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LATE MIOCENE COCCOLITHS FROM NEILL ISLAND, ANDAMAN SEA, INDIA

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ABSTRACT

A rich assemblage of calcareous nannofossils, excluding species of discoasters, which are published elsewhere (Singh and Jafar, 1996), and comprising thirty five species, are described from the East Coast and Nipple Hill sections of the Sawai Bay Formation of Neill Island. The assemblage can be assigned to *Discoaster berggrenii* subzone (CN9A) of Okada and Bukry (1980) and to the lower part of the *Discoaster quinqueramus* Zone (NN11) of Martini (1971).

Key words : Late Miocene, Coccoliths, Neill Island, Andaman Sea.

INTRODUCTION

The Andaman-Nicobar group of islands represents a part of larger Sunda Arc-Trench System of Indian Ocean. The flysch outcrops in a highly disturbed terrain, after intensive search, failed to yield calcareous nannofossils, however, a rich assemblage of calcareous nannofossils containing zonal marker species of Early Campanian to Late Eocene, was recovered from the shale-diapirism induced Mud-Volcanoes of main Andaman Islands (Jafar *et al.* 1989 a, b; Jafar, 1994). In contrast, gently dipping and uplifted Neogene sequences exposed in Ritchie's Archipelago and Southern Islands, represent organic matter rich mud-turbidites with minor sand layers and are practically devoid of marine megabenthic fossils (fig. 1). Such mud-turbidites are interpreted to have been deposited by low density turbidity currents, bringing detrital and partly organic components from rising Himalayas. For over two decades, valuable and integrated biostratigraphic data, based on rich recovery of both siliceous and calcareous microfossils, have been published from these Neogene sequences (Srinivasan *et al.*, 1983; Srinivasan, 1986; Sharma and Sharma 1989; Gupta and Srinivasan, 1992), but a detailed account of calcareous nannofossils from the same samples has only recently been published. The present paper forms a part of that effort (Singh and Jafar, 1995; Jafar and Singh, 1996).

Neill Island (figs. 1-2), ideally situated in

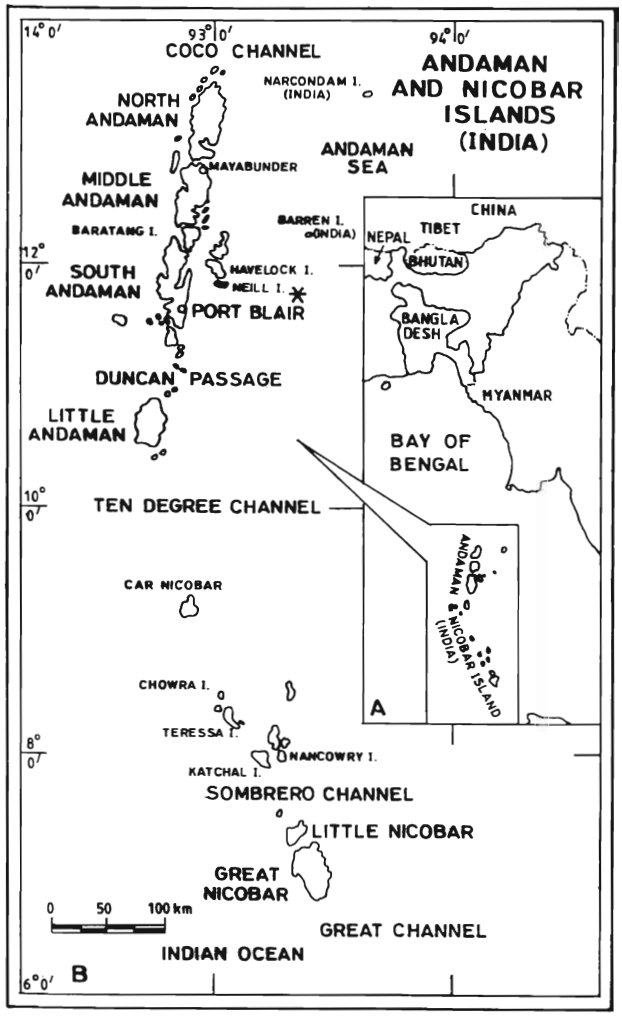

Fig. 1A. Map showing the position of Andaman-Nicobar Islands in Bay of Bengal.

Fig. 1B. Map showing the position of Neill Island (asterisk).

Ritchie's Archipelago, could serve as a type area for integrated biostratigraphy in northern Indian Ocean, as detailed published data on the late Miocene planktic microfossils including nannofossils are now available; this could be further supplemented with isotope, absolute age and geomagnetic studies for interpreting the paleoceanography. Calcareous nannofossil species distribution table tied to lithologs is provided in Jafar and Singh (1996); further documentation and relevant remarks on selected coccolith species, belonging to the families Coccolithaceae, Helicosphaerceae, Pontosphaeraceae, Prinsiaceae, Rhabdosphaeraceae, Sphenolithaceae and Thoracosphaeraceae are presented here.

SECTIONS, MATERIAL AND METHODS

The East Coast and Nipple Hill sections of Neill Island (figs.1-2), from which samples were available, are restudied and fresh supplementary collections made by one of us (SAJ), belong to the Sawai Bay formation. Light to dark gray massive mudstones are extremely rich in marine microfossils, but devoid of megafossils and trace fossils. The base of both the sections is concealed beneath the beach sand. The East Coast sections is capped by Recent to Subrecent coral rags and unconsolidated shell limestone and the Nipple Hill section is covered by soil and thick vegetation.

Thirty-two calcareous mudstone samples from East Coast and twenty-two from the Nipple Hill sections, were utilised for the present study (Singh and Jafar, 1995; Jafar and Singh, 1996); all the fifty-four samples were examined under the lightmicroscope and a few samples showing good preservation of nannofossils were observed under SEM.

Lightmicroscopy

For preparation of slides, a small fraction of the sample was taken out by means of a pointed pin or knife in a porcelain crucible. Turbid suspension was made by addition of distilled and neutral water. Little suspension was spread over a clean glass slide kept on a hot plate. After complete drying, permanent mounting was done by covering it with a cover-slip using Ceadax (artificial Canada Balsam) as mounting medium. Two slides were prepared for each sample; one slide contained the finer fraction and the other coarser fraction Calcareous nannofossils were studied by using a Leitz Polarizing Research Microscope and an 100/1.32 oil-immersion objective. The study was done both under the normal (single polarizer) and crossed-polarized illuminations. Specimens were photographed by using Black and White Film ORWO NP22 and Agfapan Copex A.H.U.

