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Middle Eocene calcareous Nannofossil Biostratigraphy and Taxonomy of onland Kutch Basin, western India

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ABSTRACT

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Rich and diversified nannofossil assemblage comprising 110 species (13 new species and 8 new taxonomic combinations) and 4 calcareous dinoflagellates species are described from the type locality of Harudi Formation and Fulra Limestone Formation of Kutch Basin. The assemblage is dominated by the families Braarudosphaeraceae, Rhabdosphaeraceae and Calyptrosphaeraceae. All holococcolith genera except genus *Peritrachelina* are recorded in the assemblage. The assemblage is typically indicative of low-latitude, nearshore, shallow water environment and can be assigned to zone NP 17 *Discoaster saipanensis* Zone (Martini, 1971a emend. Rai, 1988). It also correlates with parts of both P13 *Orbulinoides beckmanni* and P14 *Truncorotaloides rohri* planktonic foraminifera Zones (Blow, 1969) and a part of D11 Dinoflagellate Zone (Costa & Manum *in* Vinken, 1988) of Bartonian age. Critical reappraisal of published fossil records including age diagnostic planktonic and larger foraminifera species and nannofossil data along with field observations of supratrappeans indicate, three discrete lithounits in ascending order viz., shale-marl-limestone upto terminal Fulra Limestone Formation.

The proposed model questions the presence of marine sediments of Palaeocene, Lower Eocene and Lutetian age in onland Kutch Basin (Biswas & Raju, 1973; Biswas, 1992).

Key-words—Nannofossils, Bartonian, Biostratigraphy, Kutch Basin.

पश्चिमी भारत के कच्छ द्रोणी स्थल की मध्य आदिनूतन चूनेदार परासूक्ष्मजीवाश्म जैवस्तरिकी एवं वर्गिकी

ज्योत्सना राय

सारांश

कच्छ द्रोणी के हरुडी शैलसमूह एवं फूलरा चूनापत्थर शैलसमूह के प्ररुप उपबस्ती से प्राप्त प्रचुर व विविधरुपायित परासूक्ष्मजीवाश्म समुच्चय 110 प्रजातियाँ (13 नव प्रजातियाँ व 8 नवीन वर्गिकीय संयोजन) और 4 चूनेदार सन्निहित घूर्णीकशाभ जातियाँ वर्णित की गई हैं। समुच्चय ब्रारुडोस्फैरासी, र्‍हबडोस्फैरासी व कैलीप्ट्रोस्फैरासी परिवारों द्वारा प्रभावी है। समुच्चय में वंश *पैरीट्राकेलिना* के अलावा समस्त होलोकोक्कोलिथ वंश अभिलिखित किए गए हैं। समुच्चय जटिल रुप से निम्न-अक्षांश, तट निकट,

गाद जल पर्यावरण का द्योतक है तथा मंडल एन पी 17 *डिस्कोस्टर साइपेनेन्सिस* मंडल (मार्टिनी, 1971ए संशोधन राय 1988) को निर्धारित किया जा सकता है। यह पी 13 *ऑर्बुलिनोइड्स बेकमन्नी* व पी 14 *ट्रंकॉरोटेलॉइड्स रॉह्‌री* प्लवकी फोरैमिनीफेरा मंडलों (ब्लो, 1969) तथा बार्टोनी काल के डी 11 घूर्णीकशाभ मंडल (विंकेन में कॉस्टा एवं मेनम, 1988) के एक भाग से भी सहसंबंध रखते हैं। अधिट्रापीनों के क्षेत्रीय प्रेक्षणों को सन्निहित कर काल निदान प्लवकी और विशाल फारैमिनीफेरा जातियां एवं परासूक्ष्मजीवाश्म आंकड़े सहित जीवाश्म अभिलेखों के जटिल पुनर्मूल्यांकन आरोही क्रम में तीन उच्चरित अश्म इकाइयों अर्थात-शेल-मार्ल-फुलरा चूनापत्थर शैलसमूह अंत तक चूनापत्थर दर्शाते हैं।

प्रस्तावित मॉडल कच्छ द्रोणी स्थल (बिस्वास एवं राजू, 1973; बिस्वास, 1992) में पुरानूतन, निम्न आदिनूतन और ल्युटेटी काल के समुद्री अवसादों की विद्‌यमानता पर प्रश्चचिह्‌न लगाता है।

संकेत-शब्द—परासूक्ष्मजीवाश्म, बार्टोनी, जैवस्तरिकी, कच्छ द्रोणी।

INTRODUCTION

CALCAREOUS nannofossils are ideal for high resolution biostratigraphy and palaeoenvironmental interpretations of shallow marine and deep sea deposits globally (Siesser & Haq, 1987). The pericratonic Kutch Basin (also spelled as "Kachchh" in literature) is one of the oldest explored basins in the world and rocks of the Mesozoic and Tertiary ages indicate fair hydrocarbon potential in offshore areas (Biswas, 1965, 1972, 1982; Biswas & Raju, 1973; Jaikrishna *et al.*, 1983; Wynne, 1872). Scarce nannofossil data are available from the Mesozoic rocks of the Kutch Basin (Singh, 1977; Rai, 1991). Nannofloral occurrences in the organic-rich green shales in the lower part (Jaikrishna *et al.*, 1983; Jafar & Saxena, 1984) and upper part (Jaikrishna *et al.*, 1983) of Jumara Formation are described which help in precise age determination.

The Supratrappeans or Tertiary rocks (Fig. 1) yield nannofossil rarely in certain horizons of Maniyara Fort and Vinjhan Shale formations (Rai, 1988), but diversified and well-preserved assemblages are reported from the Harudi Formation (Pant & Mamgain, 1969; Singh *et al.*, 1980; Jafar & Rai, 1984; Rai, 1988; Jafar & Rai, 1994; Singh & Singh, 1986, 1987, 1991) and the Fulra Limestone Formation (Singh, 1978; 1980a, b; 1988; Singh & Singh, 1986; Rai, 1988; Singh *et al.*, 1980; Jafar & Rai, 1994; Rai, 1997). First report of nannofossils from Kutch represents inorganic crystals (Mathur, 1966). The assemblages can be compared with those from other low-latitude sections of the world. Present studies were undertaken to document a comprehensive account of calcareous nannofossils from the type section of Harudi and the overlying Fulra Limestone formations, to assess the suitability of secondary nannofossil marker species in the absence of traditional zonal markers for zonation and age determination of Eocene sediments deposited in a low-latitude, shallow marine coastal set up (Biswas, 1992) and to correlate the nannofossil data with foraminiferal zones.

GEOLOGICAL SETTING

The marine Tertiary rocks overlying the Deccan trap basement in the Kutch Basin, with excellent exposures, extend from Lakhpat to Goyela showing an arcuate pattern with gentle dips towards southwest (Fig. 1). The total thickness of the sequence up to Fulra Limestone Formation is approximately 80 m. The time-rock stratigraphic classification proposed by Biswas (1965) and Biswas and Raju (1973) have served as a basis for later studies on the Kutch Basin. The "Nummulitic Group" of Wynne (1872) corresponds to upper part of Harudi Formation (glauconitic marl) and bioclastic Fulra Limestone Formation (excluding Maniara Fort Formation of Oligocene age). The Nummulitic Group has provided one of the richest macro-and microfossils including nannofossils for which age and environment of deposition is well documented. However, the underlying "Sub-Nummulitic Group" of Wynne (1872) corresponding to the Matanomadh, Naredi and lower part of Harudi Formation remain

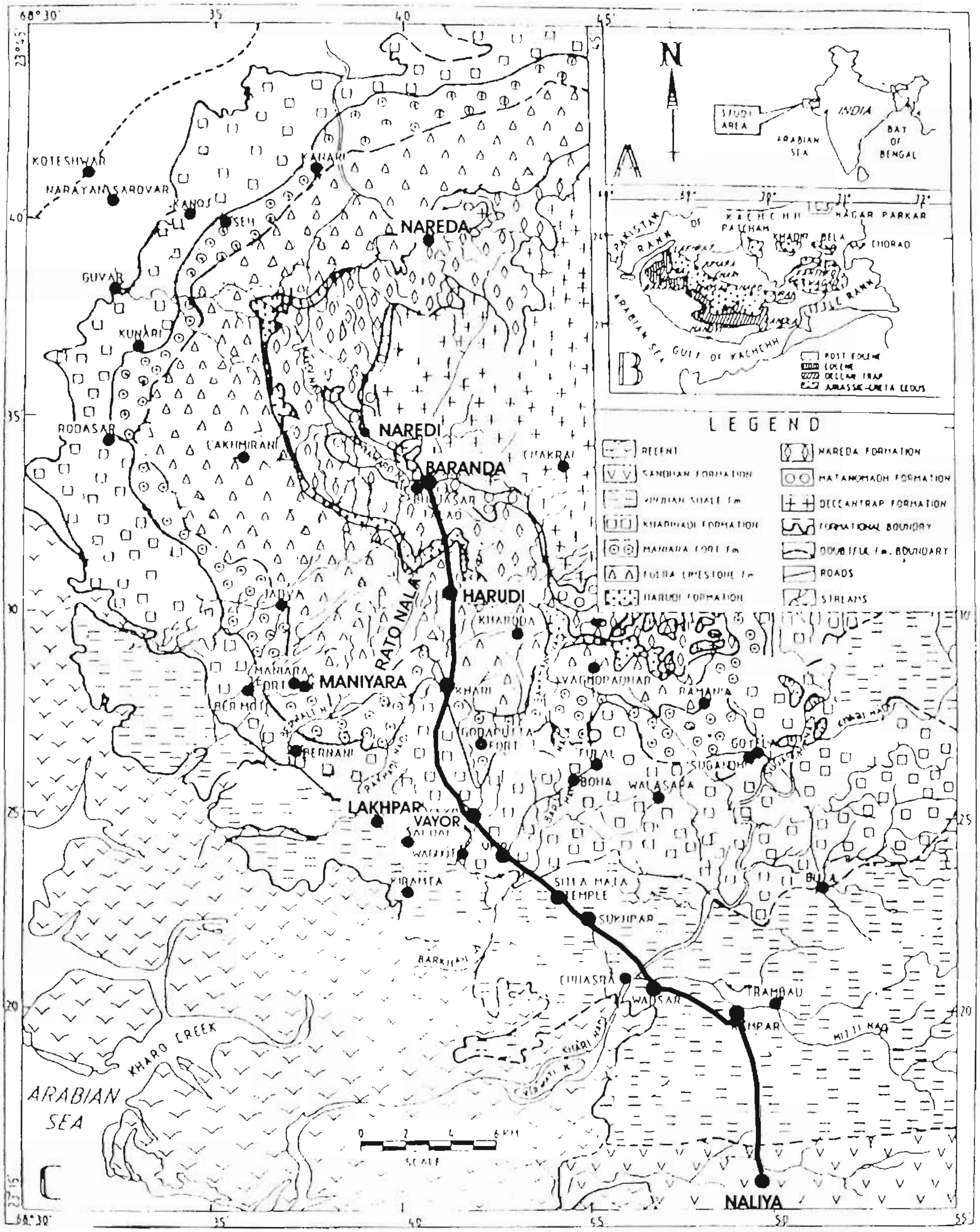


Fig. 1 — A. Map of India showing the study area. B. Map showing the distribution of Mesozoic-Tertiary marine outcrops in the Kutch Basin (modified after Wynne, 1872). C. Geological map of a part of northwestern Kutch Basin displaying drainage patterns, Tertiary outcrops and sampling area (after Rai, 1988).

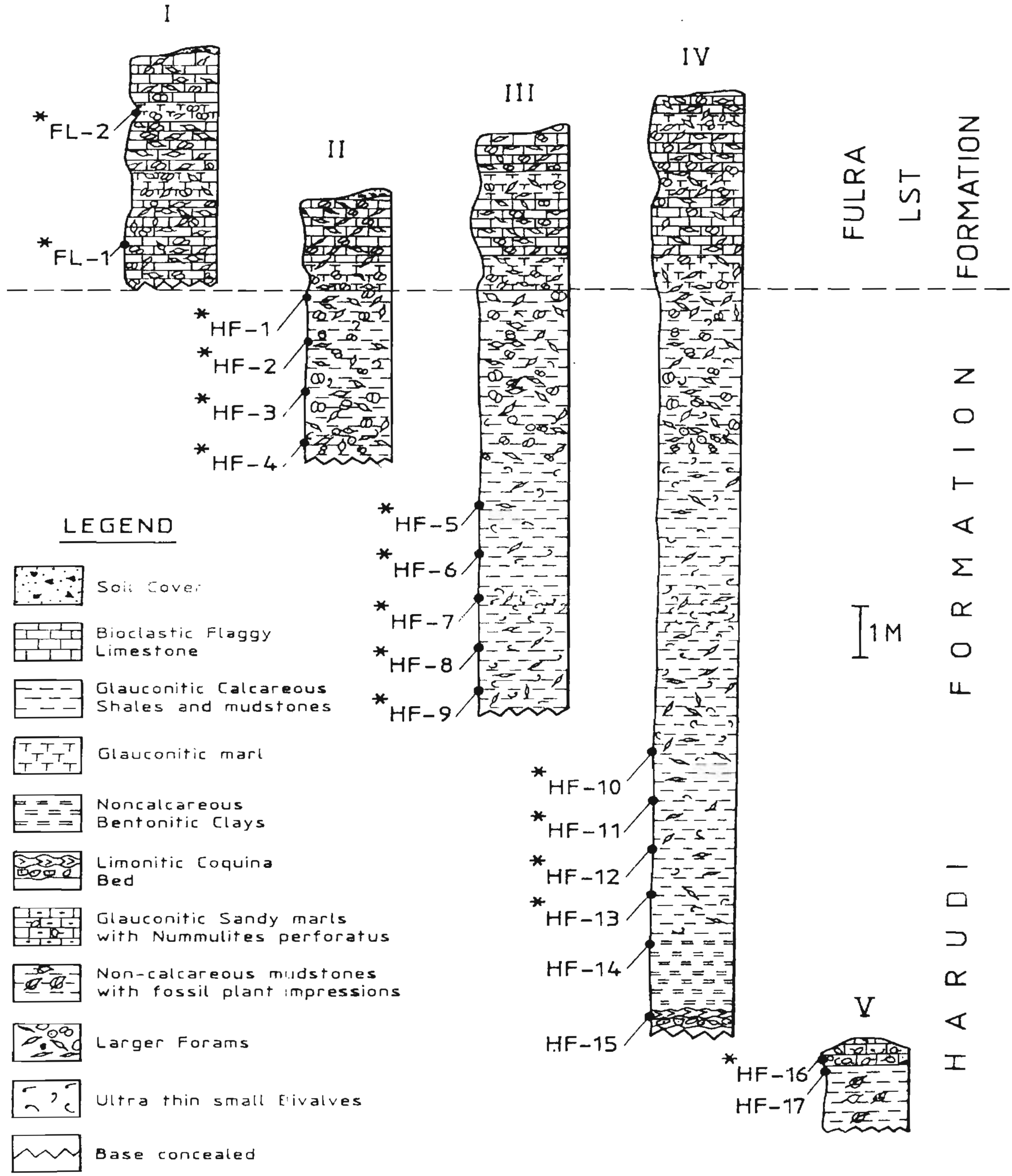


Fig. 2—Lithocolumn I-V representing sampling profiles in the Rato Nala Section covering lower part of Fulra Limestone Formation and upper part of Harudi Formation. Solid dots represent sampling points. Calcareous nannoplankton productive samples are denoted with an asterisk (after Rai, 1988).

controversial according to some authors in recent years (Ray *et al.,* 1984; Jafar, 1986; Biswas, 1986, 1990; Pandey & Ravindran, 1988; Rai, 1988; Jafar & Rai, 1994). The Palaeogene rocks show reduced thickness and represent a different facies in contrast to classical area of Sind. Biostratigraphy based on mega-and microfossils of Palaeogene rocks has been dealt by Mohan and Soodan (1967, 1970), Raju *et al.* (1979), Biswas and Raju (1973), Tandon (1971a) and Tandon *et al.* (1980) and has shown in Fig. 4.

EARLY GEOLOGICAL WORK

The earliest reports on the geology of Kutch region are found in the publications of Mac Murdo (1815, 1834), Burnes (1834), Sykes (1834), Grant (1837), Charles Lyell (1853), Carter (1857), Grant and Blanford (1836) the references of which are cited in Wynne (1872). A detailed geological map was compiled by Wynne and Fedden based on their observations during field sessions of 1867-1869 (Wynne, 1872). Wynne's (1872) memoir on the geology of Kutch reported plant and animal fossils localities and reports of larger foraminifera served as fundamental work for over a century for subsequent workers. It also contains the first informal lithostratigraphic classification of the sedimentary succession overlying the Deccan Trap.

MATERIAL AND METHODS

The samples of this study were collected from Rato Nala Section, the type area for Harudi Formation and Fulra Limestone Formation which is also well exposed there (Fig. 1). Due to lack of continuous exposures, the samples were collected from five profiles (Fig. 2) in sufficient quantity (approximately 500 gms) to check the productivity of planktonic foraminifera from the samples. Utmost care was taken, while sampling, to avoid contamination by collecting the fresh samples after deep digging. The samples, type and figured slides are deposited in the Museum of Birbal Sahni Institute of Palaeobotany, Lucknow.

Conventional smear slides were prepared in duplicate, one representing the fine and the other a coarse fraction of each sample. Canada Balsam was used as permanent embedding medium. Calcareous nannoplanktons were studied under oil immersion objective employing plane polarized light and crossed polarised illumination. An Amplival polarising light microscope was used and photographs were taken by using slow speed black and white film of Agapan-25.

The Holotype and Paratype specimens are designated by co-ordinates measured with reference to a "cross-mark" scratched on each slide.

SYSTEMATICS

The classification adopted herein is based on some morphological features of living coccolithophores (Young, 1987) and employed for fossil material as well

Kingdom—PROTISTA (Eukaryotic)
Division—HAPTOPHYTA ·
Class—PRYMNESIOPHYCEAE Hibberd, 1976

Systematic treatment of calcareous nannoplankton is followed as per Perch-Nielsen (1971). Families and genera recorded in this study are arranged in alphabetical sequence. Except Family Calyptrosphaeraceae representing holococcoliths, other families are put under heterococcoliths, including Families Braarudosphaeraceae, Calciosoleniaceae and Ceratolithaceae, otherwise considered as non-coccoliths by Young (1987).

Family—BRAARUDOSPHAERACEAE (Graan & Braarud) Deflandre, 1947
BRAARUDOSPHAERA (Graan & Braarud) Deflandre, 1947
CITROCALCULUS Troelsen & Quadros, 1971
MICRANTHOLITHUS Deflandre, 1950
PEMMA Klumpp, 1953
Family—CALCIOSOLENIACEAE Kamptner, 1927
SCAPHOLITHUS Deflandre in Deflandre & Fert, 1954
Family—CALYPTROSPHAERACEAE Boudreaux & Hay, 1969
CLATHROLITHUS Deflandre, 1954
DAKTYLETHRA Gartner, 1969

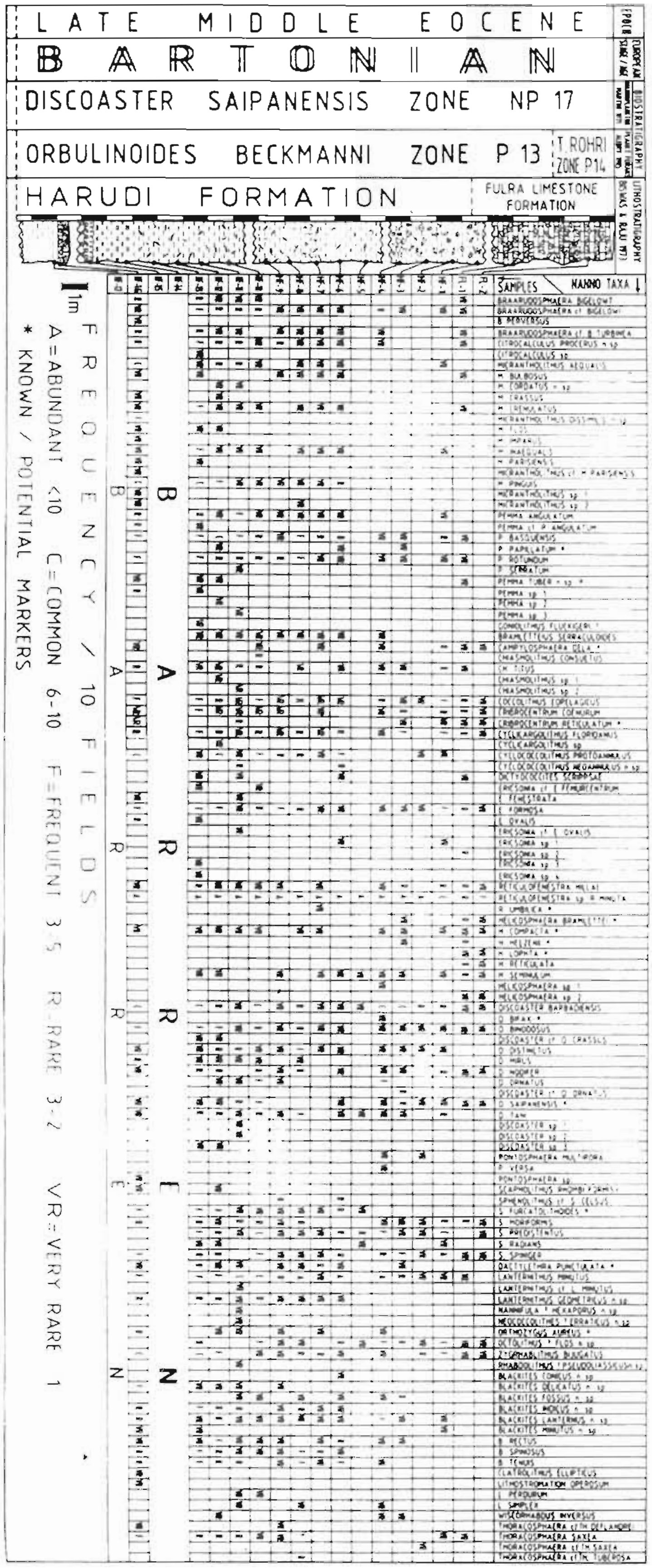


Fig. 3—Range chart showing distribution and frequency of calcareous nannoplankton taxa. Potential marker species for basinal and global correlation are shown with an asterix.

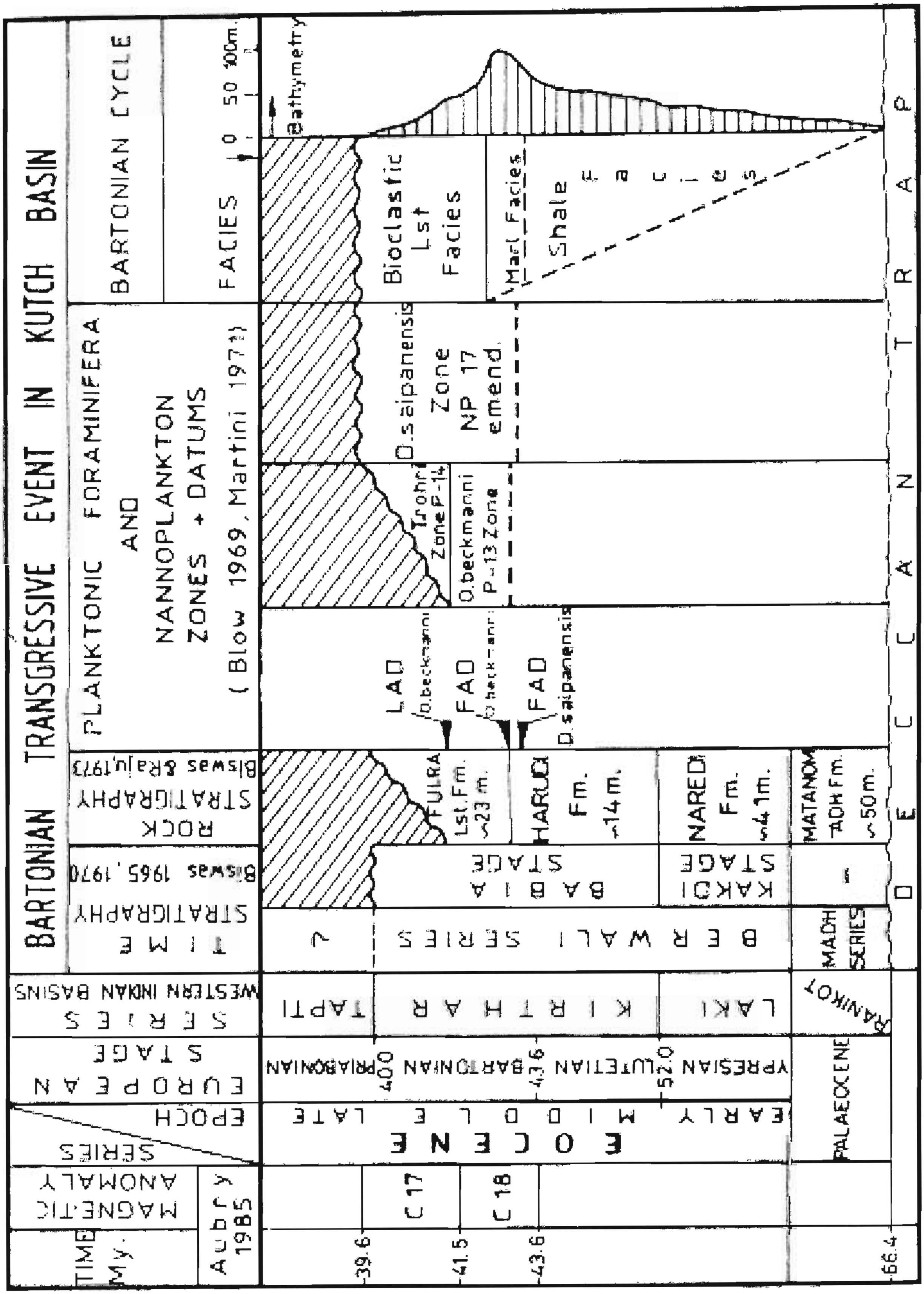
LANTERNITHUS Stradner, 1962
ORTHOZYGUS Bramlette & Wilcoxon, 1969
ZYGRHABLITHUS Deflandre, 1959
Family—COCCOLITHACEAE Poche, 1913
BRAMLETTEIUS Gartner, 1969
CAMPYLOSPHAERA Kamptner, 1963
CHIASMOLITHUS Hay *et al.*, 1966
COCCOLITHUS Schwarz, 1894
CRUCIPLACOLITHUS Hay & Mohler, 1967
CYCLOCOCCOLITHUS Kamptner 1954 ex Kamptner, 1956
ERICSONIA Black, 1964
Family—DISCOASTERACEAE Vekshina, 1959
DISCOASTER Tan Sin Hok, 1927
Family—HELICOSPHAERACEAE Black, 1971 emend. Jafar & Martini, 1975
HELICOSPHAERA Kamptner, 1954 ex Kamptner, 1956
Family—LITHOSTROMATIONACEAE Deflandre, 1959
LITHOSTROMATION Deflandre, 1942
Family—PONTOSPHAERACEAE Lemmermann in Brandt & Apstein, 1908
PONTOSPHAERA Lohmann, 1902
Family—PRINSIACEAE Hay & Mohler, 1967
CYCLICARGOLITHUS Bukry, 1971a
DICTYOCOCCITES Black, 1967
RETICULOFENESTRA Hay *et al.*, 1966
Family—RHABDOSPHAERACEAE Lemmermann, 1908
BLACKITES Hay & Towe, 1962
Family—SPHENOLITHACEAE Deflandre, 1952
SPHENOLITHUS Deflandre, 1952
Family—THORACOSPHAERACEAE Schiller, 1930
THORACOSPHAERA Kamptner, 1927

Family—BRAARUDOSPHAERACEAE
(Graan & Braarud) Deflandre, 1947

The family Braarudosphaeraceae is characterised by dodecahedral symmetry. In living representatives (type species *Braarudosphaera bigelowii*), twelve regular pentaliths fit together to produce hollow cells of quasicrystalline symmetry. Each pentalith is further subdivided into five trapezoidal segments by dextral rotation of radial sutures and display rotatory symmetry (Black, 1972). The entire cell thus consists of 60 well defined units, produced by incremental growth of laminae parallel to the pentagonal face.

Tappan (1980) included genera *Astrionis, Biantholithus, Braarudosphaera, Hexalithus, Hexangulolithus, Micrantholithus, Octolithites, Pemma, Pentaster, Quinquerhabdus* and *Vermiculithina* whereas Perch-Nielsen (1985b) assigned only four genera, viz. *Braarudosphaera, Micrantholithus, Pemma* and *Pentaster* to this family. Since dodecahedral symmetry is a characteristic feature of the family, the view of Perch-Nielsen (1985b) is agreed upon to consider only limited number of genera including genus *Citrocalculus* which is considered here as distinct and independent of *Micrantholithus*.

Braarudosphaera is distinguished by trapezoidal or variant of trapezoidal shape of pentalith elements. *Micrantholithus* is characterised by triangular shape, while *Pemma* is recognised by a distinct pore situated in middle part of each of its pentalith segments. *Pentaster* shows development of small protruding rays between each pentalith segment. *Citrocalculus* is characterised by pentaliths which are high (usually twice the width) and are easily recognised in side-views. This genus was previously included under *Micrantholithus*. Although dodecahedral cells of only *B. bigelowii* are known, theoretical modelling suggests dodecahedral cells for other species known by only isolated pentaliths. In this respect, the family shares similar symmetry with living *Tergestiella adriatica* Kamptner (circular coccoliths limited to 12 on the cell) and *Goniolithus fluckigeri* Deflandre. Recent suggestions by Lambert (1986) that species of *Braarudosphaera* occur on a single coccosphere seem doubtful. The Albian coccosphere described by Lambert (1986), certainly contains new species besides *B. africana* but the proposed theoretical model is not consistent with the stratigraphical data of various species of *Braarudosphaera*. The family Braarudosphaeraceae


BARTONIAN TRANSGRESSIVE EVENT IN KUTCH BASIN
TIME My.
Aubry 1985
MAGNETIC ANOMALY
SERIES
EPOCH
EUROPEAN STAGE
WESTERN INDIAN BASINS SERIES
TIME STRATIGRAPHY Biswas 1965, 1970
ROCK STRATIGRAPHY Biswas & Raju 1973
PLANKTONIC FORAMINIFERA AND NANNOPLANKTON ZONES + DATUMS (Blow 1969, Martini 1971)
BARTONIAN CYCLE
FACIES
0 50 100m
Bathymetry
39.6
41.5
43.6
66.4
C 17
C 18
EOCENE
LATE
MIDDLE
EARLY
PALAEOCENE
PRIABONIAN
BARTONIAN
LUTETIAN
YPRESIAN
40.0
43.6
52.0
TAPTI
KIRTHAR
LAKI
RANIKOT
BERWALI SERIES
MADH SERIES
BABIA STAGE
KAKDI STAGE
FULRA Lst. Fm. ~23 m.
HARUDI Fm. ~14 m.
NAREDI Fm. ~41 m.
MATANOMADH Fm. ~50 m.
LAD O. beckmanni
FAD O. beckmanni
FAD O. saipanensis
O. beckmanni P-13 Zone
T. rohri Zone P-14
O. saipanensis Zone NP 17 emend.
Bioclastic Lst Facies
Marl Facies
Shale Facies
DECCAN TRAP

is indicative of typically nearshore, shallow, warm water deposits (Sullivan, 1964, 1965; Martini, 1965, 1970; Bukry *et al.*, 1971; Bybell & Gartner, 1972). Possible provincialism among mid-Eocene Braarudosphaeraceae is dealt by Bybell (1975). Exceptional record of *B. rosa* bloom from open ocean Oligocene sediments of South Atlantic and Black Sea possibly related to reduced salinity is discussed by Bukry (1974) and others. The stratigraphic range of this family is from Tithonian to Recent. A few species of *Braarudosphaera* and *Micrantholithus* have been used as markers for Early Cretaceous biostratigraphy. The easily recognisable and large sized *P. papillatum* was utilised for marking zonal boundary in the middle Eocene in Alabama (Gartner, 1971).

In the studied material, Braarudosphaeraceae forms a major constituent of the nannofloral assemblages. Species of *Micrantholithus* dominate over that of *Pemma*. *Braarudosphaera* is rare. It seems that other factors, besides nearshore and shallow water conditions may be responsible for the abundance of braarudosphaerids. *Pentaster* is absent in the studied material.

Genus—BRAARUDOSPHAERA
(Graan & Braarud) Deflandre, 1947

Braarudosphaera bigelowii (Graan & Braarud) Deflandre, 1947

(Pl. 2.1A-B, 2-3, 4A-B, 5)

Synonymy list—

1935 *Pontosphaera bigelowii* Graan & Braarud p. 388, Abb. 67.

1947 *Braarudosphaera bigelowii* (Graan & Braarud) Deflandre, p. 439, figs 1-5.

1963 *Braarudosphaera bigelowii* (Graan & Braarud) Deflandre in Narasimhan, p. 112-113, pl. 11, fig. 4.

1969 *Braarudosphaera bigelowii* (Graan & Braarud) Deflandre in Pant & Mamgain, p. 118-119, pl. 21, fig. 7; pl. 23, fig. 17.

1971 *Braarudosphaera bigelowii* (Graan & Braarud) Deflandre in Haq, p. 47-48, pl. 6, fig. 3.

1973 *Braarudosphaera bigelowii* (Graan & Braarud) Deflandre in Pant & Mathur, p. 212, pl. 26, figs H-I.

non1978a *Braarudosphaera bigelowii* (Graan & Braarud) Deflandre in Singh *et al.*, p. 346-347, fig. 21.

non1978b *Braarudosphaera bigelowii* (Graan & Braarud) Deflandre in Singh *et al.*, p. 8, pl. 5, figs 4-7.

1978a *Braarudosphaera bigelowii* (Graan & Braarud) Deflandre in Singh, p. 53-54.

1978b *Braarudosphaera bigelowii* (Graan & Braarud) Deflandre in Singh, p. 87-88.

1979 *Braarudosphaera bigelowii* (Graan & Braarud) Deflandre in Singh, p. 6, pl. I, fig. 57, non figs 58-59.

1980a *Braarudosphaera bigelowii* (Graan & Braarud) Deflandre in Singh, p. 9, pl. 5, fig. 5.

non1980b *Braarudosphaera bigelowii* (Graan & Braarud) Deflandre in Singh, p. 25, pl. I, fig. 27.

1986 *Braarudosphaera bigelowii* (Graan & Braarud) Deflandre in Singh & Singh, p. 148, pl. 3, figs 1-2.

1987 *Braarudosphaera bigelowii* (Graan & Braarud) Deflandre in Singh & Singh, p. 203.

1991 *Braarudosphaera bigelowii* (Graan & Braarud) Deflandre in Martini, p. 323, taf. 1, fig. 12.

1994 *Braarudosphaera bigelowii* (Graan & Braarud) Deflandre in Jafar & Rai, p. 25-26, fig. 1.

Remarks—This well known species was originally described from the Atlantic Ocean as *Pontosphaera bigelowii* (Graan & Braarud, 1935). Later Deflandre (1947) based on detailed morphology, proposed the new genus *Braarudosphaera*. *B. bigelowii* is characterised by trapezoidal shaped elements making regular pentaliths. Thus sixty of these units form

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Fig. 4—Correlation chart showing calcareous nannoplankton and planktonic foraminifera zones with some markers from the studied sections tied to Time – and rock – stratigraphic classifications of Kutch Basin, series of western Indian basins and correlated with European Stage/ Epoch, magnetic events and absolute time (after Rai, 1988).

complete pentagonal dodecahedral cyst cell of quasicrystalline symmetry. The sutures between adjacent regular pentaliths are weak and contain slit like openings corresponding to thirty edges of the pentagonal dodecahedron with hollow interior.

The species is reported from the Cretaceous to Recent marine sediments globally, except for a solitary record by Nöel (1965) from Tithonian. The depositional environment is confined to nearshore, shallow and warm water areas (Bybell & Garner, 1972). In the studied material *B. bigelowii* is rare to very rare in both the Fulra Limestone and Harudi formations, implying that some other controlling factors existed besides shallow nearshore environment.

Braarudosphaera* cf. *B. bigelowii
(Graan & Braarud) Deflandre, 1947

(Pl. 2.7A-B)

Remarks—Specimens are larger than that of typical *Braarudosphaera bigelowii* and display rounded edges of trapezoidal elements making each pentalith. This does not appear to be due to calcite overgrowth.

Braarudosphaera perversus Sullivan, 1965

(Pl. 4.6A-B)

1965 *Braarudosphaera perversus* Sullivan p. 39, pl. 8, figs 2a-b.

Remarks—Originally described under light microscope from Palaeocene-Eocene sediments of Californian coast. Kutch specimens are nearly of the same size as reported from the type locality and found as extremely rare in Harudi Formation. *B. perversus* is distinguished from *B. bigelowii* by thickened radial sutures and a protruding outline of the trapezoidal elements.

Braarudosphaera* cf. *B. turbinea Stradner, 1963

(Pl. 2.6)

Remarks—Specimens resemble *B. turbinea* in displaying imbrication and curvature of pentalith elements, but lack typical rounded outline and more conspicuous overlapping of elements. It is rare to very rare in both the formations.

Genus—CITROCALCULUS
Troelsen & Quadros 1971

Citrocalculus procerus (Bukry & Bramlette, 1969) Rai, 1997 comb. nov.

(Pl. 2.10A-B, 11A-B, 13A-B)

Basionym—*Micrantholithus procerus* Bukry & Bramlette 1969; p. 136, pl. 2, fig. 12-15, Tulane Stud. Geol. Paeont., 7(3-4).

Synonymy list—

1972 *Micrantholithus procerus* Bukry & Bramlette in Bybell & Gartner, p. 325, pl. 3, figs 1-6.

1972 *Micrantholithus altus* Bybell & Gartner p. 325, pl. 2, figs 1-10.

PLATE 1 ⟶

Photomicrographs are printed in the same orientation with respect to the axes of nicols as observed under the microscope; coordinates measured with reference to a cross engraved on each slide. x 2000 Scale bar represents all photographs unless otherwise stated; PPL = normal light with single polariser; XPL = crossed nicols. HFm = Harudi Formation; FLFm = Fulra Limestone Formation.

1, 2. *Pemma tuber* sp. nov., 1A-B. Paratype, FL Fm; BSIP Slide No. 9893: FL 1(2), Coordinates : 76.9/19.2; 1A PPL; 1B XPL; 2A-B. Holotype; HFm; BSIP Slide No. 9892 : HF 16 (1); coordinates : 80.4/43.7; 2A PPL; 2B XPL.

3-5. *Pemma papillatum* Martini, 1959; HFm; BSIP Slide No. 9992 : 3A PPL; 3B, 4-5 XPL.

6-7. *Pemma rotundum* Klumpp, 1953; HFm; BSIP Slide No. 9892 : 6A, 7A PPL; 6B, 7B XPL.

8. *Pemma* sp. 1.; HFm; BSIP Slide No. 9892 : 8A PPL; 8B XPL.

9-10. *Pemma basquensis* (Martini) Báldi- Beke, 1971; HFm; BSIP Slide No. 9892 : 9A, 10A PPL; 9B, 10B XPL.

