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BARTONIAN AGE CALCAREOUS NANNOFOSSIL BIOSTRATIGRAPHY OF TANOT WELL-1, JAISALMER BASIN AND ITS IMPLICATIONS

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ABSTRACT

A fairly rich and moderately diversified nannofossil assemblage comprising thirty-eight species belonging to eighteen genera and one calcareous dinoflagellate species are described from subsurface samples of Tanot #1 well (Oil India Limited) representing the Bandah Formation of the Jaisalmer Basin. The assemblage though contains little overgrowth in delicate forms, yet displays exceptional preservation at some levels. The assemblage is dominated by reticulofenestrids specially *Cribrocentrum reticulatum.* The assemblage is typically indicative of low-latitude, near-shore, shallow and warm water environment and can be assigned to zone NP17 *Discoaster saipanensis* Zone. This is correlatable with parts of both P13 *Orbulinoides beckmanni* and P14 *Truncorotaloides rohri* planktonic foraminiferal Zones and a part of D11 dinoflagellate Zone of Bartonian age. This nannofossil data from subsurface of Jaisalmer is coeval with more diversified nannofossil assemblage from Kachchh and less diversified assemblages from the Dilni River section, Meghalaya. Though the entire Bartonian spans (41.3-37.my) ca. four million years, it appears that the nannofossil assemblages in both western and eastern sectors of India pertain only to 1.5 my. time slice (39.5-38.0 my) of global eustatic rise. The late Eocene (Priabonian) is hiatus both in the Kachchh and Jaisalmer basins of western India, whereas the sedimentation continued in Meghalaya in the eastern sector and the sea encroached on the Cambay Basin in western India in late Eocene.

Keywords: Nannofossils, Bartonian, Biostratigraphy, Jaisalmer Basin

INTRODUCTION

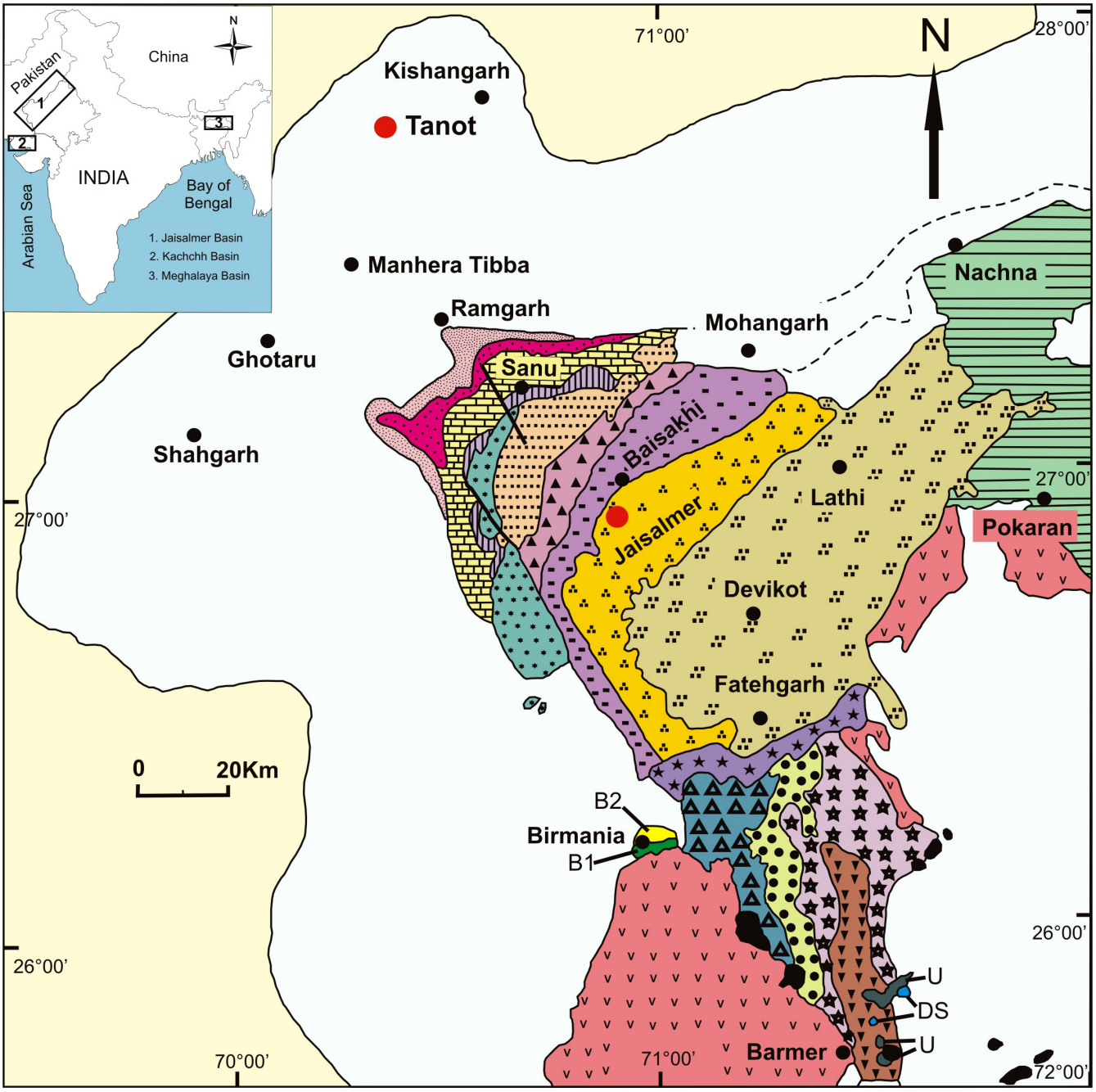
Calcareous nannofossils are ideal for high-resolution biostratigraphy and palaeoenvironmental interpretations of shallow marine and deep sea deposits (Siesser and Haq, 1987). Jaisalmer Basin, situated in the north-western part of Rajasthan, western India displays a nearly flat topography covered with recent desertic alluvium. Marine Mesozoic-Tertiary rocks crop out in a few prominent hillocks. The occurrence of marine Tertiary rocks in the Jaisalmer Basin was first noted by Blanford (1876). The outcropping marine Cenozoic rocks on surface in the Jaisalmer Basin overlying Deccan traps are classified as the Sanu, Khuiala, Bandah and continental Shumar formations in ascending order. The Khuiala and Bandah formations of the Jaisalmer Sub-basin are dated on the basis of ostracod assemblages as lower and middle Eocene respectively (Khosla, 1972). The age of echinoid-bearing horizon of the Khuiala Formation (calcareous sandy marl) is constrained by the presence of index larger foraminifer *Assilina lacunata* Cizancourt (Srivastava *et al*., 2008) which indicates an Early Eocene (Ypresian) age. The ostracode, bivalve and other biotic elements previously described from the Khuiala and Bandah formations (Khosla, 1972; Das Gupta, 1974; Pareek, 1984; Ghosh, 1987; Bhandari, 1995; Singh, 1996; Singh, 1997; Singh, 2003) are also consistent with these age assignments. The surface samples from the Khuiala and Bandah formations proved barren of nannofossils. In order to examine the basinal continuity and better preserved datable microfossils, the samples from bore well material of Oil India Limited have been studied. Study of calcareous nannofossils from Paleocene-Eocene succession of the Jaisalmer Basin has been carried out by Singh (1998) and from the Cambay Basin by Samanta *et al.* (2013a, 2013b).

In the present paper, a systematic study of nannofossil assemblage (under light and scanning electron microscope) is presented along with their application in age determination, biozonation and palaeoenvironmental interpretation of the subsurface Bandah Formation of Tanot #1. A comparison of the recorded nannofossil assemblages is made with known assemblages from coeval succession in other Indian sedimentary basins of Kachchh (Rai, 1988, 1997, 2007; Jafar and Rai, 1994) and Dilni River Section, Meghalaya (Rai and Garg, 2009).

Khartar well-C from the Jaisalmer Basin has yielded poorly preserved undatable calcareous nannofossils from the Khuiala Formation and datable nannofossil assemblage belonging to CP14 *Reticulofenestra umblica*/NP17 *Discoaster saipanensis* zone from the Bandah Formation (Singh, 1998). The present finding of nannofossil from Tanot #1 is actually lateral coeval extension of same deposits in another well. The assemblage in Tanot #1 is more diversified and in Khartar well-C several forms remained unidentified (Singh, 1998 Pl. 3, p. 168-169).