Scanning Electronmicroscopy (SEM)

A small fraction of a sample was taken in a beaker (50 ml). Suspension was made by adding the distilled and neutral water. Agitation treatment was given to the suspension for 15 seconds in a vortex mixer to disperse the material properly. The suspension, was then poured off and spread over a cover-slip. After complete drying, the cover-slip was cut in small pieces to fit within the diameter of the SEM Stub. One piece of cover-slip containing the material was fixed on the SEM Stub with quick-silver and later coated with Gold-Palladium alloy. The coated stubs were examined under the SEM 505 Philips model installed at BSIP, Lucknow with accelerating voltage of 30.0 K.V.

SYSTEMATIC DESCRIPTION

The higher classification of the calcareous nannoplankton adopted herein is after Young (1987).

Kingdom **Protista** (Eukaryotic)

Division **Haptophyta**

Class **Primnesiophyseae**

Family **Coccolithaceae** Poche, 1913

Genus ***Coccolithus*** Schwarz, 1894

Coccolithus pelagicus (Wallich, 1877) Schiller, 1930
(P1.I, figs. la-b)

Coccosphaera pelagica Wallich, 1877, p. 348, pl. 17, figs. 1,3.-7.10.

Coccolithus pelagicus (Wallich), Schiller, 1930, p.246, fig.123.

Coccolithus pelagicus (Wallich) Schiller, Jafar & Singh, 1996, pl . 1, figs. la–b, 2a-b

Remarks : *C. pelagicus* can be distinguished from older *C. eopelagicus* by its smaller size and fewer number of elements in the shield and from

younger C. *miopelagicus* by its thinner rim and smaller size.

In the Neill Island samples, specimens of *C. pelagicus* vary in size between 6-13 μm and rim elements from about 30 to 48.

Stratigraphic Occurrence : It is rare both in the East Coast and Nipple Hill sections.

Recorded Stratigraphic Range : early Miocene to Recent.

Coccolithus radiatus Kamptner, 1955
(Pl.I, figs. 2a-b,3)

Coccolithus radiatus Kamptner, 1955. p.34, pl.7, figs. 92a-b

Coccolithus pataecus Gartner, 1967, p.4, pl.5, figs. 6, 7a-b

Calcidiscus leptoporus (Murray & Blackman) Loeblich & Tappan, Perch-Nielsen, 1985, p. 462, fig 23-5.

Coccolithus radiatus Kamptner, Jafar & Singh, 1996, pl.1, figs. 3a-b, 4.

Remarks : Originally described from Miocene of Rotti Island, Indonesia. It is subcircular to elliptical small-sized placolith constructed of two shields with a small central opening aligned along the long axis. The distal shield is made up of about 15-25 coarse radiating elements. The placolith produces characteristic interference figure between the crossed nicols.

The SEM picture given by Backman (1980, pl. 2, fig. 4) clearly shows a small elliptical central pore with wedge like outwardly radiating elements in the shield. The sutures between the elements are straight.

It can be distinguished from similar coccoliths by its coarsely radiating rim elements and its characteristic interference figure between the crossed-nicols.

Stratigraphic Occurrence : Moderately to poorly preserved specimens occur as rare in both East Coast and Nipple Hill sections.

Recorded Stratigraphic Range : middle Miocene to late Pliocene.

Coccolithus sp.

Coccolithus sp. Jafar & Singh , 1996, pl. 1, figs. 5a-b.

Remarks : Coccolithus sp. is a medium-sized (9 μm), elliptical placolith having a central region encircled by two rims. The central region is about half the length of the whole placolith. It has an elliptical central opening. The periphery of the central opening is surrounded by nodes. Both rims are constructed of fine elements. The external rim has about 40 dextrally imbricated elements and the internal rim has about 30 elements. In the crossed polarized light, central area is birefringent with fused extinction bands when both the rims are faintly visible.

It can be distinguished from closely related *Coccolithus pelagicus* by its indistinct extinction band and by the nodes encircling the central pore.

Stratigraphic Occurrence : Rare in the East Coast and Nipple Hill sections.

Recorded Stratigraphic Range : late Miocene.

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

Cyclococcolithus cf. *C. krejcigrafii* Jafar 1975a

Cyclococcolithus krejcigrafii Jafar, 1975a, p. 74-75, pl 8, figs. 4-5.

Cyclococcolithus cf. *C. krejcigrafii* Jafar, Jafar & Singh 1996, pl.4, figs.1-3

Remarks : C. cf. *C. krejcigrafii* is a small-sized circular placolith. It has a small, crater-like depression in the centre which is pierced by a circular opening as seen in SEM pictures (Jafar and Singh, 1996, pl.4, figs. 1-3) . The rim is constructed of 20-31 characteristic wedge-shaped elements.

It closely matches *C. krejcigrafii* Jafar, in size and morphology, but differs in having a smaller crater-like central depression and a larger central opening. Specimens from Neill Island also show variable imbrication and curvature of suture-line patterns.

Stratigraphic Occurrence : Rare specimens recorded in East Coast section only.

Recorded Stratigraphic Range : late middle Miocene to late Miocene.

Cyclococcolithus leptoporus
(Murray & Blackman, 1898) Kamptner, 1954

Coccosphaera leptopora Murray & Blackman, 1898, pp. 430-432,439, pl.15, figs.1-7.

Cyclococcolithus leptoporus (Murray & Blackman) Kamptner, 1954, p.23, fig. 20.

Cyclococcolithina leptoporus (Murray & Blackman) Wilcoxon, 1970, p.82.

Calcidiscus leptoporus (Murray & Blackman) Loeblich & Tappan, 1978, p. 1391.

Coccolithus sp. I, Singh, 1979, pp. 227-228, pl.l, figs. 19-21.

Cyclococcolithus leptoporus (Murray & Blackman) Kamptner, Jafar & Singh, 1996, p.l, figs 7a-b, 8a-b; pl.4, figs. 4-6.

Remarks : *C. leptoporus* is a well known medium-sized circular to slightly elliptical placolith having a small central depression. The shield of the placolith is constructed of 22-33 curved elements.

Stratigraphic Occurrence : Rare occurrence with moderate to poor preservation in the samples of the East Coast and Nipple Hill sections.

Recorded Stratigraphic Range : early Miocene to Recent.

Cyclococcolithus macintyrei Bukry and Bramlette, 1969

Coccolithus leptoporus var. A (Murray & Blackman) McIntyre, Bé & Preikstas, 1967, pp 9-10, pl.4, figs.C-D

Cyclococcolithus leptoporus (Murray & Blackman) Gartner, 1967, p. l, pl. l, figs. 1-2, 4a-c; pl. 2, figs. l, 3a –c, 4a-d.