11. *Pemma* sp. 2; BSIP Slide No. 9892 : HFm; XPL.

12. *Micrantholithus cordatus* sp. nov., HFm; BSIP Slide No. 9880; Coordinates : 86.1/17.8 : XPL.

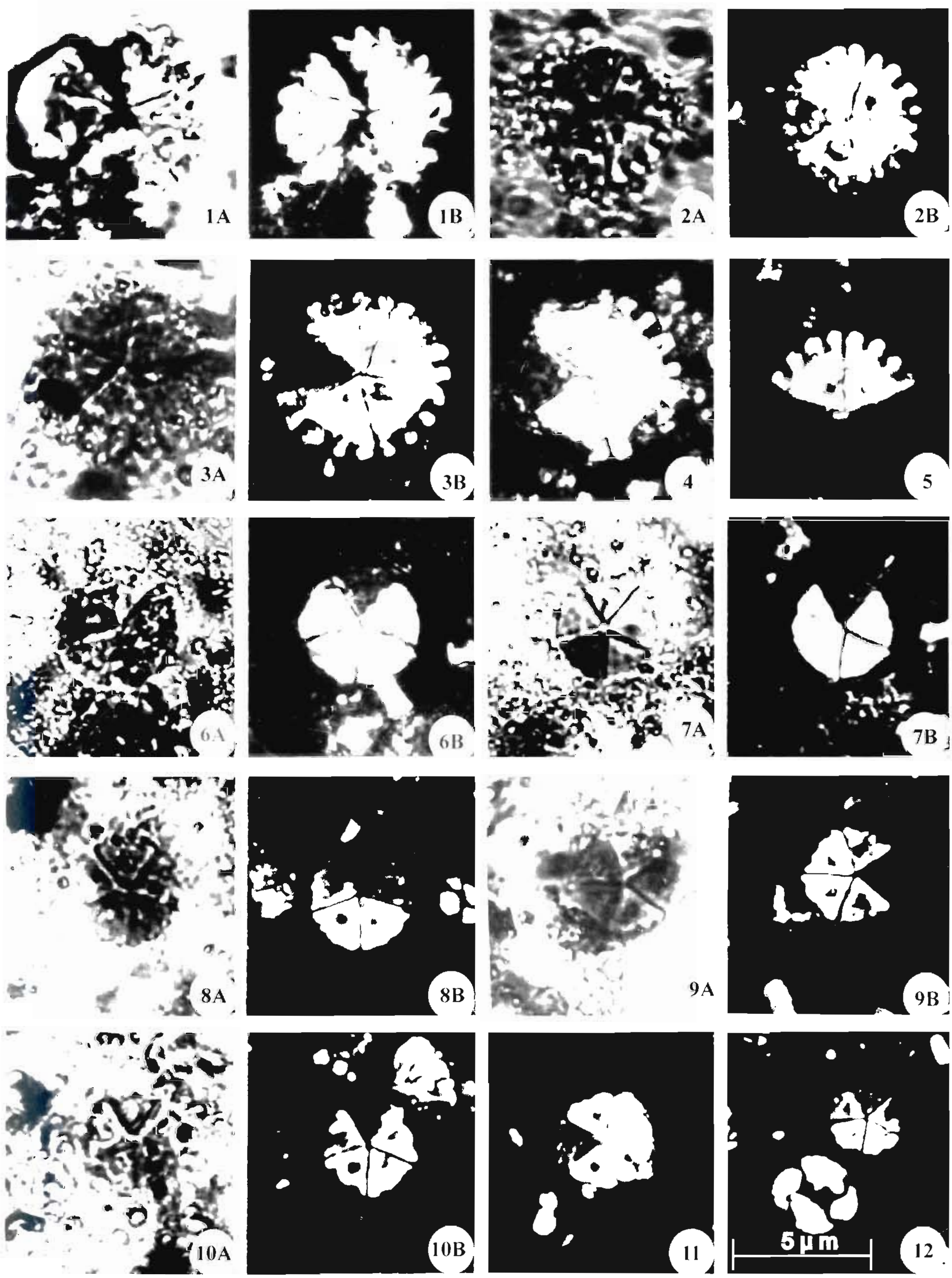

PLATE 1

1975 *Micrantholithus procerus* Bukry & Bramlette in Bybell, p. 189-190, pl. 9, figs 5-8.

1975 *Micrantholithus altus* Bybell & Gartner in Bybell, p. 189, pl. 11, figs 1-7.

1978 *Micrantholithus procerus* Bukry & Bramlette in Bukry, p. 842, pl. 9, fig. 12.

1994 *Micrantholithus procerus* Bukry & Bramlette in Jafar & Rai, p. 26, pl. 1, figs 6a-b, 7.

1997 *Micrantholithus procerus* Bukry & Bramlette in Rai, p. 150, pl. I, fig. 9.

Remarks—Originally described from late Middle Eocene of Guayabal Formation, Mexico and Cook Mountain Formation, U.S.A. The species typically present in shallow marine sediments of Palaeocene-Middle Eocene ages.

Pentaliths are characterised by elongated outline in side view. In plan view, each of the five triangular pentalith segments has a median indentation along outer margin. Readily identified in side view, the height of the pentaliths is almost double the width. A typical cone shaped outline is characteristic of this species. It resembles a citrus-press in shape. The placement of the species under already known genus *Citrocalculus* is preferred due to the extended height-width ratio of the pentalith.

The species is frequent to very rare in assemblages.

Genus—MICRANTHOLITHUS Deflandre, 1950

Micrantholithus aequalis Sullivan, 1964

(Pl. 4.8A-B, 9-10, 11A-B)

Synonymy list—

1961 *Micrantholithus* aff. *M. attentuatus* Bramlette & Sullivan, p.154, pl. 8, figs 12a-b.

1961 *Micrantholithus vesper* Deflandre in Stradner & Papp, p.121, pl. 39, figs 5a-b.

?1962 *Micrantholithus* aff. *M. attentuatus* Bramlette & Sullivan in Bouché, P. 87, pl. 2, fig. 22.

1964 *Micrantholithus aequalis* Sullivan, p. 188, pl. 9, figs 6a-b.

1965 *Micrantholithus aequalis* Sullivan in Sullivan, p. 39.

1994 *Micrantholithus aequalis* Sullivan in Jafar & Rai, p. 26, pl. 1, figs 12a-b.

Remarks—Originally reported from Palaeocene of Lodo section, California (Sullivan, 1964). Pentaliths are distinctly star-shaped formed by joining of 'V' shaped segments and the adjacent sides of which are of equal length. It is common to very rare in Harudi Formation and absent in Fulra Limestone Formation.

Micrantholithus bulbosus Bouché, 1962

(Pl. 4.4A-B)

Synonymy list—

1962 *Micrantholithus bulbosus* Bouché, p. 87, pl. 2, figs 4-7, text-fig. 12.

PLATE 2 ⟶

Photomicrographs are printed in the same orientation with respect to the axes of nicols as observed under the microscope; coordinates measured with reference to a cross engraved on each slide. x 2000 Scale bar represents all photographs unless otherwise stated; PPL = normal light with single polariser; XPL = crossed nicols. HFm = Harudi Formation; FLFm = Fulra Limestone Formation.

1-5. *Braarudosphaera bigelowii* (Graan & Braarud) Deflandre, 1947; HFm; BSIP Slide No. 9892 : 1A, 4A PPL; 1A, 2-3, 4B, 5 XPL.

6. *Braarudosphaera* cf. *B. turbinea* Stradner, 1963; HFm; BSIP Slide No. 9888 : XPL.

7. *Braarudosphaera* cf. *B. bigelowii* (Graan & Braarud) Deflandre, 1947; HFm; BSIP Slide No. 9892 : 7A PPL; 7B XPL.

8. *Micrantholithus crenulatus* Bramlette & Sullivan, 1961, HFm; BSIP Slide No. 9892 : XPL.

9. *Pemma angulatum* Martini, 1959; HFm; BSIP Slide No. 9892 : XPL.

10-11,13. *Citrocalculus procerus* (Bukry & Bramlette) Rai, 1997; BSIP Slide No. 9888 : HFm; 10A, 11A, 13A PPL; 10B, 11B, 13B XPL.

12. *Micrantholithus pinguis* Bramlette & Sullivan, 1961; HFm; BSIP Slide No. 9892 : 12a PPL; 12b XPL.

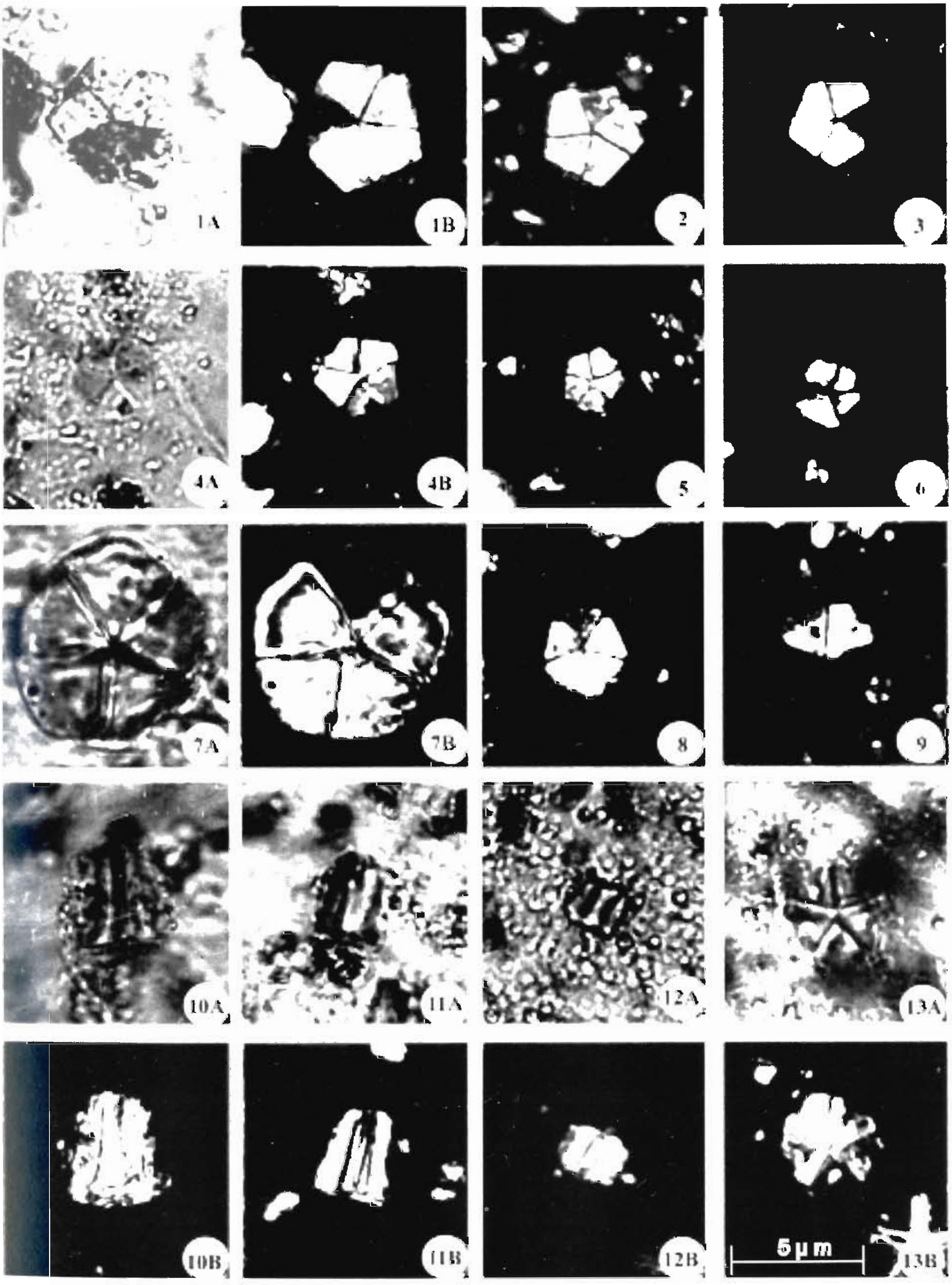

PLATE 2

1969 *Pemma papillatum* Martini in Pant & Mamgain (partim), p. 122, pl. 24, fig. 8.

1994 *Micrantholithus bulbosus* Bouché in Jafar & Rai, p. 26, pl. 1, figs 21, 22a-b.

Remarks—Originally reported from Lutetian of France. It is differentiated from other pentaliths in having a circular outline and 'V' shaped segments with distinctly rounded marginal tips of segments containing a circular depression covered with a thin membrane. It is very rare throughout the Harudi and Fulra Limestone formations.

Micrantholithus cordatus sp. nov

(Pl. 1.12; Pl. 3.8-9)

Derivation of name—"*cordis*" (Latin) meaning heart.

Holotype—Pl. 3.8. HF 11 (1) Coordinates—80.9/35.3. Size—8 µm maximum diameter; 5.5 µm minimum diameter. BSIP Slide No. 9887.

Paratype—Pl. 3.9. HF 12 (2) Coordinates—86.1/17.8. Size—6 µm maximum diameter; 4.5 µm minimum diameter. BSIP Slide No. 9888; Pl. 1.12. HF 16 (1) Coordinates 78.6/31.3, BSIP Slide No. 9892.

Type locality—SW of village Harudi in 'Rato Nala Section', Kutch; western India.

Type level—Late Middle Eocene, Harudi Formation; *D. saipanensis* Zone = NP 17 of Martini, 1971a emend. Rai, 1988.

Diagnosis—Pentalith characteristically heart-shape in outline. Triangular segments pierced by a subrounded pore merging with smooth rounded periphery, thus making confident assignment to *Micrantholithus*.

Remarks—It differs from all the existing species of *Micrantholithus* and *Pemma* in its peculiar heart shape outline. Similar looking forms, but without pores (? concealed due to calcite overgrowth) have been reported from the middle Eocene of Atlantic Ocean at Site 390 by Bukry (1978). It is recorded very rarely from Harudi Formation only.

Micrantholithus crassus
(Bouché, 1962) comb. nov.

(Pl. 5.3, 5A-B)

Basionym—*Micrantholithus basquensis crassus* Bouché 1962; p. 85, pl. 2, figs 3, 9-10, p. 81, text-figs 7-8, Micropaléontologie, 5(2).

Synonymy list—

1972 *Pemma basquense crassum* (Bouché) Bybell & Gartner, p. 326-328, pl. 4, figs 3-4, non figs 1-2, 5-6.

PLATE 3 ⟶

Photomicrographs are printed in the same orientation with respect to the axes of nicols as observed under the microscope; coordinates measured with reference to a cross engraved on each slide. x 2000 Scale bar represents all photographs unless otherwise stated; PPL = normal light with single polariser; XPL = crossed nicols. HFm = Harudi Formation; FLFm = Fulra Limestone Formation.

1-7. *Micrantholithus imparus* sp. nov., 1. Holotype: HFm; BSIP Slide No. 9892 : HF 16 (1) : Coordinates : 77.0/34.6 XPL; 2A-B, 3, 4A-B, 5-6, 7A-B. 2. Paratype : HFm; BSIP Slide No. 9892 : HF 16 (1) : Coordinates : 80.0/20.6 : 2A PPL; 2B XPL; BSIP Slide No. 9892 : HF 16 (1) : Coordinates : 76.0/22.5; 4A PPL, 4B XPL; BSIP Slide No. 9892: HF 16 (1) : Coordinates: 75.3/27.8; 5 XPL; BSIP Slide No. 9892: HF 16 (1): Coordinates : 78.6/35.4; 6 XPL; BSIP Slide No. 9892: HF 16 (1) : Coordinates : 84.9/23.2; 7A PPL : 7B XPL. All from HFm.

8-9. *Micrantholithus cordatus* sp. nov., 8. Holotype: HFm; BSIP Slide No. 9887 : HF 11(1) Coordinates : 80.9/35.3; XPL; 9. Paratype HFm ; BSIP Slide No. 9888: HF12 (2): Coordinates : 86.1/17.8; XPL.

10-15. *Micrantholithus dissimilis* sp. nov., 10. Paratype; HFm; BSIP Slide No. 9892 : HF 16 (1) : Coordinates: 76.1/37.0; XPL; 11. Holotype: HFm; BSIP Slide No. 9892 : HF 16 (1) : 75.0/26.7 ; XPL; 12A-B, 13-15. Paratypes; BSIP Slide No. 9892 : HF 16(1); coordinates : 76.1/28.2; 12A, PPL : 12B XPL; BSIP Slide No. 9892 : HF 16(1); coordinates 77.0/19.0; 13 XPL; BSIP Slide No. HF 16 (1); coordinates 75.5/31.8; 14 XPL; BSIP Slide No. 9892 : HF 16(1); coordinates : 75.4/35.4; 15 XPL; all from HFm.

16. *Micrantholithus* cf. *M. parisiensis* Bouché, 1962 ; HFm; BSIP Slide No. 9892 : XPL

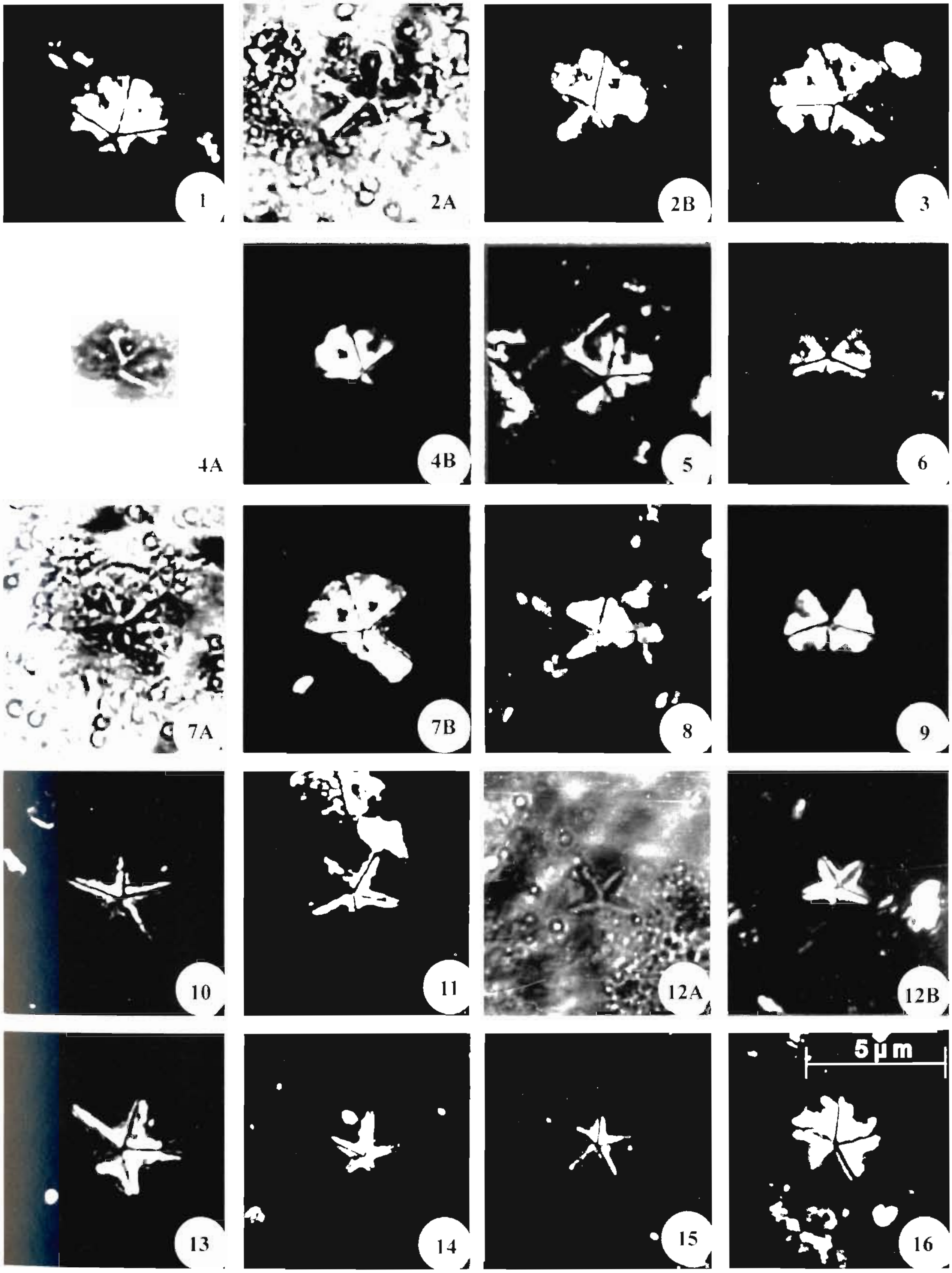

PLATE 3

Remarks—Pentaliths display a faint pentagonal outline. Each triangular segment of pentalith is pierced by comparatively large pore connected to outer smooth and distinctly depressed periphery by a narrow opening, which may be closed even on a solitary pentalith. Due to highly variable subspecies of (Bouché) Bybell and Gartner (1972) and its pore dissection up to periphery the new combination is proposed. The form has been recorded rarely from Harudi Formation.

Micrantholithus crenulatus
Bramlette & Sullivan, 1961

(Pl. 2.8; Pl. 4.12A-B)

1961 *Micrantholithus crenulatus* Bramlette & Sullivan, p. 155, pl. 9, figs 3a-b, 4.

1965 *Micrantholithus crenulatus* Bramlette & Sullivan in Sullivan, p. 39, pl. 8, figs 6a-b.

1975 *Braarudosphaera discula* Bramlette & Riedel in Proto Decima *et al.*, p. 44, pl. 1, figs 3a-b, non figs 6a-b.

Remarks—Small to medium sized pentaliths display poreless triangular segments with crenulated peripheral margin and an overall regular pentagonal outline. The specimens recovered here resemble the holotype. It is frequent to very rare in both the formations.

Micrantholithus dissimilis sp. nov.

(Pl. 3.10-11, 12A-B, 13-15)

Derivation of name—"*dissimilis*" (Latin) meaning dissimilar.

Holotype—Pl. 3.11. HF 16 (1). Coordinates—75.0/36.7. Size—8.5 µm maximum diameter; 7 µm minimum diameter. BSIP Slide No.—9892.

Paratypes—Pl. 3.12A-B. HF 16 (1). Coordinates—76.1/28.2 6 µm maximum diameter; Size—4 µm minimum diameter. BSIP Slide No. 9892; Pl. 3.10, HF 16 (1). Coordinates—76.1/37.0; Size—9 µm maximum diameter. BSIP Slide No. 9892; Pl. 3.13. HF 16 (1). Coordinates—77.0/19.0; Size—10 µm maximum diameter; 4 µm minimum diameter. BSIP Slide No. 9892; Pl. 3.14. HF 16 (1). Coordinates—75.5/31.8; Size—7 µm maximum diameter. BSIP Slide No. 9892; Pl. 3.15. HF 16 (1). Coordinates—75.4/35.4; Size—5 µm maximum diameter. BSIP Slide No. 9892.

Type locality—SW of village Harudi in 'Rato Nala Section', Kutch; western India.

Type level—Late Middle Eocene, Harudi Formation; *D. saipanensis* Zone = NP 17 of Martini, 1971a emend. Rai, 1988.

Diagnosis—Small to medium sized asymmetrical pentalith with 'V' or 'L' shaped segments displaying 3 segments of almost identical size and a pair of segment greatly reduced. 'V' shaped isolated segments may be

PLATE 4 ⟶

Photomicrographs are printed in the same orientation with respect to the axes of nicols as observed under the microscope; coordinates measured with reference to a cross engraved on each slide. x 2000 Scale bar represents all photographs unless otherwise stated; PPL = normal light with single polariser; XPL = crossed nicols. HFm = Harudi Formation; FLFm = Fulra Limestone Formation.

1. *Micrantholithus parisiensis* Bouché, 1962: HFm; BSIP Slide No. 9892 : XPL.
2, 3. *Micrantholithus inaequalis* Martini, 1961a: HFm; BSIP Slide No. 9888 : 2 XPL; 3A PPL; 3B XPL.
4. *Micrantholithus bulbosus* Bouché, 1962: HFm; BSIP Slide No. 9892 : 4A PPL; 4B XPL.
5. *Micrantholithus* sp.1: HFm; BSIP Slide No. 9892 : 5A PPL; 5B XPL.
6. *Braarudosphaera perversus* Sullivan, 1965; HFm; BSIP Slide No. 9888 : 6A PPL; 6B XPL.
7. *Micrantholithus* sp. 2., BSIP Slide No. 9892 : HFm; 7A PPL; 7b XPL.
8-11. *Micrantholithus aequalis* Sullivan, 1964; HFm; 8, 10. BSIP Slide No. 9879; 9. BSIP Slide No. 9892, 11. BSIP Slide No. 9879 : 8A & 11A PPL; 8B, 9, 10, 11B XPL.
12. *Micrantholithus crenulatus* Bramlette & Sullivan, 1961; HFm; BSIP Slide No. 9892 : 12A PPL; 12B XPL.

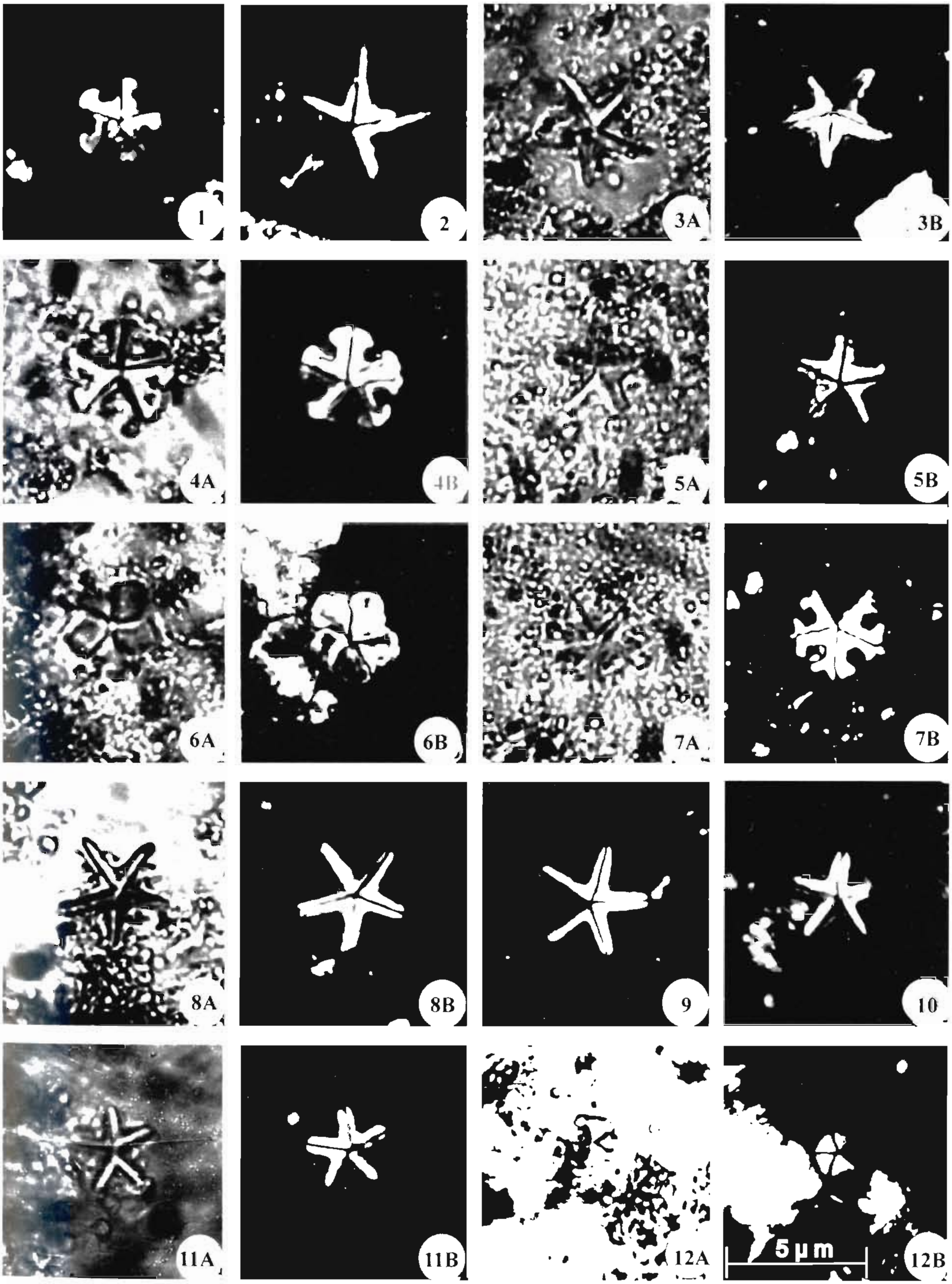

PLATE 4

indistinguishable from those of *M. aequalis* Sullivan (1964). Frequently recovered from Harudi Formation.

Remarks—It differs from *M. aequalis* Sullivan (1964) in showing asymmetrical nature of pentaliths.

Micrantholithus flos Deflandre, 1950

(Pl. 5.6A-B)

Synonymy list—

1950 *Micrantholithus flos* Deflandre, p.1157, text-figs 8-11.

1954 *Micrantholithus flos* Deflandre in Deflandre & Fert, p. 166, pl. 13, figs 10-11, text-figs 113-114.

1958 *Micrantholithus flos* Deflandre in Martini, p. 356, pl. 1, figs 2a-c.

1961 *Micrantholithus flos* Deflandre in Bramlette & Sullivan, p. 155, pl. 9, figs 8a-b.

1962 *Micrantholithus flos* Deflandre in Bouché, p. 87, pl. 2, figs 1-2; text-figs 13-14.

1965 *Micrantholithus flos* Deflandre in Sullivan, p. 40, pl. 9, figs 1 a-b, 2 a-b, 3 a-b.

1969 *Micrantholithus flos* Deflandre in Bukry & Kennedy, p. 40, fig. 4 (7).

1997 *Micrantholithus flos* Deflandre in Rai, p. 150, pl. I, fig. 6.

Remarks—Pentaliths are characterised by triangular shaped segments displaying distinct thickening along the radial sutures and a thin "web" between each segment which is best seen under plane polarised light. It is rarely recorded in Harudi Formation.

Micrantholithus imparus sp. nov.

(Pl. 3.1, 2A-B, 3, 4A-B, 5-6, 7A-B)

Derivation of name—"*impar*" (Latin) meaning uneven.

Holotype—Pl. 3.1. HF 16 (1). Coordinates—77.0/34.6. Size—9 µm maximum diameter; 7 µm minimum diameter. BSIP Slide No.—9892.

Paratype—Pl. 3.2A-B. HF 16 (1). Coordinates—80.0/20.6. BSIP Slide No. 9892.

Type locality—SW of village Harudi in 'Rato Nala Section', Kutch; western India.

Type level—Late Middle Eocene, Harudi Formation; *D. saipanensis* Zone = NP 17 of Martini, 1971a emend. Rai, 1988.

Diagnosis—Semicircular in outline. Pair of large segments followed by another smaller pair and a fifth segment of much reduced size (holotype). Characteristic triangular shape of segments containing a pore joined with peripheral margin observed only in large segments.

Remarks—This apparently anomalous form of pentalith is distinctive and shows considerable variability and is not comparable with other existing species. The species is rare in Harudi Formation.

Micrantholithus inaequalis Martini, 1961a

(Pl. 4.2, 3A-B)

Synonymy list—

1961a *Micrantholithus inaequalis* Martini, p.7, pl. 2, fig. 7; pl. 5, fig. 45.

PLATE 5 ⟶

Photomicrographs are printed in the same orientation with respect to the axes of nicols as observed under the microscope; coordinate measured with reference to a cross engraved on each slide. x 2000 Scale bar represents all photographs unless otherwise stated; PPL = normal light with single polariser; XPL = crossed nicols. HFm = Harudi Formation; FLFm = Fulra Limestone Formation.

1-2, 4. *Pemma* cf. *P. angulatum* Martini, 1959, 1-2. HFm; BSIP Slide No. 9892: XPL; 4. HFm; BSIP Slide No. 9992 : XPL.

3, 5. *Micrantholithus crassus* (Bouché) comb. nov., 3. HFm; BSIP Slide No. 9892 : XPL; 5A-B. HFm; BSIP Slide No. 9892 : 5A PPL; 5B XPL.

6. *Micrantholithus flos* Deflandre, 1950; HFm; BSIP Slide No. 9892 : 6B XPL.

7-14. *Micrantholithus pinguis* Bramlette & Sullivan, 1961; HFm; 7-10. BSIP Slide No. 9892; 11, 14. BSIP Slide No. 9882; 12-13. BSIP Slide No. 9879 : 11A, 12A, PPL; 7-10, 11B, 12B, 13-14 XPL.

15. *Ericsonia ovalis* Black, 1964; HFm; BSIP Slide No. 9892: 15A PPL; 15B, XPL.

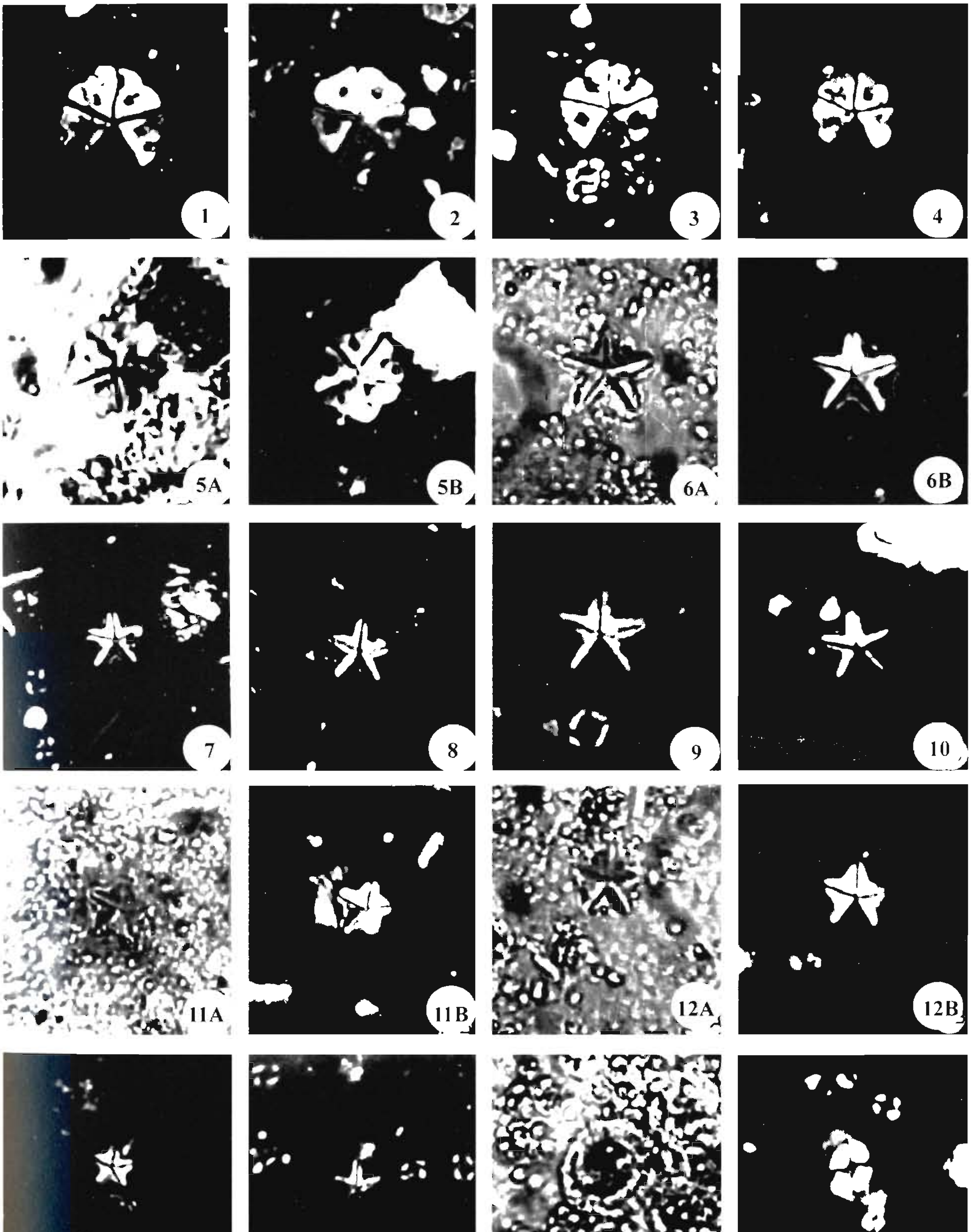

PLATE 5

1961 *Micrantholithus attenuatus* Bramlette & Sullivan, p.154, pl. 8, figs 8a-b, 9-11.

1964 *Micrantholithus attenuatus* Bramlette & Sullivan in Sullivan, p.188, pl. 8, figs 8a-b.

1994 *Micrantholithus inaequalis* Bramlette & Sullivan in Jafar & Rai, p. 26, pl. 1, figs 10a-b, 11.

Remarks—Medium to large sized, star shaped pentaliths are characterised by unequal lengths of 'V' shaped segments producing 'L' shaped fragments. A Ypresian occurrence of this species (Martini, 1961a) seems to have priority over *M. attenuatus* Bramlette & Sullivan (1961). It occurs frequently to rarely in Harudi Formation.

Micrantholithus parisiensis Bouché, 1962

(Pl. 4.1)

Synonymy list—

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

1997 *Micrantholithus parisiensis* Bouché in Rai, p. 150, pl. I, fig. 3.

Remarks—Medium sized pentaliths characterised by differential thickening of triangular shaped segments producing a "hook" like thicker part of segments sinistrally rotated to the plane of pentaliths. It is very rare in Harudi Formation.

Micrantholithus* cf. *M. parisiensis Bouché, 1962

(Pl. 3.16)

Remarks—Pentalith resemble the forms illustrated by Bouché (1962) in shape of triangular segments with curvature at peripheral margin. A single specimen was found in Harudi Formation.

Micrantholithus pinguis
Bramlette & Sullivan, 1961

(Pl. 2.12A-B; Pl. 5.7-10, 11A-B, 12A-B, 13-14)

Synonymy list—

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

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

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

1994 *Micrantholithus pinguis* Bramlette & Sullivan in Jafar & Rai, p. 26, pl. 1, fig. 9.

1997 *Micrantholithus pinguis* Bramlette & Sullivan in Rai, pl. I, fig. 5.

Remarks—Relatively small and star shaped robust pentaliths are without characteristic thin membrane observed in *M. flos*. The specimens display considerable variation in size (4-12 μm). The species is common to rare in Harudi Formation and not observed in Fulra Limestone Formation. Widely reported from shallow marine sediments of Palaeocene to Eocene age.

Micrantholithus sp. 1

(Pl. 4.5A-B)

PLATE 6 ⟶

Photomicrographs are printed in the same orientation with respect to the axes of nicols as observed under the microscope; coordinates measured with reference to a cross engraved on each slide. x 2000 Scale bar represents all photographs unless otherwise stated; PPL = normal light with single polariser; XPL = crossed nicols. HFm = Harudi Formation; FLFm = Fulra Limestone Formation.