GEOLOGICAL SETTING

Rajasthan is endowed with a continuous geological sequence of rocks from the oldest Archaean metamorphic to sub-recent, alluvium and wind- blown sand (Fig.1). The sedimentary sequences include the rocks of Aravalli Super group, Delhi Super group, Upper Precambrian Vindhyan Super group and of Cambrian to Jurassic, Cretaceous and Tertiary ages. The southeastern extremity of the State is occupied by a pile of basaltic flows of Deccan Traps of Late Cretaceous age. Rajasthan Basin forms the eastern flank of Indus geo-syncline and comprises the sedimentary tract to the west and northwest of Aravallis up to Indo-Pakistan border**.** Encroachment of an arm of the sea from the south-westerly direction into western Rajasthan during the Jurassic period laid down thick fossiliferous marine sequence. During ?Paleocene-Eocene times, fresh marine transgression seems to have inundated a large part of western Rajasthan with the deposition of thick beds of fossilliferous limestone. To the North of Jaisalmer, the



LEGEND

Sand Dune-Recent	Jaisalmer Basin	Gravel/Sand-Recent	Barmer Basin
Shumar Fm.-Quaternary	Bhadasar Fm.-Tithonian	Uttarlai Fm.-Quaternary	Barmer Fm. — Palaeocene
Bandah Fm.-Mid. Eocene	Baisakhi Fm.-Kimmeridgian	Kapurdi Fm.	Fatehgarh Fm. — Palaeocene
Khuiala Fm.-Lr. Eocene	Jaisalmer Fm.-Callo.-Oxford.	Dykes/Sills	Sarnu Fm.-Lr. Cretaceous
Sanu Fm.-Palaeocene	Lathi Formation-Lias-Batho.?	Mata.Dungar Fm. — Lower Eocene	Birmania Fm. — Proterozoic-Lr. Cambrian
Habur Fm. — Lower Cretaceous	Marwar Supergroup-Port-Lr.Camb.	Akli Formation — Lower Eocene	Randha Fm. — Proterozoic-Lr. Cambrian
Pariwar Fm. — Lower Cretaceous	Malani Group-Precambrian		Malani Group/ Basement — Precambrian

Fig. 1. Location map of the Jaisalmer Basin showing location of study area.

Jurassics are overlapped by Tertiary age nummulitic limestone. In view of exploration of hydrocarbons the Jaisalmer Basin is kept under essentially unexplored basins of India (Raghavendra Rao, 1972; JaiKrishna, 1987).

PREVIOUS WORK

Earlier work on the stratigraphy of the Jaisalmer Basin was done by several workers (Blanford, 1876; Oldham, 1886; Raghavendra Rao, 1972; Das Gupta, 1973, 1975). Das Gupta (1975) revised the Mesozoic-Tertiary stratigraphy of the Jaisalmer Basin on the basis of detailed surface and subsurface geological investigations of the area. Pareek (1981, 1984) gave an account of the basin configuration and stratigraphy of western Rajasthan. Singh *et al.* (2005) gave an overview of structural elements and stratigraphy while working for hydrocarbons in the Jaisalmer Basin.

Narayanan (1959) identified Kirthar foraminifera in the Bandah Formation, west of Ramgarh in Jaisalmer district. Khosla (1972) provided ostracode assemblage based ages from the Khuiala and Bandah formations of Bikaner and Jaisalmer districts. Kalia and Kintso (2006) described planktonic foraminifera of the Paleocene/Eocene boundary in the Jaisalmer Basin. Singh (1998) provided calcareous nannoplankton and foraminiferal biostratigraphy of Paleocene and middle Eocene (Bartonian) age nannofossils from Khartar well-C of the Jaisalmer Basin from Parh, Sanu and Bandah formations. The Khuiala Formation showed absence of calcareous nannofossils.

LITHOSTRATIGRAPHY OF THE BANDAH FORMATION

The formation is named after the Bandah village (Narayanan, 1959). The formation consists of argillaceous limestones and clay. Khosla (1973) recognized two larger foraminiferal assemblage zones namely lower *Discocyclina sella* and upper *Discocyclina dispansa* assemblage zones, within the Bandah Formation of the Jaisalmer Basin, based on which the middle Eocene age has been assigned to the Bandah formation. Singh (1998) recorded only one *Nummulites acutus* zone from Bandah Formation of Kharatar well-C of the Jaisalmer Basin. Besides this, the planktonic foraminiferal assemblage containing *Truncorotaloides rohri* indicates top of middle Eocene. The nannofossil assemblage recorded from the Bandah Formation also provides precise Bartonian age (NP17=CP14b) zone (Singh, 1998).

MATERIAL AND METHODS

In the Jaisalmer Basin Oil India Limited had drilled a number of exploratory wells in search of hydrocarbons at Bakhri-Tibba, Ghotaru, Manhera Tibba, Dandewala and Tanot area. Twenty two well cuttings samples were studied from Tanot Bore Well-1 (27° 46' N and 70° 17' E) at different intervals (between 528m to 627m depths) (Fig.2).

The studied succession represents Bandah Formation from which well to moderately preserved, highly diversified nannofossils have been recorded.

Light Microscopy (LM)

Smear-slides were prepared for nannofossil studies. 1gm (dry weight) of material is taken and kept in the covered crucible. 10ml of distilled water was poured to make an even suspension by stirring it. A thin film of sediment on the slide was made by pouring few drops of the suspension with the help of a clean dropper. Two slides, one containing finer and the other comparatively coarser fraction were prepared and allowed to dry on a hot plate. Two drops of mounting medium (Canada Balsam) was poured with the help of a glass rod and a cover slip of appropriate dimension (22 X 40mm) to cover the slide containing dry suspension film. The air bubbles were allowed to escape. The slide was cooled and the coverslip was evenly pressed so that permanent slide of uniform thickness was prepared. Nannofossils were observed with a Leitz make polarizing Microscope with X10 or X12.5 occulars and X100 objective, the latter requiring oil immersion. Polarization and / or phase contrast equipments are necessary for the study of most of the forms. The use of gypsum plate helps in the identification of some critical forms.

Scanning Electron Microscopy (SEM)

For the scanning electron microscopy two samples (14544 and 14562) bearing sample number 528 and 615 (which showed best preservation amongst all the samples under light microscope) were selected and used short centrifugation method (Bown, 1998) for the preparation of the suspension. The suspension were spread over numbered coverslips and allowed to dry up. Coverslips were then mounted on aluminium stubs with both sided sticking tape. The side containing suspension was masked by quick silver, coated with gold-palladium and examined under SEM LEO 430 model microscope.

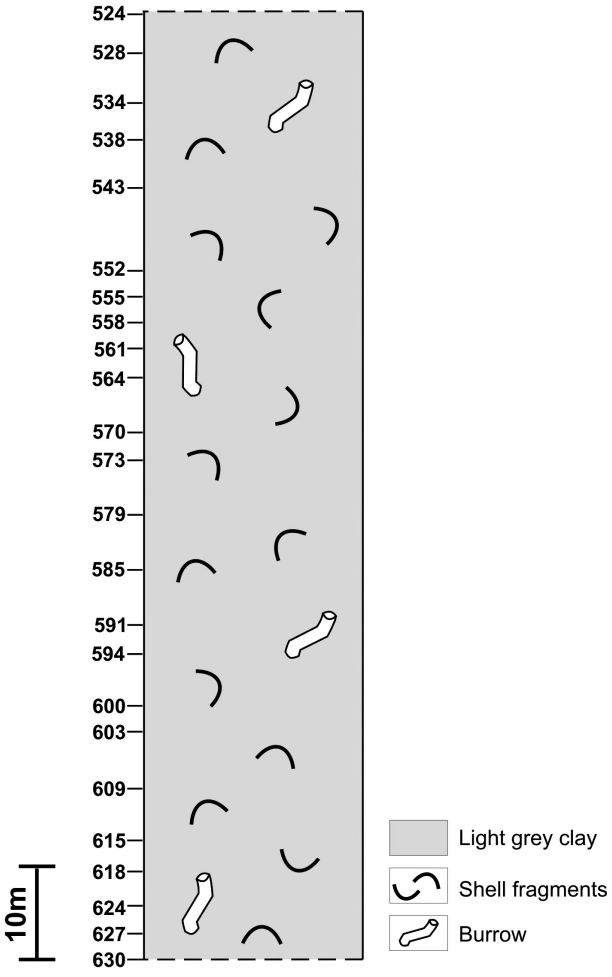


Fig. 2. Litholog of Tanot well #1.

