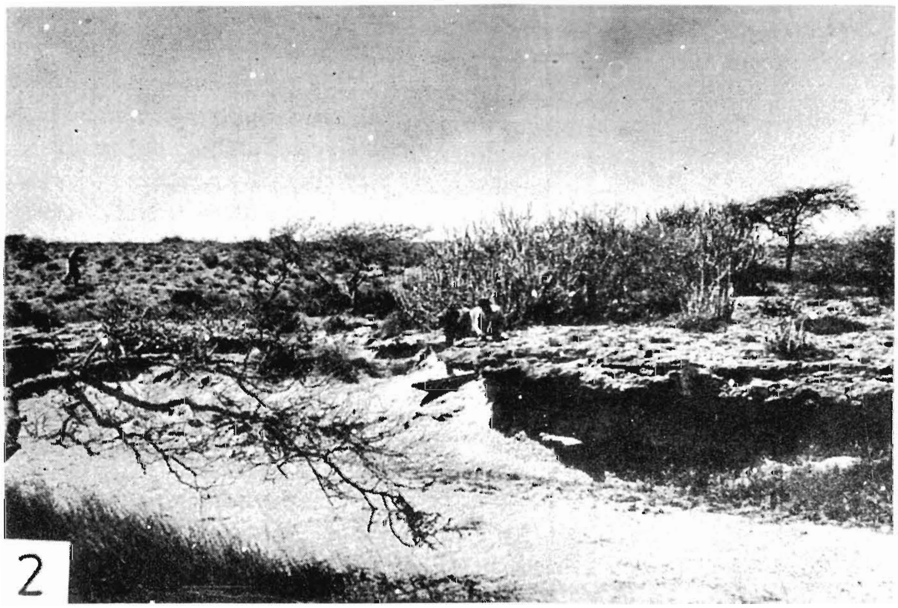


Fig. 2. *1.* Exposure of typical glauconitic marls overlain by basal Fulra Limestone Formation in a cliff at Type Section of Harudi Formation in Rato Nala Section. All Scanning Electron Micrographs of calcareous nannofossils are made from samples of this Section. 2. An important Section, a few hundred meters away from the Maniara Fort, displaying the contact of cream coloured Fulra Limestone Formation and green sandy - glauconitic marls of Maniara Fort Formation flooded with *Nummulites fichteli* of Early Oligocene Age. The arrow points at the contact of the two formations and may involve a hiatus of a part of Late Middle Eocene, Early Oligocene and the entire Late Eocene (Priabonian).

Nannoflora have been described by light microscopy from the Kutch Basin from the Fulra Limestone by Pant and Mamgain (1969), Singh (1978a, 1978b, 1980a, 1980b) and from Harudi marls Singh and Singh (1986) Singh *et al.* (1980), Jafar and Rai (1984), Rai (1988), Jafar and Rai (1994).

This is the first scanning electron microscopic documentation of the calcareous nannofossils from the Kutch Basin. The most productive samples under light microscope were treated for SEM preparation. The samples taken herein are from the Harudi Formation (HF11, HF 12, HF 13). The nannofossils show heavy calcitic overgrowth and recrystallization hampering precise identification in some forms. But the SEM studies have helped in deciphering ultrastructural details of nannofossils. The tropical desertic climatic conditions could account for calcitic overgrowth which is very pronounced under SEM.

MATERIAL AND METHOD

Sample suspension in distilled water is spread over a cover slip and allowed to dry. Coverslips were then mounted on Aluminium stubs with quick silver, coated with gold palladium and examined under SEM 505 PHILIPS model.

The Negatives of scanning electronmicrographs serve as the type specimen (holotypes). Each negative bears a B.S.I.P. Negative Number and is stored in the Museum of Birbal Sahni Institute of Palaeobotany, Lucknow.

SYSTEMATIC PALAEONTOLOGY

The classification adopted herein for calcareous nannofossils is after the morphological features of their living counterparts (Young, 1987).

Kingdom **Protista** (Eukaryotic)

Division **Haptophyta**

Class **Primnesiophyceae** Hibberd, 1976

Systematic treatment of calcareous nannoplankton is after Perch-Nielsen (1971). Families and genera discussed herein are in alphabetical order (fig. 3).

Family **Braarudosphaeraceae** (Gran & Braarud) Deflandre, 1947

Type Genus : ***Braarudosphaera*** (Gran & Braarud) Deflandre, 1947

Genus ***Citrocalculus*** Troelsen & Quadros, 1971

Citrocalculus procerus (Bukry & Bramlette, 1969) n. comb.

Basionym *Micrantholithus procerus* Bukry & Bramlette, 1969 (P. 1 36, Pl. 2, figs. 12-15)
(Pl. I, fig. 9)

Micrantholithus procerus Bukry & Bramlette-Bybell & Gartner, 1972 P. 325, Pl. 3, figs. 1-6.

Micrantholithus altus Bybell & Gartner, 1972, p. 325, pl. 2, figs. 1-10. - Bybell, 1975, p. 189, pl. 11, figs. 1-7.

Micrantholithus procerus Bukry and Bramlette-Buky, 1978, p. 842, pl. 11, fig. 12. - Jafar & Rai, 1994, pl. 1, figs. 6a-b, 7.

Remarks: First reported from late Middle Eocene of the Guayabal Formation of Mexico and the Cook Mountain formation, U.S.A., it is a typical representative of shallow marine sediments of Palaeocene - Middle Eocene age.

The pentaliths typically display elongate outline in side view. In plan view, each of the five triangular shaped pentalith segment bears a median furrow along its outer margin. Easily identified in side view; the height of the pentaliths slightly over double the width at base. Typical cone shaped out line, resembling a citrus-press.

Frequent to very rare in both the Harudi and the Fulra Limestone Formations.

Genus ***Micrantholithus***

Micrantholithus parisiensis Bouché, 1962
(Pl. I, fig. 3)

Micrantholithus parisiensis Bouché, 1962, p. 86 (partim).

Remarks: Pentaliths usually medium sized. The typical triangular shape of the segments display varied thickening and is produced into "hook"-like structures showing sinistral rotation in the plane of the pentalith. Observed very rarely in the Harudi Formation (fig. 3).

Micrantholithus pinguis Bramlette & Sullivan, 1961
(Pl. I, fig 5)

Micrantholithus pinguis Bramlette & Sullivan, 1961, p. 155, Pl. 8, figs. 13a-b.

Micrantholithus vesper Deflandre - Pant & Mamgain, 1969, p. 120-121, pl. 24, figs. 10-11.

Micrantholithus pinguis Bramlette & Sullivan - Haq & Lohmann, 1976 p. 158, pl. 10, fig. 8.

Remarks: Pentaliths relatively small sized (4-12 µm size range in Kutch specimens), robust and characterised by star-shaped appearance, lacking membrane in between the segments, which is typical of *M. flos*. Also reported from shallow marine sediments of widely separated areas of Palaeocene to Eocene age.

Micrantholithus flos Deflandre, 1950
(Pl. I, fig. 6)

Micrantholithus flos Deflandre, 1950 p. 1157, text-figs. 8-11.- Deflandre in Deflandre and Fert, 1954, p. 166, pl.13, figs. 10-11, text-figs. 113-114. - Bramlette and Sullivan, 1961, p. 155, pl. 9, figs. 8a-b.- Bukry and Kennedy, 1969, p. 40, fig. 4 (7).

Remarks: This is the type species of genus Micrantholithus. The triangular shape of the segments is distinguished by thin "web" between them. The segments also display differential thickening. Rarely observed in the Harudi Formation (fig. 3).

Genus ***Pemma*** Klumpp 1953

Pemma cf. *P. angulatum* Martini, 1959
(Pl. I, figs. 7,12)

Remarks: Specimens display resemblance with *P. angulatum* but the angular depression at the margin of the segments is less conspicuous. The central pore visible under Light microscopy employing strong illumination but is not seen in SEM due to calcite overgrowth. However, the general outline is similar to *P. angulatum*. Rarely observed in the Harudi Formation (fig.3)

Pemma basquensis (Martini) Báldi-beke, 1971
(Pl. I, fig. 8)

Micrantholithus basquensis Martini, 1959, p.417, pl.1, figs. 9-12,-. -Bukry & Kennedy, 1962 p. 40, fig. 4 (6).

Pemma snavelyi Bukry & Bramlette, 1969, p.138, pl.2, figs.16-19.

Pemma basquensis (Martini) Baldi-Beke, 1971, p. 32, pl. 4, figs. 11-14; pl. 5, fig. 1.

Pemma basquense basquense (Martini) Bybell n. comb., 1975, p. 190, pl.10, figs. 1-5.

Micrantholithus basquensis Martini-Singh, 1979, pl. 1, fig. 56. - Singh, *et al.*, 1980, p. 175, figs. 70-71.- Jafar & Rai, 1994, pl.1, figs.13a-b, 23-24.

Remarks: Originally described and illustrated by Martini (1959). Several variants with protruding radial sutures (*P. snavelyi*) with small to large opening, giving characteristic outline to pentaliths, are incorporated under this species. Its subdivision at subspecies level proposed by several workers is not followed here. Reported from the mid Eocene - Oligocene sediments of many shallow marine regions. In India, it has been reported from the Late Eocene of Assam and the Late Middle Eocene of the Kutch basin (Singh, 1979; Singh *et al.*, 1980). Frequent to rare both in Harudi and the Fulra Limestone Formations.

Pemma papillatum Martini, 1959
(Pl. I. fig. 4; Pl. IV, figs. 1-2)

Pemma papillatum Martini, 1959,p. 139, Abb. 1a-b. - Pant and Mamgain, 1969, p. 112, non pl.21, fig. 1; pl. 24, figs. 1-2, 7-8, 12-13. - Haq, 1971 p. 45, pl. 6, figs. 5-7, pl. 7, fig. 3, non fig. 4; pl. 3, figs. 2, 4-5. -Pant and Mathur, 1973 p. 212-213, non pl. 26, fig. E; pl. 27, fig., I. -Singh, 1979 p. 8, pl. 1, figs. 52-53, 55; non fig. 54. - Singh *et al.*, 1980 p. 175, figs. 66-67. - Hamilton and Hozzatzadeh, 1982, p. 158, pl. 6.2, non figs. 24-25. - Jafar & Rai, 1994 p.27, pl.1, figs.1a b.