1-2. *Ericsonia* sp.1, 1A-B. HFm; BSIP Slide No. 9888 : 1A PPL; 1B XPL; 2. HFm; BSIP Slide No. 9892 : XPL.

3. *Ericsonia formosa* (Kamptner) Haq 1971; HFm; BSIP Slide No. 9892 : 3A PPL; 3B XPL.

4-5. *Ericsonia* cf. *E. femurcentrum* Perch-Nielsen, 1971; HFm; BSIP Slide No. 9892 : 4a PPL; 4b, 5 XPL.

6-10. *Coccolithus eopelagicus* (Bramlette & Riedel, 1954) comb. nov., 6A, 7A, 8A, 9A, 10A. PPL; 6B, 7B, 8B, 9B, 10B XPL. All from HFm; 6, 9. BSIP Slide No. 9892; 7, 8, 10. BSIP Slide No. 9888.

11. *Ericsonia formosa* (Kamptner) Haq, 1971; HFm; BSIP Slide No. 9892 : 11A PPL; 11B XPL.

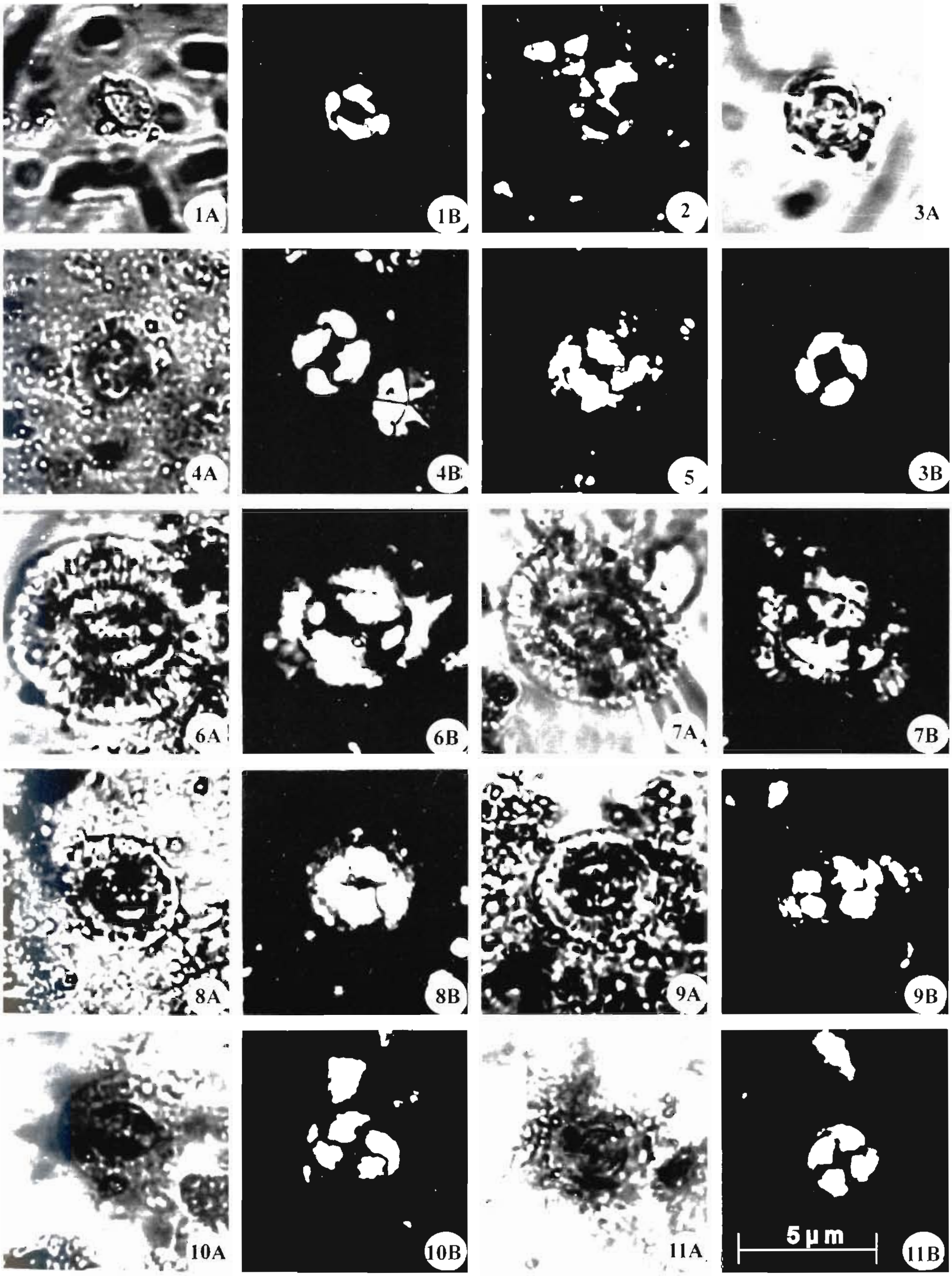

PLATE 6

Remarks—Moderate size species (ca. 8 μm) with tips of the pentalith segments showing thickening and a slight inward curvature. A single specimen was observed in Harudi Formation.

Micrantholithus **sp. 2**

(Pl. 4.7A-B)

Remarks—A species of *Micrantholithus* with thickening and bifurcation of the tips of pentalith segments producing characteristic outline. Very rare in Harudi Formation.

Genus—PEMMA Klumpp, 1953

Pemma angulatum Martini, 1959

(Pl. 2.9)

Synonymy list—

1959 *Pemma angulatum* Martini, p. 416, pl. 1, figs 1-4.

1975 *Pemma angulatum* Martini in Proto Decima *et al.*, p. 46, pl. 1, figs 10a-b.

Remarks—Originally described from Upper Eocene of Germany. This medium sized species of *Pemma* is distinguished by angular depression at the margin of each pentalith segment. Frequent to rare in Harudi Formation with specimens ranging in size of 11-17 μm.

Pemma* cf. *P. angulatum Martini, 1959

(Pl. 5.1-2, 4)

1997 *Pemma* cf. *P. angulatum* Martini in Rai, p. 150, pl. I, figs 7, 12.

Remarks—Typical specimens resemble *P. angulatum* but differ in showing less conspicuous angular depression at the margin of pentalith segments. It is rarely observed in Harudi Formation.

Pemma basquensis (Martini) Báldi-Beke, 1971

(Pl. 1.9A-B, 10A-B)

Synonymy list—

1959 *Micrantholithus basquensis* Martini, p. 417, pl. 1, figs 9-12.

1961 *Micrantholithus basquensis* Martini in Bramlette & Sullivan, p.154, pl. 8, figs ? 14a-c, 15.

1962 *Micrantholithus basquensis* Martini in Bouché, p. 85, pl. 2, fig. 11.

non1965 *Micrantholithus basquensis* Martini in Sullivan, p. 39, pl. 8, figs 4, 5a-b.

1969 *Micrantholithus basquensis* Martini in Bukry & Kennedy, p. 40, fig. 4(6).

1969 *Micrantholithus basquensis* Martini in Bilgütay, *et al.*, pl. 5, figs 1-4.

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

PLATE 7 ⟶

Photomicrographs are printed in the same orientation with respect to the axes of nicols as observed under the microscope; coordinates measured with reference to a cross engraved on each slide. x 2000 Scale bar represents all photographs unless otherwise stated; PPL = normal light with single polariser; XPL = crossed nicols. HFm = Harudi Formation; FLFm = Fulra Limestone Formation.

1-2, 5. *Ericsonia formosa* (Kamptner) Haq, 1971a; 1A-B, 2A-B. HFm; BSIP Slide No. 9892 : 1A PPL; 2A PPL; 1B, 2B. XPL; 5. HFm; BSIP Slide No. 9892 , XPL.

3-4. *Cyclococcolithus protoannulus* (Gartner) Rai, 1997. HFm; BSIP Slide No. 9892 : 3A PPL; 3B, 4 XPL.

6. *Cyclococcolithus protoannulus* (Gartner) Rai, 1997; HFm; BSIP Slide No. 9892 : XPL.

7-8. *Cyclococcolithus neoannulus* sp. nov., 7A-B. Holotype; HFm; BSIP Slide No. 9887 : HF 11 (1); Coordinates : 85.0/19.4 : 7A PPL; 7B XPL; 8. Paratype; HFm; BSIP Slide No. 9882 : HF 6(1) : Coordinates : 75.0/35.0; XPL.

9-10. *Chiasmolithus consuetus* (Bramlette & Sullivan) Hay & Mohler, 1967; HFm; BSIP Slide No. 9888 : 9A PPL; 9B-C, 10A-B XPL.

11. *Chiasmolithus titus* Gartner, 1970, HFm; BSIP Slide No. 9882 : 11A PPL; 11B-C.

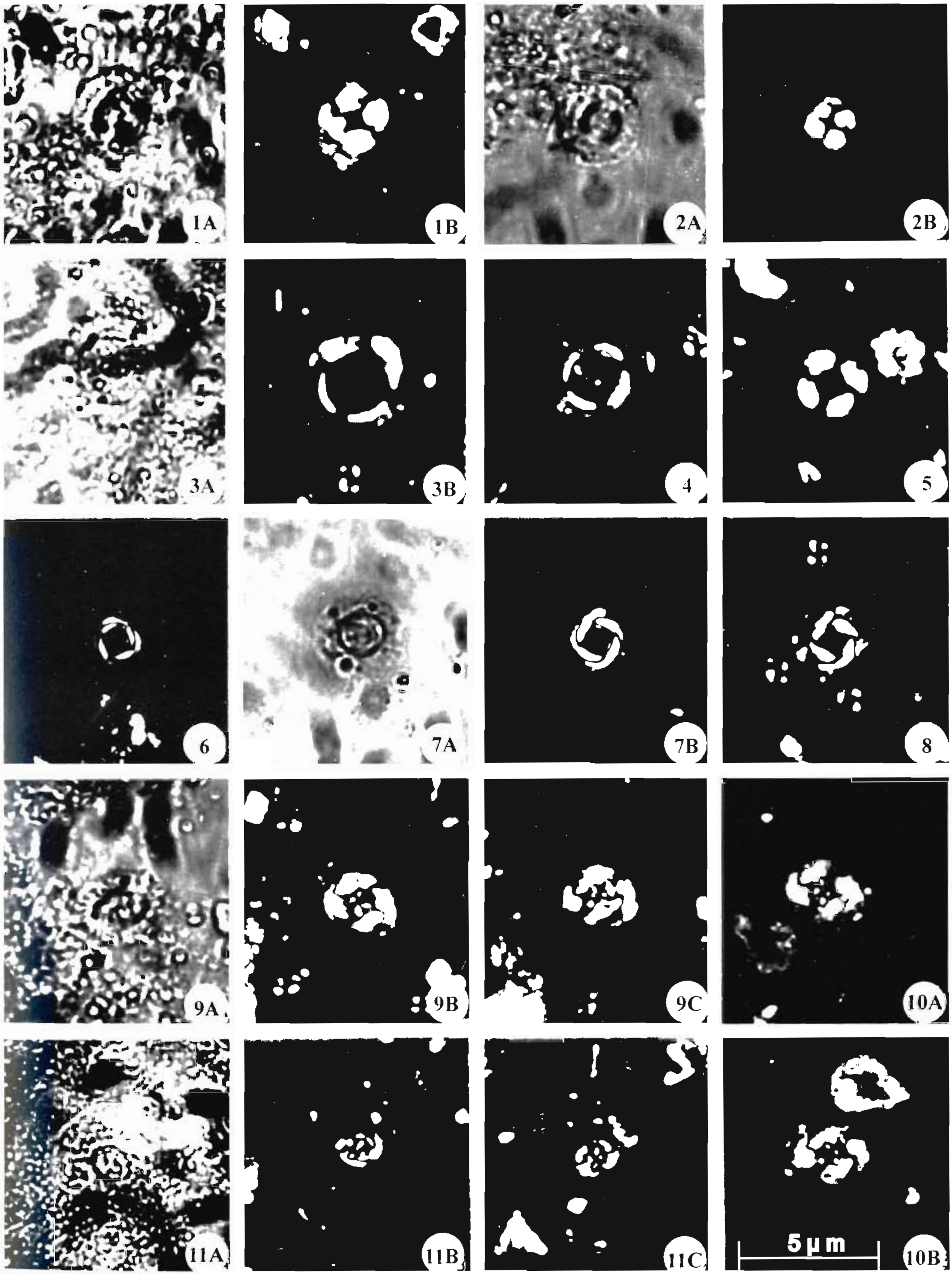

PLATE 7

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

1971 *Micrantholithus basquensis* Martini in Perch-Nielsen, p. 56, pl. 56, fig. 1.

1975 *Micrantholithus basquensis* Martini in Proto Decima *et al.*, p. 44, pl. 1, figs 4-5.

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

1979 *Micrantholithus basquensis* Martini in Singh, p. 6, pl. 1, fig. 56.

1980 *Micrantholithus basquensis* Martini in Singh *et al.*, p.175, figs 70-71.

1994 *Pemma basquensis* (Martini) Báldi-Beke in Jafar & Rai, p. 27, figs 13a-b, 23-24.

1997 *Pemma basquensis* (Martini) Báldi-Beke in Rai, p. 151, pl. I, fig. 8.

Remarks—This is fairly characteristic species of *Pemma* and following the original definition and illustrations of Martini (1959), variants with protruding elements along radial sutures (*P. snavelyi*), small to large opening with extremely thin peripheral margin, are included in this species with no differentiation of sub-species as done by several authors. Reported from the middle Eocene to Oligocene shallow marine sediments of Hungry, France and California. Frequent to rare in Harudi and Fulra Limestone formations.

Pemma papillatum Martini, 1959

(Pl. 1.3A-B, 4-5)

Synonymy list—

1959 *Pemma papillatum* Martini, p. 139, abb. 1a-b.

1961 *Pemma papillatum* Martini in Stradner & Papp, p. 120-121, pl. 38, figs 4, 6, non figs 2-3, text-fig. 12/7.

1969 *Pemma papillatum* Martini in Stradner, pl. 6, figs 6-7.

non1969 *Pemma papillatum* Martini in Pant & Mamgain, p. 112, pl. 21, fig. 1; pl. 24, figs 1-2, 7-8, 12-13.

1971 *Pemma papillatum* Martini in Haq, p. 45, pl. 6, figs 5-7; pl. 7, fig. 3, non fig. 4; pl. 3, figs 2, 4-5.

1972 *Pemma papillatum* Martini in Reinhardt, p. 82, fig. 161.

non1973 *Pemma papillatum* Martini in Pant & Mathur, p. 212-213, pl. 26, fig. E; pl. 27, fig. I.

1975 *Pemma papillatum* Martini in Proto Decima *et al.*, p. 46, pl. 1, figs 11a-b.

1975 *Pemma papillatum* Martini in Benic, pl. 1, fig. 3.

1975 *Pemma papillatum* Martini in Bybell, p. 191.

1979 *Pemma papillatum* Martini in Singh, p. 8, pl. 1, figs 52-53, 55; non fig. 54.

1980 *Pemma papillatum* Martini in Singh *et al.*, p. 3, pl. 175, figs 66-67.

1982 *Pemma papillatum* Martini in Hamilton & Hozzatzadeh, p.158, pl. 6.2, non figs 24-25.

PLATE 8 ⟶

Photomicrographs are printed in the same orientation with respect to the axes of nicols as observed under the microscope; coordinates measured with reference to a cross engraved on each slide. x 2000 Scale bar represents all photographs unless otherwise stated; PPL = normal light with single polariser; XPL = crossed nicols. HFm = Harudi Formation; FLFm = Fulra Limestone Formation.

1,3,4,7. *Chiasmolithus titus* Gartner, 1970, 1A-B. HFm; BSIP Slide No. 9892 : 1A PPL; 1B XPL; 3A-B, 4A-B. HFm; BSIP Slide No. 9888 : 3A PPL; 3B, 4B XPL; 7. HFm; BSIP Slide No. 9882 : XPL.

2. *Chiasmolithus* sp.1. HFm; BSIP Slide No. 9887 : 2A-B XPL.

5-6, 8. *Campylosphaera dela* (Bramlette & Sullivan) Hay & Mohler, 1967; HFm; BSIP Slide No. 9892 : 5A PPL; 5B, 6. XPL; 8. HFm; BSIP Slide No. 9888 : XPL.

9-10, 12. *Cribrocentrum coenurum* (Reinhardt) Perch-Nielsen, 1971; 9A-B, 10. HFm; BSIP Slide No. 9892 : 9A PPL; 9B, 10 XPL; 12A-B. FLFm; BSIP Slide No. 9894 : 12A PPL; 12B XPL.

11. *Cyclicargolithus floridanus* (Roth & Hay) Bukry, 1971a; FLFm, BSIP Slide No. 9893 : 11A PPL; 11B XPL.

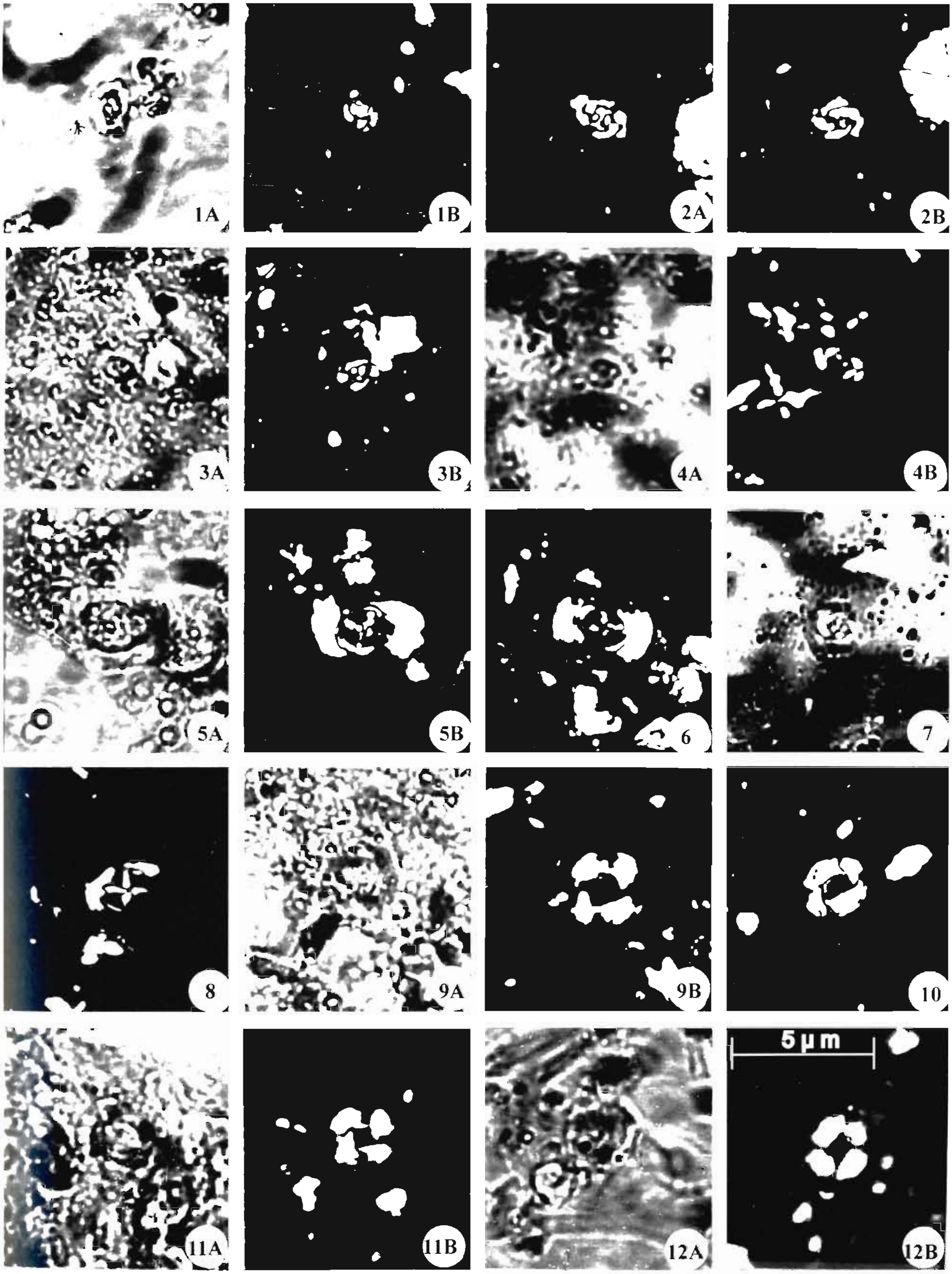

PLATE 8

1994 *Pemma papillatum* Martini in Jafar & Rai, p. 27, pl. 1, figs 1a-b.

1997 *Pemma papillatum* Martini in Rai, p. 151, pl. 1, fig. 4, Pl. IV, figs 1-2.

Remarks—Pemma papillatum is characterised by fairly large specimens with typically short club shaped protuberances on peripheral margin of each pentalith segment. Even fragmented specimens can be easily identified under LM. *P. papillatum* is known to range from middle to late Eocene shallow marine sediments and was used as zonal marker for middle Eocene in Alabama (Gartner, 1971). It is associated with typical specimens of *P. papillatum* in middle-late Eocene sediments. The forms with characteristic finger like protuberances are described herein as a new species *P. tuber*.

In Late Eocene sediments of Surat (Jafar *et al.*, 1985) and Broach (Pant & Mathur, 1973) only *P. tuber* sp. nov. is recorded, while in Late Eocene sediments of eastern India, both *P. papillatum* and *P. tuber* co-occur as in other parts of the world. Detailed work might indicate relative environmental significance of these species occurring in shallow marine Middle-Late Eocene sediments. This is rarely recorded from Harudi Formation.

Pemma rotundum Klumpp, 1953

(Pl. 1.6A-B, 7A-B)

Synonymy list—

1953 *Pemma rotundum* Klumpp, pl. 16 (partim), figs 3-4; text-fig. 2/3.

1958 *Pemma rotundum* Klumpp in Martini, pl. 2, figs 7a-b.

non1959 *Pemma rotundum* Klumpp in Martini , pl. 1, figs 6-8.

?1959 *Pemma rotundum* Klumpp in Stradner, text-fig. 66.

?1961 *Pemma rotundum* Klumpp in Stradner & Papp, pl. 38, figs 1a-b.

non1971 *Pemma rotundum* Klumpp in Báldi-Beke, pl. 4, figs 10a-c.

1971a *Pemma rotundum* Klumpp in Haq, pl. 7, fig. 10.

non1971a *Pemma rotundum* Klumpp in Perch-Nielsen, pl. 56, figs 5-6.

Remarks—Pemma rotundum is characterised by fairly large specimens with nearly circular outline and smooth periphery of the pentalith segments. The species is reported from the middle-late Eocene shallow marine sediments. It is frequent to rare in both the formations.

Pemma tuber sp. nov.

(Pl. 1.1A-B, 2A-B)

Derivation of name—"*tuber*" (latin) meaning protuberance.

PLATE 9 ⟶

Photomicrographs are printed in the same orientation with respect to the axes of nicols as observed under the microscope; coordinates measured with reference to a cross engraved on each slide. x 2000 Scale bar represents all photographs unless otherwise stated; PPL = normal light with single polariser; XPL = crossed nicols. HFm = Harudi Formation; FLFm = Fulra Limestone Formation.

1, 2. *Ericsonia* sp. 2; FLFm; BSIP Slide No. 9893 : 1A, 2A. PPL; 1B, 2B. XPL.

3-5. *Cyclicargolithus floridanus* (Roth & Hay) Bukry, 1971a; HFm; BSIP Slide No. 9892 : 3A. PPL; 3B, 4-5. XPL.

6. *Dictyococcites scrippsae* Bukry & Percival, 1971; HFm; BSIP Slide No. 9888 : XPL.

7-9. *Cyclicargolithus floridanus* (Roth & Hay) Bukry, 1971a; All from HFm; BSIP Slide No. 9892 : 7-9. XPL.

10-11. *Cribrocentrum reticulatum* (Gartner & Smith) Perch-Nielsen, 1971; HFm; BSIP Slide No. 9892 : 10-11. XPL.

12. *Reticulofenestra hillae* Bukry & Percival, 1971; HFm; BSIP Slide No. 9887 : XPL.

13. *Reticulofenestra* cf. *R. minuta* Roth, 1970 and *Cyclicargolithus floridanus* (Roth & Hay) Bukry, 1971; HFm; BSIP Slide No. 9892 : XPL.

14-16. *Bramletteius serraculoides* Gartner, 1969; HFm; BSIP Slide No. 9892 : 16A. PPL; 14-15, 16B. XPL.

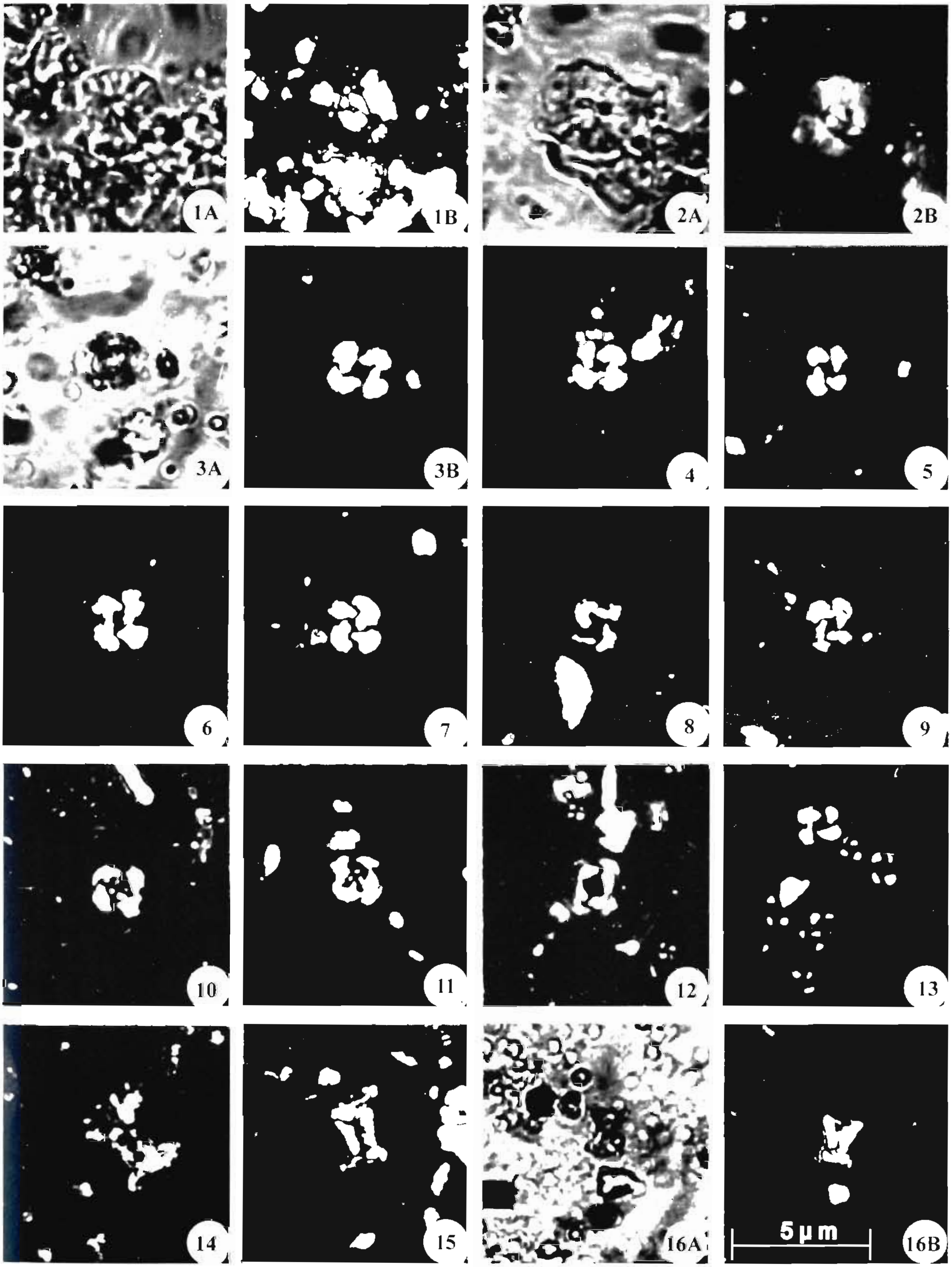

PLATE 9

Holotype—Pl. 1.2A-B. HF 16 (1) Coordinates—80.4/43.7. Size—12.5 μm diameter; 1.5 μm protuberance. BSIP Slide No.—9892.

Paratype—Pl. 1.1A-B. FL 1 (2). Coordinates—76.9/19.2. Size—15 μm diameter; 2 μm protuberance. BSIP Slide No.—9893.

Type locality—SW of village Harudi in 'Rato Nala Section', Kutch, western India.

Type level—Late Middle Eocene, Harudi Formation; *D. saipanensis* Zone = NP 17 of Martini, 1971a emend. Rai, 1988.

Diagnosis—Pentaliths characterised by elongated finger like protuberance, usually four on periphery of each segment.

Remarks—Several forms of *Pemma papillatum* recorded possessing finger like protuberances on the margin of each segment rather than short club-like protuberances as in typical *P. papillatum*. Those forms are now assigned to a new species *Pemma tuber*.

Stratigraphic range—This has similar stratigraphic range (Middle-Late Eocene) as *P. papillatum* but their relative abundance and distribution may be environmentally controlled.

Distribution—Forms similar to *Pemma tuber* are noticed in Indian west-coast late Eocene shallow marine deposits of Surat (Jafar *et al.*, 1985), Broach (Pant & Mathur, 1973) without *Pemma papillatum* but present in association with *P. papillatum* in other areas during the middle to late Eocene sediments. It occurs rarely in Harudi and Fulra Limestone formations together with *P. papillatum*.

Pemma sp. 1

(Pl. 1.8A-B)

Remarks—The medium size (3-5 μm) form is closely related to *P. basquensis* group, but differs in the serrations of the margin of pentalith segment. *M. crenulatus* (Bramlette & Sullivan, 1961), lacks pore and is of pentagonal outline, but resembles *Pemma* sp. 1 in the marginal serrations. It occurs rarely in Harudi Formation.

Pemma sp. 2

(Pl. 1.11)

Remarks—Medium size (3-5 μm) *Pemma* sp. 2 belongs to *P. basquensis* group, but differs in the nature of crenulations at the margin of segments and in lacking pentagonal outline. The nature and the position of pores in the segment are similar to those observed in *P. basquensis*. A single specimen was found in Harudi Formation.

Family—CALCIOSOLENIACEAE
Kamptner, 1927

PLATE 10 ⟶

Photomicrographs are printed in the same orientation with respect to the axes of nicols as observed under the microscope; coordinates measured with reference to a cross engraved on each slide. x 2000 Scale bar represents all photographs unless otherwise stated; PPL = normal light with single polariser; XPL = crossed nicols. HFm = Harudi Formation; FLFm = Fulra Limestone Formation.

1-2. *Helicosphaera heezenii* (Bukry) Jafar & Martini, 1975; 1A-C. HFm; BSIP Slide No. 9892 : PPL; 1B, 1C XPL; 2A-B. FLFm; BSIP Slide No. 9893 : 2A PPL; 2B, XPL.

3. *Helicosphaera* sp. 1, HFm; BSIP Slide No. 9892 : 3A. PPL: 3B, 3C. XPL.

4. *Helicosphaera reticulata* Bramlette & Wilcoxon, 1967; FLFm; BSIP Slide No. 9893 : 4A. PPL; 4B. XPL.

5. *Helicosphaera* sp. 2, FLFm; BSIP Slide No. 9894 : 5A. PPL; 5B. XPL.

6, 8. *Helicosphaera bramlettei* (Müller) Jafar & Martini, 1975; 6A-B. HFm; BSIP Slide No. 9888 : 6A. PPL; 6B. XPL; 8. HFm; BSIP Slide No. 9892 : 6A. PPL; 6B. XPL.

7. *Helicosphaera compacta* Bramlette & Wilcoxon, 1967; FLFm; BSIP Slide No. 9893 : 7A PPL; 7B, XPL.

9, 10. *Helicosphaera seminulum* (Bramlette & Sullivan) Jafar & Martini, 1975; HFm; BSIP Slide No. 9892 : 9, 10A, 10B. XPL.

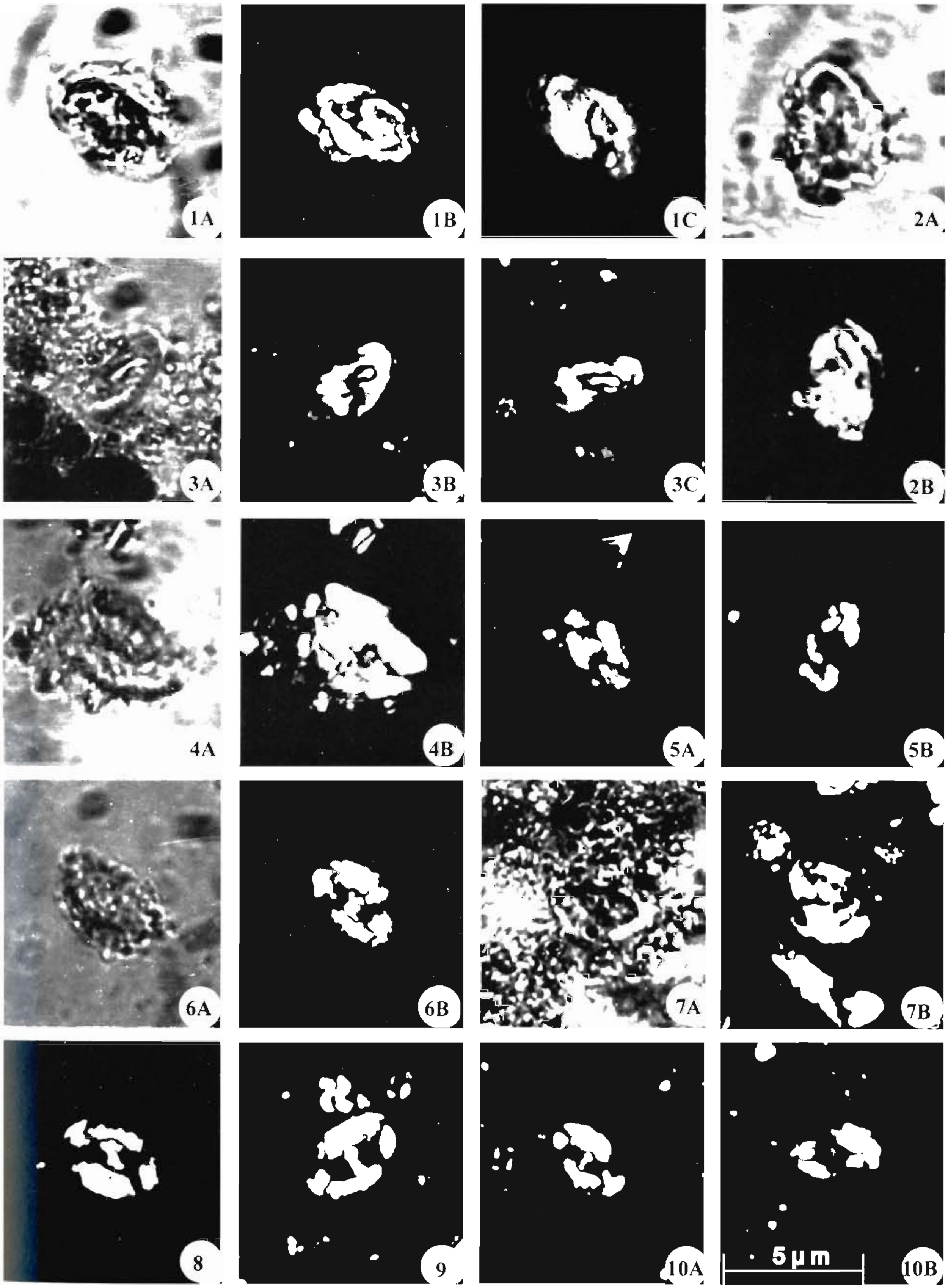

PLATE 10

The living family Calciosoleniaceae is represented by solitary fossil genus *Scapholithus* (Deflandre in Deflandre & Fert, 1954) and a number of modern genera (Tappan, 1980) including *Calciosolenia* Graan, 1912. The cell is characteristically fusiform containing closely packed 'Scapholiths'. On the interior side, a grid of transverse bars is seen under electron microscope. Variations in grid pattern account for differentiation of several modern genera. Living cells may possess spines at one or both ends (Tappan, 1980). The environmental and stratigraphic value of scapholiths has yet to be demonstrated. However, these constitute a rare component of nannofloral assemblage of Early Cretaceous to Recent marine sediments.

Genus—SCAPHOLITHUS Deflandre in Deflandre & Fert, 1954

Scapholithus rhombiformis Hay & Mohler, 1967

(Pl. 12.18-19)

Synonymy list—

1967 *Scapholithus rhombiformis* Hay & Mohler, p. 1534, pl. 201, figs 13, 16-18.

1972 *Scapholithus rhombiformis* Hay & Mohler in Perch-Nielsen, p. 1040, pl. 8, figs 3-4.

1994 *Scapholithus rhombiformis* Hay & Mohler in Jafar & Rai, p. 28, pl. 2, figs 6a-b.

Remarks—Under LM it is very similar to *S. fossilis*, but differs in having broad rhomboidal outline. This species is known from Palaeocene to Eocene sediments of several regions (e.g. North Atlantic Ocean fide Perch-Nielsen, 1972). It rarely occurs in Harudi Formation.

Family—CALYPTROSPHAERACEAE Boudreaux & Hay, 1969

The living family Calyptrosphaeraceae is based on recent genus *Calyptrosphaera* characterised by motile cells bearing calyptroform or zygoform holococcoliths, and consisting of equidimensional and small calcite crystallites of the order of 0.07 to 0.1 μm in diameter. A majority of modern and fossil holococcoliths are composed of this special type of calcite rhombohedron called "spaltrhomboeder" (Jafar, 1977). The nature and size of holococcolith crystallites could only be ascertained under electron microscopes, especially TEM (Gartner & Bukry, 1969; Heimdal & Gaarder, 1980).

The family includes a number of living and fossil genera (Tappan, 1980; Perch-Nielsen, 1985b). The common Eocene genera *Dactylethra, Lanternithus, Orthozygus, Peritrachelina, Zygrhablithus* and *Clathrolithus* are distinguished by their shape and outline, depressions, pores, knobs or processes. Holococcoliths are typically found in shallow marine nearshore sediments of epicontinental setting (Martini, 1965, 1970; Bukry *et al.*, 1971; Bybell, 1975) and are scarce to absent in deep sea, open-ocean sediments.

Fossil holococcoliths were first described from Tertiary sediments by Stradner and Adamiker (1966). Later Gartner and Bukry (1969) provided a

PLATE 11 ⟶

Photomicrographs are printed in the same orientation with respect to the axes of nicols as observed under the microscope; coordinates measured with reference to a cross engraved on each slide. x 2000 Scale bar represents all photographs unless otherwise stated; PPL = normal light with single polariser; XPL = crossed nicols. HFm = Harudi Formation; FLFm = Fulra Limestone Formation.

1. *Helicosphaera seminulum* (Bramlette & Sullivan) Jafar & Martini, 1975; HFm; BSIP Slide No. 9892 : 1A; 1B XPL.