AGE	EUROPEAN STAGE/AGE	NANNOFOSSIL ZONE/SUBZONE MARTINI 1971 EMENDED RAI, 1988	LITHOSTRATIGRAPHY	SAMPLE	PRESERVATION	ABUNDANCE	*Braarudosphaera bigelowii*	*Braarudosphaera discula*	*Campylosphaera dela*	*Coccolithus eopelagicus*	*Coccolithus subpertusus*	*Cyclococcolithus formosus*	*Cyclococcolithus kingii*	*Cyclicargolithus floridanus*	*Cribocentrum reticulatum*	*Dictyococcites stavensis*	*Discoaster barbadiensis*	*Discoaster saipanensis*	*Discoaster tanii*	*Discoaster distinctus*	*Discoaster binodosus*	*Helicosphaera euphratis/parallela*	*Helicosphaera bramletti*	*Helicosphaera compacta*	*Helicosphaera heezenii*	*Helicosphaera lophota*	*Lanternithus minutus*	*Micrantholithus crenulatus*	*Pemma basquensis*	*Pemma papillatum*	*Pontosphaera vesca*	*Pontosphaera pectinata*	*Reticulofenestra pseudoumbilica*	*Reticulofenestra sp.*	*Reticulofenestra minuta*	*Reticulofenestra hillae*	*Sphenolithus moriformis*	*Sphenolithus predistentus*
LATE MIDDLE EOCENE	BARTONIAN	DISCOASTER SAIPANENSIS ZONE NP-17	BANDAH FORMATION	**528**	**M**	**A**	R			F		A	R	C	C	A	R	F	R	R		R		R		R	F		R		F	R	A	R	R		F	R
				534	**G**	**A**	R			R		F	R	F	F	C	R	R			R	R					R				R	R	R	R	F		C	R
				538	**G**	**A**				F	F	A	F	A	C	C	R	F	R		R		R	R		R	R	R			R	F	F	R	R		C	R
				543	**G**	**A**				R	F	A	C	A	R	C	F	R		R		R									R	F	F		R		C	R
				552	**G**	**A**						A		A	R	C	R									R						F	R				F	R
				555	**G**	**A**					F	A	R	C	F	A	R	F	R	F						R			R		F	F	R				R	R
				558	**G**	**A**				R		F	R	F	C	F	R	R									R		R				R		R		R	R
				561	**M**	**A**						F			C	F	R	R														R	R	R	R		R	
				564	**G**	**A**						C		R	F	C		R	R		R					R			F		R		R	R	F		F	
				570	**G**	**C**				R		C		R	C	F	C				R								R		R	R	R	F	F		F	R
				573	**M**	**C**				R		R	R	F	R	F		R																	R		R	
				579	**M**	**C**					R	R		F	R		R	R			R	R				R	F						C	C	F		R	R
				585	**P**	**F**						R	R		R	F	R									R								R	R			
				591	**P**	**R**							R																					R	R			R
				594	**M**	**R**																													R	R		
				600	**M**	**F**				F				R																			R		R	F		R
				603	**M**	**F**				R				F	R		R																		R	F	R	R
				609	**G**	**C**				R				F	R		R					R		R			R		R						R	F	R	
				615	**G**	**A**	R			A	R	F	F	F	C	R	C	R	R			F	F			R	R	R	C		R	R	R	R	F	R	F	R
				618	**G**	**C**				F	R	R	R														R	R							R		R	F
				624	**G**	**C**		R	R	F	R	R	R	R									R	R	R		R			R			R			F	F	
				627	**G**	**A**		R	R	F	R	R		C									R	R	R	R	R	R									C	R

Fig. 3. Distribution chart of nannofossil assemblage recorded from Tanot well #1.

SYSTEMATIC PALAEONOTLOGY

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

Kingdom **Protista**
Division **Haptophyta**
Class **Prymnesiophyceae** Hibberd, 1976

Systematic treatment of calcareous nannoplankton is after Perch-Nielsen (1971). Families and genera contained herein are arranged in alphabetical sequence.

Genus ***Braarudosphaera*** Deflandre, 1947
Braarudosphaera bigelowii (Gran and Braarud, 1935) Deflandre, 1947
(Pl. I, figs. 1a-b)

Remarks: It is originally described from plankton of Atlantic Ocean as *Pontosphaera bigelowi* (Gran and Braarud, 1935). Later Deflandre (1947) based on trapezoidal shape of the morphology, proposed new genus and transferred it under *Braarudosphaera bigelowii.* It is characterized by having trapezoidal shaped elements making regular pentaliths. 60 of these units form complete pentagonal dodecahedral cyst cell. The sutures between the adjacent regular pentaliths are weak and contain slit like openings corresponding to 30 edges of the pentagonal dodecahedron with hollow interior. They are characteristically confined to nearshore, shallow and warm water areas. It is reported from Cretaceous to recent marine sediments all over the world. In the study material *B. bigelowii* is rare in Bandah Formation.

Occurrence in India: Known from Bartonian of Kachchh and Jaisalmer.

Braarudosphaera discula Bramlette and Riedel, 1954

Remarks: Pentaliths nearly round, tending to be more or less pentagonal in shape, with sutures between the five segments reaching the margin at or very near the angles of the pentagon. Diameter is usually 6-9 microns. Its stratigraphic range has not been established but it seems to be common only in the Eocene and particularly in the Lower-Middle Eocene.

Occurrence in India: Known from Bartonian of Jaisalmer.

Genus ***Micrantholithus*** Deflandre, 1950
Micrantholithus crenulatus Bramlette and Sullivan, 1961

Remarks: Small to medium sized pentaliths displaying poreless triangular segments with crenulated peripheral margin and an overall regular pentagonal outline. Rare in the studied samples.

Occurrence in India: Known from Bartonian of Kachchh, Jaisalmer and Meghalaya.

Genus ***Pemma*** Klumpp, 1953
Pemma basquense (Martini, 1959) Báldi-Beke, 1971
(Pl. II, fig. 5a-5c; Pl. IV, fig.2,3)

Remarks: Fairly characteristic species of *Pemma* with protruding elements along radial sutures, small to large openings, one in each segment of the pentalith are included in this species with no differentiation of sub-species as done by several authors. Reported from Middle Eocene to Oligocene age shallow marine sediments of several regions.

Occurrence in India: Known from Bartonian of Kachchh, Jaisalmer and Meghalaya.

Pemma papillatum Martini, 1959

Remarks: *Pemma papillatum* is fairly large pentalith characterised by typically club shaped protuberances on peripheral margin. 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 a zonal marker for middle Eocene of Alabama (Gartner, 1971).

Occurrence in India: Known from Bartonian of Kachchh and Jaisalmer.

Genus ***Lanternithus*** Stradner, 1962
Lanternithus minutus Stradner, 1962
(Pl. II, fig. 4a-4b)

Remarks: It is common constituent of nannoflora of Middle Eocene to early Oligocene shallow marine deposits of several regions of the world. Detailed morphology both under LM and EM of this interesting holococcolith can be found in Gartner and Bukry (1969). It is a rectangular holococcolith with distinct lateral and rim blocks with a large central pore. In side view it has a box-like appearance that tapers slightly to one end where it is capped by a cover.

Occurrence in India: Known from Bartonian of Kachchh, Jaisalmer and Meghalaya.

Genus ***Campylosphaera*** Kamptner, 1963
Campylosphaera dela (Bramlette and Sullivan, 1961) Hay and Mohler, 1967
(Pl. III, fig. 4)

Remarks: It is a large species (5-6µm) with a delicate cross, the bars being aligned to the major and minor axes of the coccolith. Typical rectangular outline and distinct proximal and lateral curving of the shields differentiate it from *Cruciplacolithus*. It is documented only under SEM in the present material. It ranges from early to late Middle Eocene Zone NP10 to base of NP17 (Perch- Nielsen, 1985).