Cyclococcolithus macintyrei Bukry & Bramlette, 1969, p. 132, pl.l, figs.1-3.

Calcidiscus macintyrei (Bukry & Bramlette) Loeblich & Tappan, Steinmetz & Stradner, 1984, p. 703,pl.4, figs. 3-4; p. 709, pl.10, figs.2,4. *Cyclococcolithus macintyrei* Bukry & Bramlette, Jafar & Singh, 1996, pl. I, figs. 9a-b, 10a-b.

Remarks: It is a medium-sized circular placolith constructed of two shields with a central depression. The number of elements in the shields varies from 38 to 48.

It can be distinguished from closely related *Cyclococcolithus leptoporus* by its larger size (> 8 μm) and greater number of elements in the shields. Both species appear in the Early Miocene.

Stratigraphic Occurrence: Rare in the East Coast and Nipple Hill sections.

Recorded Stratigraphic Range : early Miocene to early Pleistocene.

Cyclococcolithus protoannulus (Gartner, 1971) Jafar *et al.*, 1989a (Pl.I, figs. 5a-b)

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

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

Cyclococcolithina protoannula Gartner, 1971, p. 109, pl. 5, figs. 1A-C, 2.

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

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

Cyclococcolithus protoannulus (Gartner), Jafar, *et al.*, 1989a, p. 67.

Cyclococcolithus protoannulus (Gartner), Jafar & Singh, 1996, pl. I, figs. 11a-b, 12a-b; p.l4. figs. 7-8.

Remarks: The circular placolith is made up of two shields with a very large central opening. The width of the proximal shield is less than the distal shield. It can be best recognised under the light microscope employing crossed nicols.

Stratigraphic Occurrence : It is common to rare in both sections studied at Neill Island.

Recorded Stratigraphic Range : early Eocene to middle Oligocene. The younger occurrence in the late Miocene is recorded for the first time in this study.

Family **Helicosphaeraceae** Black 1971, ex Jafar & Martini, 1975

Genus ***Helicosphaera*** Kamptner, 1954, ex Kamptner, 1956.

Helicosphaera carteri (Wallich,1877) Kamptner, 1941 (Pl. I, figs. 6-10a-b, 11)

Coccosphaera carteri Wallich, 1877, pp. 347-348, pl.17, figs. 3-4, 6,7,17.

Coccolithus carteri (Wallich) Kamptner, 1941, pp. 93, 111, pl. 13, fig. 136.

Helicosphaera carteri (Wallich) Kamptner, 1954, p. 21, figs. 17-19.

Helicopontosphaera kamptneri Hay & Mohler, 1967, p. 448, pls. 10-11, fig. 5.

Helicosphaera carteri (Wallich) Kamptner; Jafar & Singh, 1996, pl. I figs. 13a-17; pl. 4 fig 9; pl. 5, figs. 1-3.

Remarks: Originally described from the Recent sediments of Indian and Atlantic Oceans (Wallich, 1877). Detailed taxonomic and nomenclatural problems are dealt elsewhere (Jafar and Martini, 1975; Aubry, 1988). It is a medium-sized helicolith having oval to more or less elliptical outline. It is constructed of two shields. The outer rim is terminated into an expanded wing in most of the specimens. Few specimens do not possess an expanded wing. The central portion consists of more or less circular or slit-like two central openings aligned along the long axis of the helicolith.

Stratigraphic Occurrence : Common to rare in the East Coast and Nipple Hill sections.

Recorded Stratigraphic Range : early Miocene to Recent.

Helicosphaera intermedia Martini, 1965
(Pl. I, figs. 12-13)

Helicosphaera intermedia Martini, 1965, p. 404, pl. 35, figs. 1-2.

Helicosphaera intermedia Martini, Jafar & Singh, 1996, pl. 1. fig. 18.

Remarks: Originally described from the Oligocene to Miocene DSDP cores from the Pacific Ocean. It is a medium-sized helicolith having an elliptical outline. The central area is spanned by an inclined sigmoidal bar. The inclination of the bar is 20^0 to 30^0 from long axis of the helicolith. The bar can be better seen at 45^0 under the crossed polarized light.

Stratigraphic Occurrence : Rarely but consistently occurs in the East Coast and Nipple Hill section.

Recorded Stratigraphic Range : late Eocene to late Miocene.

Helicosphaera pacifica Müller & Brönnimann, 1974.

Helicosphaera pacifica Müller & Brönnimann, 1974, pp. 661-662, pl.1, figs.1-10.

Helicosphaera pacifica Müller & Brönnimann, Jafar and Singh, 1996, pl. 2, figs. 1a-b; pl. 5, fig. 5.

Remarks : Originally described from the Middle Miocene sediments of the Solomon Sea (Pacific Ocean). It is a small-sized (5 to 7 µm) helicolith having an almost rectangular outline. Under the lightmicroscope, the central area perforations (with 35 to 40 pores, distinct in SEM) cannot be resolved and only a narrow, slit-like opening can be seen. It has a low relief when viewed under single polarizer, and is difficult to differentiate from *Helicosphaera orientalis*. The only difference is that the *H. pacifica* shows a much lower relief than *H. orientalis*.

Stratigraphic Occurrence : Rare in the East Coast and Nipple Hill sections.

Recorded Stratigraphic Range : middle Miocene to late Miocene (fide Aubry, 1988).

Helicosphaera sp. 1
(Pl.I, fig. 14)

Helicosphaera sp. 1, Jafar and Singh, 1996, pl.2, figs. 2a-b.

Remarks : It is a small-sized (6.5 µm) helicolith with an imperforate central area.

Stratigraphic Occurrence : Rare in the East Coast and Nipple Hill sections.

Recorded Stratigraphic Range : late Miocene.

Helicosphaera sp. 2

Helicosphaera sp. 2, Jafar and Singh, 1996, pl.5, fig. 4.

Remarks : It is a medium-sized (8.8 µm) helicolith having a broadly elliptical outline. The central area has two small circular openings. These two openings are separated from each other by a bridge aligned along the short axis of the helicolith. It is similar to *Helicosphaera carteri*, only differing in its outline.

Stratigraphic Occurrence : Rare in the East Coast and Nipple Hill sections.

Recorded Stratigraphic Range : late Miocene.

Family **Pontosphaeraceae** Lemmermann, 1908

Genus ***Pontosphaera*** Lohmann, 1902

Pontosphaera anisotrema (Kamptner, 1955) Backman, 1980
(Pl. I, figs. 15 a – b)

Coccolithites anisotrema Kamptner, 1955, p. 16, pl.2, figs. 22a-b.