Remarks: This ornate species of *Pemma* is characterised by its large size and typical club-shaped knobs along the periphery of each segment. Readily distinguishable even by broken specimens both under LM and SEM, its known range is from Mid-Late Eocene of shallow marine sediments of widely separated areas. It is utilized as a zonal marker for the Middle Eocene in Alabama (Gartner, 1971). A broadly resembling form with typical finger-like protuberances was observed in the Late Eocene sediments along with typical specimens of *P. papillatum* (Jafar *et al.*, 1985; Pant and Mathur, 1973).

Detailed work on its relative abundance may indicate its stratigraphic potential and its environmental significance in shallow water regime.

Pemma serratum (Chang) Bybell And Gartner, 1972
(Pl. I, fig. 11)

Micrantholithus serratus Chang, 1969, pl. 1, figs. 5-6.

Pemma serratum (Chang) Bybell & Gartner, 1972, pl. 5 (partim), figs. 5-13. -Bybell, 1975, p. 192, pl. 12, figs. 1-6.

Remarks: Though similar in having crenulations on the margin of segments, the recorded specimen differs from specimens of *P. serratum* in lacking pentagonal outline of the pentalith. SEM-microphotograph fails to show pores in the segments due to calcitic overgrowth. Solitary specimen was observed in the Harudi Formation.

Pemma sp. 1
(Pl. I, fig. 10)

Remarks: This medium-sized species is closely related to *P. basquensis*, but differs in the serrations of the margin of pentalith segment. *M. crenulatus* Bramlette and Sullivan, lacks pore and is of pentagonal outline, but resembles *Pemma* sp. 1 in the marginal serrations. It occurs rarely in the Harudi formation.

Family **Calyptrosphaeraceae** Boudreaux & Hay 1969

Genus ***Lanternithus*** Stradner, 1962

Lanternithus minutus Stradner, 1962
(Pl. II, fig. 18; Pl. IV, fig. 17)

Lanternithus minutus Stradner, 1962, p. 375, pl. 2, figs. 12-15.- Locker, 1967 p.361, text-figs. 1a-c, 2-3; pl. 9, figs. 1-8. - Gartner & Bukry, 1969, p. 1217, pl. 139, figs. 4-6; pl. 142, figs. 8 a-h, I.- Jafar & Rai, 1994 pl.3, figs.26-27 a-b, 28.

Remarks: Originally described from the Late Eocene of Austria and subsequently recorded from similar level by Locker (1967), its detailed morphology has been studied both under LM and SEM and holococcolith nature (formed of uniform sized rhombs) illustrated by Gartner and Bukry (1969), The features in the illustrated Kutch specimens are obscured due to calcite overgrowth.

L. minutus is easily identified under LM. The suggestion of Locker (1967), Gartner and Bukry (1969) that it may be related to Braarudosphaeraceae is not followed here. This is reported for the first time from the Indian Tertiary sediments and is commonly associated with nannoflora of Middle Eocene to Early Oligocene shallow marine sediments of several regions of the world.

It is abundant to rare in the Harudi Formation and rare in the Fulra Limestone Formation (fig. 3).

Genus ***Orthozygus*** Bramlette & Wilcoxon, 1967

Orthozygùs aureus (Stradner) Bramlette & Wilcoxon, 1967
(Pl. III, figs. 1-2)

Zygolithus aureus Stradner, 1962, p. 368-369, pl.1, figs. 31-36.

Orthozygus aureus (Stradner) Bramlette & Wilcoxon comb. nov., 1967, p. 116, pl. 7, fig. 1-4.

Zygosphaera aurea (Stradner) Stradner & Edwards, 1968, p.11, 46; pl. 4, fig. 6.

Orthozygus aureus (Stradner) Bramlette & Wilcoxon - Gartner & Bukry, 1969, p. 1216, pl. 139, figs. 1-3; pl. 142, figs. 5-6. - Jafar & Rai, 1994 p. 28,30, pl. 3, figs. 17-18, 19a-b, 20a-b, 21.

Remarks: Originally described from the Late Eocene of Austria, it is one of the earliest nannofossils to reveal holococcolith nature (Stradner and Adamiker, 1966). Well documented by several workers under SEM. It is known from the Middle Eocene-Early Oligocene sediments of widely separated areas of shallow marine deposits.

Common and well preserved specimens observed from the Harudi Formation under LM and rare in Fulra Limestone Formation (fig. 3).

Genus ***Zygrhablithus*** Deflandre, 1959

Zygrhablithus bijugatus (Deflandre) Deflandre, 1959
(Pl. II, figs. 13 - 14; Pl. IV, fig. 16)

Zygrhablithus bijugatus Deflandre in Deflandre & Fert, 1954, p.148, pl. 11, figs. 20-21, text-fig. 59.

Rhabdolithus costatus Deflandre in Deflandre & Fert, 1954, p. 157, pl. 11, figs. 8-11, text-figs. 41-42, 77-79.

Zygrhablithus bijugatus (Deflandre) Deflandre Comb. nov., 1959, p. 135-136.

Isthmolithus claviformis Brönnimann & Stradner, 1960, p. 7, figs. 25-43.

Rhabdosphaera ? semiformis Bramlette & Sullivan, 1961, p. 147, pl. 5, figs. 8-9, 10a-b.

Sujkowskiella enigmatica Hay *et al.*, 1966, p.397, pl.13, figs. 6-7.

Zygrhablithus bijugatus (Deflandre) Deflandre-Gartner & Bukry, 1969, p. 1218-1219, pl. 140, figs. 3-6; pl. 142, figs. 1a-b, 2. - Bybell, 1975, p.244-246, pl. 24, figs. 1-7.

Zygrhablithus bijugatus (Deflandre) Deflandre - Jafar & Rai , 1994, p.30, pl.3, figs. 33,35, 36a-b, 39a-b, 40, 41a-b.

Remarks: Originally reported from the Late Eocene-Oligocene of Oamaru diatomite, New zealand under LM, it is readily identifiable, and is a common constituent of shallow marine sediments of Palaeogene nannofloral assemblages. A wide range of specimens with variable difference in length-breadth, are included in it. Besides, it shows entirely different morphologies in side and plan views and typical shapes of broken specimens.

Illustrated well both under LM and EM, this holococcolith genus is monospecific and is commonly observed in the shallow marine sediments of Early Eocene to terminal Oligocene age. Common to rare in the Harudi Formation and rare in the Fulra Limestone Formation (fig. 3).

Family **Coccolithaceae** Poche, 1913

Genus ***Chiasmolithus*** Hay, Mohler & Wade, 1966

Chiasmolithus titus Gartner, 1970
(Pl. II, fig. 3)

Coccolithus consuetus Bramlette & Sullivan-Levin & Joerger, 1967 p.164, pl.1, figs. 1a-b.

Chiasmolithus titus Gartner, 1970, p. 945, fig. 17 (1-2, 3a-c). Bybell, 1975, p. 194, pl. 14, fig. 3. - Jafar & Rai, 1994, p. 30, pl. 1, figs. 27a-b, 28, 29a-b.

Remarks: Originally reported from the Late Eocene of U.S.A., it is a small chiasmolith species with central area spanned by a characteristic cross bar. Its Known range is from Middle Eocene to Early Oligocene.

It is rare both in the Harudi and the Fulra Limestone Formations (fig. 3).

Chiasmolithus sp.
(Pl. II, fig. 4)

Remarks: Coccospheres of *Chiasmolithus* sp. show small elliptic coccoliths spanned by cross - bars covering a relatively large central area resembling both *Ch. solitus* and *Ch. consuetus.* Rare specimens were found in the Harudi Formation.

Genus ***Cyclococcolithus*** Kamptner, 1954 ex Kamptner, *1956*

Cyclococcolithus protoannulus Gartner n. comb.
(Pl. I figs. 14,16; Pl. IV, fig. 5)

Basionym: Gartner 1971, p. 109, pl. 5, figs. 1 A-C,2.

Cyclolithella robusta (Bramlette & Sullivan) Stradner, 1969, p. 414, pl. 86, figs. 1-4.

Coccolithus sp. Pant & Mamgain, 1969, p. 124, pl. 26, figs. 2,6.

Cyclococcolithus kingi Roth, ?1970, p. 855, pl. 6, fig. 5; pl. 7, fig. 1.

Cyclolithella pakistanika Haq, 1971, p. 21, pl. 2, figs. 1-5; pl. 6, fig. 1.

Cyclococcolithina protoannula Gartner, 1971, p. 109, pl. 5, figs. 1a-c,2.

Cyclococcolithina kingi (Roth) Roth, 1973, p. 730.

Calcidiscus kingi (Roth) Loeblich & Tappan, ?1978 p. 1391.

Cyclolithella pakistanika Haq-Singh, 1979, p.4 pl. 1, figs. 19-20, ? 21-22.- Singh *et al.*, 1980, p.175, pl. 2, figs. 28-36, 38 (partim).

Cyclococcolithus kingi (Roth) Roth *et al.*, 1994 p. 30-32, pl.2, figs. 8, 9a-b.

Remarks : A fairly large and distinctive species, best recognised under LM, it is recorded as a minor constituent of the Eocene nannoflora from several regions, but due to lack of correlation between LM & EM photographs a considerable confusion exists in literature. Earliest doubtful forms are described from the Late Palaeocene of South Atlantic (Steinmetz and Stradner, 1984, Pl. 42, fig. 4) coupled with typical and common E.

robusta from which it differs under LM in showing much thinner bright collar spanned by dark extinction lines. *C. protoannulus* has also been reported from the Eocene of Austria (Stradner, 1969). The typical forms comparable with *C. protoannulus* recorded herein, are illustrated under LM from the Middle Eocene of Kutch (Pant and Mamgain, 1969), Late Eocene (Singh, 1979), the Middle Eocene (Singh *et al.*, 1980), the Middle to Early Oligocene (Roth *et al.*, 1971), Middle Eocene (Gartner, 1971).

Cyclococcolithus kingi (Roth, 1970) is based on two different forms designated as holotype and paratype documented under EM. The suggestion of Roth (1970) that wide central area is caused due to damage of central plug is erroneous. Possibly, a few circular coccoliths with a wide central opening identified with C. *protoannulus* require differentiation under EM.

C. protoannulus (Gartner) comb. nov. is thus useful and easily differentiated from similar looking *E. robusta* under LM. The earliest available name for such forms is by Gartner (1971); however, in view of the importance of conserving the generic name *Cyclococcolithus* in preference to *Calcidiscus* and *Cyclococcolithna*, this new combination became necessary. Since Gartner (1971, figs. 1a-c) failed to designate a holotype for *C. protounnula*, fig. 1a-c is hereby designated as lectotype for *Cyclococcolithina protoannula* Gartner 1971.