Occurrence in India: Known from Bartonian of Kachchh and Jaisalmer.

Genus ***Coccolithus*** Scwarz, 1894
Coccolithus eopelagicus Bramlette and Riedel, 1961
(Pl. I, fig. 2a-2c; Pl. IV, fig. 2,3,5)

Remarks: *C. eopelagicus* has been widely reported from Middle Eocene to Late Eocene of several regions. Morphology is very similar to that of living *C. pelagicus*, except for large sizes of Paleogene specimens. Possible relationships between *Ericsonia* and *Coccolithus* are discussed by Perch-Nielsen (1985).

Occurrence in India: Known from Bartonian of Kachchh, Jaisalmer and Meghalaya.

Coccolithus subpertusus (Hay and Mohler, 1967) van Heck and Prins, 1987
(Pl. I, fig. 3a-3c)

Remarks: Circular to subcircular species having large central opening. The complex distal shield is formed of four cycles. The proximal shield is more than half as wide as the distal shield, and sutures are inclined clock wise in proximal view. The central opening appears plugged under normal light.

Occurrence in India: Recorded from Bartonian of Jaisalmer Basin.

Genus ***Discoaster*** Tan Sin Hok, 1927
Discoaster barbadiensis Tan Sin Hok, 1927
(Pl. I, fig. 9-11; Pl. III, fig. 9-11)

Remarks: It is the most characteristic Eocene discoaster. These are rosette shaped asteroliths containing 7-14 rays joined along most of their length with blunt to pointed tips. The asteroliths display proximal curvature with characteristic stem, best observed in side views. In India *D. barbadiensis* is reported from Bartonian equivalent sediments of Kachchh Basin (Singh *et al*., 1980) and late Eocene of western India (Jafar *et al.*, 1985).

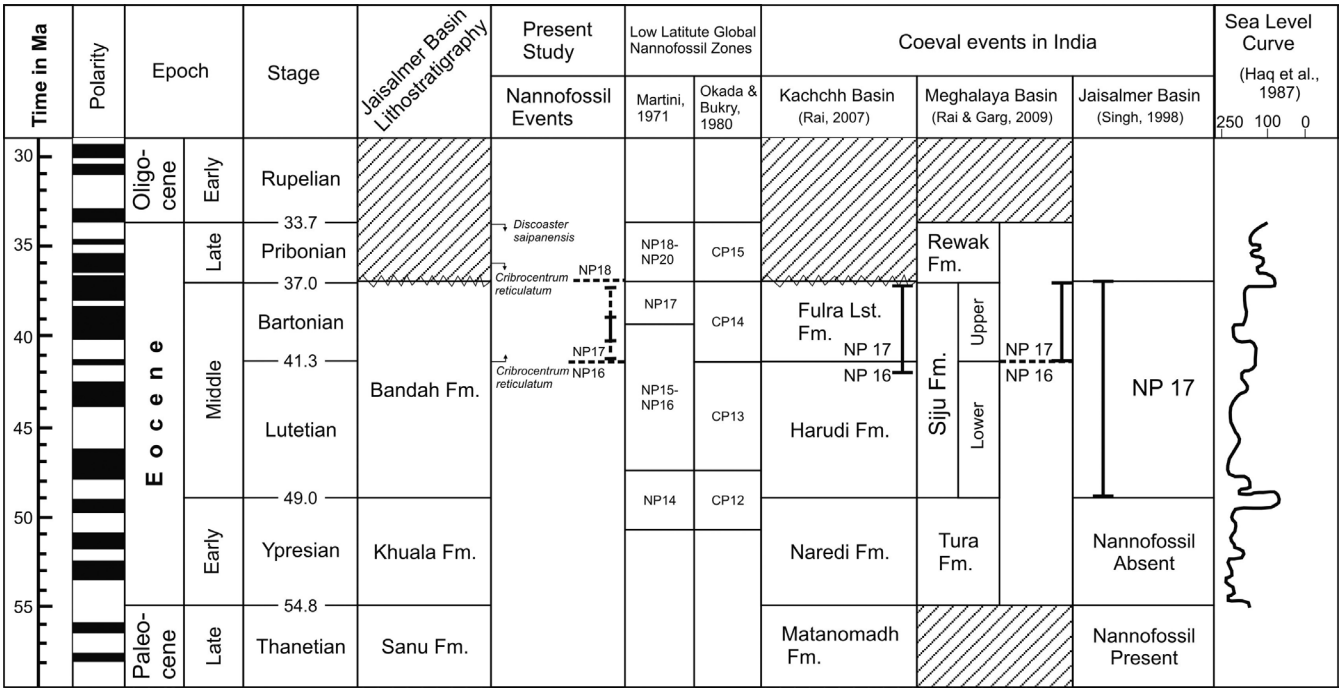


Fig. 4. Correlation chart showing nannofossil zones and events in present study along with the nannofossil studies in same age bracket from Kachchh, Meghalaya and the Jaisalmer Basin with sea-level fluctuations.

Occurrence in India: Known from Bartonian of Kachchh and Meghalaya.

Discoaster binododsus Martini, 1958

(Pl. I, fig. 12)

Remarks: They are characterized by the presence of notch on the ray tips, diameter of central area, thickness and number of arms (5-8) which are variable. More than one pair of nodes may be seen on each ray with short free length in 8-rayed asteroliths. It may look very similar to *D. mirus* (Stradner and Papp, 1961) but the suture lines in wide central area are more prominent in *D. mirus* which differ it from *D. binododsus*.

Occurrence in India: Known from Bartonian of Kachchh.

Discoaster distinctus Martini, 1958

(Pl. I, fig. 14)

Remarks: *D. distinctus* was originally described from Early Late Eocene. Six (sometimes 5) rayed stellate discoasters with heavily noded, bifurcate ray-tips that resemble spanners. In overgrown specimens, it is often difficult to recognize.

Occurrence in India: Known from Bartonian of Kachchh and Meghalaya.

Discoaster saipanensis Bramlette and Riedel, 1954

(Pl. I, fig. 15-17; Pl. III, fig. 12; Pl. IV, fig. 1)

Remarks: It was originally reported from the Late Eocene of Saipan islands (Bramlette and Riedel, 1954; Bramlette, 1959). These are discoasters with 5-8 straight or curved rays joined through half their length and which then taper to a point. A central stem and distinct radial sutural ridges and depressions are visible in some specimens. *D. saipanensis* is extremely useful for biostratigraphy. Extinction of *D. saipanenesis* along with *D. barbadiensis* defines Eocene-Oligocene boundary.

Occurrence in India: Known from Bartonian of Kachchh.

Discoaster cf. *D. saipanensis* Bramlette and Riedel, 1954

(Pl. I, fig. 13)

Remarks: It is a seven-rayed asterolith which shows curvature and termination of rays resembling *D. saipanensis* however, the rays are slightly blunt in termination.

Occurrence in India: Known from Bartonian of Jaisalmer.

Discoaster tanii Bramlette and Riedel, 1954

(Pl. I, fig. 18)

Remarks: Originally described from Late Eocene (Bramlette and Riedel, 1954). 5-6 rayed stellate discoaster with long free rays of uniform width terminating in a flat or slightly notched ray-end. They may show poorly developed unpaired lateral nodes on some rays.

Occurrence in India: Known from Bartonian of Kachchh.

Genus ***Helicosphaera*** Kamptner, 1954 ex Jafar and Martini, 1975

Helicosphaera bramletti (Müller, 1970) Jafar and Martini, 1975

(Pl. I, fig. 19a-19b)

Remarks: *H. bramletti* was originally described from Late Middle Oligocene of borehole material of Southern Germany. Under LM observation, diagnostic for *H. bramletti*, is the characteristic bridge in the form of thick "I" with oblique orientation and spanning a comparatively small central area.

Occurrence in India: Known from Bartonian of Kachchh.

Helicosphaera compacta Bramlette and Wilcoxon, 1967

Remarks: *H. compacta* was originally described from Oligocene of Cipero section (Bramlette and Wilcoxon, 1967) and indicated to range from Late Eocene to Late Oligocene. These are elliptical *Helicosphaera* with well defined birefringent blanket in XPL and narrow central area spanned by a conjunct bar. Under crossed nicols, large part of the helicolith remains dark, while bright small central area shows characteristic and tiny pair of openings separated by a thin birefringent bar.