2-3. *Helicosphaera lophota* (Bramlette & Sullivan) Jafar & Martini, 1975; FLFm; 2. BSIP Slide No. 9993; 3. BSIP Slide No. 9894 : 2-3. XPL.

4-10. *Discoaster saipanensis* Bramlette & Riedel, 1954; HFm; BSIP Slide No. 9892 : all under PPL.

11-15. *Discoaster barbadiensis* Tan Sin Hok, 1927; HFm; BSIP Slide No. 9892 : 11-15. PPL.

16-17. *Discoaster distinctus* Martini, 1958; HFm; BSIP Slide No. 9892 : 16-17. PPL.

18-19. *Discoaster binodosus* Martini, 1958; HFm; BSIP Slide No. 9892 : 18-19. PPL

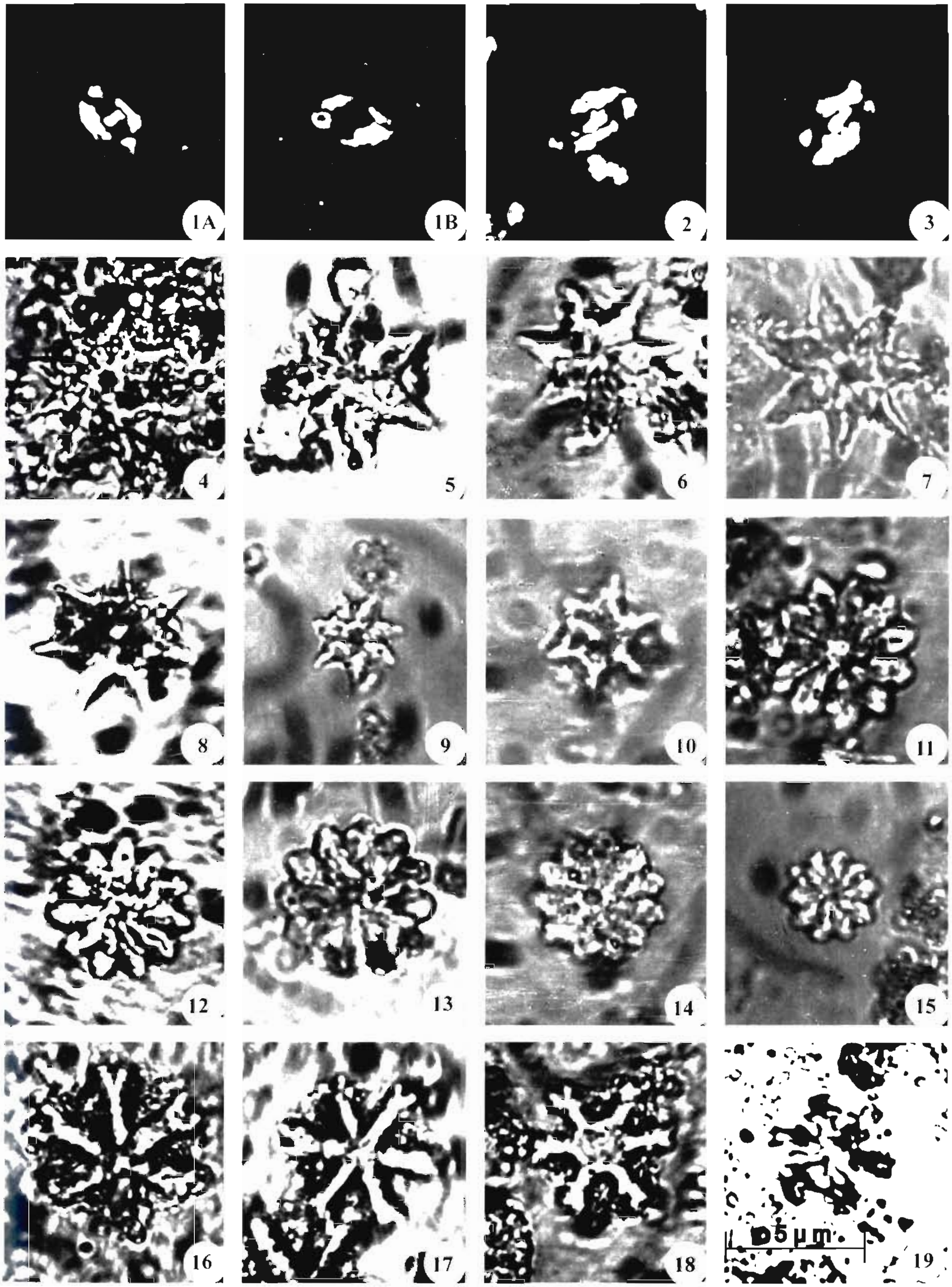

PLATE 11

comprehensive account and described a number of genera from the Tertiary. The first definite holococcolith in Mesozoic was indicated by Jafar (1977). The earliest holococcoliths are known from Late Jurassic sediments (Medd, 1979). A few holococcoliths have been employed as markers for Late Cretaceous. First appearance of *Clathrolithus spinosus* marks the terminal Eocene, while last occurrence of *Zygrhablithus bijugatus* defines the terminal Oligocene (Perch-Nielsen, 1985b).

The present material contains all known genera of Eocene holococcoliths except *Peritrachelina*. Their abundance in the study material signifies nearshore and shallow water deposition, as in other parts of the world.

Genus—DACTYLETHRA Gartner, 1969

Dactylethra punctulata Gartner, 1969

(Pl. 15.4A-B, 6A-B, 7A-B)

Synonymy list—

1969 *Dactylethra punctulata* Gartner in Gartner & Bukry, p. 1219, pl. 141, figs 1-3; pl. 142, fig. 10.

1971a *Dactylethra punctulata* Gartner in Perch-Nielsen, p. 56, pl. 58, figs 1, 3-5.

1975 *Dactylethra punctulata* Gartner in Proto Decima *et al.*, p. 46, pl. 1, figs 12a-b.

1994 *Dactylethra punctulata* Gartner in Jafar & Rai, p. 28, pl. 3, figs 2, 3a-b, 24.

Remarks—Originally described from the middle Eocene of Alabama. *Dactylethra* is a monospecific genus. It is characteristically helmet-shaped holococcolith displaying concave base in side view and is known to range from middle to late Eocene nearshore, shallow water sediments of widely separated areas. It does not bear resemblance to any fossil material but similar holococcoliths are produced by modern species of *Homozygosphaera* (Kamptner). It rarely occurs in Harudi Formation.

Genus—LANTERNITHUS Stradner, 1962

Lanternithus minutus Stradner, 1962

(Pl. 14.14, 17)

Synonymy list—

1962 *Lanternithus minutus* Stradner, p. 375, pl. 2, figs 12-15.

1967 *Lanternithus minutus* Stradner in Locker, p. 361, text-figs 1a-c, 2-3; pl. 9, figs 1-8.

1969 *Lanternithus minutus* Stradner in Gartner & Bukry, p. 1217, pl. 139, figs 4-6; pl. 142, figs 8a-h, 9.

PLATE 12 ⟶

Photomicrographs are printed in the same orientation with respect to the axes of nicols as observed under the microscope; coordinates measured with reference to a cross engraved on each slide. x 2000 Scale bar represents all photographs unless otherwise stated; PPL = normal light with single polariser; XPL = crossed nicols. HFm = Harudi Formation; FLFm = Fulra Limestone Formation.

1-4. *Discoaster binodosus* Martini, 1958; HFm; 1-3. BSIP Slide No. 9892 : 4. BSIP Slide No. 9888 : all under PPL.

5-6. *Discoaster nodifer* (Bramlette & Riedel) Bukry1973; HFm; BSIP Slide No. 9892 : 5-6. PPL.

7. *Discoaster tanii* Bramlette & Riedel, 1954; HFm; BSIP Slide No. 9892 : PPL.

8. *Discoaster bifax* Bukry, 1971a; HFm; BSIP Slide No. 9892 : PPL.

9-10. *Discoaster mirus* Deflandre in Deflandre & Fert, 1954; HFm; BSIP Slide No. 9888 : PPL.

11. *Discoaster ornatus* Stradner, 1958; HFm; BSIP Slide No. 9892 : PPL.

12. *Discoaster* cf. *D. ornatus* Stradner, 1958; HFm; BSIP Slide No. 9882 : PPL.

13-15. *Pontosphaera multipora* (Kamptner) Roth, 1970; HFm; 13-14. BSIP Slide No. 9892; 15. BSIP Slide No. 9888 : 13A, 14A. PPL; 13A, 14B, 15. XPL.

16. *Pontosphaera versa* (Bramlette & Sullivan) Sherwood, 1974; HFm; BSIP Slide No. 9892 : XPL.

17. *Pontosphaera* sp.; HFm; BSIP Slide No. 9892 : XPL.

18-19. *Scapholithus rhombiformis* Hay & Mohler, 1967; HFm; 18. BSIP Slide No. 9892, 19. BSIP Slide No. 9888 : 18-19. XPL.

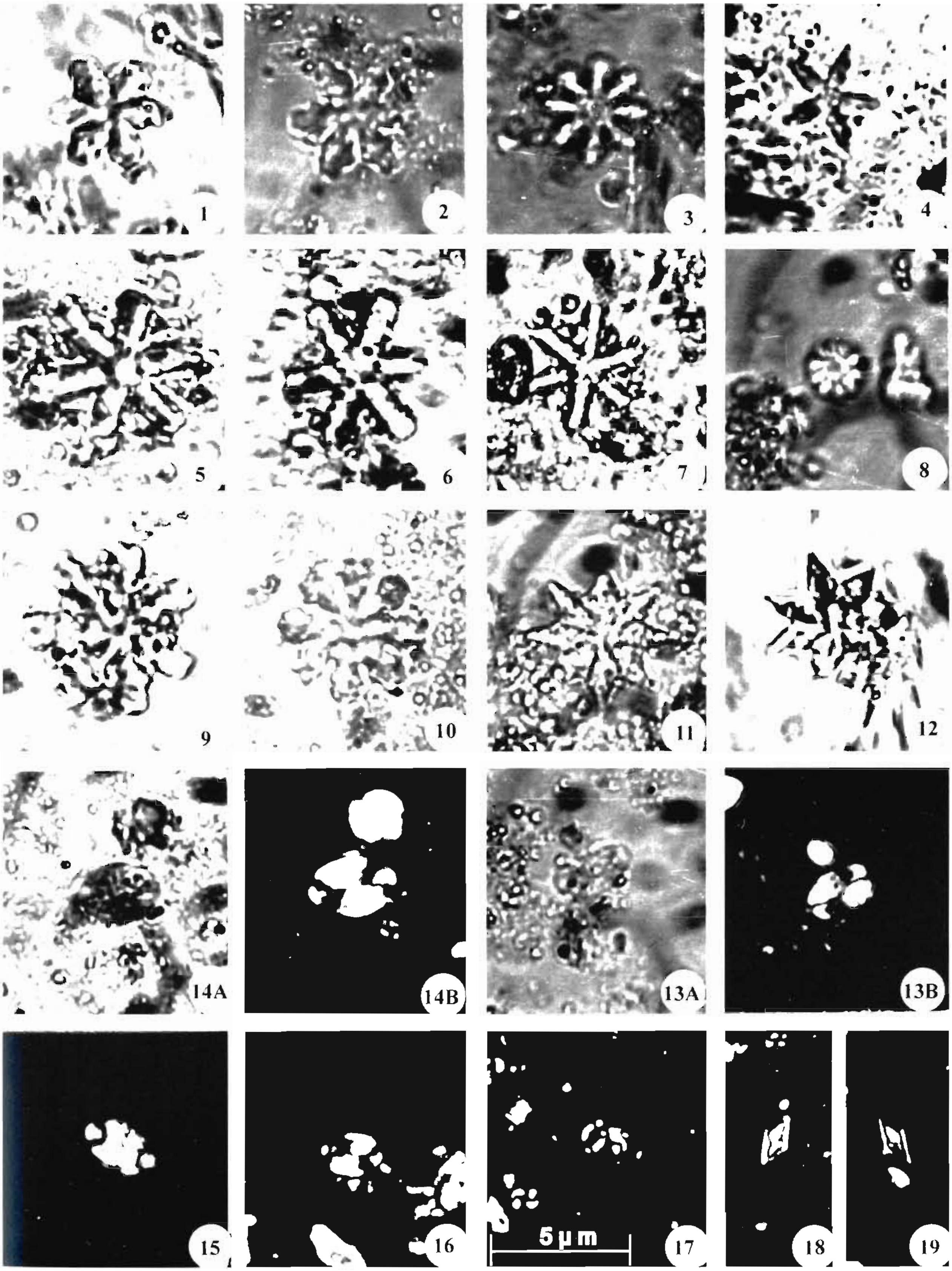

PLATE 12

1975 *Lanternithus minutus* Stradner in Proto Decima *et al.*, p. 46, pl. 1, figs 19a-b, 20.

1977 *Lanternithus minutus* Stradner in Baldi-Beke, p. 75, pl. 5, figs 1-7.

1994 *Lanternithus minutus* Stradner in Jafar & Rai, p. 28, pl. 3, figs 26, 27 a-b, 28.

1997 *Lanternithus minutus* Stradner in Rai, p. 151, pl. II, fig. 18; pl. IV, fig. 17.

Remarks—Originally described from the late Eocene of Austria and subsequently described from similar level by Locker (1967). Detailed morphology both under LM and EM of this holococcolith can be found in Gartner and Bukry (1969). Stradner (1962) failed to designate a holotype and therefore pl. 2., fig. 12, is herein designated as lectotype. *L. minutus* is readily identified under LM. The suggestion of Locker (1967), that *Lanternithus* may be related to Braarudosphaeraceae is erroneous, a view was also not supported by Gartner & Bukry (1969). This was recorded for the first time from Indian Tertiary sediments (Rai, 1988) and is a common constituent of nannofloras of middle Eocene to early Oligocene shallow marine deposits.

This is abundant to rare in Harudi Formation and rare in Fulra Limestone Formation.

Lanternithus geometricus sp. nov.

(Pl. 14.15A-B, 16)

1994 *Lanternithus* sp. 1 Jafar & Rai, p. 28 pl. 3, figs 29a-b.

Holotype—Pl. 14.15A-B, HF 5 (1). Coordinates—75.0/28.2. Size—4 µm length; 4 µm width. BSIP Slide No.—9881.

Paratype—Pl. 14.16, HF 16 (1). Coordinates—77.0/31.1. Size—4 µm length. BSIP Slide No.—9893.

Type locality—SW of village Harudi in 'Rato Nala Section', Kutch, western India.

Type level—Late Middle Eocene, Harudi Formation; *D. saipanensis* Zone = NP 17 of Martini, 1971a emend. Rai, 1988.

Diagnosis—Holococcolith of typically rectangular outline with relatively large central hollow depression.

Remarks—Under crossed nicols, the thin rectangular rim remains bright, traversed by four dark extinction lines. It differs from *L. minutus* in having a thin rim of rectangular shape instead of a hexagonal outline, and possessing a relatively large central hollow depression.

L. geometricus sp. nov. is recorded as rare to very rare from Harudi Formation.

Genus—OCTOLITHUS Romein, 1979

Octolithus flos sp. nov.

(Pl. 15.1A-B, 2)

1994 *Lanternithus* sp. 2 Jafar & Rai, p. 28, pl. 3, figs 30a-b, 31a-b.

PLATE 13 ⟶

Photomicrographs are printed in the same orientation with respect to the axes of nicols as observed under the microscope; coordinates measured with reference to a cross engraved on each slide. x 2000 Scale bar represents all photographs unless otherwise stated; PPL = normal light with single polariser; XPL = crossed nicols. HFm = Harudi Formation; FLFm = Fulra Limestone Formation.

1-2. *Sphenolithus* cf. *S. celsus* Haq 1971b; HFm; BSIP Slide No. 9892 : 1-2. XPL.

3. *Sphenolithus predistentus* Bramlette & Wilcoxon, 1967; HFm; BSIP Slide No. 9892 : 3. PPL.

4. *Sphenolithus radians* Deflandre in Deflandre & Fert, 1954; HFm; BSIP Slide No. 9892 : 4A. PPL ; 4C. XPL.

5. *Sphenolithus moriformis* (Brönnimann & Stradner) Bramlette & Wilcoxon, 1967; HFm; BSIP Slide No. 9888 : XPL.

6-8. *Sphenolithus predistentus* Bramlette & Wilcoxon, 1967; 7-8 HFm; 6; BSIP Slide No. 9892 : 8. BSIP Slide No. 9888, 6A. PPL; 6B, 7-8. XPL.

9-12. *Sphenolithus spiniger* Bukry, 1971a; HFm; 9, 12. BSIP Slide No. 9892 , 10-11. BSIP Slide No. 9888 : all under XPL.

13-14. *Sphenolithus furcatolithoides* Locker, 1967b; HFm; BSIP Slide No. 9892 : 13-14. XPL.

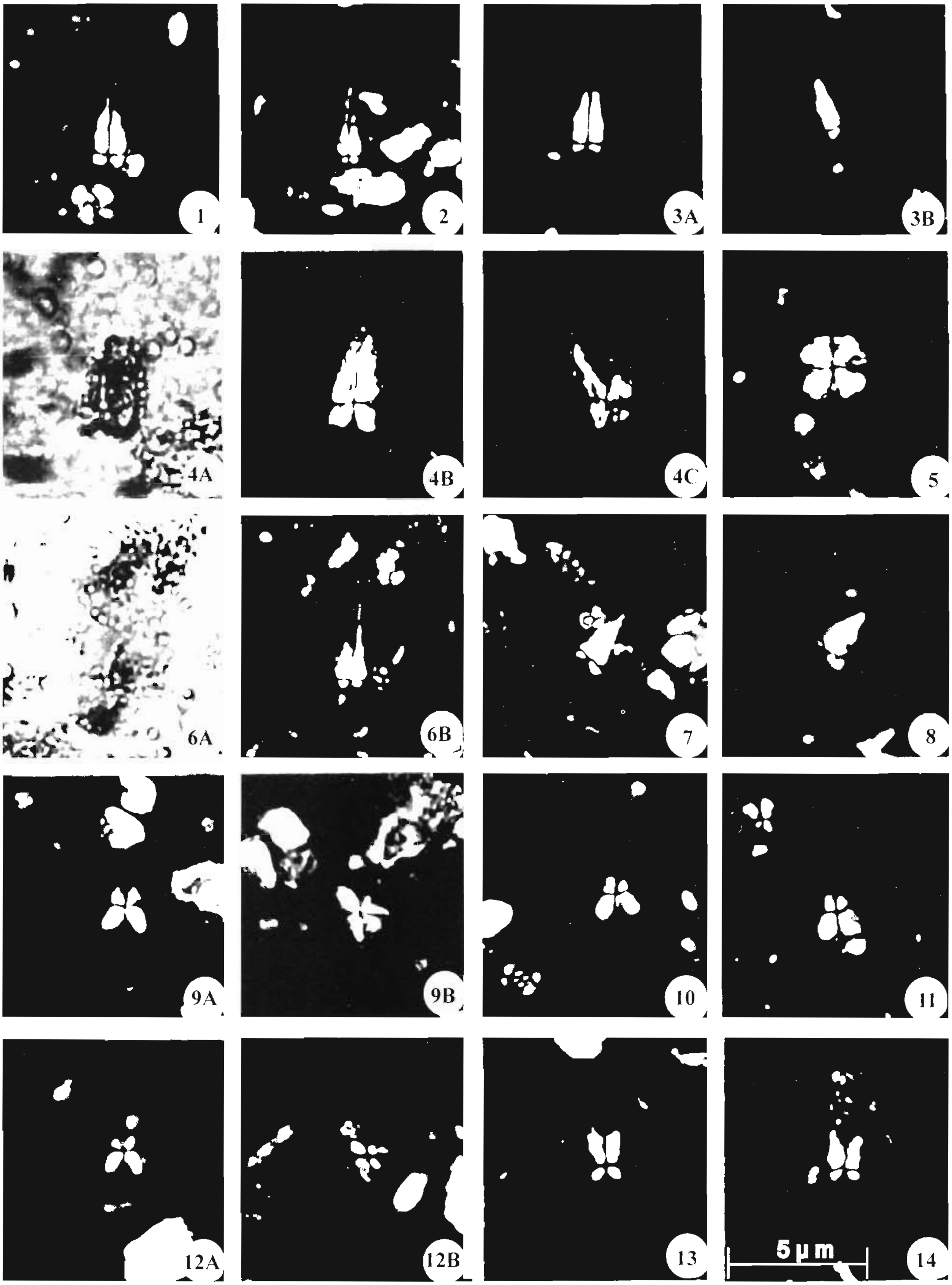

PLATE 13

Derivation of name—*flos* (latin) meaning flower

Holotype—Pl. 15.1A-B, HF 1 (1). Coordinates—79.0/17.4. Size—6 μm maximum diameter; 5 μm minimum diameter. BSIP Slide No.—9877.

Paratype—Pl. 15.2, HF 3 (1). Coordinates—82.2/38.8. Size—6 μm maximum diameter; 5 μm minimum diameter. BSIP Slide No.—9879.

Type locality—SW of village Harudi in 'Rato Nala Section', Kutch, western India.

Type level—Late Middle Eocene, Harudi Formation; *D. saipanensis* Zone = NP 17 of Martini, 1971a emend. Rai, 1988.

Diagnosis—Nannofossil consisting of six crystal units (2 large + 1 small pair) displaying strong relief and birefringence under normal and crossed nicols.

Remarks—This was assigned to Maastrichtian-Danian genus *Octolithus* Romein (1979), with which it shows some resemblance in the nature of birefringence. This is a common element of nannofloras of Harudi and very rare in Fulra Limestone formations.

Genus—ORTHOZYGUS
Bramlette & Wilcoxon, 1967

Orthozygus aureus (Stradner)
Bramlette & Wilcoxon, 1967

(Pl. 15.3, 5A-B)

Synonymy list—

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

1966 *Zygolithus aureus* Stradner in Stradner & Adamiker, p. 340, pl. 3, fig. 2.

1967 *Zygolithus aureus* Stradner in Levin & Joerger, p. 169, pl. 2, figs 19-21; pl. 4, figs 15a-b.

1967 *Orthozygus aureus* (Stradner) Bramlette & Wilcoxon, p. 116, pl. 9, figs 1-4.

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

1969 *Orthozygus aureus* (Stradner) Bramlette & Wilcoxon in Gartner & Bukry, p. 1216, pl. 139; figs 1-3; pl. 142, figs 5-6.

1971b *Orthozygus aureus* (Stradner) Bramlette & Wilcoxon in Perch-Nielsen, p. 57, pl. 58, figs 11-12.

1975 *Zygosphaera aurea* (Stradner) Stradner & Edwards in Proto Decima *et al.*, p. 46, pl. 1, figs 21-22.

1994 *Orthozygus aureus* (Stradner) Bramlette & Wilcoxon in Jafar & Rai, p. 28, 30, pl. 3, figs 17-18, 19a-b, 20a-b, 21.

1997 *Orthozygus aureus* (Stradner) Bramlette & Wilcoxon in Rai, p. 151-152, pl. III, figs 1-2.

Remarks—Originally described from late Eocene of Austria and one of the earliest nannofossils to reveal holococcolith nature (Stradner & Adamiker, 1966). Stradner (1962, pl. 1, figs 31-36) failed to designate a holotype and therefore Pl. 1., fig. 35, is hereby designated as lectotype for this characteristic species, which is best recognised in side views under LM. This has been well documented under electron microscope by several authors matching the original description given by Stradner (1962). This species has so far been

PLATE 14 ⟶

Photomicrographs are printed in the same orientation with respect to the axes of nicols as observed under the microscope; coordinates measured with reference to a cross engraved on each slide. x 2000 Scale bar represents all photographs unless otherwise stated; PPL = normal light with single polariser; XPL = crossed nicols. HFm = Harudi Formation; FLFm = Fulra Limestone Formation.

1-3. *Sphenolithus furcatolithoides* Locker, 1967; HFm; 1; BSIP Slide No. 9892, 2-3. BSIP Slide No. 9988 : 1A, 1B, 2-3. XPL.

4-13. *Zygrhablithus bijugatus* (Deflandre) Deflandre, 1959; HFm; BSIP Slide No. 9892 : 4A PPL: 4B, 5-13 XPL.

14, 17. *Lanternithus minutus* Stradner, 1962; 14. HFm; BSIP Slide No. 9892 : XPL; 17. HFm; BSIP Slide No. 9892 : XPL.

15-16. *Lanternithus geometricus* sp. nov., 15A-B. Holotype; HFm; BSIP Slide No. 9881 : HF 5(1) Coordinates : 75.0/28.2; 15A. PPL; 15B. XPL; 16. HFm; BSIP Slide No. 9893 : HF16 (1) Coordinates : 77.0/31.1; XPL.

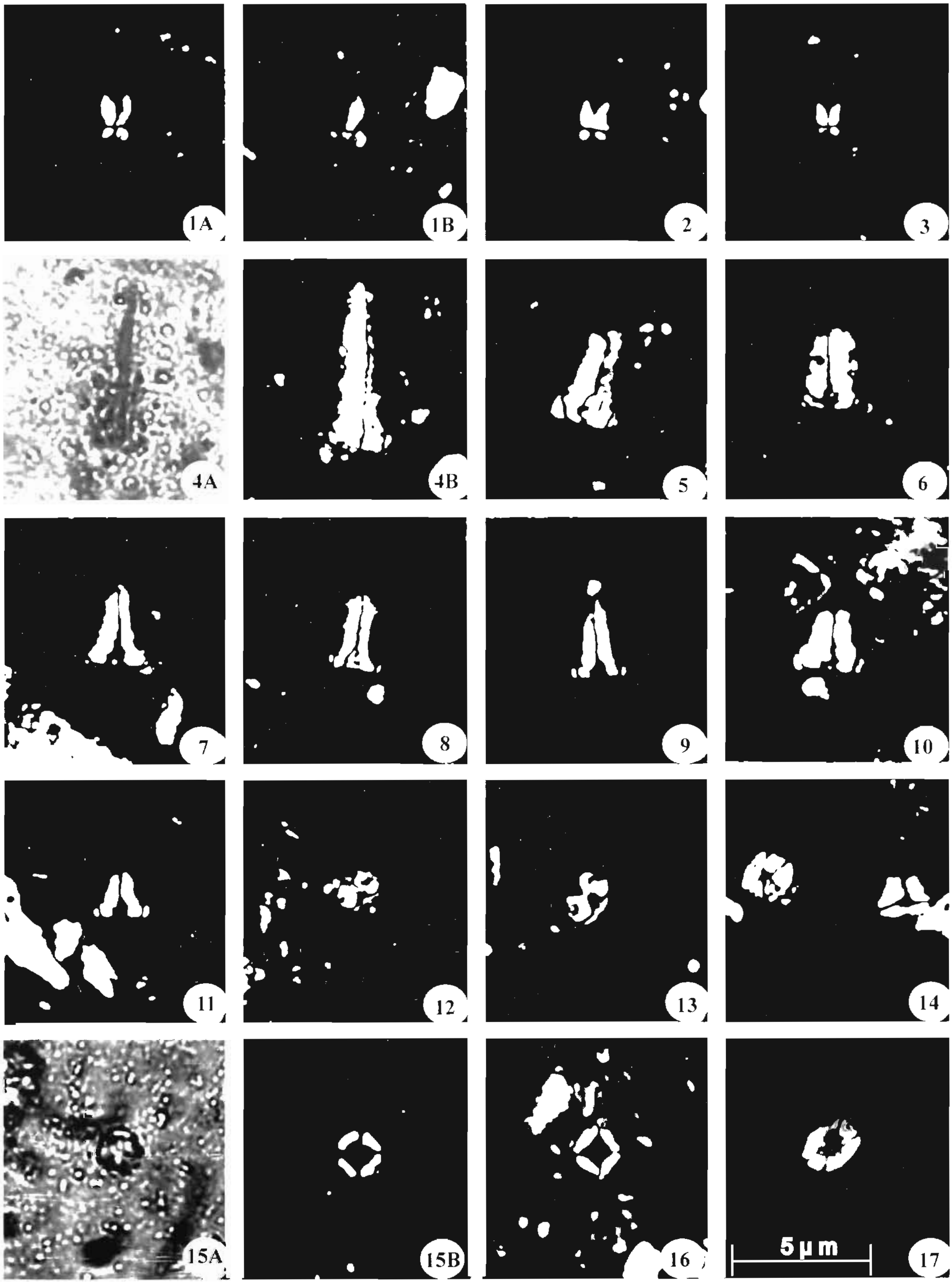

PLATE 14

reported from shallow marine deposits of middle Eocene to early Oligocene age from widely separated areas. In the studied material, well-preserved complete specimens were found and are common in Harudi and rare in Fulra Limestone formations.

Genus—ZYGRHABLITHUS Deflandre, 1959

Zygrhablithus bijugatus (Deflandre) Deflandre, 1959

(Pl. 14.4A-B, 5-13)

Synonymy list—

1954 *Zygolithus bijugatus* Deflandre in Deflandre & Fert, p. 148, pl. 11; figs 20-21, ?text-fig. 59.

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

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

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

1961 *Zygrhablithus bijugatus* (Deflandre) Deflandre in Bramlette & Sullivan, p. 151, pl. 6, figs 16a-b, 17a-c, 18.

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

1962 *Zygrhablithus bijugatus* (Deflandre) Deflandre in Bouché, p. 84, pl. 1, figs 4, 9-11.

1964 *Zygrhablithus bijugatus* (Deflandre) Deflandre in Sullivan, p.187, pl. 7, figs 9a-b, 10a-b.

1965 *Zygrhablithus bijugatus* (Deflandre) Deflandre in Sullivan, p. 38.

1966 *Zygrhablithus bijugatus* (Deflandre) Deflandre in Reinhardt, p. 38, pl. 21, fig. 12.

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

1968 *Zygrhablithus bijugatus* (Deflandre) Deflandre in Stradner & Edwards, p. 44-46, pls. 42-43.

1969 *Zygrhablithus bijugatus* (Deflandre) Deflandre in Gartner & Bukry, p. 1218-1219, pl. 140, figs 3-6; pl. 142, figs 1a-b, 2.

1971a *Zygrhablithus bijugatus* (Deflandre) Deflandre in Perch-Nielsen, p. 58

1975 *Zygrhablithus bijugatus* (Deflandre) Deflandre in Bybell, p. 244-246, pl. 24, figs 1-7.

1977 *Zygrhablithus bijugatus* (Deflandre) Deflandre in Perch-Nielsen, p. 744, pl. 37, fig. 15.

1994 *Zygrhablithus bijugatus* (Deflandre) Deflandre in Jafar & Rai, p. 30, pl. 3, figs 33, 35, 36a-b, 38a-b, 39a-b, 40, 41a-b.

1997 *Zygrhablithus bijugatus* (Deflandre) Deflandre in Rai, p. 152, pl. II, figs 13-14; pl. IV, fig. 16.

Remarks—Originally reported under LM from late Eocene/Oligocene of Oamaru diatomite, New Zealand. *Z. bijugatus* is characteristic and readily recognisable species in Palaeogene nannofloral assemblages.

PLATE 15 ⟶

Photomicrographs are printed in the same orientation with respect to the axes of nicols as observed under the microscope; coordinates measured with reference to a cross engraved on each slide. x 2000 Scale bar represents all photographs unless otherwise stated; PPL = normal light with single polariser; XPL = crossed nicols. HFm = Harudi Formation; FLFm = Fulra Limestone Formation.

1-2. *Octolithus flos* sp. nov., 1A-B. Holotype; HFm; BSIP Slide No. 9877 : HF 1(1) : Coordinates; 79.0/17.4 ; 1A. PPL; 1B XPL; 2. Paratype; HFm; BSIP Slide No. 9879: HF 3(1) : Coordinates; 82.2/3.8; XPL.

3, 5. *Orthozygus aureus* (Stradner) Bramlette & Wilcoxon, 1967: 3. HFm; BSIP Slide No. 9886 : XP; 5A-B. HFm; BSIP Slide No. 9892 : 5A. PPL; 5B. XPL.

4, 6-7. *Dactylethra punctulata* Gartner, 1969; HFm; BSIP Slide No. 9892 : 4A, 4B. XPL. 6-7. HFm; BSIP Slide No. 9892 : 6A, 7A. PPL; 6B, 7B. XPL.

8-12. *Blackites lanternus* sp. nov., 8A-C. Holotype; HFm; BSIP Slide No. 9892 : HF 16(1); Coordinates; 82.2/3.8; XPL; 9A-B, Paratypes; 10-12. HFm; BSIP Slide No. 9892: HF 16(1); Coordinates: 76.5/32.9; 9A. PPL; 9B, 8C. XPL; BSIP Slide No. 9892 : HF 16(1); Coordinates:79.1/32.2; 11. XPL; BSIP Slide No. 9892 : HF 16(1); Coordinates: 82.0/17.8; 12. XPL. All from HFm.

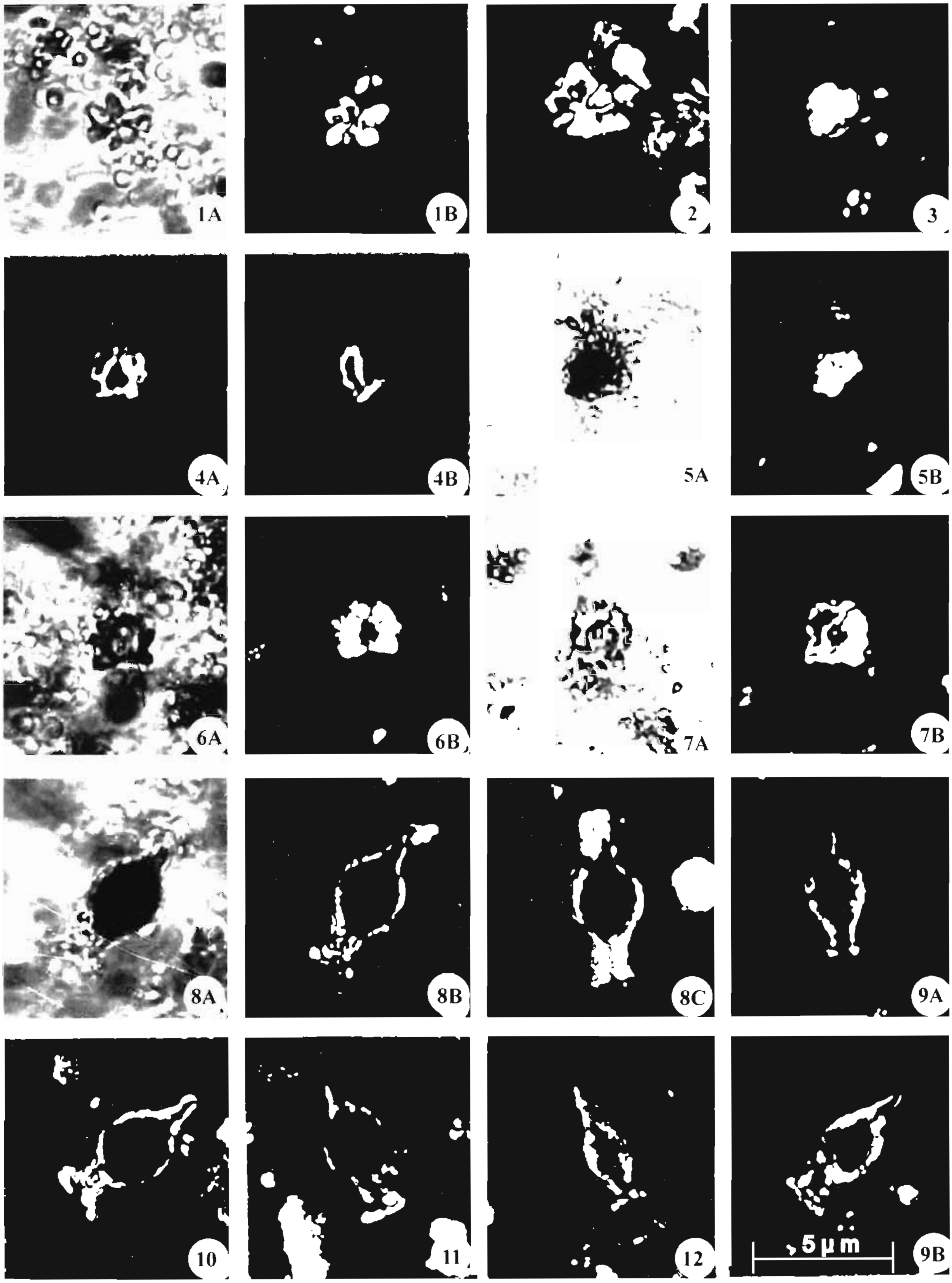

PLATE 15

Considerable variations in size, length and breadth of spine can be visible under plan and side views including the peculiar shapes of broken specimens.

The monospecific holococcolith genus *Zygrhablithus* is well illustrated both under LM and EM and frequently occurs in shallow marine sediments of the early Eocene to the terminal Oligocene.

Genus—CLATHROLITHUS Deflandre in Deflandre & Fert, 1954

Clathrolithus ellipticus Deflandre, 1954

Synonymy list—

1954 *Clathrolithus ellipticus* Deflandre in Deflandre & Fert, p. 55, p. 12, fig. 19; pl. 14, fig. 7, text-figs 123-124.

1961 *Clathrolithus ellipticus* Deflandre in Bramlette & Sullivan, p. 157, pl. 10, figs 16A-B, 17.

1964 *Clathrolithus ellipticus* Deflandre in Sullivan, p. 189, pl. 9, fig. 9.

1969 *Clathrolithus ellipticus* Deflandre in Stradner, p. 421, pl. 86, fig. 12, text-fig. 4.

1994 *Clathrolithus ellipticus* Deflandre in Jafar & Rai, p. 30, pl. 3, fig. 34.

Remarks—C. ellipticus first reported from Lutetian of Donzacq, France and later reported from several other Eocene horizons. This holococcolith is always rare and is found only in Harudi Formation.

Family—COCCOLITHACEAE Poche, 1913

One of the earliest proposed families is now left with a few well defined genera and several problematic forms. Generic and specific differentiation is based on the nature of proximally curved proximal and distal shields, the number and nature of elements comprising each cycle and the structure of central area. Under LM, the elliptic or circular outline of the coccolith and the relative birefringence of proximal and distal shields coupled with the appearance of extinction gyres are employed for taxonomic differentiation. While Tappan (1980) recognised two subfamilies based on circular or elliptical outline of coccoliths coupled with birefringence pattern, Perch-Nielsen (1985b) followed a three-fold classification of the family based on elliptical or circular outline of coccoliths coupled with characters of central area. As per the definition of the family adopted by Perch-Nielsen (1985b), it ranges from Late Cretaceous to Recent, and several species are used as important zonal markers specially in the Palaeogene.

PLATE 16 ⟶

Photomicrographs are printed in the same orientation with respect to the axes of nicols as observed under the microscope; coordinates measured with reference to a cross engraved on each slide. x 2000 Scale bar represents all photographs unless otherwise stated; PPL = normal light with single polariser; XPL = crossed nicols. HFm = Harudi Formation; FLFm = Fulra Limestone Formation.