C. protoannulus (Gartner) is recorded as common to rare in the Harudi Formation.

Genus ***Ericsonia*** Black, 1994

Ericsonia fenestrata (Deflandre & Fert) Stradner & Edwards, 1968
(Pl. II, fig. 1)

Discolithus fenestratus Deflandre & Fert, 1954, p. 139, pl. 11, fig. 25, text-fig. 52 (?) 18.

Ericsonia fenestrata (Deflandre & Fert) Stradner & Edwards, 1968, p. 18, pl. 10, figs. 1-4; pl. 11, figs. 1-4. - Haq, 1971, p.68, pl. 3, figs. 7-9 (partim). - Bybell, 1975 p. 196, pl. 21, fig. 7.

Remarks : This is a small species of *Ericsonia* displaying features similar to forms described under EM (Stradner and Edwards, 1968) as *E. fenestrata*. Synonymy list is based on the broader concept of species, where central area shows larger number of pores than seen in coccosphere illustrated in this study.

This could not be distinguished under LM, as it is associated with a number of small coccoliths.

Ericsonia formosa (Kampner, 1963) Haq, 1971
(Pl. I, figs. 13, 15)

Coccolithus formosus Kamptner, 1963, p. 163, pl. 2, fig. 8, text fig. 20.

Coccolithus lusitanicus Black, 1964, p. 309, pl. 50. figs. 1-2.

Cyclococcolithus lusitanicus (Black) Hay *et al.* - Bramlette & Wilcoxon, 1967, p. 103, pl. 3, figs. 16-17.

Cyclococcolithus orbis Gartner & Smith, 1967, p.4, pl.4, figs.1-3.

Cyclococcolithus formous Kamptner-Martini, 1969, p. 132. pl. 1, figs. 1-2.

Ericsonia formosa (Kamptner) Haq, 1971, p. 17, pl. 4, figs. 7-8.

Cyclococcolithina formosa (Kamptner) Wilcoxon-Bybell, 1975, p.195, pl. 16, figs. 4a-b, 5. - Singh *et al.*, 1980, p. 172-176, figs. 22-24. - Singh, p. 4, 1980a, pl. 1, figs. 6-10, 14-17. - Singh, 1980b, p. 22-23, pl. 1, figs. 21-26.

Calcidiscus formosus (Kamptner) Loeblich & Tappan-Steinmetz & Stradner, 1984, p. 677, pl. 42, fig. 7.

Coccolithus formosus (Kamptner) Singh & Singh, 1986, p. 149, pl. 3, figs. 17-18.

Ericsonia formosa (Kamptner) Haq-Jafar & Rai, 1994,p.32, pl.2, figs. 1a-b.

Remarks : Originally reported from the Eocene of the Pacific Ocean (Kamptner, 1963), this is a readily recognisable species both under LM and EM. It is utilized as an important stratigraphic marker for delineating Eocene-Oligocene boundary. It appears in the Late Early Eocene and disappears in Early Oligocene (Martini, 1971) and ranges between NP12 and NP21.

Reported from the coeval sediments of Bartonian age in Kutch Basin viz., Lakhpat (Singh, 1980a), Vinjhan-Miani (Singh, 1980b), Rakhadi river section (Singh *et al.*, 1980), Babia Hill (Singh and Singh, 1986) and Priabonian (Late Eocene) of Surat (Jafar *et al.*, 1985).

Common to rare in the Harudi Formation ard rare in the Fulra Limestone Formation (fig. 3).

Ericsonia cf. *E. ovalis* Black, 1964
(Pl. I, fig. 14)

Remarks : A solitary specimen from the Harudi Formation. As seen under SEM, it displays rim elements of *Ericsonia* and a central opening. Probably referable to *E. ovalis* Black.

Ericsonia sp. 1
(Pl. I, fig. 17)

Remarks : Fairly large sized species of *Ericsonia* with damaged central area, but otherwise similar in structure to other species of comparable size. Solitary specimen found in the Harudi Formation.

Ericsonia sp. 2
(Pl. I, fig. 18)

Remarks : A solitary specimen was found under SEM from the Harudi Foramtion. The proximal shield as compared to distal shield is diminutive in size. The central area is perforate, and the proximal view of distal shield displays distinct pits between the elements.

Family **Discoasteraceae** Tan Sin Hok, 1927

Genus ***Discoaster*** Tan Sin Hok, 1927

Discoaster barbadiensis Tan Sin Hok, 1927
(Pl. II, figs. 8,10,18)

Discoaster ehrenbergi Tan Sin Hok, 1927, p. 119, text-fig. 3.

Discoaster barbadiensis var bebalaini Tan Sin Hok, 1927, p. 118-120, text-figs. 2,4.

Heliodiscoaster barbadiensis Tan Sin Hok-Klumpp, 1953, p. 382, Abb. 3-6a,c, ?b, d.

Discoaster barbadiensis Tan Sin Hok - Sensu emend Bramlette & Riedel, 1954, p. 398, pl. 39, figs. 5a-b. - Stradner & Papp, 1961, p. 95-96, pl. 28, figs.1-2, text-figs. 9/7, 18/6, 24/3. - Pant & Mathur, 1973, p. 214, pl. 26, figs. C, F; pl. 27, fig. D. - Jafar, 1975, p. 44, pl. 15, fig. 5. - Singh, 1979 p.5, p1.1, figs. 36-43. - Singh *et al.*, 1980, p. 175, figs. 47-50. - Singh, 1980a, p. 6, pl. 2, figs. 12-13. - Singh, 1980b, p. 23-24, pl. 1. fig. 28. - Singh & Singh, 1986, pl. 4, figs. 12-13, 15-16. - Jafar & Rai, 1994, p.32, pl. 2, figs. 14-18, 22-23, 27.

Remarks: The rosette-shaped asteroliths having 7-14 rays, joined along the major part of the ray length with blunt to pointed tips. The asteroliths bear a typical central stem and indicate proximal curvature, best seen in side view. It is a typical Eocene discoaster.

The relative abundance of the number of rays and their size variation may be utilized for interpreting environmental significance as the present assemblage is dominated by eleven rayed forms but the range is from 7-18 rays. Two broad size ranges with 9 µm and 18 µm diameter dominate the assemblage.

Reported from the Bartonian equivalent sediments of the Kutch Basin (Singh, 1980a; Singh, 1980b; Singh *et al.*, 1980; Singh and Singh, 1986; Rai, 1988; Jafar and Rai, 1994) and the Late Eocene of Eastern India (Singh, 1979), it serves as an important stratigraphic marker for identifying Eocene/Oligocene boundary as it disppears along with *D. saipanensis*.

Discoaster distinctus Martini, 1958
(Pl. II, fig. 11)

Discoaster distinctus Martini, 1958 pl. 4, figs. 17a-b. - Bramlette & Sullivan, 1961, p. 159, pl. 11, figs. 11-13. - Jafar & Rai, 1994, p.32, 34, pl.2, fig. 5.

Remarks: Originally reported from the Early Late Eocene. Usually containing 6 rays with terminal bifurcation and containing two knobs on both ray sides. Diameter size ranges between 8 and 17 µm in the studied material. Specimens display calcite overgrowth in the present material.

Discoaster saipanensis Bramlette & Riedel 1954
(Pl. II, figs. 6-7; Pl. IV, fig. 11)

Discoaster saipanensis Bramlette & Riedel, 1954, p. 398, pl. 39, fig. 4. - Pant & Mamgain, 1969, p. 117-118, pl. 19, figs. 1-3, pl. 23, figs. 9,13, ? 10. - Singh *et al.*, non 1978, p. 346-347, fig. 3. - Singh, 1979, p. 5, pl. 1, figs. 45-51. - Singh *et al.*, 1980, p. 175, figs. 59-63. - Singh, 1980a, p. 6, pl.2, figs. 14-15. - Singh, ?1980b, p. 24, pl. 1, fig. 30. - Singh & Singh, ?1986, pl. 4, figs. 20-22. - Jafar & Rai, 1994, p.34, pl.2, fig. 19.

Remarks : Originally reported from Late Eocene of Saipan Islands (Bramlette and Riedel, 1954, Bramlette, 1959), the present forms are usually found with 5-8 rays joined about half of their length and then terminating abruptly to a point with little concavity giving typical feature to the inter-ray area. The depressed central area characterises typical stem and sometimes the rays display pitting under EM, which is very pronounced in *D. elegans*. The pitting feature is also seen in the present specimen and is possibly due to corrosion.

The present assemblage is dominated by 7 rayed forms though forms with 5-8 rays are also seen. Two groups of *D. saipanensis* with 9 µm and 18 µm diameter are present in the studied material. The relative size difference and the variation in the number of rays could be significant while explaining differences in hemipelagic vs opean ocean conditions.

D. saipanensis is an extremely important stratigraphic marker as its FAD is marked in the Upper part of NP 16 (Late Middle Eocene) by Martini, (1971) and is in agreement with most nannofossil workers except stray record of Perch-Nielsen, (1985) who gave a doubtful extended range of this species up to NP 15 in a chart without explaining its reason; illustration of this species from NP 13/NP14 of Northwestern Germany by Köthe, (1986) is a mis-identification and of no value.

Disappearance of *D. saipanensis* along with *D. barbadiensis* marks Eocene/Oligocene boundary. The Lower and Upper zonal markers of NP 16 zone are LAD of *R. gladius* and LAD of *Ch. solitus* respectively and are absent in the Kutch basin. The first appearance of cosmopolitan *D. saipanensis* is therefore utilized here as an alternative and the zonal definition of NP 17 is emended by Rai, 1988. The NP 17 zone of Martini (1971) is emended to incorporate Upper part of NP 16 with FAD of *D. saipanensis* marking its lower boundary. The Upper boundary remains unchanged. This definition seems useful for other low latitude sections also and would correspond to the definition of the Bartonian discussed by Aubry (1985).

Frequent to rare in the Harudi Formation and rare in the Fulra Limestone Formation (fig. 3).

Discoaster nodifer (Bramlette & Riedel) Bukry, 1973
(Pl. II, fig. 12)

Discoaster tani-nodifer Bramlette & Ridel, 1954, p. 397, pl. 39, fig. 2. -Martini, 1960, p. 78, pl. 9, fig. 19. -Haq, non1971, p. 42-43, pl.10, fig. 13.