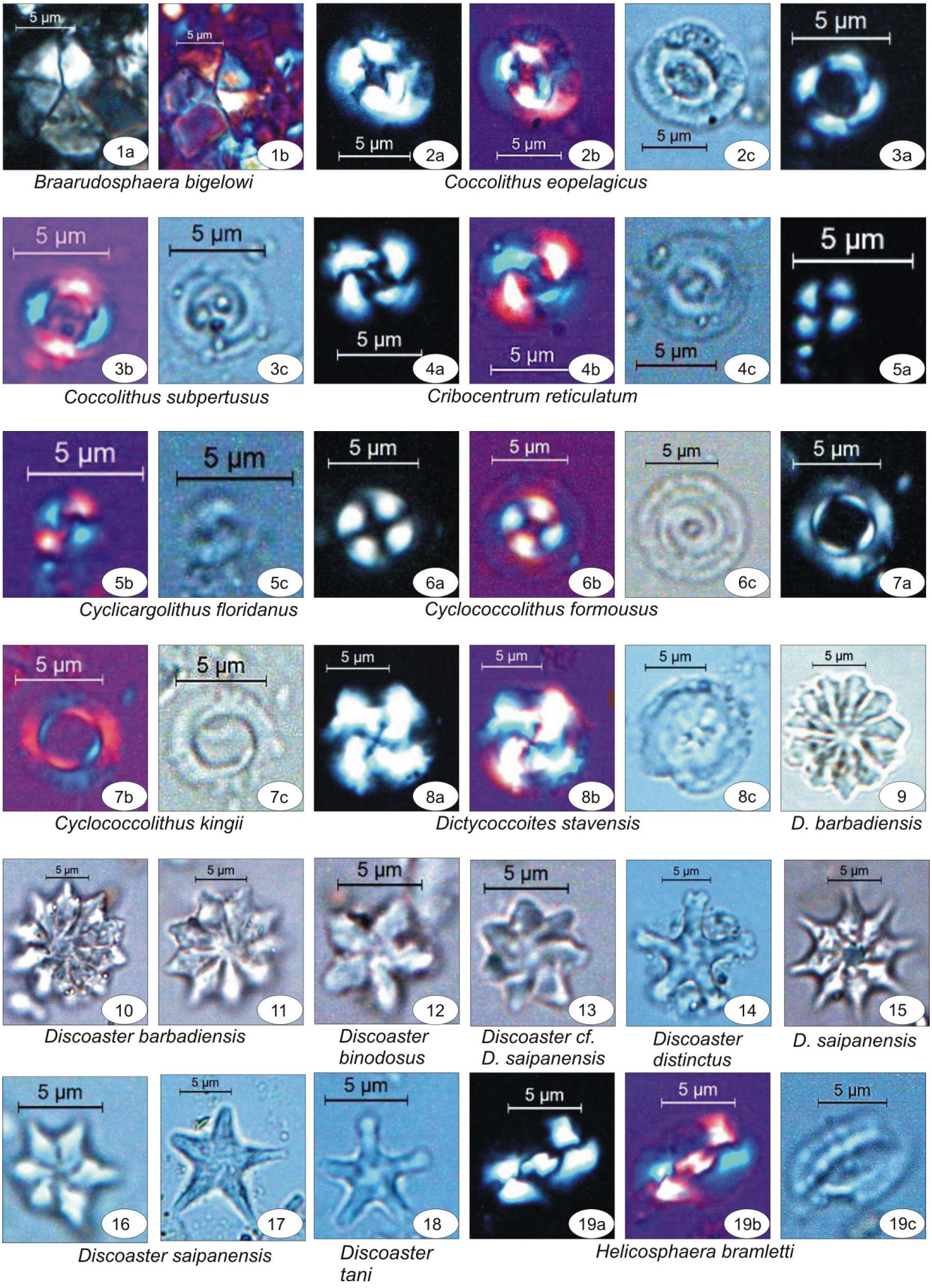
Occurrence in India: Known from Bartonian of Kachchh.

Helicosphaera lophota (Bramlette and Sullivan, 1961) Jafar and Martini, 1975

(Pl. II, fig. 2a-2c)

Remarks: Elliptical, oblong or reniform *Helicosphaera* with wide flange and central area spanned by a broad, near-longitudinal

Plate I


5 µm
1a
1b
2a
2b
2c
3a
Braarudosphaera bigelowi
Coccolithus eopelagicus
3b
3c
4a
4b
4c
5a
Coccolithus subpertusus
Cribocentrum reticulatum
5b
5c
6a
6b
6c
7a
Cyclicargolithus floridanus
Cyclococcolithus formousus
7b
7c
8a
8b
8c
9
Cyclococcolithus kingii
Dictycoccoites stavensis
D. barbadiensis
10
11
12
13
14
15
Discoaster barbadiensis
Discoaster binodosus
Discoaster cf. D. saipanensis
Discoaster distinctus
D. saipanensis
16
17
18
19a
19b
19c
Discoaster saipanensis
Discoaster tani
Helicosphaera bramletti

disjunct bar with distinct median suture. Helicoliths of *H. lophota* with oval outline are similar to that of *H. seminulum*, but distinguished by a sturdy bar aligned nearly parallel to the major axis of the helicolith.

Occurrence in India: Known from Bartonian of Kachchh and Meghalaya.

Helicosphaera parallela Bramlette and Wilcoxon, 1967
(Pl. II, fig. 3a-3c)

Remarks: A typical *Helicosphaera* but not an easily differentiated species. Central area occupied by a parallel sided bar with little or no central opening apparent even between crossed nicols although not in optical continuity with the shield, and bar nearly parallel to the long axis of specimen.

Occurrence in India: Known from Bartonian of Kachchh.

Genus ***Cribrocentrum*** Perch-Nielsen, 1971

Cribrocentrum reticulatum (Gartner and Smith, 1967) Perch- Nielsen, 1971
(Pl. I, fig. 4a-4c; Pl. IV, fig. 6)

Remarks: Circular placoliths displaying characteristic squarish central area which is traversed by dark extinction lines. It is an extremely important middle Eocene stratigraphic marker and palaeoceanographic indicator. It ranges from NP17 – NP20 (Saunders *et al.*, 1984). Perch- Nielsen reported its FAD from Zones NP16/ NP17 boundary. Aubry (1988) recorded its FAD in the Upper part of NP16 to recognize Lutetian/Bartonian boundary. The size ranges from small, medium to large. The small forms are typical of near-shore whereas large forms are usually found in open ocean setting. In the present assemblage both medium and large forms are recorded, but it appears that the larger size may be due to overgrowth.

Occurrence in India: Known from Bartonian of Kachchh and Meghalaya.

Genus ***Dictyococcites*** Black, 1967

Dictyococcites stavensis (Levin and Joerger, 1967) Bown, 1998
(Pl. I, fig. 8a-8c)

Remarks: Nearly circular plates are closely appressed, with the distal plate larger than the proximal plate. Periphery serrate, central area has two small slit like openings which are separated by raised structures resembling two 'V' with the acute angles of the 'V's facing one another. A slit like opening lies in the center of each 'V'.

Occurrence in India: Known from Bartonian of Jaisalmer.

Genus ***Reticulofenestra*** Hay *et al.*, 1966

Reticulofenestra hillae Bukry and Percival, 1971

Remarks: Originally described from Late Eocene of Mississippi and commonly found in Early Oligocene of several areas. Fairly large elliptic placoliths are characterized by wide central collar and small central opening.

Occurrence in India: Known from Bartonian of Kachchh and Meghalaya.

Reticulofenestra minuta Roth, 1970
(Pl. II, fig. 9a-9b)

Remarks: This species is fairly resistant to calcite overgrowth and found even when other common coccoliths are destroyed. It is common in Eocene of Rajasthan, Kachchh, Surat and other areas of India.

Occurrence in India: Known from Bartonian of Kachchh and Meghalaya.