1. *Blackites lanternus* sp. nov., Paratype; HFm; BSIP Slide No. 9888 : HF 12 (1) : Coordinates; 75.2/25.0; XPL.
2. *Blackites rectus* (Deflandre) Stradner & Edwards, 1968; HFm; BSIP Slide No. 9892 : XPL.

3-5. *Blackites fossus* sp. nov., 3. Holotype; HFm; BSIP Slide No. 9884 : HF 8 (2) : Coordinates; 86.1/30.2; XPL; 4, 5A-B. Paratypes; HFm; BSIP Slide No. 9892 : HF 16 (1) : Coordinates; 75.0 /28.2; 4. XPL; BSIP Slide No. 9984 : HF 8 (2) : Coordinates; 86.2/18.2; 5A. PPL; 5B. XPL.

6-7,11-13. *Blackites indicus* sp. nov., 6A-B. Holotype; HFm; BSIP Slide No. 9882 : HF 6 (2) : Coordinates; 80.0/29.9; 6A. PPL; 6B. XPL; 7A-B. Paratype; HFm; BSIP Slide No. 9884 : HF 8 (2) :Coordinates; 85.0 /11.7; 7A. PPL; 7B. XPL; 11 A-B, 12. Paratype; HFm; BSIP Slide No. 9884 : HF 8(1); Coordinates; 85.0/28.2 ; 11. PPL; 11B, 12. XPL; 13. Paratype; HFm; BSIP Slide No. 9884 : HF 8(1); Coordinates; 86.0/18.5; XPL.

8. *Blackites conicus* sp. nov., Paratype; HFm; BSIP Slide No. 9877 : HF 1 (1) : Coordinates; 77.0/13.1; 8A. PPL; 8B. XPL;

9-10. *Blackites delicates* sp. nov., Holotype; HFm; BSIP Slide No. 9892 : HF 16 (1); Coordinates; 80.9/35.2; 9A. PPL; 9B. XPL; 10 A-B. Paratype; HFm; BSIP Slide No. 9892 : HF 16(1); Coordinates; 76.0/32.1; 10A. PPL; 10B. XPL.

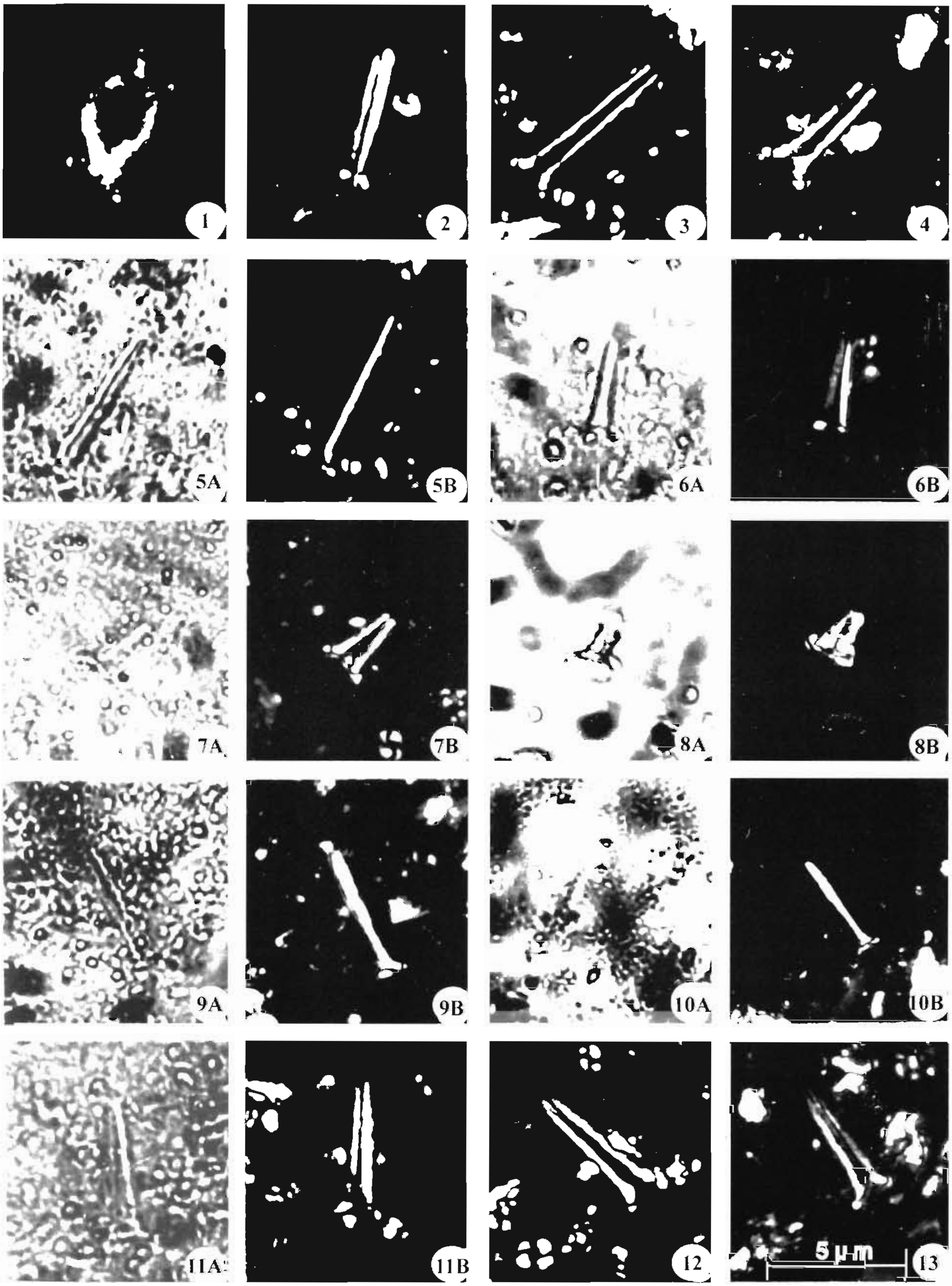

PLATE 16

Genus—CAMPYLOSPHAERA Kamptner, 1963

Campylosphaera dela (Bramlette & Sullivan) Hay & Mohler, 1967

(Pl. 8.5A-B, 6, 8)

Synonymy list—

1961 *Coccolithites delus* Bramlette & Sullivan, p. 151-152, pl. 7, figs 1a-c, 2a-b.

1964 *Coccolithites delus* Bramlette & Sullivan in Sullivan, p. 180, pl. 1, figs 7a-b, 8-9.

1967 *Campylosphaera dela* (Bramlette & Sullivan) Hay & Mohler, p. 1531, pl. 198, fig. 14.

1968 *Campylosphaera dela* (Bramlette & Sullivan) Hay & Mohler in Bukry & Kennedy, p. 39, fig. 3 (1).

1969 *Campylosphaera dela* (Bramlette & Sullivan) Hay & Mohler in Stradner, p. 414, pl. 85, figs 1-4.

1971 *Cruciplacolithus delus* (Bramlette & Sullivan) Perch-Nielsen, p. 22, pl. 13, figs 7-8.

1972 *Cruciplacolithus delus* (Bramlette & Sullivan) Perch-Nielsen in Perch-Nielsen, p. 1032, pl. 4, fig. 2.

1975 *Campylosphaera dela* (Bramlette & Sullivan) Hay & Mohler in Proto Decima *et al.*, p. 46, pl. 1, figs 27a-b.

1975 *Campylosphaera dela* (Bramlette & Sullivan) Hay & Mohler in Bybell, p. 193, pl. 14, figs 4a-b, 5-6.

1976 *Campylosphaera dela* (Bramlette & Sullivan) Hay & Mohler in Wise & Constans, p. 146, pl. 1, fig. 6.

1976 *Campylosphaera dela* (Bramlette & Sullivan) Hay & Mohler in Haq & Lohmann, pl. 9, fig. 3.

1986a *Campylosphaera dela* (Bramlette & Sullivan) Hay & Mohler in Singh & Singh, p. 149, pl. 3, figs 12-13.

1986b *Chiasmolithus* sp. Singh & Singh, pl. 3, figs 14-16.

Remarks—Original description by Bramlette & Sullivan (1961) of this species was invalid as it was described under provisional genus *Coccolithites.* It was later validated and transferred to genus *Campylosphaera* (Kamptner, 1963) by Hay and Mohler (1967).

This is fairly large species (5-6 µm) with a delicate cross, the bars being aligned to the major and minor axes of the coccolith. It shows close resemblance to *Cruciplacolithus* except for the typical rectangular outline and conspicuous proximal and lateral curving of the shields in both LM and EM.

The genus *Campylosphaera* contains only two species i.e., *C. eodela* has a short range around late Palaeocene-early Eocene, while *C. dela* ranges from

PLATE 17 ⟶

Photomicrographs are printed in the same orientation with respect to the axes of nicols as observed under the microscope; coordinates measured with reference to a cross engraved on each slide. x 2000 Scale bar represents all photographs unless otherwise stated; PPL = normal light with single polariser; XPL = crossed nicols. HFm = Harudi Formation; FLFm = Fulra Limestone Formation.

1-3. *Blackites tenuis* (Bramlette & Sullivan) Bybell, 1975; HFm; 1-2. BSIP Slide No. 9892; 3. BSIP Slide No. 9888 : 1A, 2A, 3A. PPL; 1B, 1C, 2B, 3B. XPL.

4, 6-9. *Blackites spinosus* (Deflandre & Fert) Hay & Towe, 1962; 4A-C. HFm; BSIP Slide No. 9892 : 4A. PPL; 4B, 4C. XPL; 6A-C, 7-8, 9A-B. HFm; 6, 9. BSIP Slide No. 9892; 7. BSIP Slide No. 9888; 8. BSIP Slide No. 9882: 6A, 9A . PPL; 6B, 6C, 7, 8, 9B. XPL.

5. *Blackites tenuis* (Bramlette & Sullivan) Bybell, 1975; HFm; 5. BSIP Slide No. 9892 : 5A. PPL; 5B. XPL.

10-11. *Blackites minutus* sp. nov., 10. Holotype; HFm; BSIP Slide No. 9892 : HF 16(1); coordinates: 76.5/30.8; XPL; 11. Paratype; HFm; BSIP Slide No. 9877: HF 1 (1); coordinates: 75.0/30.3; XPL.

12-14. *Blackites conicus* sp. nov., 12A-B. Holotype; HFm; BSIP Slide No. 9882 : HF 6(1); coordinates: 85.1/44.3; 12A. PPL; 12B. XPL; 13-14. Paratypes; HFm; BSIP Slide No. 9882 : HF 6(1); coordinates: 77.0/41.0; 13. XPL; BSIP Slide No.9882 : HF 6(1) : coordinates : 78.0/37.9; 14. XPL.

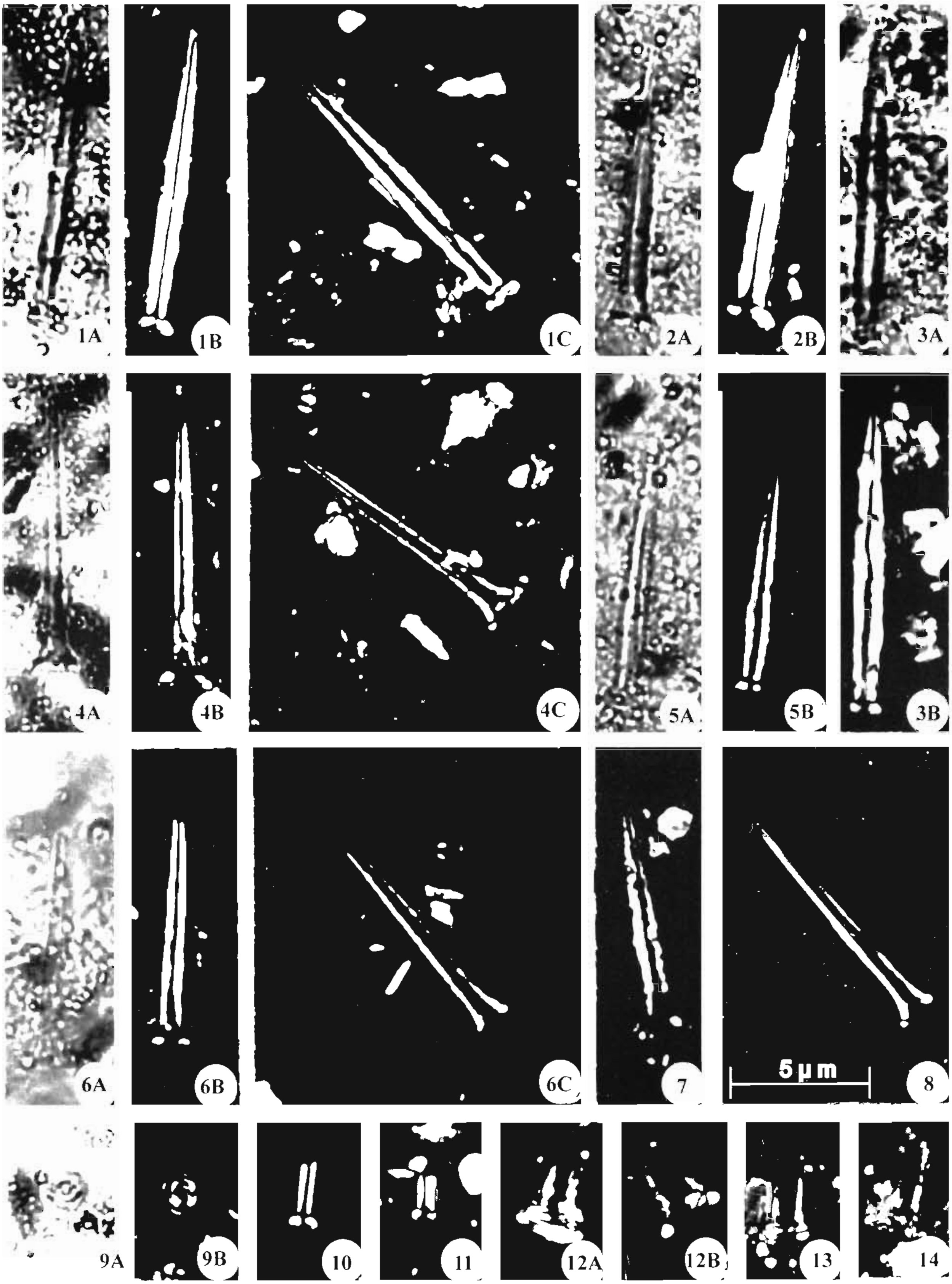
1A
1B
1C
2A
2B
3A
4A
4B
4C
5A
5B
3B
6A
6B
6C
7
5 µm
8
9A
9B
10
11
12A
12B
13
14

PLATE 17

early to late Middle Eocene Zone NP10 to base of NP17 (Perch-Nielsen, 1985b).

C. dela is reported from Babia Hill Section corresponding to Fulra Limestone Formation of Kutch Basin (Singh & Singh, 1986). In the studied material, it is rare both in Harudi and Fulra Limestone formations.

Genus—CHIASMOLITHUS Hay *et al.*, 1966

Chiasmolithus consuetus (Bramlette & Sullivan) Hay & Mohler, 1967

(Pl. 7.9A-C, 10A-B)

Synonymy list—

1961 *Coccolithus consuetus* Bramlette & Sullivan, p. 139, pl. 1, figs 2a-c.

1962 *Coccolithus consuetus* Bramlette & Sullivan in Bouché, p. 38, pl. 1, figs 18a-b.

1967 *Chiasmolithus consuetus* (Bramlette & Sullivan) Hay & Mohler, p. 1526, pl. 196, figs 23-25; pl. 198, fig. 16.

1971a *Chiasmolithus consuetus* (Bramlette & Sullivan) Hay & Mohler in Haq, p. 15-16, pl. 3, figs 6-7.

1975 *Chiasmolithus consuetus* (Bramlette & Sullivan) Hay & Mohler in Proto Decima *et al.*, p. 46, pl. 2, figs 1a-b.

1994 *Chiasmolithus consuetus* (Bramlette & Sullivan) Hay & Mohler in Jafar & Rai, p. 30, pl. 1, figs 30a-c.

Remarks—Medium size (3-4 µm) coccoliths are readily recognised under LM when the central cross is well preserved. *C. consuetus* has a long range, being reported from middle Palaeocene to late Eocene (NP 5-NP 19 *fide* Perch-Nielsen, 1985b). It occurs rarely in Harudi Formation.

Chiasmolithus titus Gartner, 1970

(Pl. 7.11A-C; Pl. 8.1A-B, 3A-B, 4A-B, 7)

Synonymy list—

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

1970 *Chiasmolithus titus* Gartner, p. 945, fig. 77 (1-2, 3A-C).

1975 *Chiasmolithus titus* Gartner in Bybell, p. 194, pl. 14, fig. 3.

1976a *Chiasmolithus titus* Gartner in Martini, p. 404, pl. 4, fig. 3.

1994 *Chiasmolithus titus* Gartner in Jafar & Rai, p. 30, pl. 1, figs 27a-b, 28, 29a-b.

1997 *Chiasmolithus titus* Gartner in Rai, p. 152, pl. II, fig. 3.

Remarks—*Chiasmolithus titus* is a smaller species (1.5-2 µm), originally described from the late Eocene of U.S.A. The cross-bars spanning the central area are diagnostic feature though sometimes it becomes difficult to decide the assignment of such forms to *Cruciplacolithus* or *Chiasmolithus*. It is known to range from middle Eocene through early Oligocene. It

PLATE 18 ⟶

Photomicrographs are printed in the same orientation with respect to the axes of nicols as observed under the microscope; coordinates measured with reference to a cross engraved on each slide. x 2000 Scale bar represents all photographs unless otherwise stated; PPL = normal light with single polariser; XPL = crossed nicols. HFm = Harudi Formation; FLFm = Fulra Limestone Formation.

1. *Wiseorhabdus inversus* (Bukry & Bramlette) Bukry, 1981; HFm; BSIP Slide No. 9892 : 1A. PPL; 1B. XPL.
2-3. *Lithostromation simplex* (Klumpp) Bybell, 1975; HFm; 2. BSIP Slide No. 9892; 3. BSIP Slide No. 9879 : 2-3. PPL.
4. *Lithostromation perdurum* Deflandre, 1942; HFm; BSIP Slide No. 9892 : PPL.
5. *Lithostromation operosum* (Deflandre) Bybell, 1975; HFm; BSIP Slide No. 9888 : PPL.
6. *Thoracosphaera saxea* Stradner, 1961; HFm; BSIP Slide No. 9892 : 6A. PPL; 6B. XPL.
7. *Thoracosphaera* cf. *T. saxea* Stradner, 1961; HFm; BSIP Slide No. 9892 : XPL.
8, 9. *Thoracosphaera* cf. *T. deflandrei* Kamptner, 1956; HFm; BSIP Slide No. 9888 : 8A. PPL; 8B, 9. XPL.
10-12. *Thoracosphaera* cf. *T. tuberosa* Kamptner, 1963; HFm; 10. BSIP Slide No. 9892; 11-12. BSIP Slide No. 9888 : All XPL.

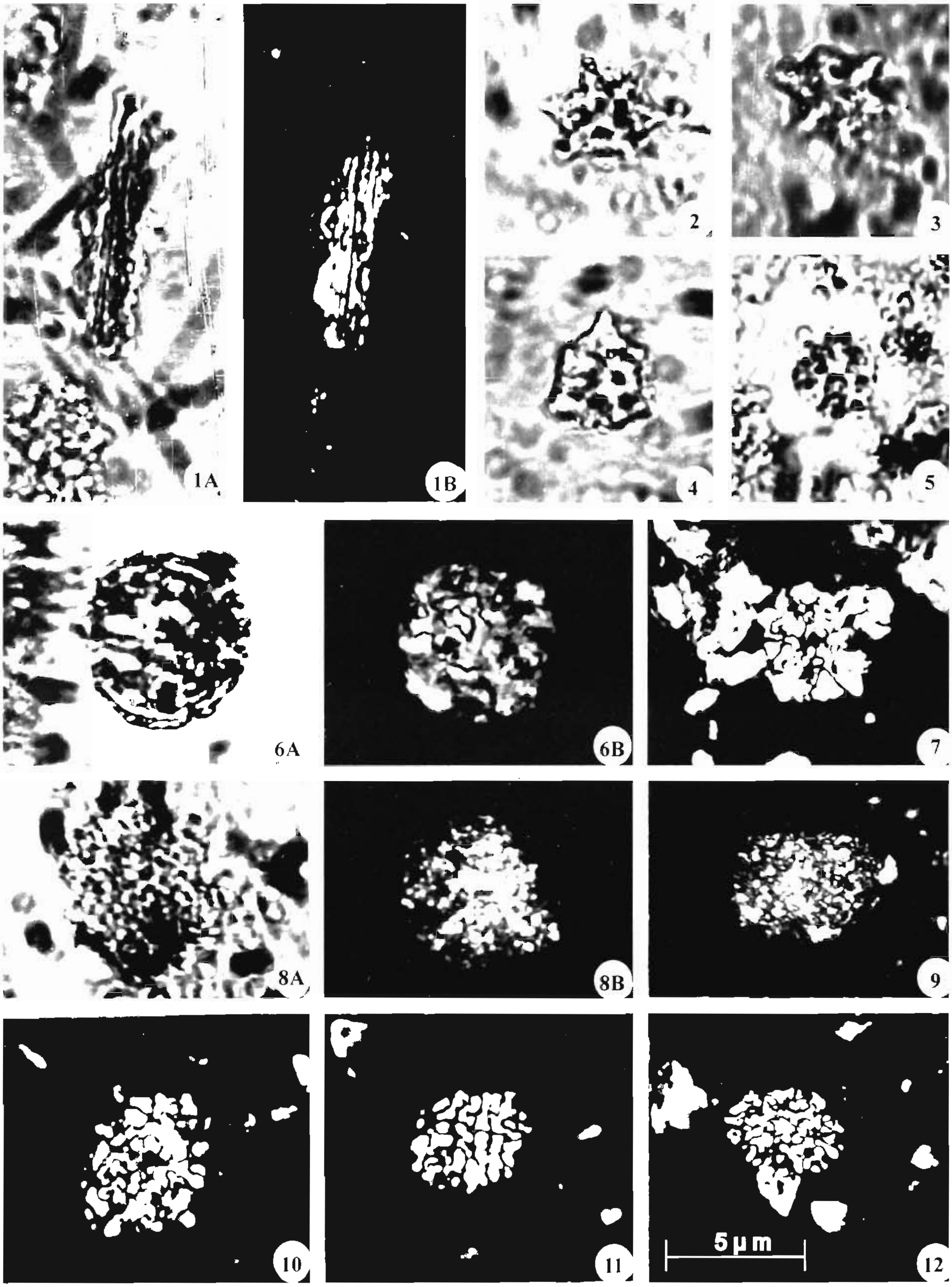

PLATE 18

is recorded as rare in Harudi and Fulra Limestone formations.

Chiasmolithus sp. 1

(Pl. 8.2A-B)

Remarks—This is a small chiasmolith. Maximum diameter 6 μm, minimum 4 μm are recorded with central area spanned by small cross-bars and displaying strongly curved extinction gyres in the rim area. Only two specimens, slightly overgrown were found in Harudi Formation.

Genus—COCCOLITHUS Schwarz, 1894

Coccolithus eopelagicus (Bramlette & Riedel) comb. nov.

(Pl. 6.6A-B, 7A-B, 8A-B, 9A-B, 10A-B)

Basionym—*Tremalithus eopelagicus* Bramlette & Riedel 1954, p. 392, pl. 38, figs 2A-B, Journal of Paleontology, 28.

Synonymy list—

1961 *Coccolithus eopelagicus* (Bramlette & Riedel) in Stradner & Edwards, p. 15-16, pl. 6 (1-4).

1969 *Coccolithus eopelagicus* (Bramlette & Riedel) in Bilgütay *et al.*, pl. 2, figs 1-2.

1971 *Ericsonia eopelagica* (Bramlette & Riedel) in Roth in Roth *et al.*, p. 1092.

1975 *Coccolithus eopelagicus* (Bramlette & Riedel) in Proto Decima *et al.*, p. 47, pl. 2, figs 15A-C.

1976 *Coccolithus eopelagicus* (Bramlette & Riedel) in Haq & Lohmann, pl. 3, figs 10-12, pl. 13, figs 3-4.

1980 *Coccolithus eopelagicus* (Bramlette & Riedel) in Singh *et al.*, p. 4, figs 1-11.

1980b *Coccolithus gigas* Bramlette & Sullivan in Singh, p.,4-5, pl. 1, figs 11-13.

1986a *Coccolithus eopelagicus* (Bramlette & Riedel) in Singh & Singh, p.149, pl. 5, figs 1, 3.

1994 *Coccolithus eopelagicus* (Bramlette & Riedel) in Jafar & Rai, p. 30, pl. 2, figs 2a-b.

Remarks—*Coccolithus eopelagicus* was originally described from the late Eocene of Barbados and has since been widely reported from middle Eocene to late Oligocene of several regions. Morphology is very similar to that of living *C. pelagicus*, except for large size of Palaeogene specimens (5-7μm). Possible relationships between *Ericsonia* and *Coccolithus* are discussed by Perch-Nielsen (1985b).

C. eopelagicus was originally described under provisional genus *Tremalithus,* which is an invalid name. The earliest validation is credited to Bramlette and Sullivan (1961, p. 141) for describing it under valid generic name *Coccolithus* Schwarz, 1894. This validation is however, not legitimate as no basionym was cited. *C. eopelagicus* is therefore validated herein by formal citation of basionym and assigning it to valid genus *Coccolithus*.

C. eopelagicus is frequent to rare in Harudi and Fulra Limestone formations.

Genus—CYCLOCOCCOLITHUS Kamptner, 1954

Cyclococcolithus neoannulus sp. nov.

(Pl. 7.7A-B, 8)

Synonymy list—

1979 *Cyclolithella* sp. Singh, p. 11, figs 23-25.

Holotype—Pl. 7.7A-B, HF 11(1). Coordinates—85.0/19.4. Size—diameter 8 μm, diameter of the collar 4.5 μm. BSIP Slide No.—9887.

Paratype—Pl. 7.8, HF 6 (1). Coordinates—75.0/35.0. Size—diameter 8 μm, diameter of the collar 5 μm. BSIP Slide No.—9882.

Type locality—SW of village Harudi in 'Rato Nala Section', Kutch, western India.

Type level—Late Middle Eocene, Harudi Formation; *Discoaster saipanensis* Zone—NP 17 of Martini, 1971a emend. Rai, 1988.

Diagnosis—Medium size (3-4 μm), circular to subcircular coccoliths displaying a large nearly squarish central opening and a birefringent collar under crossed nicols. The elements of collar strongly curved. The coccolith appears much smaller under crossed nicols than its actual size.

Remarks—It is distinguished from the similar looking *Cyclococcolithus protoannulus* Gartner (1971) by displaying strongly curved elements of collar under crossed nicols. Specimens are rarely found in Harudi Formation. *C. neoannulus* appears to have the same range as *C. protoannulus* in middle to late Eocene.

Cyclococcolithus protoannulus (Gartner) Rai, 1997

(Pl. 7.3A-B, 4, 6)

Synonymy list—

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

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

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

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

1971b *Cyclococcolithus* cf. *C. kingi* Roth in Roth *et al.*, p. 1092-1093, figs 11A-B, 12A-B.

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

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

1975 *Cyclococcolithina kingi* (Roth) Roth in Proto Decima *et al.*, p. 47, pl. 2, figs 19A-B.

?1977 *Cyclococcolithina kingi* (Roth) Roth in Perch-Nielsen, p. 807, pl. 41, fig. 8.

1977 *Cyclococcolithina protoannula* Gartner in Perch-Nielsen , p. 807, pl. 41, fig. 9.

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

1979 *Cyclolithella pakistanika* Haq in Singh, p. 4, pl. 1, figs 19-20, ? 21-22.

1980 *Cyclolithella pakistanika* Haq in Singh *et al.*, p. 175, pl. 2, figs 28-36, 38 (partim).

?1984 *Cyclolithella robusta* (Bramlette & Sullivan) Stradner in Steinmetz & Stradner, p. 678, pl. 42, figs 3-4.

1997 *Cyclococcolithus protoannulus* (Gartner) Rai, p. 152-153, pl. I, figs 14, 16; pl. IV, fig. 5.

Remarks—This is a fairly large (5-6 μm) and distinctive species, best recognised under LM. It is consistently recorded as a minor constituent of Eocene nannoflora from several regions, but due to the lack of correlation between LM and EM pictures, confusion exists in the literature. Earliest doubtful forms are recorded from the late Palaeocene of South Atlantic (Steinmetz & Stradner, 1984, pl. 42, fig. 4) associated with typical and common *Ericsonia robusta.* It differs from *E. robusta* under LM in showing much thinner, bright collar traversed by dark extinction lines. *C. protoannulus* has also been described from the early Eocene of Austria (Stradner, 1969). Typical forms assignable to *C. protoannulus* are recorded from the middle Eocene to early Oligocene (Pant & Mamgain, 1969; Roth *et al.*, 1971b; Gartner, 1971; Proto Decima *et al.*, 1975; Singh, 1979; Singh *et al.*, 1980).

C. protoannulus is common to rare in the Harudi Formation.

Genus—ERICSONIA Black, 1964

Ericsonia* cf. *E. femurcentrum Perch-Nielsen, 1971

(Pl. 6.4A-B, 5)

Synonymy list—

1971a *Ericsonia femurcentrum* Perch-Nielsen, p. 12, pl. 3, figs 1-4; pl. 61, figs 24-25.

Remarks—This is fairly large species (10-12 μm) of *Ericsonia* comparable to LM pictures of *Ericsonia femurcentrum* Perch-Nielsen. Rarely occurs in Harudi Formation.

Ericsonia formosa (Kamptner) Haq, 1971a

(Pl. 6.3A-B, 11A-B; Pl. 7.1A-B, 2A-B, 5)

Synonymy list—

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

1964 *Cyclococcolithus lusitanicus* Black, p. 308-309. pl. 50, figs 1-2.

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

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

1968 *Umblicosphaera formosa* (Kamptner) Reinhardt in Cohen & Reinhardt, p. 295.

1969 *Cyclococcolithus formosus* Kamptner in Martini, p. 132, pl. 1, figs 1-2.

1975 *Cyclococcolithus formosa* (Kamptner) Wilcoxon in Proto Decima *et al.*, p. 47, pl. 2, figs 24a-b.

1975 *Cyclococcolithus formosa* (Kamptner) Wilcoxon in Bybell, p.195, pl. 16, figs 4a-b, 5.

1976 *Cyclococcolithus formosus* Kamptner in Haq & Lohmann, p. 140, pl. 1, fig. 12, p. 158, pl. 8, fig. 7.

1976 *Cyclococcolithus formosus* Kamptner in Martini, p. 406, pl. 5, fig. 12.

1980 *Cyclococcolithus formosa* (Kamptner) Wilcoxon in Singh *et al.*, p.172-176, figs 22-24.

1980a *Cyclococcolithus formosa* (Kamptner) Wilcoxon in Singh, p. 4, pl. 1, figs 6-10.

?1980b *Cyclococcolithus formosa* (Kamptner) Wilcoxon in Singh, p. 22-23, pl. 1, figs 21-26.

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

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

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

1997 *Ericsonia formosa* (Kamptner) Haq in Rai, p. 153, pl. I, figs 13, 15.

Remarks—Ericsonia formosa was originally described from the Eocene of Pacific Ocean (Kamptner, 1963). This is readily recognisable species both under LM and EM and has been used as important stratigraphic marker. It appeared in the late early Eocene and disappeared in early Oligocene, as indicated by Martini (1971, NP 12-NP 21). *E. formosa* is widely recorded in Bartonian equivalent sediments of Kutch Basin i.e., Babia Hill (Singh & Singh, 1986), Lakhpat (Singh, 1980a), Vinjhan-Miani (Singh, 1980b), Rakhadi River (Singh *et al.*, 1980), and late Eocene of Surat (Jafar *et al.*, 1985).

It is common to rare in Harudi and rare in Fulra Limestone Formation.

Ericsonia ovalis Black, 1964

(Pl. 5.15A-B)

Synonymy list—

1964 *Ericsonia ovalis* Black, p. 312, pl. 52, figs 5-6.

1964 *Coccolithus muiri* Black, p. 309, pl. 50, figs 3-4.

1968 *Ericsonia ovalis* Black in Stradner & Edwards, p. 17, pls. 8-9.

1970 *Ericsonia muiri* (Black) Roth, p. 841-842.

Remarks—The specimens of *E. ovalis* are smaller than associated *Coccolithus eopelagicus*, but otherwise difficult to differentiate under LM observations alone. Morphological details of this species both under LM and EM are given by Stradner & Edwards (1968). It is rare in Harudi Formation.

Ericsonia sp. 1

(Pl. 6.1A-B, 2)

Remarks—A specimen of *Ericsonia* displaying large number of distinct pores in central area surrounded by relatively thin rim, but otherwise shows similar extinction pattern under crossed nicols as other species. The rare form is in Harudi Formation.

Ericsonia sp. 2

(Pl. 9.1A-B, 2A-B)

Remarks—Medium to large size species (6-10 μm) of *Ericsonia* shows distinctive extinction pattern under crossed polarised light viz. few bright central elements surrounded by a wide but has relatively less bright rim. It is rare in Fulra Limestone Formation.

Genus—BRAMLETTEIUS Gartner, 1969

Bramletteius serraculoides Gartner, 1969

(Pl. 9.14-15, 16A-B)

Synonymy list—

1969 *Bramletteius serraculoides* Gartner, p. 31, pl. 1, figs 1-3.

1970 *Bramletteius variabilis* Roth, p. 859, pl. 8, figs 3, 5.

1971c *Bramletteius serraculoides* Gartner in Bukry, p. 995, pl. 5, fig. 3.

1975 *Bramletteius serraculoides* Gartner in Bybell, p.186, pl. 20, fig. 6.

1994 *Bramletteius serraculoides* Gartner in Jafar & Rai, p. 32, pl. 1, figs 31a-c.

Remarks—Bramletteius serraculoides is a small sized species and specimens are best recognised in side view under LM by the presence of a paddle like process of variable morphology surmounted on a double shielded coccolith of *Cruciplacolithus* like structure (Bybell, 1975).

Bramletteius remained monospecific, till the discovery of *Bramletteius duoalatus* Martini (1980) from the late Pliocene. Although Martini (1980) questionably assigned this species to *Bramletteius,* the overall structure justifies its inclusion in this genus. *B. variabilis* Roth (1970) shows variations in the paddle structure, but should be assigned to *B. serraculoides*. The initial appearance of *B. serraculoides* was used by Okada and Bukry (1980) to define base of Zone CP 13C in middle Eocene, in which the species is found to be common to abundant in open ocean assemblages.

Family—DISCOASTERACEAE Tan Sin Hok, 1927

Star to rossette shaped tiny calcareous objects in the range of nannofossils were illustrated for the first time by Ehrenberg (1854) and considered to be of inorganic origin. No taxonomic work was possible on the sketches provided by Ehrenberg (1854), as these are produced in low magnification (ca. 300X). Tan Sin Hok (1927) suggested organic origin for such tiny objects and coined the word 'Discoaster' and erected formal genera and species, which were later documented under LM and EM.

The work on Discoasters by several researchers (Bramlette & Riedel, 1954; Stradner & Papp, 1961; Martini, 1971a; Bukry, 1971b; Prins, 1971; Perch-Nielsen, 1971; Black, 1972) provided a comprehensive framework for the application of these nannofossils for biostratigraphic and palaeoceanographic modelling of Tertiary marine sediments of both hemipelagic land sections and pelagic deep sea cores. Recent trend to include three genera *Discoaster, Discoasteroides* and *Catinaster* in this family has been followed here (Perch-Nielsen, 1985b), against a host of generic names proposed by Prins (1971) and Theodoridis (1983). Catalogues of Farinacci (1969-70) and Aubry (1985b), provide useful information on over a hundred species described under this family.

The preservation of discoasters in late Middle Eocene of Kutch Basin is moderate to poor chiefly due to calcite overgrowth, but species are readily recognised under LM, while SEM pictures present more problems for specific identifications.

Genus—DISCOASTER Tan Sin Hok, 1927

Discoaster barbadiensis Tan Sin Hok, 1927

(Pl. 11.11-15)

Synonymy list—

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

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

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

1954 *Discoaster barbadiensis* Tan Sin Hok *sensu emend.* Bramlette & Riedel, p. 398, pl. 39, figs 5a-b.

1960 *Discoaster barbadiensis* Tan Sin Hok in Martini, pl. 8, fig. 10.

1961 *Discoaster barbadiensis* Tan Sin Hok in Bramlette & Sullivan, p. 158, pl. 11, fig. 2.

1969 *Discoaster barbadiensis* Tan Sin Hok in Bilgûtay *et al.*, pl. 3, fig. 4.

1971b *Discoaster barbadiensis* Tan Sin Hok in Bukry, p. 46, pl. 1, fig. 15.

1972 *Discoaster barbadiensis* Tan Sin Hok in Reinhardt, p. 84, fig. 166.

1973 *Discoaster barbadiensis* Tan Sin Hok in Pant & Mathur, p. 214, pl. 24, figs C, F; pl. 27, fig. D.

1975 *Discoaster barbadiensis* Tan Sin Hok in Jafar, p. 44, pl. 15, fig. 5.

1975 *Discoaster barbadiensis* Tan Sin Hok in Edwards & Perch-Nielsen, p. 518, pl. 11, fig. 5.

1975 *Discoaster barbadiensis* Tan Sin Hok in Bybell, p. 198-199, pl. 17, figs 3a-b.

1975 *Discoaster barbadiensis* Tan Sin Hok in Proto Decima *et al.*, p. 48, pl. 3, fig. 18.

1976 *Discoaster barbadiensis* Tan Sin Hok in Wise & Constans, p. 150, pl. 3, fig. 6.

1976 *Discoaster barbadiensis* Tan Sin Hok in Haq & Lohmann, p. 154, pl. 6, figs 3, 9.

1976 *Discoaster barbadiensis* Tan Sin Hok in Martini, p. 406, pl. 5, fig. 4.

1977 *Discoaster barbadiensis* Tan Sin Hok in San-Migüel, p. 123-124, pl. 3, figs 14-15.

1979 *Discoaster barbadiensis* Tan Sin Hok in Singh, p. 5, pl. 1, figs 36-43.

1980 *Discoaster barbadiensis* Tan Sin Hok in Singh *et al.*, p. 175, figs 47-50.

1980a *Discoaster barbadiensis* Tan Sin Hok in Singh, p. 6, pl. 2, figs 12-13.

1980b *Discoaster barbadiensis* Tan Sin Hok in Singh, p. 23-24, pl. 1, fig. 28.

1986a *Discoaster barbadiensis* Tan Sin Hok in Singh & Singh, pl. 4, figs 12-13, 15-16.

1994 *Discoaster barbadiensis* Tan Sin Hok in Jafar & Rai, p. 32, pl. 2, figs 13-18, 22-23, 27.

1997 *Discoaster barbadiensis* Tan Sin Hok in Rai, p. 154, pl. II, figs 8, 10, 18.

Remarks—Discoaster barbadiensis is the most characteristic Eocene discoaster. Rosette shaped asteroliths contain 7-14 rays joined along most of their length with blunt to pointed tips. The asteroliths display proximal curvature with characteristic stem and are best observed in side views.