Discoaster nodifer (Bramlette & Ridel) Bukry Comb. nov., 1973, pl. 4, fig. 24.

Discoaster tani nodifer Bramlette & Ridel - Singh, 1980a, p. 14, pl. 4, fig. 19, non figs. 9-15, 18, 20. - Singh, non 1980b, p. 24-25, pl. I, fig. 29. - Singh & Singh, non 1986, p. 151, pl. 4, fig. 27.

Discoaster nodifer (Bramlette & Riedel) Bukry-Jafar & Rai, 1994, p. 34, pl. 2, fig. 29.

Remarks : Usually six-rayed asteroliths and rarely with 5, 7 or 8 rays of nearly even thickness with notches at the tips. A pair of nodes lying near the small central area, forms ranging between 13 µm and 19 µm are seen and are slightly overgrown. Rare in the Harudi and very rare in the Fulra Limestone Fortmation in the studied material.

Originally reported from the Late Eocene of Alabama, earliest occurrence is at the base of NP 16 zone in the Late Middle Eocene (Perch-Nielsen, 1985), possibly extending up to Early Oligocene.

Discoaster sp.
(Pl. II, fig. 9)

Remarks: Fairly large asterolith characterised by pitting in the rays. This resembles *D. elegans* but poor preservation does not allow exact identification. Observed rarely in the Harudi Formation (fig. 3).

Family **Lithostromationaceae** Deflandre, 1959

Synonym **Lithostromationaceae** Haq, 1967

Genus ***Lithostromation*** Deflandre, 1942

Lithostromation simplex (Klumpp) Bybell, 1975
(Pl. III, fig. 3)

Trochoaster simplex Klumpp, 1953, p.385, pl.16, fig.7, non fig.9.

Trochoaster duplex Klumpp, ?1953, p. 385, abb. 4(3).

Polycladolithus stellaris Stradner, 1959, p. 487, figs. 74-75.

Lithostromation simplex (Klumpp) Bybell, Comb. nov., 1975, p. 204, pl. 19 fig. 2.

Remarks : Outline hexagonal, surrounded by symmetrical depressions. Rare in the Harudi Formation (fig. 3). It is usually considered with holococcoliths.

Family **Prinsiaceae** Hay & Mohler, 1967

Genus ***Cyclicargolithus*** Bukry, 1971

Cyclicargolithus floridanus (Roth & Hay) Bukry, 1971
(Pl. II, fig. 5)

Coccolithus floridanus Roth & Hay in Hay *et al.*, 1967, p. 445, pl. 6, figs. 1-4. - Müller, 1970, p. 113, pl. 2, figs. 1-3.

Coccolithus floridanus (Roth & Hay) Bukry Comb. nov., 1971, p. 312-313. - Huang, 1977, p. 174, figs. 9, C1-C3. - Huang & Ting, 1979, p. 116, pl. 1, figs. 3a-b.

Cyclicargolithus floridanus (Roth & Hay) Bukry - Jafar & Rai, 1994, p. 35, pl. 2, fig. 2.

Remarks: Originally recorded from the Oligocene of Blake Plateau. Placoliths, usually small to medium in size, are identified by their birefringent distal shield under X-nicols. No differentiation can be made out from *C. marsmontium* under LM but under EM C. floridanus shows characteristic shield elements and a small sieveless central area.

C. floridanus is known to appear in the Upper part of NP 16 and shows its extinction in the Upper Miocene level. Its extreme abundance is noted from certain levels of Oligocene age. Frequent in the Harudi Formation and rare in the Fulra Limestone Formation in the studied area. (fig. 3).

Genus ***Reticulofenestra*** Hay, Mohler & wade, 1966

Reticulofenestra cf. *R. minuta* Roth, 1970
(Pl. II, fig. 2)

Reticulofenestra minuta Roth, 1970, p. 850-851, pl. 5, figs. 3-4. - Haq, 1971, p. 74-75, pl. 1, figs. 1-2; pl. 15, fig. 1.

Reticulofenestra minuta (Roth) Haq & Lohmann, 1976, p. 157, 851, pl. 7, figs. 4-5.

Reticulofenestra cf. *R. minuta* Roth - Jafar & Rai, 1994, p. 35, pl. 2, fig. 4.

Remarks: Placoliths of diminutive size (ca 2 µm) occur abundantly in most of the samples of the Harudi Formation and less frequently in the Fulra Limestone Formation. It is a common constituent of the Eocene and Oligocene sediments of western Indian basins. Identical forms with possibly different structure are noticed abundantly in the Neogene nannofloral assemblages.

This is a species fairly resistant to calcite overgrowth and seen profusely in the studied material in which other common coccoliths are destroyed. Common in the Eocene of Rajasthan, Kutch, Surat and other areas in India.

Family ***Rhabdosphaeraceae*** Lemmermann in Brandt & Apstein, 1908

Genus ***Blackites*** Hay & Towe, 1962

Blackites spinosus (Deflandre & Fert) Hay & Towe, 1962
(Pl. III, figs. 10-11; Pl. IV, fig. 19)

Discolithus spinosus Deflandre & Fert, 1954, p. 143, pl. 14, figs. 13-15.

Blackites spinosus (Deflandre & Fert) Hay & Towe, 1962, p. 505, pl. 4, fig. 5.

Blackites amplus Roth & Hay in Hay *et al.*, 1967, p. 445, pl. 7, fig. 10.

Rhabdosphaera sp. - Pant & Mamgain, 1969, pl. 24, fig. 6.

Blackites spinulus (Levin) Roth, 1970, p. 858-859, pl. 8, fig. 4.

Blackites spinosus (Deflandre & Fert) Hay & Towe-Bybell, 1975, p. 226-227, pl. 2, figs. 1-5; pl. 3, figs. 1-5. - Shafik, 1989, p. 75, fig. 4,C-D. - Jafar & Rai, 1994, p. 35, pl. 2, fig. 35; pl. 3, figs. 2-3.

Remarks: Originally described by Deflandre & Fert (1954) from Oamaru diatomite of Late Eocene age, it is easily discernible under both LM and EM. The spine is broadest at the base and then gradually tapers to a needle-like spine. In apical view, it shows several cycles of elements (illustrated herein).

Known from the Middle Eocene to Early Oligocene of several regions and usually found associated with quite similar *B. tenuis*. Frequent to rare in the Harudi Formation (fig. 3).

Blackites tenuis (Bramlette & Sullivan) Bybell, 1975
(Pl. III, figs. 5,7; Pl. IV, fig. 18)

Rhabdosphaera tenuis Bramlette & Sullivan, 1961, p. 147, pl. 5, figs. 14a-b.

Rhabdosphaera sp. Pant & Mamgain, 1969, p.12, pl. 22, fig. 7; pl. 24, figs. 3-4.

Blackites incompertus Roth, 1970, p.858, pl.7, figs.5; pl.8, figs. 1-2.

Blackites tenuis (Bramlette & Sullivan) Bybell, comb. nov., 1975, p. 228-230, pl. 4, figs. 1-5. - Jafar & Rai, 1994, p. 35, fig. 4.

Remarks: First reported from the Middle Eocene of California. Very closely resembling B. spinosus under LM and EM, B. tenuis shows slight constriction near the base of the spine. Its known range is from the Middle Eocene to the Middle Oligocene (in association with *B. spinosus*). Roth's (1970) *B. incompertus* seems to be considered synonymous with B. tenuis. Frequent to rare in the Harudi Formation (fig. 3).

Blackites sp. 1
(Pl. III, figs. 6,12)

Remarks: The specimens of moderate height with typical conical outline are assigned to this species. Their basal part is slightly broader than the spine base which tapers rapidly to a blunt point. It shows close resemblace with *B. creber* (Deflandre) but differs in lacking abrupt constriction of the spine near the tip. It is distinguishable from B. spinosus and B. tenuis as the latter are more slender and do not show termination of the spine to a point.

Frequent to rare in the Harudi Formation in the studied material.

Blackites sp. 2
(Pl. III, fig. 8)

Rhabdosphaera cf. *R. inflata* Bramlette & Sullivan-Pant & Mamgain, 1969, p. 123-124, pl. 22, fig. 8.

Remarks : It is differentiated from other rhabdosphaerid species in having characteristic bulbous middle part with more or less semicircular outline, a narrow base and a rapidly tapering spine of moderate height. The wall of the middle part shows maximum sculpturing and is often filled with dark pyritic fine material passed through narrow spine opening.

Frequent to rare in the Harudi Formation in the material studied.

Genus ? ***Rhabdolithus*** Kamptner ex
Deflandre in Grasse, 1952

Rhabdolithus ? *pseudoliasicus* n. sp.
(Pl. III, fig. 4)

Derivation of name : Pseudo (Latin) = false

Lias = Lower Jurassic
Holotype : Pl. III, fig. 4.
Negative Number : 0398/00
Size : Length of the spine: 4μ, width: 0.35μ
Length of the base : 1.5μ, width: 0.7μ.
Type Locality : SW of village Harudi in 'Rato Nala Section', Kutch; western India.
Type level : Late Middle Eocene, Upper Harudi Formation; *D. saipanensis* zone = NP 17 of Martini, 1971 emend. Rai, 1988.
Sample Number : HF-11.

Diagnosis: A rhabdosphaerid with exceptionally large basal part with slightly diverging profile surmounted by a long and slender spine gradually tapering to a point.

Remarks: This distinctive species is questionably assigned to genus *Rhabdolithus* as the ultrastructural details are not fully discernible.

Family **Triquetrorhabdulaceae** Lipps, 1969

Genus ***Wiseorhabdus*** Bukry, 1981

Wiseorhabdus inversus (Bukry & Bramlette)
Bukry, 1981
(Pl. III, fig. 9)

Triquetrorhabdulus inversus Bukry & Bramlette, 1969, p. 142, pl. 1, figs. 9-14.

Pseudotriquetrorhabdus inversus (Bukry & Bramlette) Wise & Constans, 1976, p. 154, pl. 4, figs. 1-9.

Wisecrhabdus inversus (Bukry & Bramlette) Bukry, comb. nov., 1981, p. 463. - Jafar & Rai, 1994, p. 36, pl. 3, figs. 5a-b.

Remarks : It contains multiple blades, up to about, eight and with opposite optic orientation in contrast to three blades of *T. carinatus*. Originally described from the Middle Eocene of Blake Plateau and several regions of similar age. Rarely observed from the Harudi Formation (slightly corroded specimens).