Reticulofenestra pseudoumbilica (Gartner, 1967) Gartner, 1969
(Pl. II, fig. 10a-10c)

Remarks: Elliptical placolith, the elliptical central area is covered by lacy network of bars which join along a longitudinal fissure at the center of the placolith. A collar is present in the distal side. It resembles with *R. umbilica* but the central area is smaller in *R. pseudoumbilica* which is formed by broken bars of central area.

Occurrence in India: Known from Bartonian of Jaisalmer.

Reticulofenestra sp.1
(Pl. II, fig. 11a-11c)

Remarks: Subcircular in outline. Proximal and distal both shields are birefraingent in cross nicols. There appears scalloped or cribrated appearance of the central area under crossed nicols.

Occurrence in India: Known from Bartonian of Jaisalmer.

Reticulofenestra sp.2
(Pl. IV, fig. 7)

Remarks: Subcircular in outline. The central sieve appears broken. Central area is about 1/5 of the total diameter of placolith.

Occurrence in India: Known from Bartonian of Jaisalmer.

Reticulofenestra sp.3
(Pl. IV, fig. 8)

Remarks: Elliptical in outline. Its total diameter about 1µm. Proximal and distal shield almost of the same size. The outline of proximal shield is crenulated, may be due to dissolution. Central area is perforated by bar like projections.

Occurrence in India: Known from Bartonian of Jaisalmer.

Genus ***Pontosphaera*** Lohmann, 1902

Pontosphaera pectinata (Bramlette and Sullivan, 1961) Sherwood, 1974
(Pl. II, fig. 6a-7c; Pl. IV, fig. 4-5)

Remarks: Reported to range from NP-14 to NP-17. The plate is scalloped towards its outer edge and pierced by two longitudinal or small holes. The scalloping is defined by narrow radial ridges and furrows, which run inwards towards the centre.

Occurrence in India: Known from Bartonian of Kachchh and Jaisalmer.

Pontosphaera vesca Sullivan, 1965
(Pl. II, fig. 8a-8c)

Remarks: Originally described by Sullivan (1965). It has several small elongated pores on its surface which are arranged in concentric rows. The rim is thin.

Occurrence in India: Known from Bartonian of Jaisalmer.

Genus ***Blackites*** Hay and Tome, 1962

Blackites spinosus (Deflandre and Fert, 1954) Hay and Towe, 1962
(Pl. III, fig. 1)

Remarks: The specimens are visible in lateral view under LM. The spine is broadest at the base and gradually tapers to needle like spine. Widely reported from Middle Eocene to Early Oligocene of several regions and usually associated with closely related *B. tenuis*. It is very rare in the present assemblage.

Occurrence in India: Known from Bartonian of Kachchh and Jaisalmer.

Genus ***Sphenolithus*** Deflandre *in* Grassé, 1952

Sphenolithus moriformis (Brönnimann and Stradner, 1960) Bramlette and Wilcoxon, 1967
(Pl. II, fig. 12a-12c)

Remarks: Originally reported from heavily overgrown material of Early Eocene of Cuba. Sphenoliths with well defined proximal ring of elements and apical part making low to high dome. They are widely reported from Early Eocene to Middle Miocene. This species is known to have no stratigraphic worth.

Occurrence in India: Known from Bartonian of Kachchh and Meghalaya.

Plate II

Helicosphaera euphratis

Helicosphaera lophota

Helicosphaera parallela

Lanternithus minutus

Pemma basquensis

Pontosphaera pectinata

Pontosphaera pectinata

Pontosphaera vesca

Reticulofenestra minuta

Reticulofenestra pseudoumbilica

Reticulofenestra sp.

Sphenolithus moriformis

Sphenolithus predistentus

Sphenolithus predistentus Bramlette and Wilcoxon, 1967
(Pl. II, fig. 13a-13b; Pl. IV, fig. 12)

Remarks: Sphenolith with a large apical spine, flat or slightly depressed at the base which is attached to a single annular ring of 10-12 lateral spines. Apical stem tapers strongly for about half its length and then gradually to a pointed or bifurcating tip. Between crossed nicols the apical spine appears to be formed of coalesced calcite units of slightly different optical orientation.

Occurrence in India: Known from Bartonian of Kachchh and Meghalaya.

Sphenolithus cf. *S. predistentus* Bramlette and Wilcoxon, 1967
(Pl. IV, fig. 11)

Remarks: It is a sphenolith which is characterized by a proximal ring of small elements surmounted by a spine. The spine is broadest at the base and becomes conical at the top. The delicate bifurcating tip is broken in the present specimen. Though overgrown, resembles with *S. predistentus*.

Occurrence in India: Known from Bartonian of Jaisalmer.

Genus ***Thoracosphaera*** Kamptner, 1927
Thoracosphaera saxea Stradner, 1961
(Pl. IV, fig. 10)

Remarks: Recorded under SEM. Test though broken appears spherical to sub-spherical showing a mosaic of polygonal elements with distinct crystal outline. The crescent –shaped pores are deep seated and seen from broken part of the test. Operculum is broken in the present specimen. The pores completely pierce the test wall. The present specimen shows signs of dissolution and thus the polygonal outline of the elements are not clearly seen. It was recorded very rare in the present material

Occurrence in India: Known from Bartonian of Kachchh.

Genus ***Cyclococcolithus*** Kamptner, 1954
Cyclococcolithus formosus Kamptner, 1954
(Pl. I, fig. 6a-6c; Pl. III, fig. 6)

Remarks: *C. formosus* was originally described from Eocene of Pacific Ocean (Kamptner, 1963). This is readily recognizable species under LM and EM and has been used as important stratigraphic marker, appearing in Late Early Eocene and disappearing in early Oligocene, as indicated by Martini (1971). It is widely recorded in Bartonian equivalent sediments of Kachchh and Meghalaya basins.

Occurrence in India: Known from Bartonian of Kachchh and Meghalaya.

Cyclococcolithus kingii Roth, 1970
(Pl. I, fig. 7a-7c; Pl. III, fig. 7-8)

Remarks: Two different forms as holotype and paratype have been documented under EM for this species (Roth, 1970). It is recorded as minor constituent of Eocene nannoflora from Kachchh Basin also.

Occurrence in India: Known from Bartonian of Kachchh and Meghalaya.

Genus ***Cyclicargolithus*** Bukry, 1971
Cyclicargolithus floridanus (Roth and Hay *in* Hay *et al.,* 1967) Bukry, 1971
(Pl. I, fig. 5a-5c)

Remarks: Originally described from Oligocene of Blake Plateau. Small to medium sized palcoliths show birefringence of the distal shield. *C. floridanus* seems to appear in the upper part of NP-16 and becomes extinct in Middle Miocene. In Oligocene it may be extremely abundant at certain levels.

Occurrence in India: Known from Bartonian of Kachchh and Meghalaya.

Genus ***Scapholithus*** Deflandre *in* Deflandre and Fert, 1954
Scapholithus fossilis Deflandre, 1954
(Pl. IV, fig. 9)

Remarks: Very small form with rhomboidal outline.

Occurrence in India: Known from Bartonian of Jaisalmer.

PRESERVATION

Nannofossil preservation is highly variable in subsurface sediments. The principal governing processes of preservation are dissolution and overgrowth, both of which may occur in varying degree in single sample. For determining the susceptibility of nannofossils to preservational changes various methods are proposed by various authors for different environmental setups (Wise, 1973; Schlanger and Douglas, 1974; Roth, 1978). The average state of preservation of the nannofossil assemblage in each sample is designated as follows:

G = good (little or no evidence of dissolution and/or overgrowth; primary morphological characteristics only slightly altered; specimens are identifiable to the species level).

M = moderate (specimens exhibit some etching and/or overgrowth; primary morphological characteristics sometimes altered; however, most specimens are identifiable to the species level).

P = poor (specimens are severely etched or exhibit overgrowth; primary morphological characteristics largely destroyed; fragmentation has occurred; specimens cannot be identified at the species and/or generic level).

13 subsurface samples out of 22 are found to be good in preservation throughout the succession. The samples at depth 528m, 561m and 579m also showed good preservation with minor effect of overgrowth only in some species. Remaining samples are moderately to poorly preserved.

DIVERSITY

Overall the diversity is good to moderate in Tanot #1. Samples are highly diversified, most of the samples contain more than 20 species average in 100 field of view. Diversity is maximum in the sample number 528. It is moderate to poor in the samples 591 and 594. Species range from 4-5 in 100 field of view in these samples.