In the study material about 11 rayed asteroliths are most common, as elsewhere in the world, but the forms with 7 rays to18 rays displaying typical features of *D. barbadiensis* are reported from several regions.

Two groups of *D. barbadiensis*, one small with ca. 9 µm and the larger with ca.18 µm diameter are recorded in the present material. Relative abundance of such small and large forms seems to be of some environmental significance.

In India, *D. barbadiednsis* together with *D. saipanensis* are reported from Bartonian equivalent sediments of Kutch Basin (Singh *et al.*, 1980; Singh, 1980a, b; Singh & Singh, 1986), late Eocene of Cambay Basin (Jafar *et al.*, 1985) and late Eocene of eastern India (Singh, 1979).

Discoaster bifax Bukry, 1971a

(Pl. 12.8)

Synonymy list—

1971a *Discoaster bifax* Bukry, p. 313-315, pl. 3, figs 6-11.

1973b *Discoaster bifax* Bukry in Bukry, p. 657, pl. 4, figs 8-9.

1973a *Discoaster bifax* Bukry in Bukry, p. 690.

Remarks—Discoaster bifax was originally described from the late Middle Eocene of Atlantic Ocean and has an extremely short stratigraphic range, which is of great value. A few specimens belong to smaller variant (ca. 5 µm) possessing 10 rays and matching the original description of the species (Bukry, 1971a) are found in the study material.

D. bifax is sparsely documented in literature and appears to be relatively rare in Pacific Ocean. This is perhaps, the only record from Indian Ocean region so far.

The total range of *D. bifax* defines subzone CP14a = *D. bifax* subzone of CP14 = *Reticulofenestra umbilica* Zone of Okada & Bukry (1980). As per the data published on European stratotype (Aubry, 1985a), this corresponds to upper part of NP 16 Zone of Martini

(1971a) matching a part of Bartonian. This age assignment is in agreement with other evidences available from Harudi Formation, which yielded *D. bifax* (Singh *et al.*, 1980).

Discoaster binodosus Martini, 1958

(Pl. 11.18-19; Pl. 12.1-4)

Synonymy list—

1958 *Discoaster binodosus* Martini, p. 361-362, pl. 4, figs 18a-b, 19a-b.

1959a *Discoaster binodosus* Martini in Stradner, p. 1085-1086, figs 18-19.

1959b *Discoaster binodosus* Martini in Stradner, p. 10, fig. 42.

1960 *Discoaster binodosus hirundinus* Martini in Martini, pl. 9, fig. 21.

1961 *Discoaster binodosus* Martini in Bramlette & Sullivan, p. 158, pl. 11, figs a-b.

1961 *Discoaster binodosus* Martini in Stradner & Papp, p. 66-68, pl. 4, figs 1-7; l. 5, ;figs 1-6.

1962 *Discoaster binodosus* Martini in Bouché, p. 90, pl. 3, fig. 9, text-fig. 27.

1969 *Discoaster binodosus* Martini in Pant & Mamgain, p.117, pl. 20, figs 1, 6; pl. 23, figs 3-4, ?7-8.

1971a *Discoaster binodosus binodosus* Martini in Perch-Nielsen, p. 61, pl. 52, fig. 6.

1975 *Discoaster binodosus* Martini in Proto Decima *et al.*, p. 8, pl. 3, figs 3-4.

1976 *Discoaster binodosus* Martini in Haq & Lohmann, p. 154, pl. 6, figs 1-2.

?1980 *Discoaster binodosus* Martini in Singh *et al.*, p. 175, fig. 76.

1980 *Discoaster tani nodifer* Martini in Singh (partim), p. 8, pl. 4, figs 13, 18-19.

1984 *Discoaster binodosus* Martini in Stienmetz & Stradner, p. 732, pl. 33, figs 2-5; pl. 32, figs 1-2.

1994 *Discoaster binodosus* Martini in Jafar & Rai, p. 32, pl. 32, figs 24-26, 28.

Remarks—Discoaster binodosus binodosus and *D. binodosus hirundinus* originally proposed as subspecies by Martini (1958) are now clubbed together under *D. binodosus*, as the presence of notch on the ray tips, diameter of central area, thickness and number of arms (5-8) are variable. More than one pair of nodes may be seen on each ray and short free length in 8-rayed asteroliths give appearance very similar to *D. mirus* (Stradner & Papp, 1961).

In the study material *D. binodosus* ranges between 9-12 µm with considerable variation in the morphology. Specimens having 6 rays are common, while 5 and 8 rayed are rare. It ranges from early Eocene Zone NP 10 to early Oligocene Zone NP 21 (Martini, 1971a). Late Palaeocene occurrence of the species as mentioned by Perch-Nielsen (1985b) remains unconfirmed.

It is frequent in Harudi and rare in Fulra Limestone formations.

Discoaster distinctus Martini, 1958

(Pl. 11.16-17)

Synonymy list—

1958 *Discoaster distinctus* Martini, p. 363, pl. 4, figs 17a-b.

1959 *Discoaster distinctus* Martini in Stradner, p. 478-479, figs 33-39 (partim).

1960 *Discoaster distinctus* Martini in Martini, p. 77, pl. 9, fig. 15.

1961 *Discoaster distinctus* Martini in Stradner & Papp, p. 72-73, pl. 11, figs a-b.

1961 *Discoaster distinctus* Martini in Bramlette & Sullivan, p.159, pl. 11, figs 11-13.

1962 *Discoaster distinctus* Martini in Bouché, p. 91, pl. 3, fig. 14.

1965 *Discoaster distinctus* Martini in Sullivan, p. 41, pl. 10, fig. 4.

1967 *Discoaster distinctus* Martini in Achutan & Stradner, p. 5, pl. 5, figs ? 1-3.

1971 *Discoaster distinctus* Martini in Báldi-Beke, p. 34, pl. 5, figs 10,14.

1971a *Discoaster distinctus* Martini in Perch-Nielsen, p. 63, pl. 52, fig. 5; pl. 53, fig. 1.

1975 *Discoaster distinctus* Martini in Proto Decima *et al.*, p. 48, pl. 3, figs 7, 14.

1975 *Discoaster* sp. in Bybell, p. 200, pl. 17, ?fig. 6, 7.

1976 *Discoaster distinctus* Martini in Haq & Lohmann, p.154, pl. 6, fig. 6.

?1979 *Discoaster distinctus* Martini in Singh, p. 5, pl. 1, figs 30-34.

1981b *Discoaster distinctus* Martini in Martini, pl. 1, fig. 8.

1984 *Discoaster distinctus* Martini in Steinmetz & Stradner, p. 735, pl. 36, fig. 2.

1994 *Discoaster distinctus* Martini in Jafar & Rai, p. 32, pl. 2, fig. 5.

1997 *Discoaster distinctus* Martini in Rai, p. 154, pl. 2, fig. 11.

Remarks—Discoaster distinctus was originally described from early Late Eocene. It usually consists of 6 rays with characteristic screw-wrench type tips. However, in overgrown samples, this character is difficult to recognise. In the study material the specimens range between 8-17 µm.

It is reported from early to late Middle Eocene sediments and is frequent to rare in Harudi Formation.

Discoaster mirus Deflandre, 1954

(Pl. 12.9-10)

Synonymy list—

1954 *Discoaster mirus* Deflandre in Deflandre & Fert, p. 168, text-fig. 118.

1958 *Discoaster* cf. *D. mirus* Deflandre in Stradner, p. 10-11, figs 28-32 (partim).

1959a *Discoaster mirus* Deflandre in Stradner, p. 1087, fig. 23.

1959b *Discoaster mirus* Deflandre in Stradner , p. 479, fig. 41.

1961 *Discoaster mirus* Deflandre in Stradner & Papp, pl. 6, figs 1-6; pl. 7, figs 1-5 (partim).

1971 *Discoaster mirus* Deflandre in Báldi-Beke, p. 34, pl. 5, fig. 9.

1975 *Discoaster mirus* Deflandre in Proto Decima *et al.*, p. 48, pl. 4, figs 2-5.

1994 *Discoaster mirus* Deflandre in Jafar & Rai, p. 34, pl. 2, figs 10-11, 21.

Remarks—Discoaster mirus is well documented under LM and EM. Asteroliths consist of usually 8 rays as in the holotype and the forms documented herein, show variable number of rays. This is a compact asterolith with thick arms and notched tips, usually containing a pair of knobs on each ray. The suture lines of wide central area are also characteristic feature.

The species originally described from Lutetian, is reported to range from early to late Middle Eocene. In the studied material, the species ranges between 14-16 µm in size. It is rarely present in Harudi Formation.

Discoaster nodifer (Bramlette & Riedel) Bukry, 1973b

(Pl. 12.5-6)

Synonymy list—

1954 *Discoaster tani nodifer* Bramlette & Riedel, p. 397, pl. 39, fig. 2.

1958 *Discoaster tani* cf. *nodifer* Bramlette & Riedel in Martini, p. 360, pl. 3, figs 14a-b.

1959a *Discoaster tani nodifer* Bramlette & Riedel in Stradner, p.1086, fig. 17.

1960 *Discoaster tani nodifer* Bramlette & Riedel in Martini, p. 78, pl. 9, fig. 19.

1967 *Discoaster tani nodifer* Bramlette & Riedel in Hay *et al.*, p. 460, pl. 1, fig. 2.

non1971a *Discoaster tani nodifer* Bramlette & Riedel in Haq, p. 42-43, pl. 10, fig. 13.

1971 *Discoaster tani nodifer* Bramlette & Riedel in Báldi-Beke, p. 35, pl. 6, figs 1-2.

non1971a *Discoaster tani nodifer* Bramlette & Riedel in Perch-Nielsen pl. 52, fig. 3.

1973b *Discoaster nodifer* (Bramlette & Riedel) Bukry, pl. 4, fig. 24.

1975 *Discoaster tani nodifer* Bramlette & Riedel in Proto Decima *et al.*, p. 49, pl. 4, figs 10-11, non fig. 12.

1975 *Discoaster nodifer* (Bramlette & Riedel) Bukry in Bybell, p. 199, pl. 17, fig. 4.

1980a *Discoaster tani nodifer* Bramlette & Riedel in Singh, p. 14, pl. 4, fig. 19, non figs 9-15, 18, 20.

non1980b *Discoaster tani nodifer* Bramlette & Riedel in Singh, p. 24-25, pl. I, fig. 29.

non1986 *Discoaster tani nodifer* Bramlette & Riedel in Singh & Singh p. 151, pl. 4, fig. 27.

1994 *Discoaster nodifer* Bramlette & Riedel in Jafar & Rai, p. 34, pl. 2, fig. 29.

Remarks—Medium to large sized asteroliths are usually with 6 rays and rarely 5, 7 or 8 rays of uniform thickness having a notch at the tips and a pair of nodes towards small central area. In the studied material, the forms range between 13-18 μm and are slightly overgrown. It is rare in Harudi and very rare in Fulra Limestone Formation. Originally reported from the late Eocene of Alabama and the earliest occurrence is at the base of NP 16 Zone in late Middle Eocene (Perch-Nielsen, 1985b), probably ranging up to early Oligocene.

Discoaster ornatus Stradner, 1958

(Pl. 12.11)

Synonymy list—

1958 *Discoaster ornatus* Stradner, p. 187-188, figs ?37-38.

1959a *Discoaster ornatus* Stradner in Stradner, p. 1088, fig. 30.

1959b *Discoaster ornatus* Stradner in Stradner, p. 478, figs 24, ? 22-23, 25-26.

1961 *Discoaster ornatus* Stradner in Stradner & Papp p. 64-65, pl. 2, fig. 5, ?1-4, 6.

1994 *Discoaster ornatus* Stradner in Jafar & Rai, p. 34, pl. 2, fig. 20.

Remarks—Stradner (1958, figs 37-38) first dealt with two different forms to which the name *Discoaster ornatus* was applied (not to be confused with *Discoaster tani ornatus* Bramlette & Wilcoxon, 1967). Formal description of the species was made in 1959a (p.1088, fig. 3) by Stradner, but no holotype was designated and asteroliths were erroneously interpreted as having a pore on each ray, as observed in *Pemma*. In 1961 (p. 64-65, figs 1-6) *D. ornatus* was described by Stradner with emended diagnosis which was abundant in Palaeocene of Salzburg area. This 8-rayed form is recorded in the study material, and (pl. 2, fig. 5) is hereby designated as lectotype (Stradner in Stradner & Papp, 1961, p. 64-65, pl. 2, figs 1-6).

D. ornatus attaining diameter of ca. 15 μm is characterised by rays in the form of 4-pairs of "twinned" rhombohedra with pointed tips and well marked straight inter-ray sutures. The other records of this species are not known. It somewhat resembles the Palaeocene species *D. falcatus* Bramlette & Sullivan (1961). Miocene record of this species was interpreted by Stradner (Stradner & Papp, 1961) as reworked. *D. ornatus* is frequent to rare in Harudi Formation.

Discoaster* cf. *D. ornatus Stradner, 1958

(Pl. 12.12)

Remarks—A solitary specimen of this 7 rayed asterolith (diameter 13 μm) was found in sample number HF-3 of Harudi Formation, whereas, typical *D. ornatus* (8 rayed) was consistently seen in several samples. Besides this, the overgrown nature of specimen offers difficulties in identification though strong resemblance is indicated with *D. ornatus*.

Discoaster saipanensis Bramlette & Riedel, 1954

(Pl. 11.4-10)

Synonymy list—

1954 *Discoaster saipanensis* Bramlette & Riedel, p. 398, pl. 39, fig. 4.

1958 *Discoaster saipanensis* Bramlette & Riedel in Martini, p. 367, pl. 6, figs 29a-b.

1959 *Discoaster saipanensis* Bramlette & Riedel in Bramlette, p. 249, pl. 61, fig. 7.

1960 *Discoaster saipanensis* Bramlette & Riedel in Martini, pl. 8, fig. 12.

1961 *Discoaster saipanensis* Bramlette & Riedel in Stradner & Papp, p. 90-91, pl. 22, figs 6-7, 9.

1967 *Discoaster saipanensis* Bramlette & Riedel in Hay *et al.*, p. 460, pl. 1, figs 4-6.

1967 *Discoaster saipanensis* Bramlette & Riedel in Bilgütay *et al.*, pl. 3, fig. 5.

1969 *Discoaster saipanensis* Bramlette & Riedel in Pant & Mamgain, p. 117-118, pl. 19, figs 1-3; pl. 23, figs 9, 13, ? 10.

?1975 *Discoaster saipanensis* Bramlette & Riedel in Proto Decima *et al.*, p. 48, pl. 3, fig. 25.

?1975 *Discoaster saipanensis* Bramlette & Riedel in Bybell, p. 200, pl. 17, figs 5a-b.

1976 *Discoaster saipanensis* Bramlette & Riedel Bramlette & Riedel in Haq & Lohmann, p. 154, pl. 6, fig. 4.

1977 *Discoaster saipanensis* Bramlette & Riedel in San-Migüel, p.160, pl. 3, fig. 16.

non1978a *Discoaster saipanensis* Bramlette & Riedel in Singh *et al.*, p. 346-347, fig. 3.

1979 *Discoaster saipanensis* Bramlette & Riedel in Singh, p. 5, pl. 1, figs 45-51.

1980 *Discoaster saipanensis* Bramlette & Riedel in Singh *et al.*, p. 175, figs 59-63.

1980a *Discoaster saipanensis* Bramlette & Riedel in Singh, p. 6, pl. 2, figs 14-15.

?1980b *Discoaster saipanensis* Bramlette & Riedel in Singh, p. 24, pl. 1, fig. 30.

?1986a *Discoaster saipanensis* Bramlette & Riedel in Singh & Singh, p. 151, pl. 4, figs 20-22.

1994 *Discoaster saipanensis* Bramlette & Riedel in Jafar & Rai, p. 34, pl. 2, fig. 19.

1997 *Discoaster saipanensis* Bramlette & Riedel in Rai, p. 154, pl. II, figs 6-7; pl. IV, fig. 11.

Remarks—Discoaster saipanensis was originally reported from the late Eocene of Saipan Islands (Bramlette & Riedel, 1954; Bramlette, 1959). Five to eight-rayed asteroliths are distinguished from similarly looking *D. barbadiensis, D. elegans* and *D. sublodoensis* by abrupt termination of ray tips with slight concavity giving inter-ray areas a characteristic outline. Typical stem on the proximal side tapers and lies in a depressed central area, often displaying pits and grooves extending into region of rays. This feature is characteristic for *D. elegans,* but seen in several EM pictures of *D. saipanensis*, often interpreted as being caused due to corrosion of asteroliths.

Asteroliths of *D. saipanensis* range in size between 9 to 18 μm in the study material and similar size variations are reported in literature. The smaller specimens are rare compared to larger forms. Seven rayed forms are most common followed by 8 rayed asteroliths, whereas 6 to 5 rayed forms are rare to extremely rare. Relative abundance of 5-8 rayed forms compared with their respective size, may prove to be of use in distinguishing open ocean vs. hemipelagic deposits (Bukry, 1971b).

D. saipanensis is extremely useful for biostratigraphy. First occurrence of *D. saipanensis* in the upper part of NP 16 (late Middle Eocene) as indicated by Martini (1971a) remains unchanged, despite doubtful lower extended range plotted for this species by Perch-Nielsen (1985b). Extinction of *D. saipanensis* together with *D. barbadiensis* defines the Eocene-Oligocene boundary. As the last occurrences of *Rhabdosphaera gladius* and *Chiasmolithus solitus* are used to define the lower and upper boundary of Zone NP 16, and both these markers being absent in Kutch Basin. First occurrence of *D. saipanensis* is used to define the base of emended NP 17 Zone (Rai, 1988), which would include upper part of Martini's (1971a) NP 16 Zone. The emended definition of NP 17, thus appears to be useful in India and other low-latitude areas, which should correspond to definition of Bartonian as suggested by Aubry (1985a). *D. saipanensis* is frequent to rare in Harudi and rare in Fulra Limestone formations.

Discoaster tanii Bramlette & Riedel, 1954

(Pl. 12.7)

Synonymy list—

1954 *Discoaster tani* Bramlette & Riedel, p. 397, pl. 39, fig. 1.

1959 *Discoaster tani* Bramlette & Riedel in Bramlette, p. 250, pl. 61, fig. 8.

1959a *Discoaster tani* Bramlette & Riedel in Stradner, p. 1085, fig. 16.

1959b *Discoaster tani* Bramlette & Riedel in Stradner, p. 479, abb. 43-44.

1961 *Discoaster tani* Bramlette & Riedel in Stradner & Papp, p. 82-83, pl. 16, figs 3-4.

non1971a *Discoaster tani nodifer* Bramlette & Riedel in Perch-Nielsen, pl. 52, fig. 3.

1975 *Discoaster tani* Bramlette & Riedel in Proto Decima *et al.*, p. 49, pl. 4, fig. 9, non fig. 13.

1984 *Discoaster tanii* Bramlette & Riedel in Steinmetz & Stradner, p. 729, pl. 30, fig. 3.

1994 *Discoaster tanii* Bramlette & Riedel in Jafar & Rai, p. 34, pl. 2, fig. 30.

Remarks—Originally described from the late Eocene (Bramlette & Riedel, 1954). Five to six rayed asteroliths are distinguished by uniform width of slender rays which end abruptly with small notch at the ray-tips. Small nodes are distributed rather irregularly which may or may not be present.

Record of so called *Turbodiscoaster tanii tanii* from the late Palaeocene by Prins (1971) is doubtful and has since not been confirmed. Stratigraphically useful *D. tanii* thus appears roughly at the same level as suggested by Bukry (1973a) viz. CP 14b/NP 17 and extends up to early Oligocene.

In the study material only 6 rayed *D. tanii* is consistently present as frequent to rare throughout Harudi Formation with a size range of 9-15 μm.

Family—HELICOSPHAERACEAE

Black, 1971 emend. Jafar & Martini, 1975

The Cenozoic family Helicosphaeraceae is characterised by peculiar helicoid coccoliths ("Helicoliths" of Jafar & Martini, 1975). More than 50 species have been validly published so far and included within a solitary genus *Helicosphaera* (Kamptner, 1954). Several species have short stratigraphic range, and have been used as markers or serve as supplementary guide fossils in the Tertiary hemipelagic deposits. Curiously enough, only one living species viz. *Helicosphaera carteri* (Wallich, 1877) Kamptner 1954, was known till 1961, when Bramlette & Sullivan (1961) recorded first fossil species from Eocene of California, and since then number of fossil species have been recorded.

The taxonomic and nomenclatural problems of the valid genus *Helicosphaera* (Kamptner, 1954) against invalidly published genus *Helicopontosphaera* (Hay & Mohler), is thoroughly discussed in Jafar & Martini (1975), wherein strong arguments were put forward to support the validity of generotype *Coccolithus carteri* (Wallich, 1877) Kamptner 1941 ex "Coccosphaera" carteri Wallich, 1877. Coccosphere morphology, rather than structure of individual coccolith, is crucial in making the distinction between cells of *C. carterii* and *C. pelagica*, as done by Wallich (1877). Thus, there are no two school of thoughts as far as validity of *Helicosphaera* is concerned (Perch-Nielsen, 1985b, p. 485) and there is widespread consensus among the workers to use the name *Helicosphaera* for taxonomic purpose. The oldest reported species of *Helicosphaera* viz. *Helicopontosphaera* cf. *H. lophota* (Bramlette & Sullivan, 1961) is from Palaeocene of Persia (Zone NP 5). Haq, 1971a ; Pl. III, fig. 2 reported a large specimen with a sturdy bar and a pair of openings. The other record of Palaeocene helicolith (Zone NP 9) is by Perch-Nielsen (1977), reproduced in Perch-Nielsen (1985b; fig. 46.13) which shows *H. seminulum* like structure in distal view of an electronmicrograph. Thus, two distinct and large helicoliths representing *H. seminulum* and *H. lophota* type morphotypes recorded in Palaeocene which proliferated into a variety of species in the younger part of the Tertiary. Overviews being provided by Martini (1971b), Haq (1973), Perch-Nielsen (1985b), Theodoridis (1984) and Aubry (1988).

Helicosphaera species are rather scarce in Indian Tertiary deposits, which represent extremely shallow water facies in outcrop sections. However, in a borewell section in Karaikal (Cauvery Basin, southeastern India) extremely well preserved helicoliths were observed throughout the Palaeogene and the earliest helicolith bearing sample of NP 11 Zone contained well preserved *H. lophota* (Jafar & Rai unpublished data). Late Eocene (NP 20) *Pellatispira* bearing beds of Surat area in western India yielded *H. compacta*, *H. reticulata*, *H. euphratis*, *H. neolophota* and *H. salebrosa* (Jafar *et al.*, 1985).

In the study area, helicoliths are sparse owing to shallow water nature and restricted open ocean circulation pattern are doubtful. However, several late Middle Eocene (Bartonian) species are recorded here, e.g., *H. lophota, H. seminulum, H. heezenii, H. reticulata, H. compacta* and *H. bramlettei.*

Genus—HELICOSPHAERA Kamptner 1954 ex Jafar & Martini, 1975

Helicosphaera bramlettei (Müller) Jafar & Martini, 1975

(Pl. 10.6A-B, 8)

Synonymy list—

1967 *Helicosphaera* aff. *H. seminulum* Bramlette & Sullivan in Bramlette & Wilcoxon, p. 106, pl. 5, figs 11-12.

1970a *Helicopontosphaera bramlettei* Müller p. 114, pl. 5, figs 4-6.

1973 *Helicopontosphaera bramlettei* Müller in Haq, p. 36, pl. 3, figs 3-4.

1975 *Helicosphaera bramlettei* (Müller) Jafar & Martini, p. 390.

1976 *Helicopontosphaera bramlettei* Müller in Haq & Lohmann, p. 170, pl. 13, fig. 7.

1977 *Helicopontosphaera bramlettei* Müller in Báldi-Beke, p. 74, pl. 4, fig. 3, ?9.

1988 *Helicosphaera bramlettei* (Müller) Jafar & Martini in Aubry, p. 68, figs 2, 4.

Remarks—Helicoliths of *Helicosphaera bramlettei* were originally described from late Middle Oligocene (of borehole material) of southern Germany (Müller, 1970a), both under LM and EM, indicating its range from the late Eocene to late Oligocene (Zone NP 25). However, the credit for pointing out the usefulness and distinctive nature of this species should go to Bramlette and Wilcoxon (1967, p. 106), who found it in Oligocene of Cipero Section. The specimens of *Helicosphaera* aff. *H. seminulum* (pl. 5, figs 11-12) from *Globotruncana ampliapertura* Zone is not *H. bramlettei* as interpreted by few workers, but appear to be a form transitional between *H. seminulum* Bramlette & Sullivan (1961) and *H. bramlettei.* Beside this, *H. intermedia* illustrated by Bramlette & Wilcoxon (1967, pl. 6, figs 11-12) is also not *H. bramlettei* as considered by Perch-Nielsen (1985b, p. 488).

Under LM *H. bramlettei* shows the characteristic bridge in the form of thick "I" with oblique orientation and spanning a comparatively small central area. *H. intermedia* has 'S' shaped bridge and a distinct flange. *H. seminulum* and *H. lophota* have different shape and orientation of bridge, though share overall oval outline of *H. bramlettei.*

H. bramlettei recorded here rarely from upper part of Harudi Formation and Fulra Limestone Formation are almost indistinguishable from the holotype (Müller, 1970a, pl. 5, figs 5-6), in size and appearance under the LM.

According to Haq (1973) it ranges from late Eocene (Zone NP 18) to late Oligocene (Zone NP 25) but Perch-Nielsen (1985b) recorded it from Zone NP 17 (questionably from NP-15) to Zone NP 25 and Aubry (1988) suggested its range from Zone NP 17 to Zone NP 23. The present study shows the presence of *H. bramlettei* in the upper part of NP 16 Zone. Extinction level of *H. bramlettei* is within NP 25 (Müller, 1970b; Haq, 1973; Báldi-Beke, 1977; Perch-Nielsen, 1985b).

Helicosphaera compacta Bramlette & Wilcoxon, 1967

(Pl. 10.7A-B)

Synonymy list—

1967 *Helicosphaera compacta* Bramlette & Wilcoxon, p. 105, pl. 6, figs 5-8.

1970 *Helicopontosphaera compacta* (Bramlette & Wilcoxon) Roth, p. 861-862, pl. 10, fig. 2, non fig. 4.

1971a *Helicopontosphaera compacta* (Bramlette & Wilcoxon) Roth in Perch-Nielsen, p. 42, pl. 34, fig. 6.

1973 *Helicopontosphaera compacta* (Bramlette & Wilcoxon) Hay in Haq, p. 36-37, pl. 2, fig. 6; pl. 7, figs 1-2.

1975 *Helicopontosphaera compacta* (Bramlette & Wilcoxon) Roth in Proto Decima *et al.*, p. 50, pl. 5, figs 15a-b.

1975 *Helicopontosphaera compacta* (Bramlette & Wilcoxon) Roth in Bybell, p. 212, pl. 18, fig. 4.

1976 *Helicopontosphaera compacta* (Bramlette & Wilcoxon) Hay in Haq & Lohmann, p. 170, pl. 13, fig. 6.

1977 *Helicopontosphaera compacta* (Bramlette & Wilcoxon) Bukry in Báldi-Beke, p. 74, pl. 4, figs 1-2, ?fig. 5.

1988 *Helicosphaera compacta* Bramlette & Wilcoxon in Aubry, figs 2, 4.

1994 *Helicosphaera compacta* Bramlette & Wilcoxon in Jafar & Rai, p. 34.

Remarks—Characteristic helicoliths of *Helicosphaera compacta* displaying asymmetric oval outline were originally described from Oligocene of Cipero Section (Bramlette & Wilcoxon, 1967) and indicated to range from late Eocene to late Oligocene. Under crossed nicols, large part of the helicolith remains dark, while bright small central area shows tiny pair of openings separated by a thin birefringent bar.

The specimens from Kutch Basin show slight pitting on specimens overgrown with calcite, ranging in size between 10-13 µm. It is rarely present throughout Harudi and Fulra Limestone formations.

First appearance of *H. compacta* was indicated by Martini (1971a) to be at the base of Zone NP 17. Aubry (1988), however, shows first appearance in Zone NP 16, which agrees with our data, wherein upper part of NP 16 is included in emended definition of NP 17. Last appearance of *H. compacta* seems to be within NP 24, where it is replaced by younger and stratigraphically useful *H. recta* (Perch-Nielsen, 1985b; Aubry, 1988).

Helicosphaera heezenii (Bukry) Jafar & Martini, 1975

(Pl 10.1A-C, 2A-B)

Synonymy list—

1971a *Helicopontosphaera heezenii* Bukry, p. 318-320, pl. 5, figs 1-5.

1973 *Helicopontosphaera heezenii* Bukry in Haq, p. 37, pl. 1, fig. 5; pl. 3, figs 5-6.

1975 *Helicosphaera heezenii* (Bukry) Jafar & Martini, p. 390.

?1977 *Helicopontosphaera heezenii* Bukry in Perch-Nielsen, pl. 22, fig. 6.

1988 *Helicosphaera heezenii* (Bukry) Jafar & Martini in Aubry, fig. 2.

Remarks—Large helicoliths of *Helicosphaera heezenii*, possessing irregular oval outline were originally described from the late Middle Eocene of Pacific Ocean. Under normal and crossed polarised illumination a fairly large and conspicuous "bar" apparently consisting of composite crystallites is aligned along the longer axis of the helicolith.

It is reported from the upper part of NP 15 to NP 16 Zones (Perch-Nielsen, 1985b; Aubry, 1988). Kutch specimens (13 to 18 µm) are slightly overgrown and rarely recorded in Harudi and Fulra Limestone formations. From the evidences of other microfossils, the occurrence in Fulra Limestone would extend its upward range into NP17 Zone of Martini (1971a).

Helicosphaera lophota (Bramlette & Sullivan) Jafar & Martini, 1975

(Pl. 11.2-3)

Synonymy list—

1961 *Helicosphaera seminulum lophota* Bramlette & Sullivan, p. 144, pl. 4, figs 3a-b, 4.

1964 *Helicosphaera seminulum lophota* Bramlette & Sullivan in Sullivan, p.184, pl. 5, figs 2a-b.

1965 *Helicosphaera seminulum lophota* Bramlette & Sullivan in Sullivan, p. 35, pl. 6, figs 5a-b.

1967 *Helicosphaera seminulum lophota* Bramlette & Sullivan in Perch-Nielsen, p. 25, Pl. 3, figs 1-3.

1970 *Helicopontosphaera lophota* (Bramlette & Sullivan) Bukry *et al.*, p. 1300.

1971a *Helicopontosphaera lophota* (Bramlette & Sullivan) Bukry *et al.* in Perch-Nielsen, p. 43, pl. 34, figs 1-2; pl. 36, fig. 2, non fig. 1.

1973 *Helicopontosphaera lophota* (Bramlette & Sullivan) Bukry *et al.* in Haq, p. 40, pl. 1, figs 1-3; pl. 3, figs 9-10.

1975 *Helicosphaera lophota* (Bramlette & Sullivan) Jafar & Martini, p. 391.

1977 *Helicopontosphaera lophota* (Bramlette & Sullivan) Bukry *et al.* in Perch-Nielsen, p. 781, pl. 21, fig. 5.

1988 *Helicosphaera lophota* (Bramlette & Sullivan) Jafar & Martini in Aubry, fig. 2.

Remarks—Helicoliths of *Helicosphaera lophota* with oval outline are similar to that of *H. seminulum*, but are distinguished by a sturdy bar aligned nearly parallel to major axis of helicolith.

The species is reported from NP 12 to NP 18 Zones (Perch-Nielsen, 1971; Aubry, 1988). The taxon is rarely recorded from Fulra Limestone Formation and extremely scarce in Harudi Formation.

Helicosphaera reticulata
Bramlette & Wilcoxon, 1967

(Pl. 10.4A-B)

Synonymy list—

1967 *Helicosphaera reticulata* Bramlette & Wilcoxon, p. 106, pl. 6, fig. 15.

1971 *Helicopontosphaera reticulata* (Bramlette & Wilcoxon) Roth, p. 863, pl. 10, fig. 5.

1971 *Helicopontosphaera reticulata* (Bramlette & Wilcoxon) Bukry *et al.*, p. 1300.

1971a *Helicopontosphaera reticulata* (Bramlette & Wilcoxon) Martini in Martini, p. 782-783, pl. 3, figs 3-4.

1975 *Helicosphaera reticulata* Bramlette & Wilcoxon in Jafar & Martini, pl. 391.

1975 *Helicopontosphaera reticulata* (Bramlette & Wilcoxon) Roth in Bybell, p. 214, pl. 18, figs 8a-b.

1975 *Helicopontosphaera reticulata* (Bramlette & Wilcoxon) Roth in Proto Decima *et al.*, p. 50, pl. 5, figs 19a-b.

1977 *Helicopontosphaera reticulata* (Bramlette & Wilcoxon) Bukry *et al.* in Perch-Nielsen, p. 781-783, p. 22, fig. 4.

1988 *Helicopontosphaera reticulata* (Bramlette & Wilcoxon) Bukry *et al.* in Aubry, figs 2, 4.

Remarks—Large helicoliths of *Helicosphaera reticulata* are diagnosed by the nearly sub-rhomboidal outline with pitted appearance coupled with sturdy bar nearly parallel to major axis leaving two long slit like openings. Originally the species was described from early Oligocene.

The Kutch specimens are around 13 μm in size and associated with typical *H. compacta.* It is absent in Harudi and rarely recorded from Fulra Limestone Formation. Martini (1971a) indicated a range from Zone NP20-NP22, while Perch-Nielsen (1985b) suggested questionable occurrence in Zone NP17 and actual range from Zone NP18-NP22. Aubry (1988) suggested Zone NP18-NP23 range for *H. reticulata*. The occurrence of *H. reticulata* in Fulra Limestone Formation suggests its earliest occurrence in Zone NP 17.

Helicosphaera seminulum (Bramlette & Sullivan)
Jafar & Martini, 1975

(Pl. 10.9, 10A-B; Pl. 11, 1A-B)

Synonymy list—

1961 *Helicosphaera seminulum seminulum* Bramlette & Sullivan, p. 144, pl. 4, figs 1a-c, 2.

1968 *Helicosphaera seminulum* Bramlette & Sullivan in Stradner & Edwards, p. 38-39, fig. 1; pl. 40, figs 1-5.

1970 *Helicopontosphaera seminulum* (Bramlette & Sullivan) Roth, p. 863.

1971a *Helicopontosphaera seminulum* (Bramlette & Sullivan) Bukry in Perch-Nielsen, p. 44 pl. 34, fig. 4; pl. 35, figs 1-2, 5-6; pl. 36, figs 4, 7-8; pl. 37, fig. 6.

1973 *Helicopontosphaera seminulum* (Bramlette & Sullivan) Bukry in Haq, p. 46, pl. 1, fig. 4; pl. 3, figs 7-8.

1975 *Helicosphaera seminulum* (Bramlette & Sullivan) Jafar & Martini, p. 391.

1975 *Helicopontosphaera seminulum* (Bramlette & Sullivan) Bukry in Proto Decima *et al.*, p. 50, pl. 2, figs 15a-c; pl. 5, figs 12a-b.

1975 *Helicopontosphaera seminulum* (Bramlette & Sullivan) Roth in Bybell, p. 214, pl. 18, figs 5a-b.

1977 *Helicopontosphaera seminulum* (Bramlette & Sullivan) Bukry in Perch-Nielsen, pl. 21, fig. 4 ; pl. 22, fig. 7.

1988 *Helicosphaera seminulum* (Bramlette & Sullivan) Jafar & Martini in Aubry, figs 2, 8.

Remarks—Large to medium size helicoliths of *Helicosphaera seminulum* were originally described from Lodo Formation of California. Outline is irregular oval with small flange in some specimens. It is distinguished from similar looking *H. lophota* by the presence of distinct birefringent bridge more aligned along the minor axis of the helicolith. Intermediate forms between the two are not uncommon.

H. seminulum is reported to range from Zone NP12 to top NP 16 (Perch-Nielsen, 1985b) and Zone NP 12 to base NP16 (Aubry, 1988). It ranges between 10-13 µm and is rare both in Harudi and Fulra Limestone formations. Presence of the species suggests an upper extended range into NP17 Zone of Martini (1971a).

Helicosphaera sp. 1

(Pl. 10.3A-C)

Remarks—Rare helicoliths of *Helicosphaera* sp. 1 belong to *H. seminulum-H. lophota* plexus lacking oval outline but with a distinct flange and a narrow sturdy bar aligned parallel to major axis as in *H. lophota*. Unlike *H. seminulum*, the bar is best visible in *H. lophota*, when aligned parallel to the direction of polarization. Rarely occurs in Harudi Formation.

Helicosphaera sp. 2

(Pl. 10.5A-B)

Remarks—Elongated helicoliths of *Helicosphaera* sp. 2, grossly resemble *H. seminulum* in displaying extremely short and sturdy bar aligned more along the minor axis of helicolith, leaving a pair of openings. Rarely recorded from Fulra Limestone Formation.

Family—LITHOSTROMATIONACEAE Deflandre, 1959

(= **LITHOSTROMATIONACEAE** Haq, 1967)

The Tertiary family Lithostromationaceae is characterised by geometrical coccoliths of fairly large size, displaying trigonal, hexagonal or polygonal outline and remain practically dark under crossed polarised illumination. Depressions of varying size and shape decorate the coccoliths, which have so far not yielded evidence of being holococcoliths, due to bad preservation of material (Bybell, 1975). But the appearance under LM and common association with abundant holococcoliths in hemipelagic sediments, strongly suggests holococcolith nature of these coccoliths as suggested by Reinhardt (1972).

A survey of the literature reveals that family Lithostromationaceae should include only solitary genus *Lithostromation* Deflandre, 1942 and genera *Trochoaster* Klumpp, 1953 and *Martinaster* Loeblich & Tappan, 1963 should be considered as synonyms. Single species described under genus *Martinaster*, *M. fragilis* (Martini) Loeblich & Tappan 1963 should be transferred to *Lithostromation* by a new combination as *Lithostromation fragilis* (Martini) comb. nov.

Basionym—*Coronaster fragilis* Martini 1961b, p.102, abb. 2.

Synonym—*Martinaster fragilis* (Martini) Loeblich & Tappan 1963, p.193.

Earliest report of this genus comes from the early Eocene (Martini, 1961b) represented by *L. deflandrei* and *L. simplex* with common occurrence in the Middle Eocene. Younger occurrence of the taxon, though rare, through Oligocene-Pliocene is doubtful. Although species of *Lithostromation* are never common, even in the middle Eocene, they share similar ecological requirements as holococcoliths in shallow hemipelagic sequences.

In the study material, three well known species of *Lithostromation* viz. *L. simplex* with hexagonal outline, *L. operosum* with polygonal and *L. perdurum* with triangular outlines are documented. All the recorded species occur rarely in the Harudi Formation. Other reports of this genus from Indian region need scrutiny. *Lithostromation* sp. described from late Eocene (Zone NP 20) of Baroach (Pant & Mathur, 1973) and *Lithostromation perdurum* from Miocene of Andaman Islands (Pant & Misra, 1976) are indeterminate calcareous fragments.