Coccolithites deflandrei Kamptner, 1955, p. 16, pl. 9, figs. 141a – b.

Discolithus anisotrema Kamptner, 1956, p. 6.

Discolithus deflandrei Kamptner, 1956 p. 6.

Discolithina cf. *D. anisotrema* (Kamptner) Bramlette & Wilcoxon, 1967, p. 104, pl. 5, figs. 5-6.

Pontosphaera anisotrema (Kamptner) Backman, 1980, p. 54.

Pontosphaera anisotrema (Kamptner) Backman, Jafar & Singh, 1996, pl. 2, figs. 3a-b.

Remarks : Originally described from the Miocene sediments of Rotti Island, Indonesia. It is a medium-sized elliptical form, made up of a smooth margin and a basal plate. The basal plate is pierced by numerous small pores arranged in regular rows. The size of the pores in the outermost cycle is larger than in the inner cycle.

Stratigraphic Occurrence : Rare in the East Coast and Nipple Hill sections.

Recorded Stratigraphic Range : Miocene to Pliocene.

Pontosphaera callosa (Martini, 1969) Varol, 1982
(Pl. I, figs. 16a-b)

Discolithina callosa Martini, 1969, p. 287, pl. 26,figs. 7-9.

Pontosphaera callosa (Martini) Varol, 1982, p. 253.

Pontosphaera callosa (Martini) Varol, Jafar & Singh 1996, pl. 2, figs. 4a-6b; pl. 5, fig. 6.

Remarks : Originally described from the Middle Miocene sediments of Gabon. It is a medium-sized elliptical form constructed of an arched basal plate and an outer thick smooth rim. The basal plate is pierced by numerous small pores of equal size arranged in 5 concentric rows.

Stratigraphic Occurrence : Rare in the East Coast and Nipple Hill sections.

Recorded Stratigraphic Range : middle Miocene to Pliocene.

Pontosphaera multipora (Kamptner, 1948) Roth, 1970
(Pl. I, figs. 17-18a-b)

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

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

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

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

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

Pontosphaera multipora (Kamptner) Roth, Jafar & Singh, 1996, pl. 2, figs. 7a-9; pl. 5, fig. 7.

Remarks : Originally described from the Upper Miocene (Tortonian) sediments of the Vienna Basin, Austria. It is a broadly elliptical form and varies in size from 5 to 7 µm. It is constructed of a basal plate and an outer rim. The basal plate is characterized by 3-5 rows of pores.

Stratigraphic Occurrence : Rare in the East Coast and Nipple Hill sections.

Recorded Stratigraphic Range : early Eocene to Miocene.

Pontosphaera sp. 1

Pontosphaera sp. 1, Jafar & Singh, 1996, pl. 2, figs. 10a-b.

Remarks : It is a medium-sized elliptical form. The basal disc is characterized by numerous small pores in the central region. On rotation, at a certain angle (20^0), it shows a characteristic extinction pattern under crossed nicols.

Stratigraphic Occurrence : Rare in the East Coast and Nipple Hill sections.

Recorded Stratigraphic Range : late Miocene.

Pontosphaera sp. 2.
(Pl. II, figs. 1a-b)

Pontosphaera sp. 2, Jafar & Singh, 1996, pl. 2, figs. 11a-b.

Remarks : It is a medium-sized elliptical form constructed of a rim and a basal plate. The basal plate is perforated with numerous small pores. Under crossed polarized light, the extinction lines are thick and continue into the center in a way that it bisects the basal plate.

Stratigraphic Occurrence : Rare in the East Coast and Nipple Hill sections.

Recorded Stratigraphic Range : late Miocene.

Genus ***Scyphosphaera*** Lohmann, 1902.

Scyphosphaera amphora Deflandre, 1942

Scyphosphaera amphora Deflandre, 1942, p. 132, figs. 21-22.

Scyphosphaera lagena Kamptner, Bramlette & Wilcoxon, 1967, p. 107, figs.8-9.

Scyphosphaera amphora Deflandre : Jafar & Singh, 1996, pl.2, figs.12a-b.

Remarks : Originally described from the Miocene to Pliocene sediments of Algeria. Wall in the lower part is gently convex, converging near the distal end and then flares out to form a neck. Neck flaring is not well developed in the present specimen. Maximum width lies in the basal portion and minimum at the neck. The apical opening is slightly narrower than the base (Jafar and Singh, 1996, pl. 2, figs. 12a-b).

Stratigraphic Occurrence : Rare in the East Coast and Nipple Hill sections.

Recorded Stratigraphic Range : middle Miocene to Pleistocene.

Scyphosphaera apsteinii Lohmann, 1902

Scyphosphaera apsteinii Lohmann, 1902, p. 129, 132, pl. 4, figs. 26-30.

Scyphosphaera apsteinii Lohmann, Jafar & Singh, 1996, pl. 2, figs. 13a-15.

Remarks : Originally described from the recent

sediments of the Mediterranean Sea and Atlantic Ocean. It is a higher than wide, barrel-shaped lopadolith . The wall is curved towards the principal axis distally and at the base it is slightly concave whereas in the side it is gently to strongly convex. The outer surface of the wall exhibits fine longitudinal striations.

Stratigraphic Occurrence : Rare in the East Coast and Nipple Hill sections.

Recorded Stratigraphic Range : Miocene to Recent.

Scyphosphaera cylindrica Kamptner, 1955

Scyphosphaera cylindrica Kamptner, 1955, p. 24, pl. 9, fig. 119.

Scyphosphaera cylindrica Kamptner, Jafar & Singh, 1996, pl. 2, figs. 16a-b.

Remarks : The lopadolith consists of an arched proximal plate of nearly equal length and width. In side-view, the wall slightly diverges in the lower part and then becomes vertical. The specimens show slight flaring of the wall at the distal end. The recovered specimens are nearly identical in shape and size to the documented neotype specimen from Late Middle Miocene of Rotti Island (Jafar, 1975b).

Stratigraphic Occurrence : Rare in the East Coast section and not observed in Nipple Hill section.

Recorded Stratigraphic Range : late middle to late Miocene.

Scyphosphaera cf. *S. globulata* Bukry & Percival, 1971

Scyphosphaera globulata Bukry and Percival, 1971. p. 138. pl. 7, figs. 1-6.

non *Scyphosphaera globulata* Bukry and Percival, Mathur, 1980, p.36, pl. 1, figs. 23-24.