ABUNDANCE AND PRODUCTIVITY

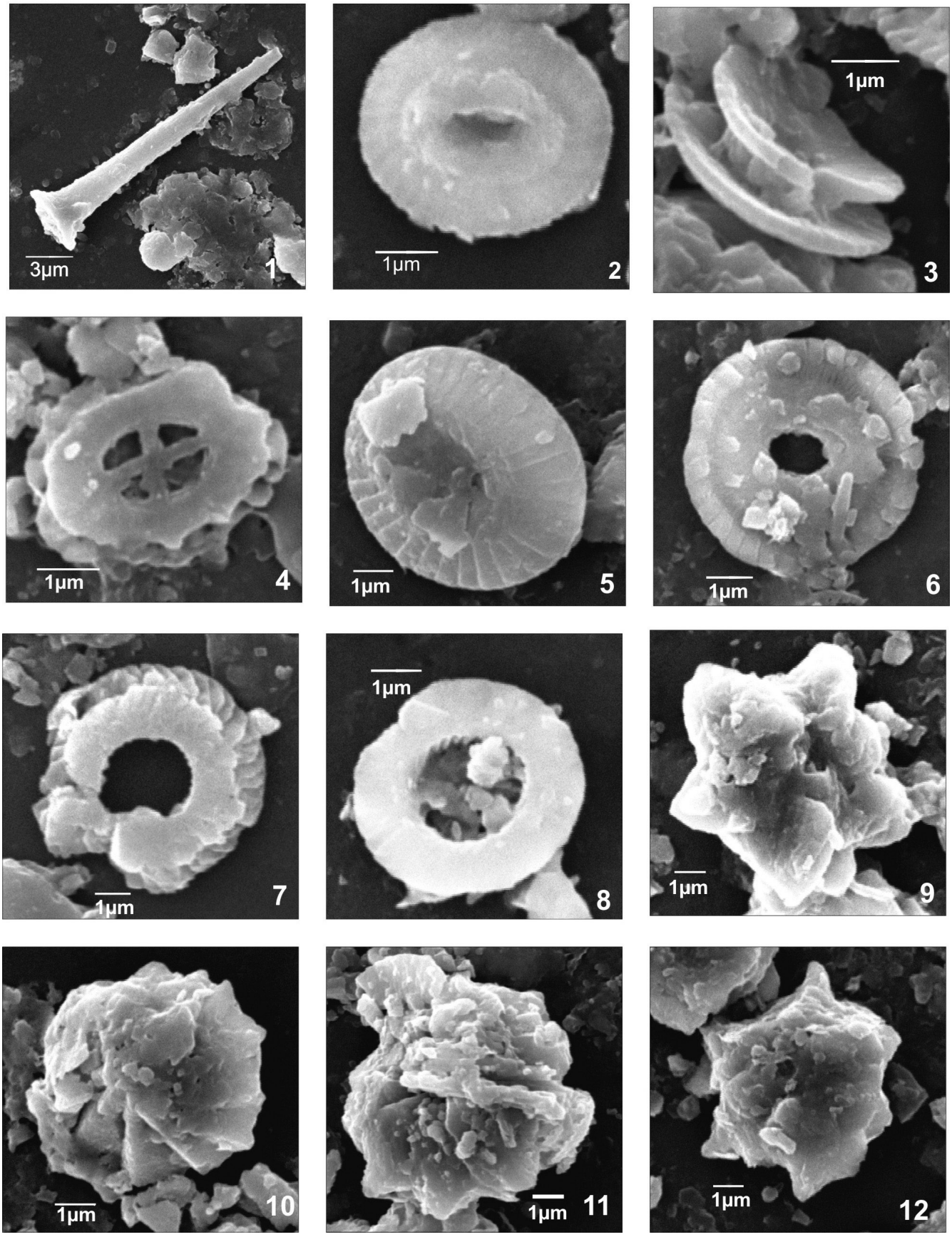
Productivity depends on the overall nannofossil assemblage recorded from each sample. Independent state of preservation of nannofossil assemblage is documented herein. To record the productivity following method is used:-

A = abundant (21 to 100/10 field of view)
C = common (11 to 20/10 field of view)
F = few (3 to 10/10 field of view)
R = rare (1 to 5/10 field of view)

EXPLANATION OF PLATE III

1. ***Blackites spinosus*** (Deflandre and Fert) Hay and Towe, 1962, 2. ***Coccolithus eopelagicus*** Bramlette and Riedel, 1961, 3. ***Coccolithus eopelagicus*** Bramlette & Riedel, 1961, 4. ***Campylosphaera dela*** (Bramlette and Sullivan) Hay and Mohler, 1967, 5. ***Coccolithus eopelagicus*** Bramlette and Riedel, 1961, 6. ***Cyclococcolithus formosus*** Kamptner, 1963, 7. ***Cyclococcolithus kingii*** Roth, 1970, 8. ***Cyclococcolithus kingii*** Roth, 1970, 9. ***Discoaster barbadiensis*** Tan Sin Hok, 1927, 10. ***Discoaster barbadiensis*** Tan Sin Hok, 1927, 11. ***Discoaster barbadiensis*** Tan Sin Hok, 1927, 12. ***Discoaster saipanensis*** Bramlette and Riedel, 1954.

Plate III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In general the productivity of Tanot #1 samples ranges between very abundant to rare (Fig.3). In the whole succession no sample is found to be barren. Sample numbers 528 and 615 are the most productive hence used for SEM studies. Productivity is high in the samples ranging 528m to 615m depth. There is gradual decrease of productivity in the sample at 591m and 594m, after that it slowly increases from the depth of 600m to 627m.

LOW PRODUCTIVITY ZONES IN ASSEMBLAGES

Nannofossil assemblage in the whole succession is fluctuating. One low productivity zone has been recorded throughout the succession alternating with high productivity zones. This zone is recorded in Middle Bartonian at depth ranging between 591m to 594m. The succession above and below of this zone are highly productive. The low productivity zone contains occurrence of only few sturdy (mostly reticulofenestrid) forms viz. *Cribrocentrum reticulatum, Reticulofenestra sp., Reticulofenestra minuta* and *Sphenolithus predistentus.*

EOCENE NANNOFOSSIL BIOSTRATIGRAPHY

Comprehensive zonal schemes employing a variety of planktonic fossil groups including calcareous nannoplankton are available. For Cenozoic the calcareous nannoplankton zonation scheme of Martini (1971) with zonal code NP for Paleogene is based on hemipelagic/epicontinental sequences of Europe and tropical regions. A few zonal markers had restricted nearshore, deep sea or high or low latitude distribution or displayed extended vertical ranges in different latitudes. Therefore, the modified version of zonal scheme based on those provided by Martini (1971) are currently used with well chosen cosmopolitan marker species, which is being further refined with progress in research (Okada and Bukry, 1980).

In the present study of Tanot #1, investigations are based on well-cutting samples only. In general, nannofossils are well preserved which do not hinder the identification of important markers. The nannofossil assemblages are exceptionally well preserved and highly diverse at some levels and low to moderately diverse at some levels in the Tanot #1, is noted with rare to abundant occurrences of selected number of species.

In the Middle Eocene, Bartonian contains upper part of NP16 and NP17. Thus the original definition of zone NP17 is important for zonal assignment of nannoplankton assemblage recovered from Khuiala-Bandah formations. Presence of *C. reticulatum* and *D. saipanensis* in sample numbers 615 (oldest occurrence) and 528 (youngest occurrence) suggests the assemblage belonging to NP 17 Zone. However presence of *C. dela* in oldest 627 number sample extends the NP 17 Zone upto this level belonging to Bartonian age. The emended definition of NP 17 Zone is as follows.

NP 17 DISCOASTER SAIPANENSIS ZONE EMEND RAI 1988

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

Author - Martini, 1970a; emended Rai, 1988. The emended definition of NP 17 would include upper part of NP 16 and NP 17 in the zonation scheme of Martini (1971). This definition has been adopted (Fig.2) 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, op. cit.).