Incertae sedis : Due to uncertain generic affiliation two species are described under incertae sedis.

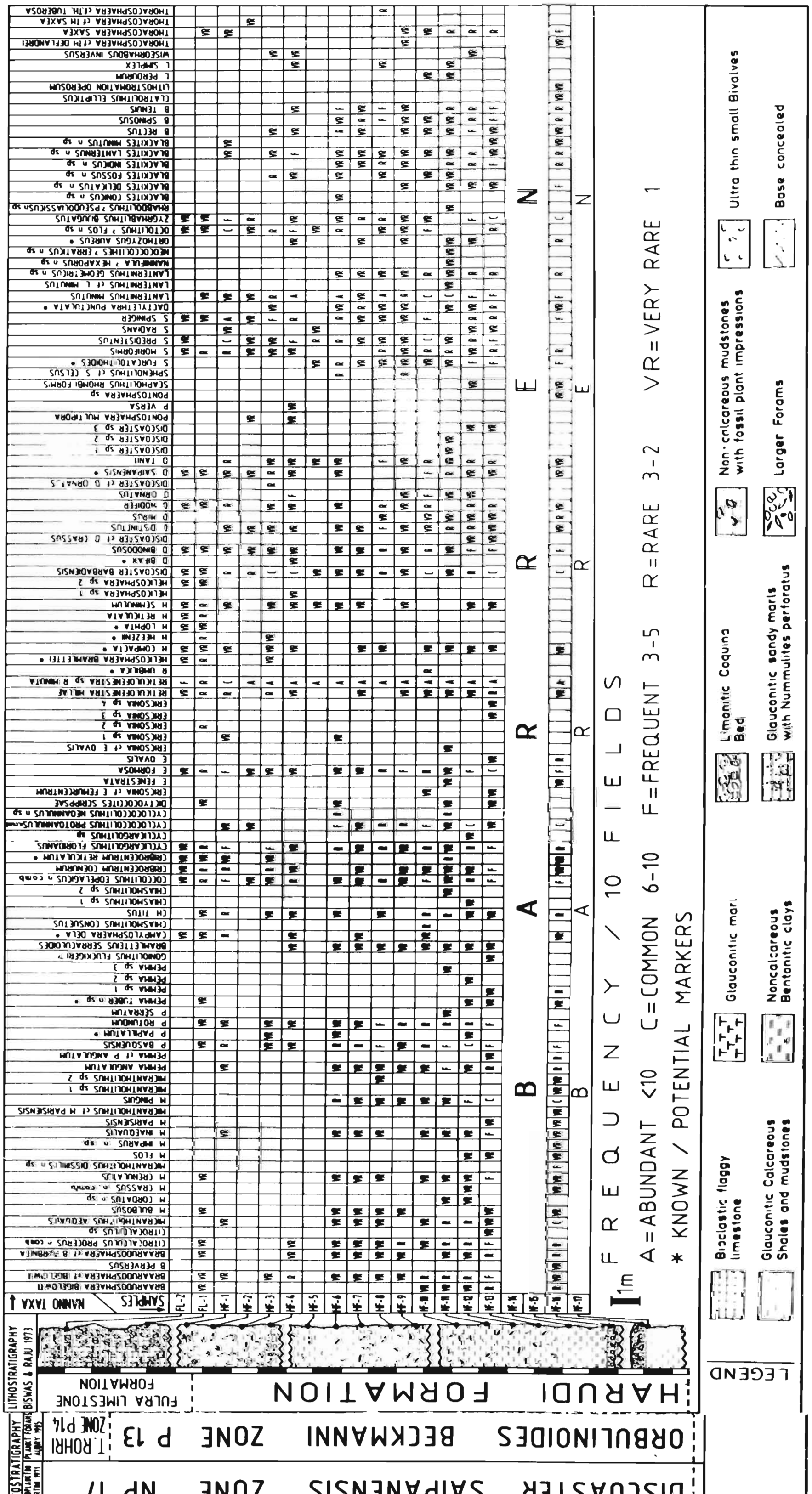


Fig. 3. Range chart showing distribution and frequency of calcareous nannofossil taxa recovered from samples of the Rato Nala Section, covering lower part of the Fulra Limestone Formation and upper part of Harudi Formation in its type locality. Potential marker species for basinal and global correlations are shown with an asterisk. (Rai 1988).

Genus ? **Neococcolithes** Sujkowski, 1931

Neococcolithes ? *erraticus* n. sp.
(Pl. II, fig. 15)

Derivation of name : errare (Latin) = stray or deviate
Holotype : Pl II, fig. 15
Negative : Number: 0425/00
Size : Length 4μ; width 2.5μ
Type locality : SW of village Harudi in 'Rato Nala Section' Kutch; Western India.
Type level : late Middle Eocene, Upper Harudi Formation; D. saipanensis zone = NP 17 of Martini, 1971 emend. Rai, 1988.

Sample Number : HF 11

Diagnosis : Small elliptic coccolith with a relatively high wall of inclined elements, central area consisting of 6 bars, resulting in four conspicuous and two invisible pores. As the ultrastructure of the central bars are obscured, this form is questionably assinged to the genus *Neococcolithes*, more so by the presence of six instead of usual four pores observed in the known species of this genus.

Genus ? **Naninfula** Perch-Nielsen, 1968

Naninfula ? *hexaporus* n. sp.
(Pl. II, fig. 17)

Derivation of name : Hexa (Latin) = six ; porus = pore
Holotype : Pl II, fig. 17
Negative Number : 0280/00
Size : Length 3μ, width 2μ.
Type Locality : SW of village Harudi in 'Rato Nala Section' Kutch; western India.
Type level : Late Middle Eocene, Upper Harudi Formation; *D. saipanensis* zone = NP 17 of Martini, 1971 emend. Rai, 1988.
Sample Number : HF 11
Diagnosis : Small elliptic coccolith with thin simple rim surmounted by a canopy on distal side consisting of six to seven irregularly spaced inclined bars which coalesce to form rather broad top portion.

In contrast to the genus *Naninfula* which displays a rather sophisticated ultrastructure, this new species shows simpler structure but similarity between the two is exhibited by the nature of canopy and the shape of pores.

BIOSTRATIGRAPHY

In the present study, the calcareous nannofossil results are dealt with reference to the standard Tertiary and Quaternary nannoplankton zonation schemes of Martini (1971) which serves as a scale worldwide. A comparision of the zonation schemes of Martini (1971) and Okada and Bukry (1980) is taken into account. The nannofloral zonal scheme is corroborated with planktic foraminiferal zonal scheme also (Berggren *et al.* 1995). The species encountered and their abundance are presented in fig. 3. The present assemblage can be assigned to NP 17 *Discoaster saipanensis* zone of Martini (1971), emended by Rai (1988) to incorporate upper part of NP 16 and entire NP 17 Zone. The lower boundary is marked by FAD of *D. saipanensis* and upper boundary by FAD of *Chiasmolithus oamaruensis*. Rare Chiasmolithus spp. and absence of marker *Chiasmolithus solitus* and *Ch. oamaruensis* in the Indian basins create problems for locating the NP16-NP17 boundary, using the zonation scheme of Martini (1971). This absence or rarity of *Chiasmolithus* spp. is more likely due to the shallow water neritic setting than to tropical latitude as they are present in NP 16 zone of the Cauvery Basin. (unpublised data, Jafar & Rai). Varol (1989,. p. 282) quotes "*Chiaomolithus solitus* is often extremely rare or absent in many studied sections in low to mid latitude regions". *Discoster saipanensis* is a cosmopolitan species with its range from Upper NP 16-NP20 and its FAD roughly corresponds with LAD of *Ch. solitus* (Müller, 1974) and hence can be used as a substitute marker. This emended NP 17 zone partly correlates with CP 14 *Reticulofenestra umbilica* zone of Okada and Bukry (1980). In the absence of marker *Chiasmolithus* spp., NP 16 - NP 17 and CP14a - CP14b boundaries are delineated by the FAD of *Helicosphaera reticulata* and LAD of *Sphenolithus furcatolithoides* in low latitude assemblages. The Lutetian/Bartonian boundary is marked by FAD of *Reticulofenestra reticulata* (Aubry, 1985). In Kutch, NP 16 - NP 17 boundary roughly corresponds to the Harudi-Fulra Limestone Formation boundary in Rato Nala Section, and represents Bartonian age. The nannofloral zonal scheme is integerated with planktic foraminiferal zones by Bolli *et al.* (1985) and indicates that the NP 16 - NP 17 or CP14a-CP14b boundary lies within the zone P13 (=*Orbulinoides beckmanni* zone). In the present section and possibly in other sections of Kutch, the zones P13 (=*Orbulinoides beckmanni zone*) and P14 (=*Truncorotaloides rohri* zone) are partly present (fig. 4) and even the P14 zone is missing in the Vinjhan and Ramania areas.

Thus, the present calcareous nannoplankton assemblage can be assigned to NP 17 *D. saipanensis* zone (*sensu* Rai, 1988) to contain partly both the P 13 and P14 planktic feraminiferal zones and is referable to the Bartonian chronostratigraphic division in the present context and to the magnetic anomaly C19 with absolute date of 43.6 Ma (Aubry, 1985).