Scyphosphaera cf. *S. globulata* Bukry & Percival, Jafar & Singh 1996, pl. 2, figs. 17a-b.

Remarks : Originally described from Upper Miocene to Lower Pliocene sediments of the Gulf of Mexico. It is a small globular lopadolith with a small base and a slightly wide distal opening. The present specimen is similar to *Scyphosphaera globulata* but differs in having a more arched basal plate. True *S. globulata* are fairly common in younger levels of the *D. quinqueramus* zone in other sections of the Andaman Islands.

Stratigraphic Occurrence : Rare in the East Coast and Nipple Hill sections.

Recorded Stratigraphic Range: late Miocene to early Pliocene.

Scyphosphaera pulcherrima Deflandre, 1942

Scyphosphaera pulcherrima Deflandre, 1942, p. 133, figs. 28-31.

Scyphosphaera pulcherrima Deflandre, Jafar & Singh, 1996,pl. 2, figs. 18a-b.

Remarks : Originally described from the Miocene to Pliocene sediments of El Medhi, Algeria. It is a basket-shaped lopadolith, characterized by a neck with a funnel-shaped flaring collar. Ribs on the surface of the wall are not distinct in light micrographs.

Stratigraphic Occurrence : Rare in the East Coast section and not observed in the Nipple Hill section.

Recorded Stratigraphic Range : middle Miocene to Pliocene.

Scyphosphaera queenslandensis Rade, 1975
(Pl. II, figs. 2a-b)

Scyphosphaera queenslandensis Rade, 1975, p. 158, pl. 2, fig. 9; pl. 3, figs. 4-5.

Scyphosphaera queenslandensis Rade, Jafar & Singh, 1996, pl. 3, figs. 1a-b.

Remarks : Originally described from the Upper Miocene sediments of Capricorn Basin, Coral Sea. It is a barrel-shaped lopadolith characterized by a short neck with a very short collar. The surface of the wall is ornamented by longitudinal ribs. The height of the lopadolith is much greater than its maximum width in the middle part. The distal opening is more or less equal or slightly wider than the base.

Stratigraphic Occurrence : Rare in the East Coast section and not observed in the Nipple Hill section.

Recorded Stratigraphic Range : late Miocene.

Family **Prinsiaceae** Hay & Mohler, 1967

Genus ***Dictyococcites*** Black, 1967

Dictyococcites productus (Kamptner, 1963) Backman, 1980
(Pl.II, fig.3)

Ellipsoplacolithus productus Kamptner, 1963,p. 172, pl. 8, figs. 42, 44.

Gephyrocapsa producta (Kamptner) Bukry, 1971, pl. 2, fig. 2.

Coccolithus productus Gartner, 1973, p. 2029. fig. 5.

Crenalithus productellus Bukry, 1975, p. 688.

Dictyococcites productus (Kamptner) Backman, 1980, p. 49, pl. 4, figs. 1A, 2A, 3,6.7.

Dictyococcites cf. *D. productus* (Kamptner) Backman, Jafar & Singh, 1992, p. 410, figs. 8a-b.

Dictyococcites productus (Kamptner) Backman: Jafar & Singh, 1996, pl.3,fig. 4.

Remarks : It is a small-sized (3.5μm), elliptical placolith, having a closed central area. Under crossed polarized light, the central area and the distal rim are birefringent with thin and sharp extinction lines. Backman (1980) considered the size range of *D. productus* as ca. 3.5-4.5 μm.

Stratigraphic Occurrence : Abundant to rare in the East Coast and Nipple Hill sections.

Recorded Stratigraphic Range : early Miocene to Pleistocene.

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

Reticulofenestra haqii Backman, 1978 (Pl. II, figs. 4-6, 19)

Reticulofenestra sp. Haq & Berggren, 1978, pl. 1, figs. 23-26.

Reticulofenestra haqii Backman, 1978, p. 110, pl. 1, figs. 1-4; pl. 2, fig. 10.

Reticulofenestra haqii Backman , Jafar & Singh, 1996, pl. 3, figs. 5a-b; pl. 5, figs. 8–9.

Remarks: Originally described from the Upper Miocene sediments of the Vera Basin, southeast Spain. It is a small-sized (3.0-5.5 μm), elliptical placolith with a small central opening ranging from 0.75-1.5 μm. Backman (1980) proposed that the specimens of *Reticulofenesra* ranging in size from ca-3-5 μm with a central opening of 0.5-1.5 μm. are referred to as *Reticulofenestra haqii.*

Stratigraphic Occurrence : Abundant to rare in the East Coast and Nipple Hill sections.

Recorded Stratigraphic Range : early Miocene to Pleistocene.