ZONAL ASSIGNMENT OF THE PRESENT ASSEMBLAGE

NP-17 Discoaster saipanensis zone

Definition: Interval from the last occurrence of *Chiasmolithus solitus* (Bramlette and Sullivan, 1961) to the first occurrence of *Chiasmolithus oamaruensis* (Hay *et al.,* 1966).

Author: Martini, 1970

Martini (1970) suggested last occurrence of *Sphenolithus furcatolithoides* Locker (1967) and first occurrence of *Helicosphaera compacta* (Bramlette and Wilcoxon, 1967) in the lower part of NP17.

Discoaster saipanensis is well developed and common species in Indian Eocene and in view of the absence of traditional *Chiasmolith* markers has been used to emend the definition of *Discoaster saipanensis* zone of Martini (1970), so that it can be used for dating other shallow marine low latitude assemblages lacking marker *Chiasmoliths*. The emended definition of NP17 would correspond to Bartonian as suggested by Aubry (1985). Frequent occurrences of *Cribrocentrum reticulatum* in Bandah formation suggest that it cannot be older than Bartonian (Fig.4).

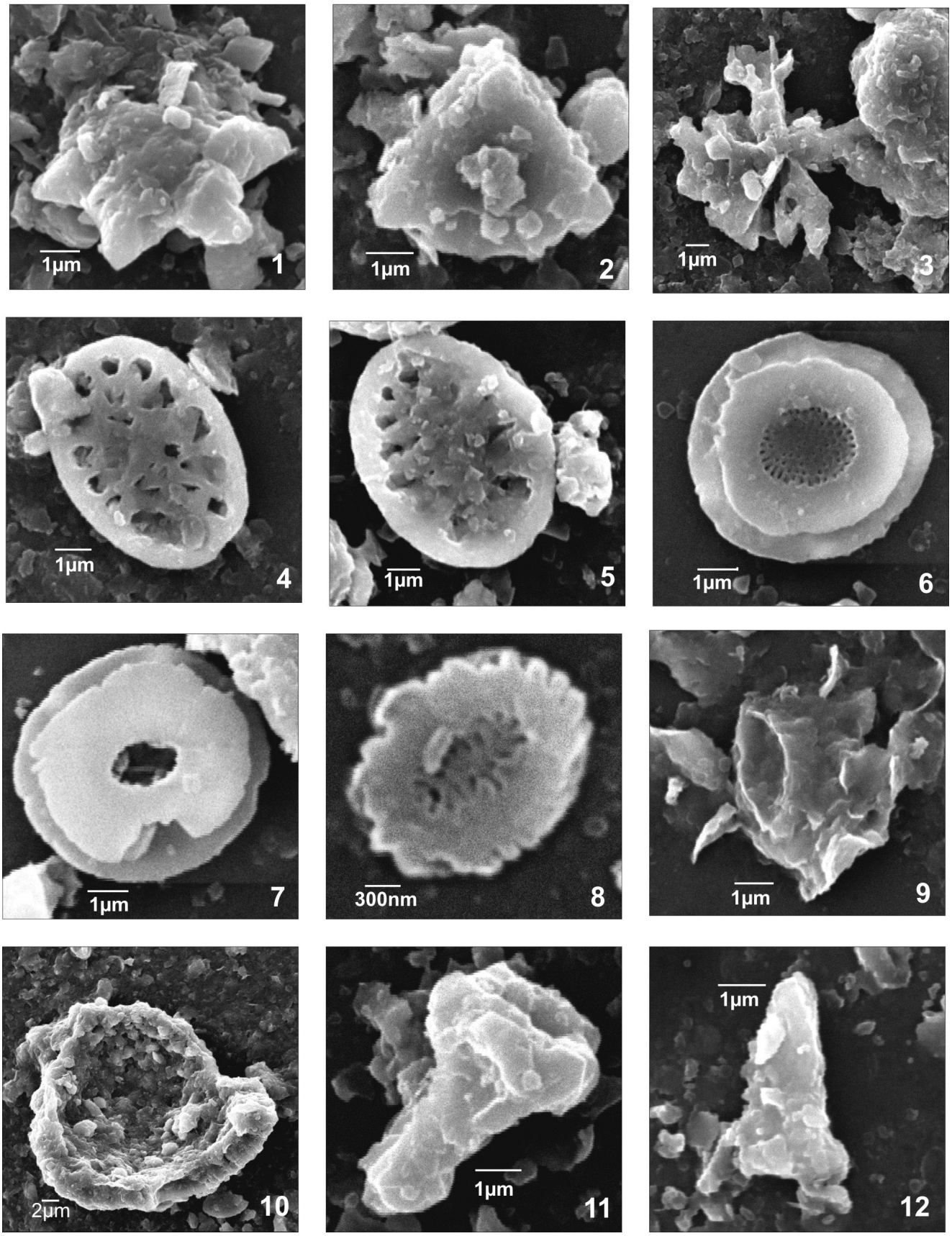
PALAEOCEANOGRAPHIC REMARKS

In response to activation of basinal faults probably coinciding with the collision of Indian-Asiatic landmasses around 40my, grossly arresting the spreading rate during Bartonian, a shallow epeiric sea invaded the margin of the Jaisalmer Basin and laid down the Bandah Formation. The eustatic global rise showed its imprints of inundating both eastern and western part of Indian craton. Nannofossil assemblage of *Discoaster saipanensis* NP17 Zone emended Rai (1988) has been recognized earlier both in the Kachchh Basin, western India (Rai, 1997, 2007) and in the Dilni River section of Meghalaya in eastern India (Rai and Garg, 2009). Though, the entire Bartonian spans (41.3-37my) ca. four million years, there appears that the nannofossil assemblage pertains to only 1.5my time slice (39.5-38.0 my) of eustatic rise (Fig.4). Late Eocene (Priabonian) is a hiatus both in the Kachchh and Jaisalmer basins, whereas the sea remained on the craton in Mehgalaya and encroached the Cambay Basin during the Priabonian.

EXPLANATION OF PLATE IV

1. ***Discoaster saipanensis*** Bramlette and Riedel, 1954, 2. ***Pemma basquensis*** (Martini) Baldi-Beke, 1971, 3. ***Pemma basquensis*** (Martini) Baldi-Beke, 1971, 4. ***Pontosphaera pectinata*** (Bramlette and Sullivan) Sherwood, 1974, 5. ***Pontosphaera pectinata*** (Bramlette and Sullivan) Sherwood, 1974, 6. ***Cribrocentrum reticulaum*** (Gartner and Smith) Perch-Nielsen, 1971, 7. ***Reticulofenestra*** sp. 2, 8. ***Reticulfenestra*** sp.3, 9. ***Scapholithus fossilis*** Deflandre, 1954, 10. ***Thoracosphaera saxea*** Stradner, 1961, 11. ***Sphenolithus*** cf. ***S. predistentus*** Bramlette and Wilcoxon, 1967, 12. ***Sphenolithus predistentus*** Bramlette and Wilcoxon, 1967.

Plate IV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CONCLUSIONS

1. The nannofossil assemblage recorded from Tanot #1 is moderately diversified and well preserved.
2. In all 38 species belonging to 18 genera are recorded.
3. The assemblage belongs to the late Middle Eocene or precisely dated as Bartonian (partim).
4. The Scanning electron microscopy suggests overgrown nature of most of the forms.
5. Presence of *Cribrocentrum reticulatum*, *Dicoaster saipanensis* suggests NP 17 *Discoater saipanensis* Zone (Martini, 1971 emend. Rai, 1988). This is correlatable with parts of both P13 *Orbulinoides beckmanni* and P14 *Truncorotaloides rohri* planktonic foraminiferal Zones (Blow, 1969) and a part of D11 dinoflagellate Zone (Costa and Manum, 1988) of Bartonian age.
6. Record of *B. bigelowii* and other pentaliths, *L. minutus* (holococcolith) suggests nearness to the shore.
7. Coeval nannofossil record, though more diversified in the adjacent Kachchh Basin in western India and less diverse assemblage from Dilni River Section, Meghalaya, eastern India suggests imprints of eustatic global sea level rise (Haq *et al.*, 1987) affecting and inundating cratons of the both extremities of India.
8. The nannofossil diversity, richness in organic material maturity from samples representing Bandah Formation suggests possibility of petroleum source material. Record of adequate structural traps will help in finding hydrocarbon rich horizons in Jaisalmer Basin.

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