DISCUSSION

The present assemblage comprising over 100 nannofloral species recovered from the type Harudi Formation and the basal Fulra Limestone Formation belonging to the Bartonian chronostratigraphic division, corresponding to CP 14 *Reticulofenestra umbilica* zone of

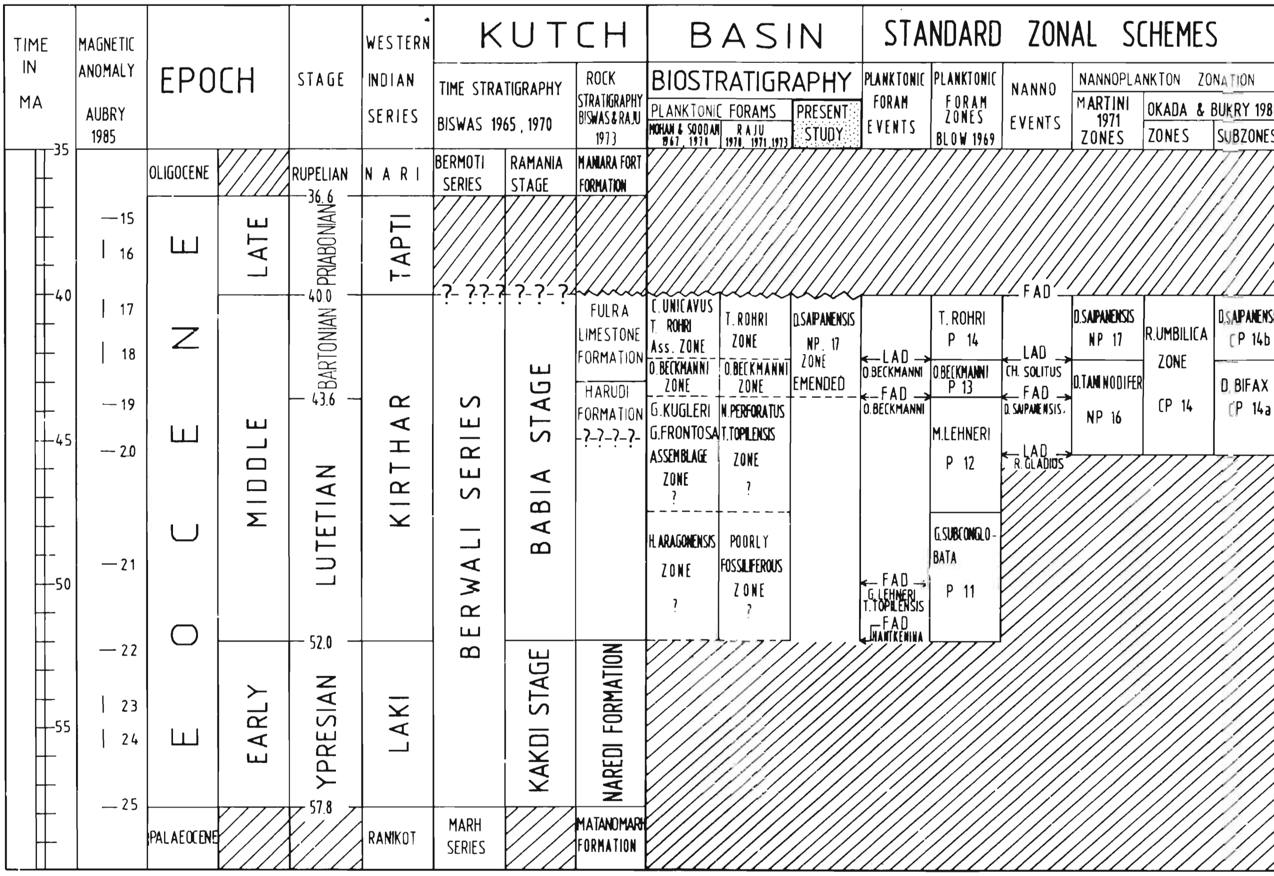


Fig. 4. Rock-and Time stratigraphy of the early part of supratrappean sedimentaries of Kutch basin tied to magnetic anomaly and absolute time scales; integrated planktonic foraminifera - nannoplankton zones and datums are tagged with major facies developed due to the onset and culmination of proposed Bartonian (Late Middle Eocene) transgressive cycle.

Okada and Bukry (1980), the upper NP 16 and NP 17 part of Martini (1971), and the planktic foraminiferal zones P13 (part) and P14 (part). On the basis of presence of marker and substitute marker species viz. *R. umbilica*, *C. reticulatum*, *D. bifax*, *S. furcatolithoides* (LAD), *D. distinctus* (LAD) and *H. bramlettei* (FAD), the assemblage is considered Bartonian in age. The Harudi Formation in its type area is referable to the zone NP 16 (Upper part), whereas the FAD of *H. reticulata* in the Fulra Limestone is taken here to mark the NP 17 zone retained in the Bartonian. The NP 16/NP17 zonal boundary thus roughly corresponds to the Harudi/ Fulra Limestone formational boundary. Thus the nannoflora from the Fulra limestone of Lakhpat, Babia Hill, Maniara fort also represent NP 17 zone. The early assignment of Lutetian age to the barren Harudi Formation (barren not due to natural cause but due to calcite overgrowth) by Singh (1978a, 1978b, 1980a, 1980b) Singh *et al.* (1980) is not supported here. The NP 16 and NP 17 zones thus agree with the Bartonian age assignment for the Fulra Limestone of Babia Hill which is the type section of Babia stage (Singh and Singh 1986). Its correlation with P 13 and P 14 zones is not tenable since characteristic zonal markers for NP 17 are absent. The Fulra Limestone Formation from Lakhpat (Singh, 1980a), Vinjhan (Singh, 1980b) and Rakhadi River Section near Harudi (Singh *et al.*, 1980) is assigned to the NP 16 zone (Lutetian) and is correlated with the P 13 and P 14 planktic foraminiferal zones, but traditionally the Lutetian contains Upper NP 14 - Lower NP 16, which does not seem to be present in the Kutch Basin. Nannofloral Assemblage define only older than Upper part of NP 16 here, not so far been recovered from the Kutch Basin. Presence of *C. reticulatum* in the basal productive sample from the Harudi Formation is significant, FAD of *C. reticulatum* is taken to mark Lutetian/Bartonian boundary (Aubry, 1985). It shows larger size at younger level and its extinction along with *D. saipanensis* and *D. barbadiensis* at Eocene/Oligocene boundary is important.

Thus, the Fulra Limestone and the Harudi Formation can be taken as a single mappable unit with rich mega and microfossils including fossil plankton and is equivalent of the upper Kirthar of western Indian Series and Berwali series, Babia stage of Late Middle Eocene of Bartonian age. The Priabonian is represented by an hiatus in the Kutch Basin. Near Maniara Fort, the Fulra Limestone is overlain by the *Nummulites fichteli* bearing glauconitic marls of the Mainiara Fort Formation of Oligocene age (fig. 2).

BARTONIAN TRANSGRESSIVE CYCLE IN KUTCH BASIN

Wynne (1872), while discussing the Kutch Basin, delineated Nummulitics (containing Oligocene age Maniara Fort Formation also) overlying Sub Nummulitics and Gypseous shales on Deccan Traps. He noted the sequence below Nummulitics, showing development only in north-western Kutch and laterally pinching behaviour. Biswas and Raju (1973) equated Sub Nummulitics with Matanomarh Formation and Gypseous shales with Naredi Formation. The Nummulitics includes Harudi Formation, Fulra Limestone Formation and Maniara Fort Formation. The Harudi Formation also shows lateral pinching nature and the Fulra Limestone is the only consistent litho-unit both in NW and SW part of Kutch.

To study and date the entire sequence above the traps, samples were studied. The lower part below the Harudi Formation proved barren in nannofossils. Hence taken clue from negative evidence all the existing literature on the lower part combined to call Shale Sequence was critically checked. Nannofossil barren horizons are normally not expected in pelagic and hemipelagic sequences but occur commonly in coastal setting of shallow epicontinental seas. Barren horizon can be due to coastal geomorphology restricting plankton bearing currents, lowered salinities, or to poor preservation.

CONCLUSION

Detailed field work carried out in the Kutch Basin and analysis of calareous nannofossils from the Harudi Formation (in the type area) and the basal Fulra Limestone Formation allow the following conclusions to be drawn :

1. The Pericratonic Kutch Basin shows an uninterrupted marine sequence above the Deccan Trap, laid possibly down by single Bartonian age transgressive sequence. Priabonian is represented by hiatus.
2. The Fulra Limestone and the marly Harudi Formation or Nummulitics (part) are more consistent in both NW and SW Kutch than underlying Shale sequence.
3. The *Shale sequence* shows rapid lateral variation. Its marine nature is indicated by presence of glauconite, bioturbated horizons, marine shell horizons and presence of larger forams, small benthics with ostracodes and forams, and dwarf planktic forams. This sequence is dominated by rich palynoflora with extensive terrestrial influx leading to mineable lignites at Panandhro, the palynoflora containing reworked early Cretaceous and palaeocene palynofossils.
4. In the *Shale sequence*, early Eocene microfossils are known only from section of Nareda which in the evidence of dwarfism are not fit for dating.
5. The *Marl-Bioclastic Limestone sequence* represents increased bathymetry up to inner shelf level. Maximum depth is displayed in the middle of the Harudi Formation by incoming of nannofossils and marine nektons. Bottom of the sea is dominated by holothuroids and bivalves adapted to pseudopelagic mode of life. Shallow trend is indicated in the upper part of the Harudi Formation with improved velocity. High energy Fulra Limestone is laid down in a progradational phase and by in situ reworking and cementation in all possible directions. The high energy in the regressive phase influenced inhabiting larger forams and molluscs on embayment banks but supported calcareous planktic forams. Dinoflagellates indicated periodic bloom of solitary species. Nannofossil frequency is reduced due to diagenetic overgrowth of calcite mineral (clearly seen under SEM).
6. The Planktic foraminifers and nannofossils recovered from the Harudi marl and the bioclastic Fulra Limestone of many sections suggest lack of reworking in the Kutch Basin. The Planktic foraminiferal zones P13 and P14 encompass the Harudi and the Fulra Limestone Formations. The Nannofossil zone NP 17 *D. saipanensis* zone of Martini (1971) emended by Rai, (1988) to include top part of NP 16 zone, in the absence of marker *Chiasmoliths* partly corroborates with CP 14 *R. umbilica* zone of Okada and Bukry 1980. NP16/NP17 boundary is resolved on the basis of FAD of *Helicosphaera reticulata*. The LAD of *Sthenolithus furcatolithoides* roughly corresponds to the Harudi/Fulra Limestone formational boundary. NP16/NP17 or CP14a/CP14b boundary is found to lie within P13 *O. beckmanni* planktic foraminiferal zone. Older zones reported by several workers appear to be due to difficulty in recognising FAD of very rare *O. beckmanni* in several sections of Kutch.
7. A very rich and diversified nannofloral assemblage comprising over hundred species recovered from the Harudi and the Fulra Limestone Formations typically indicates nearshore, warm water environment and is comparable to the low latitude assemblage known from the widely separated areas. The lower sequence with negative evidence at hand does not support the evidence of the Palaeocene, presian and Lutetian sediments in the Kutch Basin, though data for radiometric or geomagnetic dating of the lower sequence are lacking.

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EXPLANATION OF PLATES

Plate I

(The bar in each figure represents 5 µm except where indicated otherwise.)