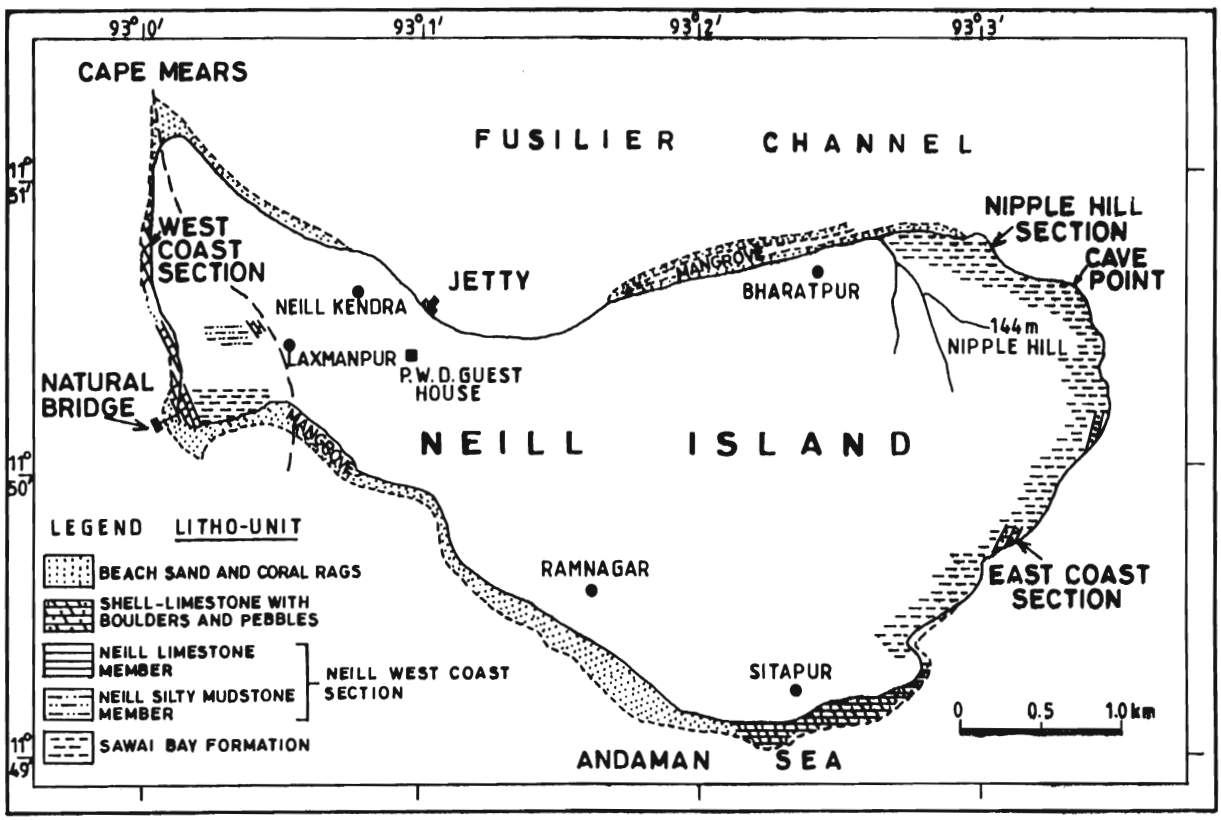

Fig. 2. Detailed geological map of Neill Island, displaying outcrops, studied sections and important localities (after Singh and Jafar, 1995).

Reticulofenestra minuta Roth, 1970
(Pl. II, figs. 7-8)

Reticulofenestra minuta Roth, 1970, p. 850, pl. 5, figs. 3-4.

Dictyococcites minutus (Haq) Haq & Berggren, 1978,pl. l, figs. 19-20.

Reticulofenestra minuta Roth : Jafar & Singh, 1996, pl. 3, fig. 6.

Remarks : Roth (1970) described it from Oligocene sediments of the Atlantic Ocean. He studied it under Electron microscope and observed that the species is charaterized by very small size with 10 to 15 pores in the central net. The present specimen is photographed under the light microscope. It is a very small (2.5 μm), elliptical placolith, having a small central opening. Backman (1980, p. 45) proposed that the reticulofenestrid placoliths which are smaller than the ca. 3.0 μm should be considered as *R. minuta.*

Stratigraphic Occurrence : Abundant to frequent in the East Coast and Nipple Hill sections.

Recorded Stratigraphic Range : early Eocene to late Pliocene.

Reticulofenestra minutula (Gartner, 1967) Haq and Berggren, 1978
(Pl. II, figs. 9-10)

Coccolithus minutulus Gartner, 1967, p. 3, pl. 29, figs. 3-5.

Crenalithus doronicoides (Black & Barnes) Roth, 1973, pl. 3, fig. 3.

Reticulofenestra minutula (Gartner) Haq & Berggren, 1978, p.1190.

Reticulofenestra minutula (Gartner) Haq & Berggren, Jafar & Singh, 1996, pl. 5, fig. 10.

Remarks : It is a small, elliptical form of *Reticulofenstra*. The size of the placolith is about 4.3 μm and has a central opening of about 1.9 μm legth. SEM photograph (Jafar and Singh, 1996, pl. 5, fig. 10) shows that the central opening is surrounded by a narrow collar. The margins of both shields are crenulated. Backman (1980) proposed that the placoliths in the size range of 3-5 μm (as *R.haqii*) with a central opening larger than 1.5 μm can be referred to *Reticulofenestra minutula.*

Stratigraphic Occurrence : Common to rare in both the East Coast and the Nipple Hill sections.

Recorded Stratigraphic Range : middle Miocene to Pleistocene.

Reticulofenestra pseudoumbilicus (Gartner, 1967) Gartner, 1969
(Pl. II, figs. lla-b)

Coccolithus pseudoumbilicus Gartner, 1967, p. 4, pl. 6, fig. 3.

Reticulofenestra pseudombilica (Gartner) Gartner, 1969, pp. 587-589.

Reticulofenestra pseudoumbilica (Gartner) Gartner, Jafar & Singh, 1996, pl. 3, figs. 7a-b 8-9.

Remarks : Originally described from the Miocene to Lower Pliocene sediments of the Gulf of Mexico (Gartner, 1967). It is a medium-sized, elliptical placolith. The placolith ranges in size from 6-8 μm and has a central opening of 2.0-2.5 μm. The central opening is surrounded by a collar.

It can be distinguished from the closely related *Reticulofenestra gelida* by its relatively larger central opening. Backman (1980) discussed *R. pseudoumbilicus* and *R. gelida* in detail and considered *R. gelida* as a junior synonym of *R. pseudoumbilicus*. He furhter concluded that *R. gelida* is found only in high latitude cool-water conditions, and represents a winter morphovariant of *R. pseudoumbilicus*.

Stratigraphic Occurrence : Abundant to rare in the East Coast section and common to rare in the Nipple Hill section.

Recorded Stratigraphic Range : early Miocene to late Pliocene.

Family **Rhabdosphaeraceae** Lemmermann, 1908

Genus ***Rhabdosphaera*** Haeckel, 1894

Rhabdosphaera procera Martini, 1969, emend. Jafar, 1975a
(Pl. II, figs. 12a-b, 13,20).

Rhabdosphaera stylifer (Lohmann), Kamptner, 1955, pp. 37-38, pl. 8, fig. 106.

Rhabdosphaera claviger Murray & Blackman, Kamptner, 1956, p.7.

Rhabdosphaera procera Martini, 1969, p. 289, pl. 26, figs. 10-11.

Rhabdosphaera procera Martini, emend . Jafar, 1975a, p. 59, pl. 7, figs. 3-4, 23-24.

Rhabdosphaera procera Martini, emend. Jafar, Jafar & Singh, 1996, pl. 3, fig. 11; pl. 5, fig. 11.

Remarks : Originally described from *Discoaster calcaris* zone (NN10=Late Miocene) of Gabon. It is constructed of an arched proximal disc and a long slender stem. Under the light microscope, the stem exhibits a prominent central canal traversing throughout its length. Under crossed polarized light, the stem appears to be thickened towards its distal end.

The SEM photograph in Jafar and Singh (1996, pl. 5, fig.11) shows that the species consists of an arched proximal plate with a more or less parallel sided long stem. The stem is made up of fine elongate elements which are showing slight dextral imbrication. The details of the elements in proximal shield are not distinct .

Stratigraphic Occurrence : Rare in the East Coast and Nipple Hill sections.

Recorded Stratigraphic Range : middle Miocene to Pliocene.