Genus—LITHOSTROMATION Deflandre, 1942

Lithostromation operosum (Deflandre) Bybell, 1975

(Pl. 18.5)

Synonymy list—

1954 *Polycladolithus operosus* Deflandre in Deflandre & Fert, p. 56, pl. 12, figs 3-6, text-fig. 125.

non 1959 *Polycladolithus operosus* Deflandre in Stradner, text-fig. 73.

1961 *Polycladolithus operosus* Deflandre in Bramlette & Sullivan, pl. 14, figs 13a-d.

1961 *Trochoaster operosus* (Deflandre) Stradner & Papp, p. 133-134, pl. 41, fig. 6.

1962 *Trochoaster operosus* (Deflandre) Stradner & Papp in Bouché, pl. 4, figs 7a-b, 8.

1964 *Polycladolithus operosus* Deflandre in Sullivan, pl. 9, figs 8a-b.

1970 *Trochoaster operosus* (Deflandre) Stradner & Papp in Hodson & West, pl. 4, fig. 8.

1971 *Trochoaster operosus* (Deflandre) Stradner & Papp in Bàldi-Beke, pl. 6, figs 17, ?10.

1975 *Lithostromation operosum* (Deflandre) Bybell, p. 202, pl. 19, figs 1, 3-4.

Remarks—The species was originally described from the late Eocene of New Zealand (Deflandre in Deflandre & Fert, 1954). Spherical coccoliths have symmetrically arranged depressions. The outline is slightly serrated with six protruding ridges sometimes with a smaller ridge in between. The overall morphology bears close resemblance with *L. fragilis* (Martini) comb. nov.

A single record of this species is known from Palaeocene (Sullivan, 1964), otherwise confined to Eocene. Original description from Oamaru Diatomite (Deflandre & Fert, 1954) is considered late Eocene (Zone NP 20) rather than Oligocene.

Lithostromation perdurum Deflandre, 1942

(Pl. 18.4)

Synonymy list—

1942 *Lithostromation perdurum* Deflandre, p. 918, text-figs 1-9.

1959b *Lithostromation perdurum* Deflandre in Stradner, figs 70-72.

1962b *Lithostromation robustum* Martini, pl. 2, abb. 1a-b.

1963 *Lithostromation perdurum* Deflandre in Martini & Bramlette, pl. 102, fig. 8.

1970 *Lithostromation perdurum* Deflandre in Roth, p. 868-869, pl. 13, figs 1-2.

1971 *Lithostromation perdurum* Deflandre in Bàldi-Beke, pl. 6, fig. 18.

1971a *Lithostromation perdurum* Deflandre in Perch-Nielsen, pl. 6, fig. 18.

1975 *Lithostromation perdurum* Deflandre in Bybell, p. 203-204, pl. 19, fig. 6.

Remarks—Lithostromation perdurum, the type species of the genus was originally described from the Miocene of Algeria (Deflandre, 1942). It is reported sporadically from Eocene to Miocene sediments. Triangular outline of coccolith is characteristic, though considerable variations occur viz., pronounced tapering of arms during the Miocene. Variable crenulations on the sides with straight or slightly convex outline is seen.

Lithostromation simplex (Klumpp) Bybell, 1975

(Pl. 18.2-3)

Synonymy list—

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

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

1958 *Trochoaster simplex* Klumpp in Martini, p. 368, pl. 5, figs 25a-b.

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

1960 *Trochoaster simplex* Klumpp in Martini, pl. 10, fig. 35.

1961a *Trochoaster simplex* Klumpp in Martini, p. 2.

1961 *Trochoaster simplex* Klumpp in Stradner & Papp, p.131, pl. 42, figs 1-4, 6a-d.

1962 *Trochoaster simplex* Klumpp in Bouchè, p. 91-92, pl. 4, figs 6a-b.

1962 *Trochoaster simplex* Klumpp in Stradner, pl. 2, fig. 17.

1970 *Trochoaster simplex* Klumpp in Hodson & West, p. 170.

1971a *Trochoaster simplex* Klumpp in Perch-Nielsen, p. 58, pl. 57, fig. 8.

1971 *Trochoaster simplex* Klumpp in Bàldi-Beke, p. 36, pl. 6, fig. 12.

1972 *Trochoaster simplex* Klumpp Reinhardt, p. 80, fig. 142.

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

1997 *Lithostromation simplex* (Klumpp) Bybell in Rai, p. 155, pl. III, fig. 3.

Remarks—Hexagonal outline coupled with symmetrical depressions on coccolith surfaces are diagnostic features of *L. simplex*.

Family—PONTOSPHAERACEAE
Lemmermann in Brandt & Apstein, 1908

Family Pontosphaeraceae Lemmermann (1908) includes genera *Pontosphaera* Lohmann (1902), *Transversopontis* Hay *et al.* (1966) and *Scyphosphaera* Lohmann (1902), besides a few doubtful genera assigned to this family (Perch-Nielsen 1985a). Ancestry of this family can be traced down to Late Cretaceous, being represented by small species of *Pontosphaera* (Perch-Nielsen 1985b).

In the study material, only genus *Pontosphaera* has been found, which seems to be more controlled by facies in extremely shallow water setting. In bore-well material of Karaikal in Cauvery Basin, southeastern India, the family is commonly represented by well preserved forms throughout Palaeogene section (Jafar & Rai unpublished data).

Genus—PONTOSPHAERA Lohmann, 1902

Pontosphaera multipora (Kamptner) Roth, 1970

(Pl. 12.13A-B, 14A-B, 15)

Synonymy list—

1948 *Discolithus multiporus* Kamptner, p. 5, pl. 1, fig. 9.

1965 *Discolithus distinctus* Bramlette & Sullivan in Sullivan, p. 33, pl. 4, figs 1-6.

1967 *Discolithina vigintiforata* (Kamptner ex Deflandre) Loeblich & Tappan-Bramlette & Wilcoxon, p. 104, pl. 5, figs 3-4.

1968 *Discolithina multipora* (Kamptner) Martini in Stradner & Edwards, pl. 32, figs 1-4; pl. 33, figs 1-3; pl. 34, figs 1-2; pl. 35, figs 1-8.

1970 *Pontosphaera multipora* (Kamptner) Roth, p. 860.

1971a *Pontosphaera multipora* (Kamptner) Roth in Haq, p. 21-22.

1971b *Pontosphaera multipora* (Kamptner) Roth in Haq, p. 21-22, pl. 4, figs 4-6, 8-9; pl. 7, figs 3-4; pl. 14, figs 4-5.

1971 *Discolithina multipora* (Kamptner) Martini in Báldi-Beke, p. 26, pl. 1, figs 2-4.

1971a *Discolithina multipora* (Kamptner) Martini in Perch-Nielsen, p. 34, pl. 26, figs 1-5.

1975 *Discolithina multipora* (Kamptner) Martini in Haq-Bybell, p. 206, pl. 20, figs 1, 4a-b.

1975 *Pontosphaera multipora* (Kamptner) Roth in Proto Decima *et al.*, p. 50, pl. 5, figs 24a-b.

1977 *Pontosphaera multipora* (Kamptner) Roth in Perch-Nielsen, pl. 27, fig. 9.

1977 *Discolithina multipora* (Kamptner) Martini in Báldi-Beke, p. 74, pl. 2, fig. 12.

Remarks—*Pontosphaera multipora* was originally described from the Miocene of Austria. It is characterised by three or more rows of pores in the basal plate with a thin rim and much reduced height of the wall. Overgrown specimens, such as those found in the study area display characteristic extinction pattern under crossed polarised light with faintly visible pores. The specimens measure ca. 9 µm in Harudi Formation.

Pontosphaera versa (Bramlette & Sullivan) Sherwood, 1974

(Pl. 12.16)

Synonymy list—

1961 *Discolithus versus* Bramlette & Sullivan, p. 144, pl. 3, figs 16a-d.

1964 *Discolithus versus* Bramlette & Sullivan in Sullivan, p.183, pl. 4, fig. 11.

1965 *Discolithus versus* Bramlette & Sullivan in Sullivan, p. 35, pl. 5, figs 8a-b, 9a-b.

Remarks—Pontosphaera versa was originally described from Early-Middle Eocene of California (Bramlette & Sullivan, 1961). Under LM, distinct bright rim with characteristic extinction pattern under crossed polarised illumination are diagnostic features. The present specimens are ca. 6 µm in size.

Pontosphaera sp.

(Pl. 12.17)

Remarks—Pontosphaera species of dimunitive size (ca. 3 µm) is distinguished by characteristic extinction pattern under crossed polarized light. Such tiny specimens are expected to be found in Palaeocene and Late Cretaceous.

Family—PRINSIACEAE Hay & Mohler, 1967

Family Prinsiaceae Hay and Mohler (1967) includes placoliths of circular-subcircular to elliptical outline, having practically no change in size of coccoliths under crossed polarised illumination, because both the shields remain bright. Generic differentiation is best done with combined character observed through LM & EM.

The origin of Prinsiaceae from genus *Biscutum* remains uncertain which appears in Late Triassic (Jafar, 1983), and gives rise to several evolutionary lineages during the Jurassic (Bown, 1987; Crux, 1987). Members of Prinsiaceae are important constituent of nannoflora throughout Tertiary, but species differentiation can be difficult based only on light microscope.

In the present study, genera *Cribrocentrum* Perch-Nielsen (1971), *Cyclicargolithus* Bukry (1971a), *Dictyococcites* Black (1967) and *Reticulofenestra* Hay *et al.* (1966) are discussed with reference to other occurrences in Indian Tertiary where such forms show overgrowth.

Cribrocentrum coenurum (Reinhardt) Perch-Nielsen, 1971

(Pl. 8.9A-B, 10, 12A-B)

Synonymy list—

1966 *Coccolithus coenurus* Reinhardt, pl. 1, fig. 7, text-fig. 6.

1970 *Reticulofenestra coenura* (Reinhardt) Roth, p. 847.

1971a *Cribrocentrum coenurum* (Reinhardt) Perch-Nielsen., p. 26, pl. 21, figs 1-6.

1973 *Reticulofenestra coenura* (Reinhardt) Roth in Roth, p. 732.

1975 *Cribrocentrum coenurum* (Reinhardt) Perch-Nielsen in Edwards & Perch-Nielsen, p. 520, pl. 12, figs 8, 10.

1975 *Reticulofenestra coenura* (Reinhardt) Roth in Proto Decima *et al.*, p. 48, pl. 2, figs 13a-b.

Remarks—The species was originally described from the Eocene of Germany, both under LM and EM. Under LM, *C. coenurum* is distinguished by smaller size, but showing similar extinction pattern under crossed nicols as *Reticulofenestra umbilica*. The genus *Cribrocentrum* is defined based on EM studies, where a sturdier network of central area and details of rim elements are recognised supporting separation from the genus *Reticulofenestra* Perch-Nielsen (1971).

Kutch specimens are slightly overgrown (7-10 µm) and frequently occur in Harudi and rarely in Fulra Limestone Formation.

Cribrocentrum reticulatum (Gartner & Smith) Perch-Nielsen, 1971

(Pl. 9.10, 11)

Synonymy list—

1967 *Cyclococcolithus reticulatus* Gartner & Smith, p. 4, pl. 5, figs 1-4.

1971a *Cribrocentrum reticulatum* (Gartner & Smith) Perch-Nielsen, p. 28, pl. 25, figs 9.

1971a *Cyclicargolithus reticulatus* (Gartner & Smith) Bukry, p. 313.

1975 *Reticulofenestra reticulata* (Gartner & Smith) Roth in Proto Decima *et al.*, p. 48, pl. 2, figs 21a-b.

1975 *Cyclococcolithina reticulata* (Gartner & Smith) Bybell, p. 195-196, pl. 16, figs 1-3.

1978b *Heliolithus* sp. Singh *et al.*, p. 7, pl. 4, figs 16-26.

1981a *Cribrocentrum reticulatum* (Gartner & Smith) Perch-Nielsen in Martini, pl. 4, figs 7-8.

1985 *Reticulofenestra reticulata* (Gartner & Smith) Roth in Jafar, p. 172, fig. 18.

Remarks—Originally described from late Eocene of Louisiana (small forms). The species can be readily identified both under LM and EM. It possesses nearly circular placoliths, displaying a characteristic squarish area, traversed by dark extinction lines. *Cribrocentrum reticulatum* appears to be valuable both as stratigraphic marker and palaeoceanographic indicator. Saunders *et al.* (1984) indicated Zone NP 17-NP 20 range. Perch-Nielsen (1985b) recorded the first occurrence (FO) around Zone NP 16/NP 17 boundary and last occurrence (LO) shortly before Zone NP 20/NP 21 boundary. Martini (1981a) recorded this species from combined NP 19/NP 20 Zone with *I. recurvus* indicating a range from the upper part of Zone NP 16 to NP 20. This data is consistent with that of Aubry (1988), who recognises the FO of *C. reticulatum* in upper part of NP 16 to recognise Lutetian/Bartonian boundary.

In India, *C. reticulatum* occurs (large and small forms) commonly with *Pellatispira* bearing Priabonian beds (NP 20) of Surat in western India (Singh *et al.*, 1978b; Jafar *et al.*, 1985) and Andaman Islands (Jafar, 1985). The total range of *C. reticulatum* is thus spanning Bartonian-Priabonian time slice. Biometric analysis of assemblages containing small, medium and large forms would be useful in recognising open ocean influences in nearshore deposits, as larger forms are more frequent in open-ocean setting (Saunders *et al.*, 1984).

In the present material only small forms (ca. 6 µm, nearly matching the size of the holotype) were rarely recorded in both the formations.

Genus—CYCLICARGOLITHUS Bukry, 1971a

Cyclicargolithus floridanus (Roth & Hay) Bukry, 1971a

(Pl. 8.11A-B; Pl. 9.3A-B, 4-5, 7-9)

Synonymy list—

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

1967 *Cyclococcolithus neogammation* Bramlette & Wilcoxon, p. 104, pl. 1, figs 1-3; pl. 4, figs 3-5.

1970a *Cyclococcolithus floridanus* (Roth & Ray) Müller, p.113, pl. 2, figs 1-3.

1971a *Cyclicargolithus floridanus* (Roth & Hay) Bukry, p. 312-313.

1973 *Cyclicargolithus floridanus* (Roth & Hay) Bukry in Roth, p. 731, pl. 6, figs 2-5; pl. 8, fig. 4; pl. 11, figs 1-2.

1975 *Cyclicargolithus floridanus* (Roth & Hay) Bukry in Proto Decima *et al.*, p. 47, pl. 2, figs 12a-b.

1977 *Cyclicargolithus floridanus* (Roth & Hay) Bukry in Huang, p. 174, fig. 9, C1-C3.

1979 *Cyclicargolithus floridanus* (Roth & Hay) Bukry in Huang & Ting, p. 116, pl. 1, figs 3a-b.

1980 *Cyclicargolithus floridanus* (Roth & Hay) Bukry in Backmann, pl. 2, fig. 5.

1984 *Cyclicargolithus floridanus* (Roth & Hay) Bukry in Steinmetz & Stradner, p. 677, pl. 28, figs 1-2.

1994 *Cyclicargolithus floridanus* (Roth & Hay) Bukry in Jafar & Rai, p. 35, pl. 2, fig. 3.

Remarks—Originally described from Oligocene of Blake Plateau. Small to medium size placoliths show birefringent distal shield. Under LM, no distinction can be made with similar *C. marismontium* Black (Perch-Nielsen, 1985b). Under EM, *C. floridanus* is quite distinctive by having characteristic shield elements and a small netless central opening. Broken extinction lines are a distinguishing feature of this species.

C. floridanus appears in the upper part of Zone NP 16 and becomes extinct in middle Miocene. In Oligocene it may be extremely abundant at certain levels. *C. floridanus* is frequent in Harudi and rare in Fulra Limestone Formation.

Genus—DICTYOCOCCITES Black, 1967

Dictyococcites scrippsae Bukry & Percival, 1971

(Pl. 9.6)

Synonymy list—

1971 *Dictyococcites scrippsae* Bukry & Percival, p.128, pl. 2, figs 7-8.

1973 *Reticulofenestra scrippsae* (Bukry & Percival) Roth, p. 732.

non1979 *Dictyococcites scrippsae* Bukry & Percival in Huang & Ting, p.116, pl. I, fig. 4.

Remarks—Originally described from Late Eocene of Mississippi. Small placoliths of elliptic outline show distinctive extinction lines under crossed polarised illumination as described by Bukry and Percival (1971). However, assignment to genus *Dictyococcites* is based on EM studies, revealing central plug with radially arranged elements, thus setting it apart from *Reticulofenestra* and *Cribrocentrum*.

Dictyococcites scrippsae is cosmopolitan in distribution and reported from the late Middle Eocene (Zone NP 16) to terminal Oligocene (Zone NP 25). It is rare both in Harudi and Fulra Limestone formations.

Genus—RETICULOFENESTRA
Hay *et al.*, 1966

Reticulofenestra hillae Bukry & Percival, 1971

(Pl. 9.12)

Synonymy list—

1971 *Reticulofenestra hillae* Bukry & Percival, p. 136, pl. 6, figs 1-3.

1975 *Reticulofenestra hillae* Bukry & Percival in Bybell, p.197, pl. 15, figs 4a-b.

Remarks—Reticulofenestra hillae was originally described from Late Eocene of Mississippi and is commonly found in the Early Oligocene. Fairly large elliptical placoliths are characterised by wide central collar and small central opening and thus differ from *R. umbilica* which has a large central opening. It may be readily distinguished from similar looking *Cyclicargolithus abisectus* by elliptical shape and having a larger central opening. Outline of both *Reticulofenestra umbilica* and *Cribrocentrum coenurum* lacks distinct and wide collar as in *R. hillae*. This species is yet to be observed under EM.

The specimens of *R. hillae* (ca. 6 µm) recorded rarely from Harudi and Fulra Limestone formations. The recorded specimens from late Middle Eocene of Gulf Coast (Bybell, 1975) are nearly 1/2 to 1/3 of the size of holotype, but otherwise are similar. This study suggests that *R. hillae* was smaller in size during its initial appearance in the upper part of Zone NP 16 (upper Zone NP 17 given by Perch-Nielsen, 1985b) as compared to the younger late Eocene and early Oligocene occurrences.

Reticulofenestra* cf. *R. minuta Roth, 1970

(Pl. 9.13)

Synonymy list—

1970 *Reticulofenestra minuta* Roth, p. 850-851, pl. 5, figs 3-4.

1971b *Reticulofenestra minuta* Roth in Haq, p. 74-75, pl. 1, figs 1-2; pl. 15, fig. 1.

1976 *Dictyococcites minutus* (Roth) Haq & Lohmann, p. 157, pl. 7, figs 4-5.

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

1997 *Reticulofenestra cf. R.minuta* Roth in Rai, p. 155, pl. II, fig. 2.

Remarks—Coccoliths of *Reticulofenestra* cf. *R. minuta* (about 2 µm) occur abundantly in most samples of Harudi Formation and less frequently in Fulra Limestone Formation. Due to bad preservation and damage of central part, these are referred as comparable species.

R. minuta is fairly resistant to calcite overgrowth and found when other common coccoliths are destroyed. It is common in Eocene of Rajasthan, Kutch, Surat and other areas in India.

Reticulofenestra umbilica (Levin) Martini & Ritzkowski, 1968

Synonymy list—

1965 *Coccolithus umbilicus* Levin, p. 265, pl. 41, fig. 2.

1967 *Apertapertra umbilicus* (Levin) Levin & Joerger, p.166, pl. 1, figs 9a-c.

1968 *Reticulofenestra umbilica* (Levin) Martini & Ritzkowski, pl. 1, figs 11-12.

1971a *Reticulofenestra umbilica* (Levin) Martini & Ritzkowski in Martini, p. 780, pl. 2, figs 18-19.

1978a *Reticulofenestra placomorpha* (Kamptner) Deflandre in Singh *et al.*, p. 5, pl. 3, figs 17-20.

1980a *Reticulofenestra umbilica* (Levin) Martini & Ritzkowski in Singh, p. 5, pl. 2, figs 1-2.

?1986a *Reticulofenestra umbilica* (Levin) Martini & Ritzkowski in Singh & Singh, p. 150, pl. 4, figs 4-5.

Remarks—*Reticulofenestra umbilica* is one of the largest coccoliths, originally described from the late Eocene of Mississippi. Large opening of rhombic outline and diffused extinction pattern on wide placolith rim under crossed polarised illumination are diagnostic features of the species.

The FO and LO of *R. umbilica* have been utilized by Martini (1971a) and Okada and Bukry, (1980) to define Zone NP 15/NP 16 (13c/14a) and Zone NP 22/NP 23 (16c/17) boundary, respectively. Rare but well-preserved specimens (ca. 16 µm) were found only in sample HF 10 of Harudi Formation. It also occurs in Eocene-Oligocene subsurface sediments of Cauvery Basin and Andaman Islands (Jafar & Rai, unpublished data). *R. umbilica* has been reported earlier from the Bartonian of Kutch Basin (Singh, 1980a; Singh & Singh, 1986) and more frequently from Priabonian (Zone NP 20) of Surat area (Singh *et al.*, 1978b; Jafar *et al.*, 1985).

Family—RHABDOSPHAERACEAE
Lemmermann in Brandt & Apstein, 1908

Family Rhabdosphaeraceae conventionally consisted of the so called "Rhabdoliths" of classic literature, which includes a variety of modern spine bearing coccoliths with single perforate shield. Paragenus *Rhabdolithus* used to describe broken *Rhabdosphaera* is thus superfluous (Bramlette & Sullivan, 1961). Well known living *Rhobdosphaera claviger* (Murray & Blackman, 1898) was subsequently designated as the type species for earlier described genus *Rhabdosphaera* Haeckel 1894 (Hay & Towe, 1962). This generic name should be used only for Neogene rhabdosphaerids, as they display much simpler architecture (Jafar, 1975) than Palaeogene forms, which are characterised by sophisticated cycle of elements constituting a single perforated basal plate of nearly circular to broadly elliptic outline, often displaying much arching and twisting (Hay & Towe, 1962, 1963; Stradner & Edwards, 1968; Bramlette & Sullivan, 1961; Bybell, 1975). Palaeogene rhabdosphaerids generic name *Blackites* (Hay & Towe, 1962) should be used as there is long stratigraphic gap between abundant occurrence of *Blackites* in Eocene with a few species surviving into Oligocene and middle Miocene to Recent *Rhabdosphaera*.

The genus *Blackites* is consistently present in Early Eocene nannoflora, but exceptionally abundant and diverse in the Middle Eocene. This sudden burst is comparable to that of the genus *Scyphosphaera* in Middle Miocene (Jafar, 1975).

Only two rhabdosphaerids viz. *R. inflata* and *R. gladius* have been used as stratigraphic markers of the middle Eocene (Perch-Nielsen, 1985b). All Palaeogene rhabdosphaerid species should preferably be changed to genus *Blackites*.

In the study material six new species and three well known species of *Blackites* viz. *B. rectus, B. spinosus* and *B. tenuis* are recorded from Harudi Formation, but none are present in the Fulra Limestone Formation. The less frequency of coccoliths recorded from Fulra Limestone can be ascribed to indurated lithology compared to the soft marls of Harudi Formation, but absence of rhabdosphaerids is noted in Fulra Limestone.

No holotype was designated for *Blackites trochos* Bybell (1975, p. 230, pl. 6, figs 1-3) from Upper Middle Eocene of Alabama, hence pl. 6, fig. 3 is hereby designated as lectotype.

Genus—BLACKITES Hay & Towe, 1962

Blackites conicus sp. nov.

(Pl. 16.8A-B; Pl. 17.12A-B, 13-14)

1975 *Blackites* sp. Bybell, p. 230, figs 4a-b.

Derivation of name—Conus (latin) means cone.

Holotype—Pl. 17.12A-B. HF 6(1). Coordinates—85.1/44.3. Size—length 7.5 µm, base width 6 µm. BSIP Slide No.—9882.

Paratype—Pl. 16.8A-B. HF 1 (1). Coordinates—77.0/13.1 Size—Length 6 µm, base width 5 µm. BSIP Slide No.—9877.

Type locality—SW of village Harudi, Rato Nala Section, Kutch, western India.

Type level—Late Middle Eocene, Harudi Formation; *Discoaster saipanensis* Zone = NP 17 (Martini, 1971a) emend. Rai, 1988.

Diagnosis—A small robust species of *Blackites* with sturdy broad base, surmounted by a thick spine, converging and terminating into a pointed apex.

Remarks—It resembles *Blackites morionum* (Deflandre in Deflandre & Fert, 1954) comb. nov. in being small and robust nature but lacks the bulbous nature of spine. More slender forms (Pl. 17.13-14) resemble *B. gladius* (Locker) Martini, 1981b, but differ in showing different birefringence pattern of basal plate and lacking characteristic basal constriction of spine observed in *B. gladius*. *B. conicus* sp. nov. grossly compares to *Blackites* sp. described from Middle Eocene of Gulf Coast (Bybell, 1975). Rarely recorded from Harudi Formation sample HF 6.

Blackites delicatus sp. nov.

(Pl. 16.9A-B, 10A-B)

Synonymy list—

1952 *Rhabdolithus perlongus* Deflandre, p. 165, fig. 362I.

1954 *Rhabdolithus perlongus* Deflandre in Deflandre, p. 158, pl. 12, figs 34-35, text-fig. 86.

1954 *Rhabdolithus pinguis* Deflandre, p. 158, pl. 12, figs 26-27.

1961 *Rhabdosphaera perlonga* Deflandre in Bramlette & Sullivan, p. 146, pl. 5, figs 7a-c.

1994 *Blackites* sp. 3 Jafar & Rai, p. 35, pl. 2, fig. 37.

Derivation of name—Delicatus (latin) meaning delicate.

Holotype—Pl. 16.9A-B. HF 16 (1). Coordinates—80.9/35.2; length 13 µm, width of base 3 µm; BSIP Slide No. 9892.

Paratype—Pl. 16.10A-B. HF 16 (1). Coordinates—76.0/32.1; length 9.5 µm, width of base 2.5 µm; BSIP Slide No. 9892.

Type locality—SW of village Harudi; Rato Nala Section, Kutch, western India.

Type level—Late Middle Eocene, Upper Harudi Formation; *D. saipanensis* zone = Zone NP 17 of Martini, 1971a emend. Rai, 1988.

Diagnosis—A delicate species of *Blackites* with slender but distinctly club-shaped stem surmounted on a small basal plate.

Remarks—*Rhabdolithus perlongus* Deflandre in Deflandre & Fert (1952, 1954) and *R. pinguis* Deflandre in Deflandre & Fert (1954) are morphologically similar to the present species but with spirally ornamented spine, and both are described from Donzacq marls of Lutetian, France. *B. delicatus* is introduced herein to avoid this confusion in literature. A comparable form, *R. solus* from the early Eocene (Perch-Nielsen, 1971) is characterised by spiral ornamentation of the spine. This is frequent to rare in Harudi Formation.

Blackites fossus sp. nov.

(Pl. 16.3-4, 5A-B)

Blackites sp.1 Jafar & Rai, p.35, pl. 2, figs 33a-c; pl. 3, figs 1a-c.

Derivation of name—*Fossa* (latin) meaning canal.

Holotype—Pl. 16.3, HF 8 (2). Coordinates—86.1/30.2. Size—length 15.5 μm width of base 4.5 μm. BSIP Slide No.—9884.

Paratypes—Pl. 16.4, 5A-B. HF 16 (1). Coordinates—75.0/28.2. Size-length 11.0 μm, width of base 4.5 μm. BSIP Slide No.—9892.

Type locality—SW of village Harudi; 'Rato Nala Section', Kutch, western India.

Type level—Late Middle Eocene, Harudi Formation; *D. saipanensis* zone = Zone NP 17 of Martini, 1971a emend. Rai, 1988.

Diagnosis—Medium to large size rhabdosphaerids with a fairly wide spine canal displaying only minor narrowing toward apical end under LM.

Remarks—Under LM, *B. fossus* n. sp. shows close similarity with *B. indicus* sp. nov. but it differs in lacking a rapidly tapering spine. *B. fossus* occurs rarely in Harudi Formation.

Blackites indicus sp. nov.

(Pl. 16.6A-B, 7A-B, 11A-B, 12-13)

Derivation of name—After India.

Holotype—Pl. 16.6A-B; HF 6(1); Coordinates—80.0/29.9; Size length 9 μm. BSIP Slide No. 9882.

Paratype—Pl. 16.7A-B; HF 8 (2). Coordinates—85.0/11.7. Size length 6.5 μm. BSIP Slide No.—9884. Pl. 16.11 A-B, 12.; BSIP Slide No. 9884—HF 8(1); Coordinates; 85.0/28.2.; Pl. 16.13. BSIP Slide No. 9884—HF 8(1); Coordinates; 86.0/18.5 ; XPL.

Type locality—SW of village Harudi in 'Rato Nala Section', Kutch, western India.

Type level—Late Middle Eocene, Harudi Formation; *D. saipanensis* zone = Zone NP 17 of Martini, 1971a emend. Rai, 1988.

Diagnosis—A rhabdosphaerid species of moderate height showing characteristic conical outline with basal portion only slightly larger than the base of spine, which rapidly tapers into a blunt point.

Remarks—*Blackites indicus* closely resembles *B.creber* (Deflandre) Sherwood, 1974 but differs in lacking abrupt narrowing of spine near the tip. *B. spinosus* and *B. tenuis* are consistently larger and more slender in construction than *B. indicus*. *B. fossus* lacks rapid tapering of spine. The species is frequent to rare in Harudi Formation.

Blackites lanternus sp. nov.

(Pl. 15.8A-C, 9A-B, 10-12; Pl. 16.1)

Synonymy list—

1969 *Rhabdosphaera* cf. *R. inflata* Bramlette & Sullivan in Pant & Mamgain, p. 123-124, pl. 22, fig. 8; pl. 24, fig. 5.

1994 *Blackites* sp.5 Jafar & Rai, p.35, pl. 2, figs 40-47.

Derivation of name—Lanterna (latin) means lantern.

Holotype—Pl. 15.8A-C. HF 16 (1). Coordinates—76.5/26.1. Size height 14 μm, maximum width 6 μm. BSIP Slide No.—9892.

Paratype—Pl. 15.9A-B. HF 16 (1). Coordinates—76.5/32.9. Size—height 12 μm, maximum width 4.5 μm. BSIP Slide No.—9892.

Type locality—SW of village Harudi in 'Rato Nala Section', Kutch, western India.

Type level—Late Middle Eocene, Harudi Formation; *D. saipanensis* zone = NP 17 of Martini, 1971a emend. Rai, 1988.

Diagnosis—Rhabdosphaerid species with bulbous middle part, semicircular in outline, narrow base and a rapidly tapering spine of moderate height, maximum sculpturing in middle part of the wall and spines usually filled with dark pyritic fine material filtered through narrow spine opening.

Remarks—Being a characteristic form, it does not compare with any known species.

Blackites minutus sp. nov.

(Pl. 17.10-11)

Holotype—Pl. 17.10. HF 16 (1). Coordinates—76.5/30.8. Size—length 6 μm, width of base 3 μm. BSIP Slide No.—9892.

Paratype—Pl. 17.11. HF 1 (1). Coordinates—75.0/30.3. Size—length 4 μm, width of base 2 μm. BSIP Slide No.—9877.

Type locality—SW of village Harudi in Rato Nala Section, Kutch, western India.

Type level—Late Middle Eocene, Harudi Formation; *D. saipanensis* zone = Zone NP 17 of Martini, 1971a emend. Rai, 1988.

Diagnosis—Small species of *Blackites* with uniform width of spine and without any tapering of spine.

Remarks—The species somewhat resembles *B. rectus* (Deflandre) Stradner and Edwards, 1968 but has a smaller spine. It also resembles primitive small *Blackites* sp. from Palaeocene of California (Bramlette & Sullivan, 1961) but has wider spine and basal plate. It is very rare in Harudi Formation.

Blackites rectus (Deflandre) Stradner & Edwards, 1968

(Pl. 16.2)

Synonymy list—

1954 *Rhabdolithus rectus* Deflandre in Deflandre & Fert, p. 157, pl. 11, fig. 12.

1968 *Blackites rectus* (Deflandre) Stradner & Edwards, p. 29-32, pl. 30-31, figs 1-5; text-fig. 4.

1994 *Blackites rectus* (Deflandre) Stradner & Edwards in Jafar & Rai, p.35, pl. 2, figs 34a-b.

Remarks—*Blackites rectus* is recognised by having a typical basal plate both under LM and EM and uniform width of spine terminating into a blunt apical part as wide as the base. Originally described from the late Eocene of Oamaru Diatomite, New Zealand. Frequently to rarely present in Harudi Formation.

Blackites spinosus (Deflandre & Fert) Hay & Towe, 1962

(Pl. 17.4A-C, 6A-C, 7-8, 9A-B)

Synonymy list—

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

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

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

1969 *Rhabdosphaera spinula* Levin in Martini, p. 138, pl. 3, figs 28-29.

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

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

1971a *Blackites spinosus* (Deflandre & Fert) Hay & Towe in Perch-Nielsen, p. 49-50, pl. 44, figs 1-8; pl. 45, figs 6-7 (partim).

?1971a *Rhabdosphaera spinula* Levin in Haq, p. 30, pl. 10, fig. 14.

1975 *Blackites spinosus* (Deflandre & Fert) Hay & Towe in Bybell, p. 226-227, pl. 2, figs 1-5; pl. 3, figs 1-5.

?1975 *Blackites spinulus* (Levin) Roth in Proto Decima *et al.*, p. 50, pl. 6, fig. 1.

1976 *Blackites spinosus* (Deflandre & Fert) Hay & Towe in Wise & Constans, p. 148, pl. 2, figs 5-6.

1981a *Blackites spinosus* (Deflandre & Fert) Hay & Towe in Martini, pl. 3, figs 2-3.

1981b *Blackites spinosus* (Deflandre & Fert) Hay & Towe in Martini, pl. 3, fig. 6.

1994 *Blackites spinosus* (Deflandre & Fert) Hay & Towe in Jafar & Rai, p. 35, pl. 2, fig. 35; pl. 3, figs 2-3.

1997 *Blackites spinosus* (Deflandre & Fert) Hay & Towe in Rai, p. 155-156, pl. III, figs 10-11, pl. IV, fig. 19.

Remarks—Despite poor original description by Deflandre and Fert (1954), *B. spinosus* can easily be identified. Stradner and Edwards (1968) on re-examination of topotype material from late Eocene Oamaru Diatomite considered *B. spinosus* as synonym of *B. rectus*, which is not followed here. The species is well illustrated both under LM and EM. Under LM, the spine is broader at the base and gradually tapers to a needle like spine in lateral view. Similar looking *B. tenuis* is characterised by a faint constriction near the base of spine before tapering of spine starts into a point. It differs from *B. indicus* sp. nov. in possessing a much thinner and longer spine which terminates into needle like apical part.

B. spinosus is widely reported from middle Eocene to early Oligocene and usually associated with closely related *B. tenuis*. It is frequent to rare in Harudi Formation.

Blackites tenuis (Bramlette & Sullivan) Bybell, 1975

(Pl. 17.1A-C, 2A-B, 3A-B, 5A-B)

Synonymy list—

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

1965 *Rhabdosphaera tenuis* Bramlette & Sullivan in Sullivan, p. 37, pl. 7, figs 10a-b.

1969 *Rhabdosphaera tenuis* Bramlette & Sullivan in Martini, p. 138-139, pl. 3, figs 30-31.

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

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

?1975 *Rhabdosphaera tenuis* Bramlette & Sullivan in Proto Decima *et al.*, p. 51, pl. 6, figs 2a-b.

1975 *Blackites tenuis* (Bramlette & Sullivan) Bybell, p. 228-230, pl. 4, figs 1-5.

1981a *Blackites tenuis* (Bramlette & Sullivan) Bybell in Martini, pl. 3, fig. 1.

1981b *Blackites tenuis* (Bramlette & Sullivan) Bybell in Martini, pl. 3, fig. 7.

1994 *Blackites tenuis* (Bramlette & Sullivan) Bybell in Jafar & Rai, p. 35, pl. 2, fig. 4.

Remarks—The species was originally reported from middle Eocene of California. It is similar to *B. spinosus* under LM and EM, but differs by having a slight constriction near the base of spine. This species has middle Eocene to middle Oligocene distribution as *B. spinosus*. *B. incompertus* must be considered a junior synonym by its close similarity. The species differs from *B. fossus* sp. nov. and *B. indicus* sp. nov. in showing more delicate construction and having a much longer spine. It is frequent to rare in Harudi Formation.

Family—SPHENOLITHACEAE Deflandre in Deflandre & Fert, 1952

Earliest illustrations of Tertiary family Sphenolithaceae can be found in Tan Sin Hok (1927), who considered them to be of inorganic origin and described as "Calcosphaerolieten". Deflandre in Deflandre & Fert (1952) erected new genus *Sphenolithus* and the family. Having been neglected for a long time, the stratigraphic significance of the species occurring in the Tertiary was pointed out by Bramlette and Wilcoxon (1967), who erected a host of new species and new combinations involving two earlier described monotypic genera *Furcatolithus* and *Nannoturbella*. The taxonomic concept and the illustrations of Bramlette and Wilcoxon (1967) were so good that these species have consistently been recognised and used for stratigraphic correlation without any revision. Excellent reviews were provided by Perch-Nielsen, 1971, 1985b; Roth *et al.*, 1971a; Aubry, 1985b wherein taxonomy, nomenclature and stratigraphic ranges of various species observed under LM and EM were described.

Sphenoliths are small to medium size nannofossils consisting of proximal radiating elements forming a cone very much resembling *Discoaster* with one or two rows of laterally projecting spines surmounted by an apical spine of variable height and thickness. Species identifications are normally possible under LM observations, though a few species can be identified with confidence under EM observations. In overgrown specimens, LM observations are useful.

Sphenoliths are valuable markers for Tertiary marine sediments. The model of Towe (1979) envisaging "Sphenosphere" with only two species viz. *S. radians* and *S. moriformis*, is not tenable. Contrary to several genera included within Sphenolithaceae by Tappan (1980), only solitary genus *Sphenolithus* is retained for this family, which is consistent with observations of Perch-Nielsen (1985b).

The appearance of *Sphenolithus* in Palaeocene and extinction in Pliocene, with common occurrence in tropical warm water is similar to that known for *Discoaster.* Origin of *Sphenolithus* during Palaeocene from *Fasciculithus* (Prins, 1971) or *Cyclagelosphaera* (Perch-Nielsen, 1981, 1985b) is highly speculative and cannot be proven for the most primitive species *S. primus*. It is a large form and almost indistinguishable from younger forms under LM observations. It is suspected that older Palaeocene level may contain even more primitive and smaller forms.

In the study material, six species with slightly overgrown specimens of *Sphenolithus*, viz. *Sphenolithus* cf. *S. celsus, S. predistentus, S. radians, S. moriformis, S. spiniger* and *S. furcatolithoides* are recognised as abundant to rare in both the formations. *S. obtusus* and *S. intercalaris* reported from similar stratigraphic level have not found in the study material. Slightly extended ranges are recognised for some of these species and the LO of *S. furcatolithoides* seems valuable for recognising Zone NP 16/NP 17 boundary (Perch-Nielsen, 1985b, fig. 69).