1-2. Pennate diatom Gen. et sp. indet. HF 13.
3. *Micrantholithus parisiensis* Bouché, 1962, distal view. HF 11.
4. *Pemma papillatum* Martini, 1959, HF 11.
5. *Micrantholithus pinguis* Bramlette & Sullivan, 1961, HF 11.
6. *Micrantholithus flos* Deflandre, 1950, HF 11.
7. *Pemma cf. P. angulatum* Martini, 1959, HF 12.
8. *Pemma basquensis* (Martini) Baldi-Beke, 1971 HF 11.
9. *Citrocalculus procerus* (Bukry & Branlette) comb. nov., side view. HF 11.
10. *Pemma* sp. displaying growthlines on pentalith segments, HF 11.
11. *Pemma serratum* (Chang) Bybell & Gartner, 1972, HF 11.
12. *Pemma* cf. *P. angulatum* Martini, 1959, HF 11.
13. *Ericsonia formosa* (Kamptner) Haq, 1971, distal view. HF 12. overgrown specimen.
14. *Cyclococcolithus protoannulus* (Gratner) comb. nov., distal view. HF 11.
15. *Ericsonia formosa* (Kamptner) Haq, 1971, distal view. HF 13.
16. *Cyclococcolithus protoannulus* (Gartner) Comb. nov, distal view. HF 11
17. *Ericsonia* sp. 1, HF 13.
18. *Ericsonia* sp. 2, HF 13.
19. *Ericsonia* cf. *E. ovalis* Black, 1964, distal view. HF 11

Plate II

(The bar in each figure represents 5 µm except where indicated otherwise)

1. *Ericsonia fenestrata* (Deflandre & Fert) Stradner & Edwards, 1968, Coccosphere. HF 11.
2. *Reticulofenestra* cf. *R. minuta* Roth, 1970, distal view, HF 11.
3. *Chiasmolithus titus* Gartner,1970, distal view. HF 11.
4. *Chiasmolithus* sp., Coccosphere. HF 11.
5. *Cyclicargolithus floridanus* (Roth & Hay) Bukry, 1971, proximal view. HF 10.
6-7. *Discoaster saipanensis* Bramlette & Riedel, 1954, proximal view. HF 11.
8. *Discoaster barbadiensis* Tan Sin Hok, 1927, distal view. HF 11.
9. *Discoaster* sp. 1. HF 11.
10. *Discoaster barbadiensis* Tan Sin Hok, 1927, distal view. HF 12.
11. *Discoaster distinctus* Martini, 1958. HF 11.
12. *Discoaster* sp. 2. HF 11.
13-14. *Zygrhablithus bijugatus* (Deflandre) Deflandre, 1959, 13 side view; 14 apical view. HF 11.
15. *Neococcolithes ? erraticus* n. sp., holotype; proximal view. HF 11.
16. *Lanternithus* cf. *L. minutus* Stradner, 1962, HF 11. Bar = 2 µm.
17. *Naninfula ? hexaporus n.* sp. holotype; distal view. HF 11.
18. *Lanternithus minutus* Stradner, 1962 and *Discoaster barbadiensis* Tan Sin Hok, 1927, HF 12.

Plate III

(The bar in each figure represents 5µm except where indicated otherwise).

1-2. *Orthozygus aureus* (Stradner) Bramlette & Wilcoxon, 1967, distal view. HF 11. Bar = 2 µm.
3. *Lithostromation simplex* (Klumpp) Bybell, 1975, HF 11.
4. *Rhabdolithus ? pseudoliasicus* n. sp., holotype; side view, HF 11, Bar = 2 µm.
5. *Blackites tenuis* (Bramlette & Sullivan) Bybell, 1975, side view. HF 11.
6. *Blackites* sp. 1. Side view. HF 11.
7. *Blackites tenuis* (Bramlette & Sullivan) Bybell, 1975, side view. HF 11.
8. *Blackites* sp. 2. side view. HF 12.
9. *Wiseorhabdus inversus* (Bukry & Bramlette) Bukry, 1981, HF 11.
10-11. *Blackites spinosus* (Deflandre & Fert) Hay & Towe, 1962, apical view. 10-HF 11 & 11-HF 13.
12. *Blackites* sp. 1. side view, HF 11.

Plate IV

Light micrographs are printed in the same orientation with respect to the axes of nicols as observed under the microscope.

All figures x2000.

1. *Braarudosphaera bigelowii* (Gran & Braarud) Deflandre, 1947
2. *Pemma papillatum* Martini, 1959
3. *Micrantholithus inaequalis* Martini, 1961
4. *Micrantholithus aequalis* Sullivan, 1964
5. *Cyclococcolithus protoannulus* (Gartner, 1971) Comb. nov.
6. *Chiasmolithus consuetus* (Bramlette & Sullivan, 1961) Hay & Mohler, 1967

7a-b *Helicosphaera compacta* Bramlette & Wilcoxon, 1967

8. *Campylosphaera dela* (Bramlette & Sullivan) Hay & Mohler, 1967
9. *Cribrocentrum reticulatum* (Gartner & Smith) Perch-Nielsen, 1971
10. *Helicosphaera bramlettei* (Müller) Jafar & Martini, 1975
11. *Discoaster saipanensis* Bramlette & Riedel, 1954
12. *Discoaster mirus* Deflandre, 1954
13. *Pontosphaera multipora* (Kamptner, 1948) Roth, 1970
14. *Sphenolithus predistentus* Bramlette & Wilcoxon, 1967
15. *Sphenolithus spiniger* Bukry, 1971
16. *Zygrhablithus bijugatus* (Deflandre) Delandre, 1959
17. *Lanternithus minutus* Stradner, 1962
18. *Blackites tenuis* (Bramlette & Sullivan) Bybell, 1975
19. *Blackites spinosus* (Deflandre & Fert) Hay & Towe, 1962

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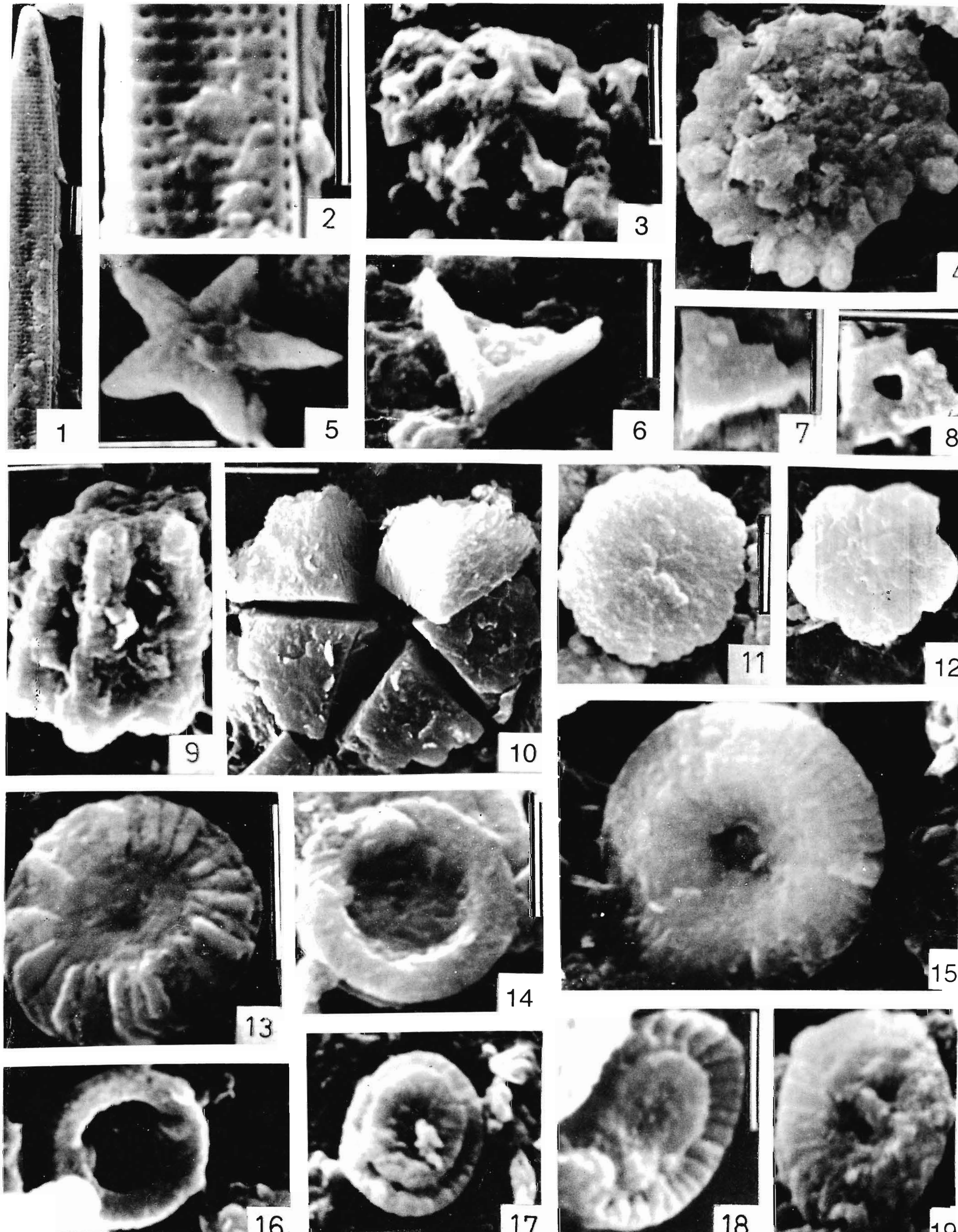
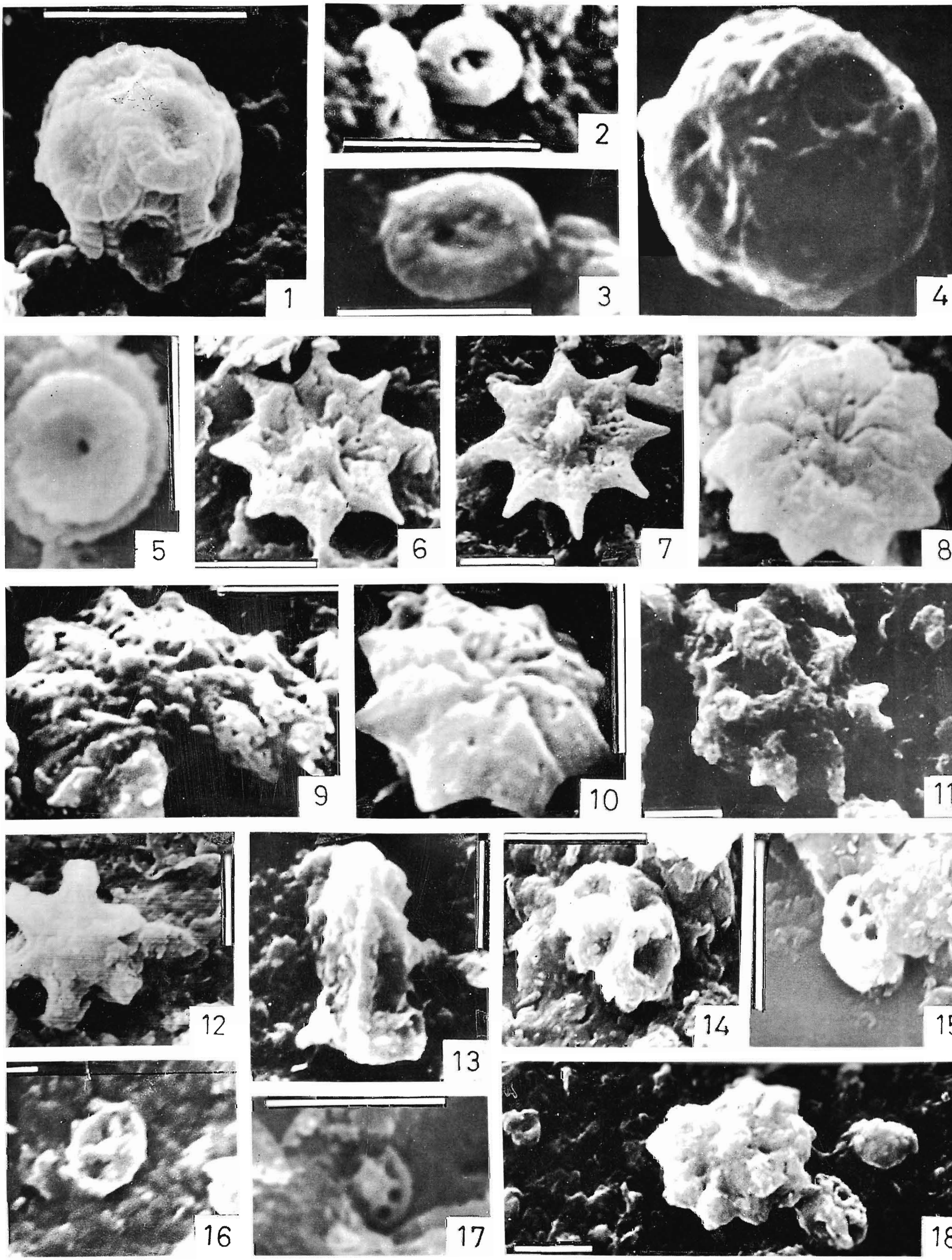
Plate I