Family **Sphenolithaceae** Deflandre, 1952

Genus ***Sphenolithus*** Deflandre, 1952.

Sphenotithus abies Deflandre, 1953
(Pl. II, figs. 14 a-b, 21)

Sphenolithus abies Deflandre, 1953,p. 1785.

Sphenolithus abies Deflandre, Jafar & Singh, 1996, pl. 3, figs. 12a-b; pl. 5, figs. 9,12.

Remarks : Originally reported from the Miocene to Pliocene sediments of Algeria, the specimens of this small species have a conical apical spine consisting of few elements extending parallel to the median axis.

SEM photograph (Pl II, fig. 21) shows that it has conical apical spine with outwardly curved proximal elements. The surface of the central part shows a net-like structure.

Stratigraphic Occurrence : Abundant to frequent in the East Coast and Nipple Hill sections.

Recorded Stratigraphic Range : early Miocene to late Pliocene.

Sphenolithus moriformis (Bronnimann & Stradner, 1960) Bramlette and Wilcoxon, 1967
(Pl. II, fig. 15)

Nannoturbella moriformis Bronnimann & Stradner, 1960, p. 368, figs. 11-16

Sphenolithus pacificus Martini, 1965, p. 407, pl. 36, figs. 7-10.

Sphenolithus moriformis (Bronnimann & Stradner) Bramlette & Wilcoxon, 1967, pp. 124-126, pl. 3, figs. 1-6.

Sphenolithus moriformis (Bronnimann & Stradner) Bramlette & Wilcoxon, Jafar & Singh, 1996, pl. 3, figs. 14-15.

Stratigraphic Occurrence : Common to frequent in both the East Coast and the Nipple Hill sections.

Recorded Stratigraphic Range : Ranges from Paleocene to Miocene.

Family **Thoracosphaeraceae** Schiller, 1930

Genus ***Thoracosphaera*** Kamptner, 1927

Thoracosphaera albatrosiana Kamptner, 1963
(Pl. II, fig. 16)

Thoracosphaera albatrosiana Kamptner, 1963, p. 177, pl. 5, fig. 30.

Thoracosphaera albatrosiana Kamptner, Jafar & Singh, 1996, pl. 3, fig. 16.

Remarks : Originally described from the middle Quaternary sediments of the Pacific Ocean, complete specimens were not observed in the present study and the species was recognised by its characteristic extinction pattern under crossed polarized-light.

Stratigraphic Occurrence : Rare in the East Coast and Nipple Hill sections.

Recorded Stratigraphic Range : Miocene to Recent.

Thoracosphaera heimii (Lohmann, 1919) Kamptner, 1941
(Pl. II, fig. 17)

Syracosphaera heimii Lohmann, 1919,p. 117, fig. 29.

Thoracophaera pelagica Kamptner, 1927,p. 180, fig. 6.

Thoracosphaera heimii (Lohmann) Kamptner, 1941, p. 118.

Thoracosphaera heimii (Lohmann) Kamptner, Jafar & Singh, 1996,pl. 3, fig.17.

Stratigraphic Occurrence : Rare in the East Coast and Nipple Hill sections.

Recorded Stratigraphic Range : Paleocene to Recent.

Thoracosphaera saxea Stradner, 1961

Thoracosphaera saxea Stradner, 1961, p. 8, fig. 71.

Thoracosphaera saxea Stradner, Jafar & Singh, 1996, pl. 3, fig. 18.

Remarks : Originally desecribed from Danian of Austria, it is constructed of a number of large crystallites, showing a characteristic extinction pattern under crossed polarized light.

Stratigraphic Occurrence : Rare in the East Coast and Nipple Hill sections.

Recorded Stratigraphic Range : Late Maastrichtian to Recent.

Thoracosphaera tuberosa Kamptner, 1963

Thoracosphaera tuberosa Kamptner, 1963, p. 179, pl. 4, fig. 26.

Thoracosphaera tuberosa Kamptner, Jafar & Singh, 1996, pl. 3, fig. 19.

Remarks : Originally described from the middle Quaternary sediments of the Pacific Ocean. Also, the broken specimens show the characteristic extinction pattern with small triangular areas under crossed polarized light.

Stratigraphic Occurrence : Rare in the East Coast and Nipple Hill sections.

Recorded Stratigraphic Range : Eocene to Recent.

REMARKS ON PALEAOCEANOGRAPHY

The calcareous nannofossil assemblage recoverd from the two sections of Neill Island, comprising fifty seven species, including twenty two species of *Discoaster* published earlier (Singh and Jafar, 1995), can be assigned to *Discoaster berggrenii* Subzone (CN 9A) of Okada and Bukry (1980), and comparable to the lower part of *Discoaster quinqueramus* Zone (NN11) of Martini (1971) of late Miocene age.

The organic matter rich massive mudstones of Sawai Bay Formation, were laid down in nearshore, tropical waters with open ocean influence by low density turbidity currents; the soft muddy bottom did not support megabenthic life, but could permit microbenthic community to flourish. Abundant remains of siliceous and calcareous plankton at certain levels suggest coastal upwelling of nutrient rich waters; Gupta and Srinivasan (1992) also recognized two upwelling levels based on diatom/ radiolaria ratio from the same sections of Neill Island. Nearshore depositional setting for the Sawai Bay Formation on the flanks of rising Andaman ridge is supported by the frequent presence of the species of *Helicosphaera, Pontosphaera, Scyphosphaera* and *Thoracosphaera.* Abundance of *Reticulofenestra, Sphenolithus* and common pesence of the species of *Coccolithus, Cyclococcolithus, Dictyococcites* and *Discoaster* suggest tropical water deposition under open ocean influence as observed by Bukry (1971) and several other workers.