Genus—SPHENOLITHUS Deflandre in Grassè, 1952

Sphenolithus* cf. *S. celsus Haq, 1971b

(Pl. 13.1-2)

1971b *Sphenolithus celsus* Haq, p.121-122, pl. 1, figs 1-5; pl. 5, fig. 4.

Remarks—Originally described from Oligocene of Syria both under LM and EM. This is a fairly large sphenolith with reduced proximal base and a distinct bulbous spine in the lower part which tapers and bifurcates into two unequal terminations. Parallel to crossed nicols, the bulbous part is without a median suture at the base but shows faint one at the apical end. The entire sphenolith including two tiny dots at the base representing proximal part remain bright. When viewed at 45° to crossed nicols, the two proximal dots and only half of the apical spine remain bright. The presence of faint median suture on distal part of spine, when viewed parallel to crossed nicols, cannot be confidently assigned to *S. celsus*. Moreover LM and EM pictures of Haq (1971b) are difficult to correlate. This species is closely related to *S. predistentus*. Perch-Nielsen (1985b) questionably reports this from Zone NP 18 to NP 22. Rarely recorded from Harudi Formation.

Sphenolithus furcatolithoides Locker, 1967

(Pl. 13.13-14; Pl. 14.1A-B, 2-3)

Synonymy list—

1967 *Sphenolithus furcatolithoides* Locker, p. 363, figs 14-16, abb. 7-8.

1971a *Sphenolithus furcatolithoides* Locker in Perch-Nielsen, p. 53, pl. 49, figs 1-4.

non 1975 *Sphenolithus furcatolithoides* Locker in Proto Decima *et al.*, p. 51, pl. 6, fig. 13.

1977 *Sphenolithus furcatolithoides* Locker in Perch-Nielsen, p. 31, figs 2-5.

1994 *Sphenolithus furcatolithoides* Locker in Jafar & Rai, p. 35-36, pl. 3, figs 10a-b, 11.

Remarks—The taxa was described from late Eocene of Germany. Under LM, when observed parallel to X-nicols, the two slightly distending proximal elements are represented by two bright dots, surmounted by a spine, which bifurcates shortly above and makes characteristic acute angle. Extremely long bifurcated tips were not seen and are believed to have been damaged. When viewed at 45° under crossed nicols, only two bright points of proximal ring are visible.

The joined part of apical spine shows considerable variation in its height.

Sphenolithus furcatolithoides has short stratigraphic range (Zone NP 15-NP 16) following Perch-Nielsen (1985b). This species is frequent to rare in Harudi and absent in Fulra Limestone Formation. This may reflect natural occurrence as Harudi Formation is correlated with upper part of Zone NP 16 and Fulra Limestone with lower part of NP 17 based on other evidences. The LO of *S. furcatolithoides* thus may be used to define NP 16/NP 17 boundary in tropical regions.

Sphenolithus moriformis
(Brönnimann & Stradner)
Bramlette & Wilcoxon, 1967

(Pl. 13.5)

Synonymy list—

1960 *Nannoturbella moriformis* Brönnimann & Stradner, p. 368, figs 11-16.

1965 *Sphenolithus pacificus* Martini, p. 407, pl. 36, figs 7-10.

1967 *Sphenolithus moriformis* (Brönnimann & Stradner) Bramlette & Wilcoxon, p.124-126, pl. 3, figs 1-6.

1971a *Sphenolithus moriformis* (Brönnimann & Stradner) Bramlette & Wilcoxon-Perch-Nielsen, p. 53, pl. 49, figs 5-10.

1975 *Sphenolithus moriformis* (Brönnimann & Stradner) Bramlette & Wilcoxon-Proto Decima *et al.*, p. 51, pl. 6, figs 12a-b.

1976 *Sphenolithus moriformis* (Brönnimann & Stradner) Bramlette & Wilcoxon in Haq & Lohmann, pl. 12, figs 4-5.

1977 *Sphenolithus moriformis* (Brönnimann & Stradner) Bramlette & Wilcoxon in Perch-Nielsen, pl. 32, fig. 11.

Remarks—The species was originally reported from heavily overgrown early Eocene material from Cuba. Sphenoliths with well-defined proximal ring of elements and apical part making low to high dome are widely reported from the early Eocene to middle Miocene. The FO can be used as a datum in Palaeocene. Medium to large forms are rarely recorded from both the formations.

Sphenolithus predistentus
Bramlette & Wilcoxon, 1967

(Pl. 13.3A-B, 6A-B, 7-8)

Synonymy list—

1967 *Sphenolithus predistentus* Bramlette & Wilcoxon, p. 126, pl. 1, fig. 6; pl. 2, figs 10-11.

1970b *Sphenolithus predistentus* Bramlette & Wilcoxon in Müller, p. 98, pl. 11, fig. 12.

1971a *Sphenolithus predistentus* Bramlette & Wilcoxon in Roth, *et al.*, p. 1103, pl. 1, figs 7-8.

1971a *Sphenolithus predistentus* Bramlette & Wilcoxon in Martini, pl. 3, figs 9-10.

1973 *Sphenolithus predistentus* Bramlette & Wilcoxon in Roth, p. 754, pl. 8, fig. 5.

1975 *Sphenolithus predistentus* Bramlette & Wilcoxon in Proto Decima *et al.*, p. 51, pl. 6, fig. 9.

1976 *Sphenolithus predistentus* Bramlette & Wilcoxon in Martini, pl. 6, figs 10-12.

1994 *Sphenolithus predistentus* Bramlette & Wilcoxon in Jafar & Rai, p.36, pl. 3, figs 12a-b, 13-14.

Remarks—Sphenolithus predistentus was originally reported from the Oligocene of Trinidad, supported by excellent LM and EM pictures, and later documented by several authors.

S. predistentus is characterised by a proximal ring of tiny elements surmounted by a spine which is broadest at the base and becomes conical and often bifurcating with long slender diverging branches. Under LM, when viewed under parallel to crossed nicols, two tiny bright dots of proximal ring and apical spine with median suture remain bright; at 45° the bright triangular apical spine lacks median suture, but contains two tiny bright dots of proximal ring.

Reported range is from Zone NP 17 to NP 23 with questionable occurrence in Zone NP 24. *S. predistentus* is common to rare in Harudi and rare in Fulra Limestone Formation. Common occurrence in

Harudi Formation would extend its lower range at least to the upper part of Zone NP 16, as per other evidences available (Perch-Nielsen, 1985b).

Sphenolithus radians Deflandre in Deflandre & Fert, 1954

(Pl. 13.4A-C)

Synonymy list—

1954 *Sphenolithus radians* Deflandre in Deflandre & Fert, p. 163, pl. 12, figs 36-38, text-figs 109-112.

1961 *Sphenolithus radians* Deflandre in Bramlette & Sullivan, p. 166, pl. 14, figs 6-7, 8a-b.

1964 *Sphenolithus radians* Deflandre in Sullivan, p. 194, pl. 9, figs 10a-b.

1965 *Sphenolithus radians* Deflandre in Sullivan, p. 45, pl. 11, fig. 3.

1971a *Sphenolithus radians* Deflandre in Roth *et al.*, p.1102, pl. 1, figs 1-2.

1971a *Sphenolithus radians* Deflandre in Perch-Nielsen, p. 53-54, pl. 47, figs 1-9; pl. 48, figs 1-7 (partim).

non1971a *Sphenolithus radians* Deflandre in Haq, p. 34, pl. 10, fig. 8.

1972 *Sphenolithus radians* Deflandre in Perch-Nielsen, pl. 17, fig. 4.

1975 *Sphenolithus radians* Deflandre in Edwards & Perch-Nielsen, pl. 7, fig. 3; pl. 9, fig. 10; non pl. 10, fig. 6.

?1975 *Sphenolithus radians* Deflandre in Bybell, p. 234, pl. 23, fig. 1.

1975 *Sphenolithus radians* Deflandre in Proto Decima *et al.*, p. 51, pl. 6, figs 14a-b.

Remarks—The species was originally described from the Eocene of Donzacq, France. There is a contradiction between the figures 36-38 on plate 12 and text-figures 109-112 (Deflandre in Deflandre & Fert, 1954). The overgrowth which is apparent in the text-figures 109-112 has resulted confusion regarding its differences with *S. pseudoradians* Bramlette and Wilcoxon (1967).

S. radians is smaller and has more delicate construction than *S. pseudoradians* and best recognised in overgrowth free material under LM. When viewed under crossed nicols at 0° it shows conspicuous median suture on spine and at 45° suture-less spine with lateral and proximal elements remains bright with 'X' shaped extinction lines. However, *S. radians* differs from *S. pseudoradians* (known range NP 19/20 to NP 23) in lacking a whorl of lateral spines protruding well beyond the limits of proximal elements in side view. More delicate nature of calcite elements making the spine with serrated outline in *S. pseudoradians* was described by Bramlette and Wilcoxon (1967) and documented by Roth *et al.* (1971a).

S. radians is questionably reported from Palaeocene, but ranges from Zone NP 11 to NP 16 with doubtful occurrences up to NP 19 (Perch-Nielsen, 1985b). Rare records in Harudi and absent in Fulra Limestone Formation supports its range up to NP 16. Doubtful records of *S. pseudoradians* in NP 15, are probably result of taxonomic confusion between *S. radians* and *S. pseudoradians* (Perch-Nielsen, 1985b).

Sphenolithus spiniger Bukry, 1971a

(Pl. 13.9A-B, 10-11, 12A-B)

Synonymy list—

1971a *Sphenolithus spiniger* Bukry, p. 321-323, pl. 6, figs 10-12; pl. 7, figs 1-2.

1975 *Sphenolithus radians* s.l. Deflandre in Edwards & Perch-Nielsen, pl. 10, fig. 6.

1977 *Sphenolithus spiniger* Bukry in Perch-Nielsen, pl. 31, figs 6-7.

1994 *Sphenolithus spiniger* Bukry in Jafar & Rai, p. 36, pl. 3, figs 15-16.

Remarks—Originally described from late-middle Eocene of Pacific Ocean. Shuttlecock like small sphenoliths show similar extinction pattern under LM as the holotype when viewed at 0° and 45°. However, overgrown material may not be distinguishable under LM from similar looking *S. conicus* of the Miocene.

S. spiniger has a short stratigraphic range from upper part of Zone NP 14 to NP 15 (Perch-Nielsen, 1985b). However, abundant to rare occurrence in Harudi and rare occurrence in Fulra Limestone Formation suggest its survival up to lower part of Zone NP 17.

Family—TRIQUETRORHABDULACEAE
Lipps, 1969

Following Bukry (1981, p. 463), the generic name *Wiseorhabdus* is retained and another genus *Triquetrorhabdulus* is included within this family for rod shaped nannofossils with three or more laths making up the rod. Although rod shaped nannofossils first appear in the Jurassic and continue through the Cretaceous, these are probably not related to Palaeogene forms. Their relations with Neogene genera also remain speculative, despite their increased stratigraphic significance in Neogene (Perch-Nielsen, 1985b). Only single species *Wiseorhabdus inversus* is recorded in the present material.

Genus—WISEORHABDUS Bukry, 1981

Wiseorhabdus inversus (Bukry & Bramlette) Bukry, 1981

(Pl. 18.1A-B)

Synonymy list—

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

1975 *Triquetrorhabdulus inversus* Bukry & Bramlette in Proto Decima *et al.*, p. 160, pl. 6, figs 30a-b.

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

1981b *Wiseorhabdus inversus* (Bukry & Bramlette) Bukry, p. 463.

1994 *Wiseorhabdus inversus (*Bukry & Bramlette) Bukry in Jafar & Rai, p. 36, pl. 3, figs 5a-b.

1997 *Wiseorhabdus inversus (*Bukry & Bramlette) Bukry in Rai, p. 156, pl. III, fig. 9.

Remarks—As opposed to three blades in *Triquetrorhabdulus carinatus,* forms with multiple blades (up to eight) and with opposite optic orientation are considered under *Wiseorhabdus inversus* (Bukry & Bramlette, 1969) Bukry, 1981. It was originally described from the middle Eocene of Blake Plateau. It is rarely recorded from the Harudi Formation (slightly corroded specimens).

Family—THORACOSPHAERACEAE
Schiller, 1930

Thoracosphaeraceae includes single-walled, perforated, spherical to ellipsoidal calcareous tests of larger size than calcareous nannoplankton. Some forms may possess an apical opening of circular or serrated outline with or without an operculum. The test consists of a mosaic of calcite crystallites which under crossed polarised illumination are distinctive in overgrowth free material (Jafar, 1979). Only a single genus *Thoracosphaera* is included in the family excluding several Mesozoic genera like *Brachiolithus* and *Centosphaera* (Tappan, 1980). Tertiary forms are documented (Jafar, 1979; Fütterer, 1976) with better definition of species, but their ranges are still not clear. Several distinct forms, known by fragmentary specimens are common in mid-Jurassic to Cretaceous marine sediments which require detailed studies. Culture of *T. heimii* and studies of Fütterer (1976) and Jafar (1979) suggest that these are calcareous dinoflagellate cysts, but present in the smear slide preparations of calcareous nannoplankton. An overview of species is provided by Perch-Nielsen (1985b).

In the study material fragmentary tests of *Thoracosphaera* are frequently found but calcite overgrowth prevented identification at species level.

Genus—THORACOSPHAERA Kamptner, 1927

Thoracosphaera* cf. *T. deflandrei Kamptner, 1956

(Pl. 18.8A-B, 9)

Remarks—Only fragmentary tests displaying fine textured extinction pattern under crossed polarised light resemble *T. deflandrei.* The LM and EM pictures of this species from Donzacq (France) material are provided by Jafar (1979). The species occurs rarely in Harudi Formation.

Thoracosphaera saxea Stradner, 1961

(Pl. 18.6A-B)

Synonymy list—

1961 *Thoracosphaera saxea* Stradner, p. 8, fig. 17.

1979 *Thoracosphaera saxea* Stradner in Jafar, p. 11, pl. 2, figs 1-7.

Remarks—The species was originally described from Danian of Austria. The characteristic extinction lines are seen under crossed polarised light. Complete spheres of *T. saxea* are reported from several levels and regions together with *T. operculata* blooms near the K/T boundary.

The species is frequent to rare in Harudi and rare in Fulra Limestone formations.

Thoracosphaera* cf. *T. saxea Stradner, 1961

(Pl. 18.7)

Remarks—The present specimens have fragmentary tests with larger elements than *T. saxea*, but exhibit similar extinction lines under crossed polarised illumination. The forms are rarely recorded from Harudi Formation.

Thoracosphaera* cf. *T. tuberosa Kamptner, 1963

(Pl. 18.10-12)

Remarks—Fragmentary tests of the present specimens display projecting crystal outlines under normal light and extinction pattern under crossed polarised illumination containing small triangular areas typical of *T. tuberosa*. Complete tests were not found which are known from the Eocene to Recent. The forms are rarely recorded from Harudi Formation.

RESULTS AND DISCUSSIONS

ZONAL SCHEMES

Various fossil groups are recorded from Early Palaeogene rocks of Kutch, e.g. fossil whale (Sahni & Misra, 1972; Sahni, 1981; Bajpai & Thewissen, 2000), molluscan shell (Tandon, 1962; Biswas, 1990), larger foraminifers (Bhatt, 1968; Biswas, 1986, 1990; Biswas & Raju, 1973; Mohan & Gupta, 1968; Singh & Singh, 1981; Tandon, 1962; Dasgupta, 1969; Sengupta, 1959, 1963a, b, 1964, 1965). Tandon (1962) erected twelve zones based on larger foraminifera. Fossil algae (Vimal, 1953), nautiloid (Tandon & Srivastava, 1980), echinoid (Tandon & Srivastava, 1980; Srivastava, 1982), mega plant fossils (Lakhanpal & Guleria, 1981; Lakhanpal *et al.*, 1984), benthic foraminifers (Tewari *et al.*, 1964; Mohan & Gupta, 1968; Jauhari, 1980), planktic foraminifers (Tewari, 1952; Mohan & Gupta, 1968; Bhatt, 1968; Tandon *et al.*, 1980; Tewari & Singh, 1967, 1968; Jafar, 1986; Rai, 1988; Jafar & Rai, 1994; Mohan & Soodan, 1970; Samanta, 1970; Raju, 1971; Jauhari & Vimal, 1978; Saxena & Singh, 1981; Jauhari, 1981), ostracodes (Lubimova *et al.*, 1960; Guha, 1968; Khosla & Pant, 1981), otoliths (Sahni & Saxena, 1982), holothurian sclerite (Tandon & Saxena, 1977), dinoflagellates (Biswas & Raju, 1973; Mathur, 1963; Jain & Tandon, 1981), radiolaria (Singh & Jauhari, 1976), sponge spicule (Saxena, 1977), palynological data (Mathur, 1963; Sah & Kar, 1969, 1970, 1972; Venkatachala & Kar, 1969a, b; Kar, 1978; Venkatachala *et al.*, 1988; Saxena, 1979, 1980, 1981; Jafar, 1986; Rai, 1988; Jafar & Rai, 1994) are provided.

Calcareous nannoplankton zonal scheme of Martini (1971a) with zonal code NP for Palaeogene was based on hemipelagic/epicontinental sequences of Europe and tropics whereas Okada and Bukry (1980) (incorporating data of Bukry, 1973a, 1975) used CP zonal code for Palaeogene of deep sea sediments of low and mid-latitudes. The correlation of the two zonation schemes is utilised by Bolli *et al.* (1985). Restricted and preferential nearshore/deep sea, low/high latitudinal distribution for few zonal markers were noted later on. Calcareous nannoplankton zonation scheme tied to planktonic foraminifer with zonal code P for Palaeogene was attempted by Blow (1969). Bolli *et al.* (1985) provided integrated zonation of planktonic foraminifera, radiolaria, diatoms, silicoflagellates and calcareous nannofossils with magnetic polarity event and absolute age calibration. Similar studies from Palaeogene of NW Europe (European stratotypes) are extremely useful (Aubry, 1985a). Haq (1984) and Wei and Alampay (1993) provided nannoplankton biochronology and correlated with European stratotypes, magnetic anomaly and absolute time.

Nannofossil biostratigraphy from litho-facies of Kutch Basin indicates rapid lateral and vertical variations and is similar to that developed in Gulf Coast sequence, indicating several barren horizons (Bybell and Gibson, 1985). Kutch Basin contains rich biotope of calcareous nannofossils, planktonic foraminifera and organic-walled dinoflagellates for high resolution biostratigraphy. Siliceous plankton are absent unlike in certain middle Eocene deep-sea and land sections (Saunders *et al.*, 1984; Barron *et al.*, 1984).

It must be emphasized that in coastal marine sequences terrigenous influx seriously affects the FAD (First appearance datum) and LAD (Last appearance datum) of marker sepcies of planktonic foraminifera and calcareous nannofossils, depending upon salinity and ocean current which results in small to large barren horizons. Rapid lateral facies variation further complicates the work of a biostratigrapher. In the present study it was observed that abundant calcarous nannofossils occur in horizons poor in larger foraminifera and larger benthonics.

ZONAL ASSIGNMENT AND AGE

Harland *et al.* (1982) is followed here for modern definition of European stages. Hardenbol and Berggren (1978) considered that confusion in the world-wide correlation framework would be minimised by restricting the Lutetian to foraminiferal zones P10 to P12 (= upper NP 14 to lower NP 16) and Bartonian equivalent to zones P13 and P14 (= upper NP 16 to NP 17). Haq (1984) expressed similar opinion regarding the Bartonian and correlated it with upper NP 16 and NP 17 zones with Lower Bartonian overlapping upper Biarritzian, a term which is not commonly used. Aubry (1985a) provided more refined zonations for Palaeogene of northwestern Europe. According to him the Lutetian/Bartonian boundary is correlative with the first occurrence of *Reticulofenestra reticulata*, the base of the Lutetian lies in the upper part of Zone NP 14 and Lutetian contains upper part of Zone NP 14, NP 15 and lower part of NP 16, while Bartonian contains upper part of Zone NP 16 and NP 17 (entirely or partly). Aubry (1985a) further correlated the base of Bartonian with the top of magnetic anomaly 19 with an absolute age of 43.6 Ma. Haq (1984), however places the base of Bartonian in middle of magnetic anomaly 20 with an absolute age of 44.3 Ma. Bolli *et al.* (1985) place the base of P13 Zone in the middle of magnetic anomaly 20 with an absolute age of 43.0 Ma. Despite these disagreements, the Bartonian stage is firmly established and according to Aubry (1985a; fig. 4), contains planktonic foraminiferal Zone P13, P14 of late Middle Eocene.

The original definitions of zones NP 16 and NP 17 (Martini, 1971a) are thus important for zonal assignment of nannoplankton assemblage recovered from Harudi and Fulra Limestone formations (Jafar & Rai 1994).

NP 16 *Discoaster tanii nodifer* Zone

Definition—Interval from the last occurrence of *Rhabdolithus gladius* Locker to the last occurrence of *Chiasmolithus solitus* Bramlette and 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 NP 16.

NP 17 *Discoaster saipanensis* Zone

Definition—Interval from the last occurrence of *Chiasmolithus solitus* Bramlette and Sullivan to the first occurrence of *Chiasmolithus oamaruensis* Deflandre.

Author—Martini, 1970.

Martini (1971a) suggested last occurrence of *Sphenolithus furcatolithoides* Locker and first occurrence of *Helicosphaera compacta* Bramlette and Wilcoxon in the lower part of NP 17.

It must however be emphasised that chiasmoliths are generally rare and *Chiasmolithus solitus* has not been found. Rare *Chiasmolithus consuetus* was found in Harudi and *Chiasmolithus titus* in both Harudi and Fulra Limestone formations. The absence of chiasmoliths is attributed to extreme shallow water coastal setting rather than tropical latitude, as *Chiasmolithus grandis* and *Chiasmolithus solitus* together with *Reticulofenestra umbilica* were found in NP 16 of subsurface Cauvery Basin well (Jafar & Rai, unpublished data).

Thus, the marker *Chiasmolithus solitus* is rare or absent in marginal Indian basins and as such, there are no available criteria to recognise Zone NP 16-17 boundaries by using zonation of Martini (1971a). Correlation between zones proposed by Okada & Bukry (1980) and Martini (1971a) are well recognised by several authors (Perch-Nielsen, 1985b). Zone CP 14 *Reticulofenestra umbilica* Zone is defined by FAD of *R. umbilica* and *Discoaster bifax* at the base and LAD of *D. bifax* and *Chiasmolithus solitus* at the top, demarcating lower CP 14a *Discoaster bifax* subzone. The upper CP 14b *Discoaster saipanensis* subzone is defined by the LAD of *C. solitus* and *D. bifax* at the base, and LAD of *C. grandis* or FAD of *C. oamaruensis* at the top. CP 14a thus corresponds to NP 16 and CP 14b to NP 17. As per the data of Aubry (1985a) CP 14 *R. umbilica* Zone of Okada and Bukry (1980) partly includes the type Bartonian.

The marker species used by Okada and Bukry (1980) for defining CP 14b, *Chiasmolithus solitus* and *Ch. grandis* are absent in Kutch Basin, but the presence of *R. umbilica* and *D. bifax* in Harudi Formation allows assignment to *R. umbilica* Zone of Okada and Bukry (1980), corresponding to NP 16 and 17 zones of Martini (1971a). Rare occurrence of *D. bifax* does not justify its usage of LAD for defining CP 14b Zone. Therefore, some other substitute markers should be found to further resolve Bartonian. Although *D. bifax* was used as Zonal marker for CP 14a, it has been found at a lower level of NP 13 in borehole of north-western Germany (Kõthe, 1986), but never occurs above NP 16.

Although range of *Discoaster saipanensis* is well established (upper NP 16-NP 20), Perch-Nielsen (1985a) showed doubtful forms up to NP 15, without assigning any reasons or illustrations of typical forms. *D. saipanensis* illustrated from NP13/NP14 of northwestern Germany is due to wrong identification (Köthe, 1986). *D. saipanensis* is common in Indian Eocene and in view of the absence of traditional markers, has been used to emend the definition of *Discoaster saipanensis* Zone of Martini (1970), so that it can be used for dating of other shallow marine low latitude assemblages lacking marker chiasmoliths. Müller (1974) preferred to roughly use FAD of *D. saipanensis* as substitute marker for the LAD of rare *C. solitus* in Arabian sea material.

NP 17 *Discoaster saipanensis* Zone emend. Rai 1988

Definition—FAD of *D. saipanensis* to FAD of *C. oamaruensis*.

Author—Martini, 1970 emend. Rai 1988. The emended definition of NP 17 includes the upper part of NP 16 and NP 17 in the zonation scheme of Martini (1971a). This definition has been adopted throughout. The emended definition of NP 17 would correspond to Bartonian as suggested by Aubry (1985a) and would encompass both P13 *O. beckmanni* and P14 *T. rohri* planktonic foraminiferal zones. Emended definition of NP 17 would partly correspond to CP 14 *R. umbilica* Zone of Okada and Bukry (1980). Frequent occurrence of *Cribrocentrum reticulatum* (= *Reticulofenestra reticulata*) in Harudi Formation suggests that it cannot be older than Bartonian or upper NP 16 (Aubry, 1985a).

POTENTIAL NANNOPLANKTON DATUM MARKERS

The nannoplankton assemblage of the Rato Nala Section (Fig. 3) is assigned to NP 17 *Discoaster saipanensis* Zone (Martini, 1971a emended Rai, 1988). No attempt was made to propose subzones, despite recognition of certain species having restricted ranges. These species may be valuable in resolving the

Bartonian Stage developed in low – latitude, shallow epicontinental facies containing marker planktonic foraminifera species viz. *M. lehneri, T. topilensis, T. rohri* and *O. beckmanni*.

Pemma tuber sp. nov. is of local stratigraphic significance in western Indian Basin. It is recorded in NP 20 Zone of Surat-Broach area without *P. papillatum* (Jafar *et al.*, 1985; Pant & Mathur, 1973).

Discoaster distinctus has its LAD in upper part of Zone NP 16 (Martini, 1971a). It was only found in Harudi Formation.

Discoaster nodifer may be used (FAD) to define base of Zone NP 16, but may range up into Oligocene.

Discoaster tanii earlier thought to have its FAD in NP 17 (Perch-Nielsen, 1985b), is found to extend down into Zone NP 16 but is extremely rare in the section.

Helicosphaera bramlettei is known to range from Zone NP 17-NP 25 and questionably shown to have FAD in NP 15 (Perch-Nielsen, 1985 b), may not have its FAD older than in upper part of NP 16. This species appears in sample HF 3 in the Rato Nala Section and is more frequent in overlying Fulra Limestone Formation.

Helicosphaera compacta was indicated to have FAD at the base of Zone NP 17 (Martini, 1971a). This led Jafar and Rai (1994) to assign nannoplankton assemblages of Harudi Formation in the Rato Nala to NP 17 Zone. Perch-Nielsen (1985b) suggested range from Zone NP 17-NP 24, while Aubry (1988) suggested range from Zone NP 16-NP 24. Presence of *H. compacta* throughout Harudi and Fulra Limestone formations support the view of Aubry (1988).

Helicosphaera reticulata was originally suggested to range from Zone NP 20 to NP 22 (Martini, 1971a). Its range was reported to be from Zone NP 18 to NP 23 (Aubry, 1988) and NP 18 to NP 22, with questionable occurrence in NP 17 (Perch-Nielsen, 1985b). This provides an evidence to recognise NP 17 in the Rato Nala Section. *H. reticulata* is only found in Fulra Limestone Formation which supports its FAD in Zone NP 17.

Sphenolithus furcatolithoides has a short range of NP 15-NP 16 (Perch-Nielsen, 1985b). This is fairly common and distinctive species and has its LAD in sample HF 5 of Harudi Formation and therefore may be roughly used as substitute marker for LAD of *C. solitus*.

The LAD of *S. furcatolithoides, D. distinctus* and the presence of *D. bifax* and *C. reticulatum* support an age assignment of Harudi Formation to upper part of NP 16 Zone of Martini (1971a). The FAD of *H. bramlettei* and presence of *H. compacta* also support this age assignment. However, FAD of *H. reticulata* in Fulra Limestone suggests that it cannot be older than NP 17, implying that the boundary between zones NP 16 / NP 17 lies somewhere close to the contact of Harudi-Fulra Limestone formations (Fig. 3).

CORRELATION WITH PLANKTONIC FORAMINIFERAL ZONES AND COMPARISON WITH OTHER SECTIONS

Low latitude planktonic foraminiferal zonation scheme of Middle Eocene by Tourmakine and Luterbacher (1985) is followed here for the definition and discussion of zones. It must be emphasised that one of the richest assemblages of calcareous nannoplankton associated with rich planktonic foraminifera and dinoflagellates are found in Fulra Limestone often underlain by soft marly Harudi Formation in widely separated areas of Kutch Basin. However, certain facies constraints in the appearance of critical marker species of planktonic foraminifera have already been pointed out. Without acknowledging this fact several authors have prompted to recognise Zone P12 (*G. lehneri* = *T. topilensis*) in several sections owing to scarcity or ecological exclusion of the marker *O. beckmanni*, which becomes frequent in younger horizons.

Analysis of samples from Rato Nala Section for planktonic foraminifera was also carried out (Rai, unpublished data). It demonstrates that samples HF 17-HF 11 are barren (Fig. 3). Rare appearance of planktonic foraminifera is observed in sample HF 10 and samples HF 9-HF 3 are either barren or extremely rare. An improved frequency of a few marker species like *O. beckmanni, T. rohri, T. topilensis, G. kugleri* and *M. lehneri* were observed in samples (HF 2-HF1, FL 1-FL 2) near the contact of Harudi and Fulra Limestone formations suggesting assignment to P13 *O. beckmanni* Zone. Presence of P14 *T. rohri* Zone higher up in the Fulra Limestone Formation has been published by several authors (Sengupta, 1964, Mohan & Soodan, 1970; Samanta, 1970, 1978, 1981; Raju, 1971). Although typical late Middle Eocene planktonic foraminifera have been reported by several workers, zonation has been attempted by only a few workers. Sengupta (1964) and Samanta (1970) distinguished P13 and P14 zones in Lakhpat area related to local larger foraminiferal zones. Samanta (1978, 1981) discussed relation of planktonic zones related to larger foraminiferal zones of Indian region and compared it with southern Europe zones. He assigned Lutetian age to the planktonic foraminiferal assemblage, as per the classical concept of Lutetian stratotype. Mohan and Soodan (1970) and Raju (1971) recognised *O. beckmanni* and *T. rohri* zones from southwestern Kutch, together with *G. frontosa-G. kugleri, H. aragonensis* and *T. topilensis* zones (Fig. 2) and unable to recognise the FAD of *O. beckmanni* in poor assemblages of lower horizons. Jauhari (1981) recognised *O. beckmanni* and *M. lehneri* zones in Vinjhan-Miani area with absence of *T. rohri* Zone. While absence of *T. rohri* Zone can be ascribed to the erosion of the terminal Fulra Limestone in that area, the recognition of *M. lehneri* Zone can be attributed to the rare initial appearance of *O. beckmanni* in the section studied by Jauhari (1981) and thus may not be valid.

The zones P13 and P14 are assignable to Bartonian (Harland *et al.*, 1982; Aubry, 1985a) which corresponds to upper NP 16 and NP 17 of Martini (1971a). These zones are recognised in widely separated sections of Kutch Basin with missing (Priabonian) Late Eocene (Biswas, 1992; Biswas & Raju, 1973).

Integration of planktonic foraminiferal and calcareous nannoplankton zones in the middle Eocene of low latitude has not been attempted by many workers and thus data from Kutch Basin are important. It has earlier demonstrated that calcareous nannoplankton of Harudi and Fulra Limestone can be assigned to Bartonian age encompassing upper NP16 and NP17 zones of Martini (1971a) or to NP17 Zone emended by Rai (1988). Based on substitute calcareous nannoplankton markers, it can be suggested that Harudi Formation belongs to upper NP16 and Fulra Limestone to NP 17 (partly). Based on published data of Kutch Basin, Zone P13 / P14 boundary lies within Fulra Limestone Formation. Thus it is suggested that Zone NP 16 / NP 17 (*sensu* Martini, 1971a) boundary falls within P13 *O. beckmanni* Zone and does not coincide with Zone P13/P14 boundary as questionably suggested in Fig. 4.

Marker and substitute markers species like *R. umbilica, D. bifax, C. reticulatum, S. furcatolithoides, H. bramlettei, D. distinctus* are used to assign Bartonian age (upper NP 16 Zone) to Harudi Formation in the type area. However, FAD of *H. reticulata* in Fulra Limestone is used to suggest NP 17 Zone assignment, still within the Bartonian. The LAD of *Sphenolithus predistentus* and *Helicosphaera bramlettei* can be utilized to assign the assemblage within NP 17 Zone of Martini (1971a) correlatable with NNTe 11A nannofossil Zone of Varol (1998). These substitute markers suggest that the NP 16 / NP 17 zonal boundary roughly corresponds to Harudi/Fulra Limestone Formation boundary in Kutch Basin.

Nannoflora recovered from the upper part of Fulra Limestone Formation of Lakhpat, Babia Hill and Maniyara Fort localities are similar and corresponds to Zone NP 17. Earlier records of nannoplankton, though poor, suggests a Lutetian age for the barren Harudi Formation (due to diagenetic overgrowth of calcite in other sections than actual absence) and a Bartonian age (Zone NP 16, NP 17) for Fulra Limestone at Babia Hill (Singh & Singh, 1986). The inadequate documentation and lack of marker nannoplankton species to identify NP 17 Zone, this zonal assignment is considered to be questionable.

Record of poor assemblages from Fulra Limestone Formation of Lakhpat (Singh, 1980a), Vinjhan (Singh, 1980b) and Rakhadi River (Singh *et al.*, 1980) near Harudi and lack of characteristic substitute markers do not favour for NP 17 zonal assignment. Singh (1980a) assigned the Fulra Limestone assemblage to Zone NP

16 containing the P13 and P14 foraminiferal zones. The Lutetian Stage (Upper NP 14 to Lower NP 16) is absent in Kutch Basin. However, presence of P13 and P14 zones (with absence of P14 in Vinjhan area) and nannoplankton zones suggests unambiguous presence of Bartonian level throughout the Kutch Basin (Rai, 1988; Jafar & Rai, 1994; Rai, 1997). Record of characteristic nannoplankton species *Cribrocentrum reticulatum* from the basal sample of Harudi Formation (Fig. 3) can be used to demarcate Lutetian-Bartonian boundary. This species attains larger size at younger levels and has been recorded from Andaman Island (Jafar, 1985) and the Priabonian (Zone NP 20) of Surat area (Jafar *et al.*, 1985). Its extinction just before Zone NP 20/NP 21 boundary containing LAD of *D. barbadiensis* and *D. saipanensis* is noteworthy (Saunders *et al.*, 1984). The presence of *C. reticulatum* has therefore been used to distinguish the Bartonian Stage in this study. The Fulra Limestone and Harudi formations containing the rich fossil calcareous plankton are comparable to upper Kirthar of western Indian series and Berwali series-Babia Stage of late Middle Eocene (Bartonian) age of Kutch Basin. The correlations are shown in Fig. 4. Late Eocene (Priabonian) has been recognised as a hiatus. The Fulra Limestone of Bartonian age is disconformably overlain by *N. fichteli* rich beds of Rupelian age near Maniyara Fort, characterised by influx of rich glauconitic marls (Jafar & Rai, 1994).

PALAEOCEANOGRAPHIC MODEL

In response to activation of basinal faults and probably coinciding with the collision of Indian-Asiatic landmasses around 40 m.y., drastically reducing the spreading rate to nearly half (Barron & Harrison, 1980) during Bartonian, a shallow epeiric sea invaded the margin of Kutch Basin. The basement rocks of Deccan traps contained thick laterite soil cover; erosion of Trap-cover together with Intertrappean and Infratrappean sediments (Early Cretaceous) contributed terrigenous matter together with pollen and spores in shallow coastal sea. System of shallow lagoons and embayments girdled the coast, initially not connected to open sea currents. Low energy clastics displaying all shades of rainbow, containing plenty of trap derivatives and showing rapid lateral facies variations developed locally with Lignites and black shales in northwestern Kutch Basin. Land supported luxuriant tropical humid vegetation. Reduced salinity inhibited growth of glauconite. Marine benthonics and planktonics were dwarfed, concentrated in thin horizons and supported different communities at a short lateral distance on the embayment bank. Coastal vegetation and palynoflora was excellently preserved in rapidly pinching black shales. Increased bathymetry and decreased supply of terrigenous clay resulted in genesis of glauconite. The change in coastline geometry permitted more open ocean influence, supporting larger foraminiferal biotope, still reduced in size and diversity. Black shales develop in pockets. Occasional bioturbated horizons, thicker ones often misinterpreted as "Laterite", developed. Further increase in bathymetry resulted in free incursion of open sea currents into the embayments inducing far better growth of rich invertebrate fauna (Holothuroids, etc.) and establishment of normal dinoflagellate and nannoplankton crop with variety of probably endemic holococcoliths, braarudosphaerids and rhabdospherids (Martini, 1981), in inner neritic shelf regime while fully grown larger-and small benthic foraminifera flourished, with population of marine vertebrates (whales and fishes), the planktonic foraminifera are still rare and stunted, till the initiation of sea regression near Harudi-Fulra Limestone Formation contact, finally culminating in, partim Bartonian, Priabonian and partim Rupelian hiatus.

The proposed model further demands indepth analysis of facies coupled with the marine invertebrate, vertebrate and microfauna, which have been barely touched upon and are beyond the scope of this study. Geomagnetic and radiometric data would provide supporting evidence in understanding the nature of horizons, either barren in age-diagnostic planktonics or containing only dwarfed population. It may not be therefore, entirely misleading at this stage to speculate a Bartonian transgressive cycle over Deccan traps in Kutch Basin, containing one of the richest Late Middle Eocene fossils in Indo-Pacific region (Jafar & Rai 1994).

CONCLUSIONS

1. Calcareous nannofossils of Harudi and Fulra Limestone formations correspond with P13 *O. beckmanni* and P14 *T. rohri* planktonic foraminifera zones with emended NP17 *Discoaster saipanensis* Zone of Martini (1971a). This correlates in part with CP14 (= *Reticulofenestra umbilica*) Zone of Okada and Bukry (1980). Though the nannofossil marker *Chiasmolithus* species (Okada & Bukry, 1980) is absent, the NP16/NP17 Zone boundary could be inferred by the first appearance of *Helicosphaera reticulata* and last appearance of *Sphenolithus furcatolithoides* roughly corresponding with Harudi-Fulra Limestone Formational boundary in the Rato Nala Section. The presence of *Cribrocentrum reticulatum* has been used to demarcate the Lutetian/Bartonian boundary in this section.

2. Combined data of planktonic foraminifera and calcareous nannoplankton suggest the presence of NP16/NP17 Zone boundary of Martini (1971a) and CP14a-CP14b boundary of Okada and Bukry (1980) and NNTe 10-NNTe11 Zone boundary of Varol (1998) to lie within *O. beckmanni* P13 planktonic foraminifera Zone. This finding is of value for low latitude biochronology. The record of *G. kugleri*, *M. lehneri* and *T. topilensis* zones can be ascribed to the nonrecognition of the FAD of rare *O. beckmanni* in several sections of Kutch Basin (Mohan & Soodan, 1970; Raju, 1971).

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