RAI



RAI

Plate III

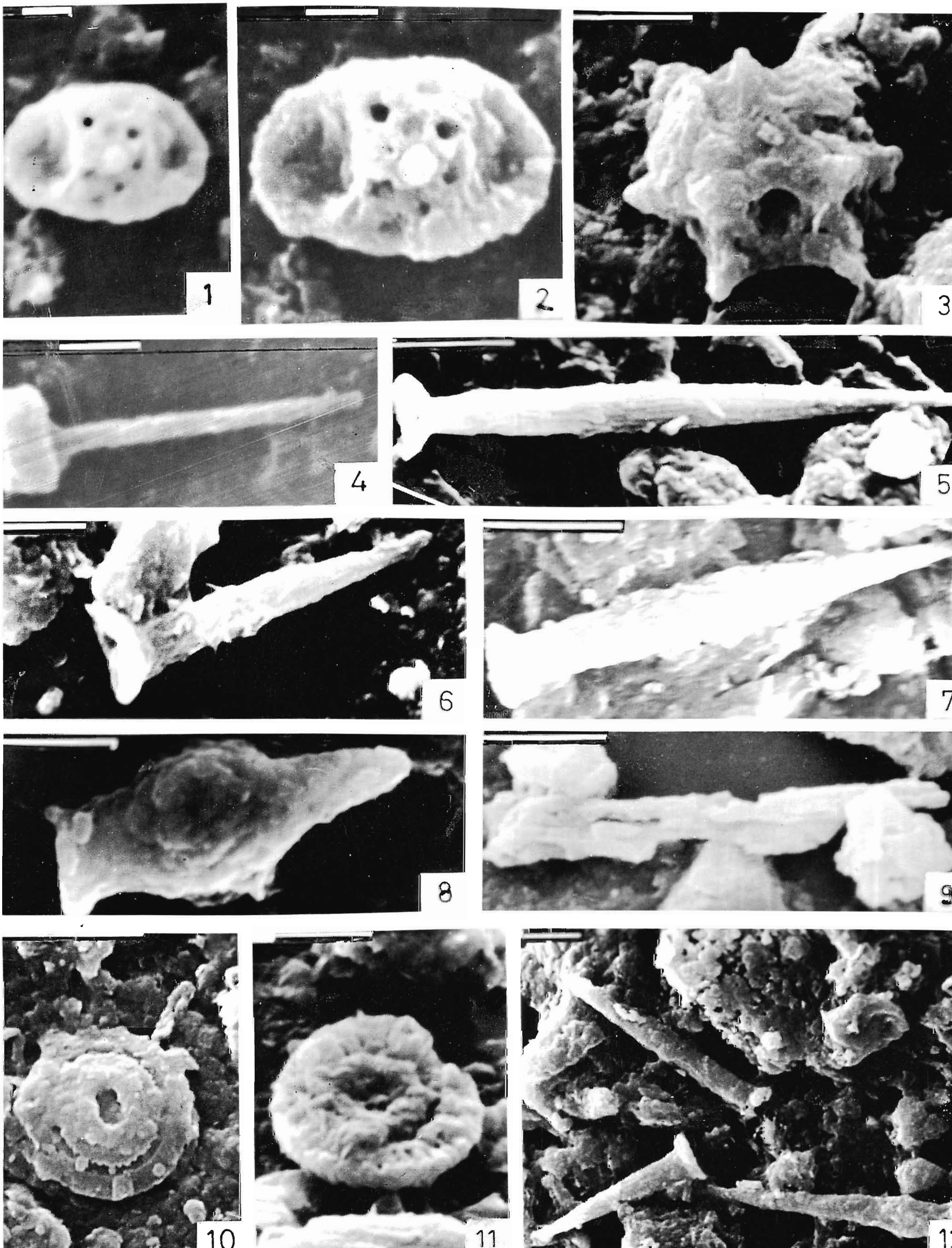


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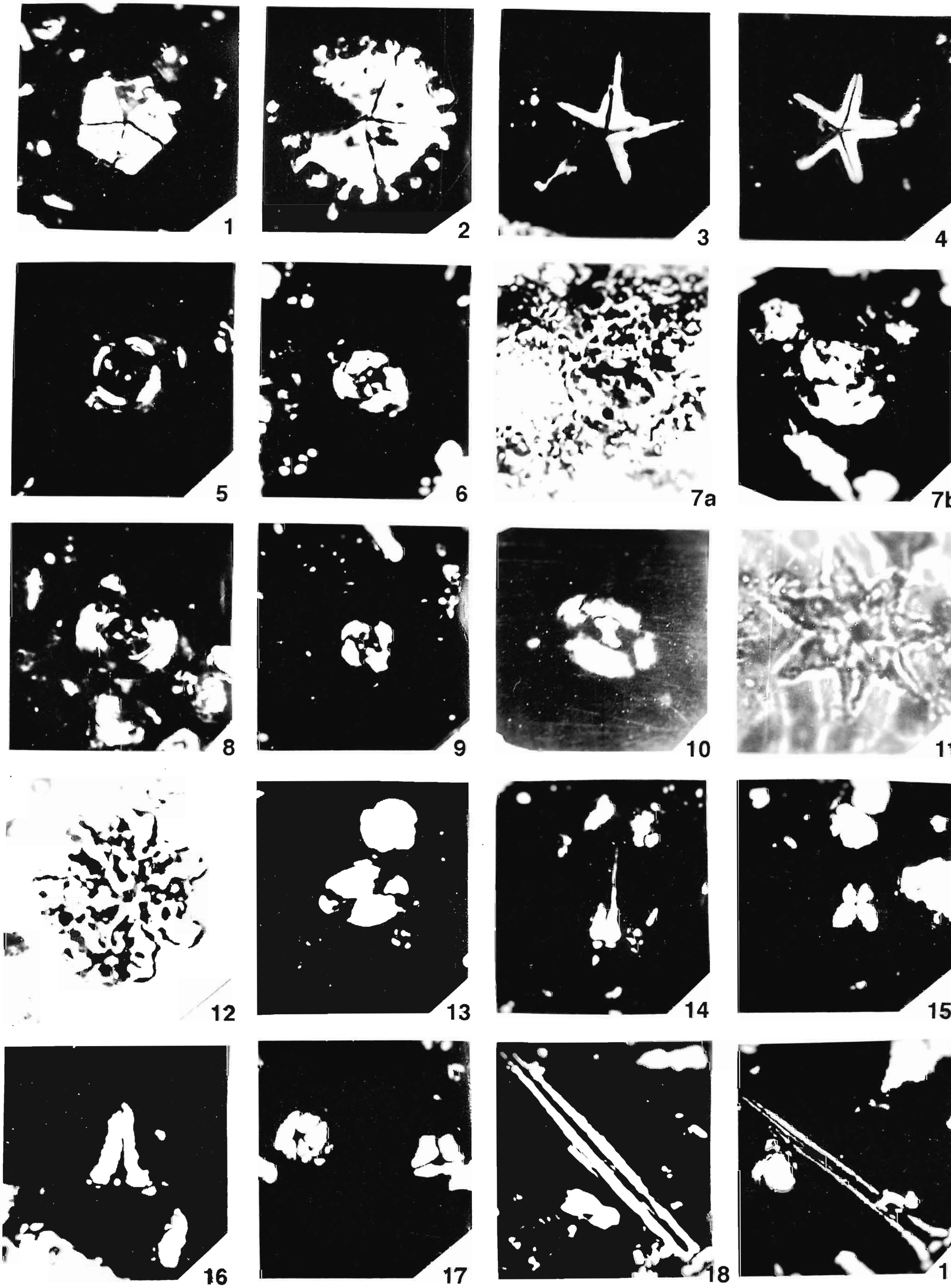
Plate IV



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