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EXPLANATION OF PLATES

Plate I

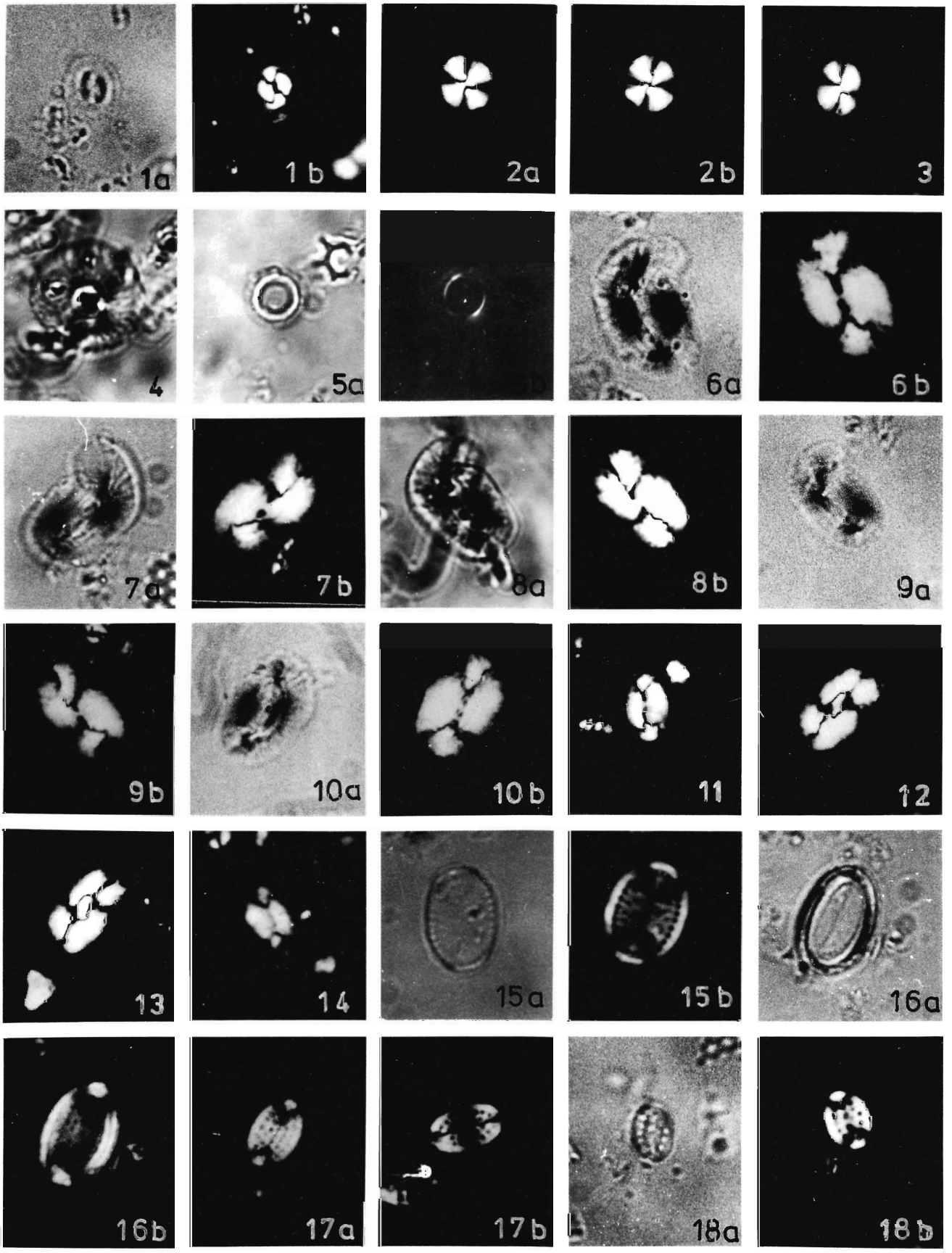
All lightmicrographs are x 2000

1. *Coccolithus pelagicus* (Wallich) Schiller, Mf. –536; 1a, single polarizer; 1b, crossed nicols.
2, 3. *Coccolithus radiatus* Kamptner, 2, Mf.-537; 3, Mf.-522; Crossed nicols.
4. *Cyclococcolithus macintyrei* Bukry and Bramlette, Mf.-507, single polarizer.
5. *Cyclococcolithus protoannulus* (Gartner), Mf.-507; 5a, single polarizer; 5b, crossed-nicols.
6-11. *Helicosphaera carteri* (Wallich) Kamptner, 6, Mf.-559; 7, Mf.-563; 8, Mf.-507; 9, Mf.-555; 10,11, Mf.-516; 6a 7a, 8a, 9a, 10a, single polarizer; 6b, 7b, 8b 9b 10b, 11, crossed-nicols.
12,13. *Helicosphaera intermedia* Martini, 12, Mf.-535; 13, Mf.-536; crossed-nicols.
14. *Helicosphaera* sp. 1, Mf.-537; crossed-nicols.
15. *Pontosphaera anisotrema* (Kamptner) Backman, Mf.-537; 15a, single polarizer; 15b, crossed-nicols.
16. *Pontosphaera callosa* (Martini) Varol, Mf.-563; 16a, single polarizer; 16b, crossed-nicols.
17-18. *Pontosphaera multipora* (Kamptner) Roth, 17, Mf.-529; 18, Mf.-553; 18a, single polarizer, 17a, 17b, 18b, crossed-nicols.

Plate II

All lightmicrographs are x 2000. Scanning electronmicrographs (18, 19, 20, 21) are of variable magnification shown by scale bar.

1. *Pontosphaera* sp. 2, Mf.-507; 1a, single polarizer; 1b, crossed nicols.
2. *Scyphosphaera queenslandensis* Rade, Mf.-507; 2a, single polarizer; 2b, crossed-nicols.
3. *Dictyococcites productus* (Kamptner) Backman, Mf.-507, crossed-nicols.
4,5,6. *Reticulofenestra haqii* Backman, 4,6, Mf.-507; 5, Mf.-516; crossed-nicols.
7,8. *Reticulofenestra minuta* Roth, 7, Mf.-509; 8, Mf.-534; crossed-nicols.
9,10. *Reticulofenestra minutula* (Gartner) Haq and Berggren, 9, Mf.-507; 10, Mf.-509; crossed-nicols.
11. *Reticulofenestra pseudoumbilicus* (Gartner) Gartner, Mf.-544; 11a, single polarizer, 11b, crossed-nicols.
12-13. *Rhabdosphaera procera* Martini, 12, Mf.-550; 13, Mf.-535, 12a, single polarizer; 12b, crossed-nicols.
14. *Sphenolithus abies* Deflander, Mf.-507; 14a, single polarizer; 14b, crossed-nicols.
15. *Sphenolithus moriformis* (Brönnimann and Stradner) Bramlette and Wilcoxon, Mf.-549, crossed-nicols.
16. *Thoracosphaera albatrosiana* Kamptner, Mf.-522, crossed-nicols.
17. *Thoracosphaera heimii* (Lohmann), Kamptner, Mf.-522, crossed-nicols.
18. *Pontosphaera multipora* (Kamptner) Roth, Mf.-511, distal view.
19. *Reticulofenestra haqii* Backman, Mf.-529, proximal view.
20. *Rhabdosphaera procera* Martini, Mf.-511.
21. *Sphenolithus abies* Deflandre, Mf.-511, side view.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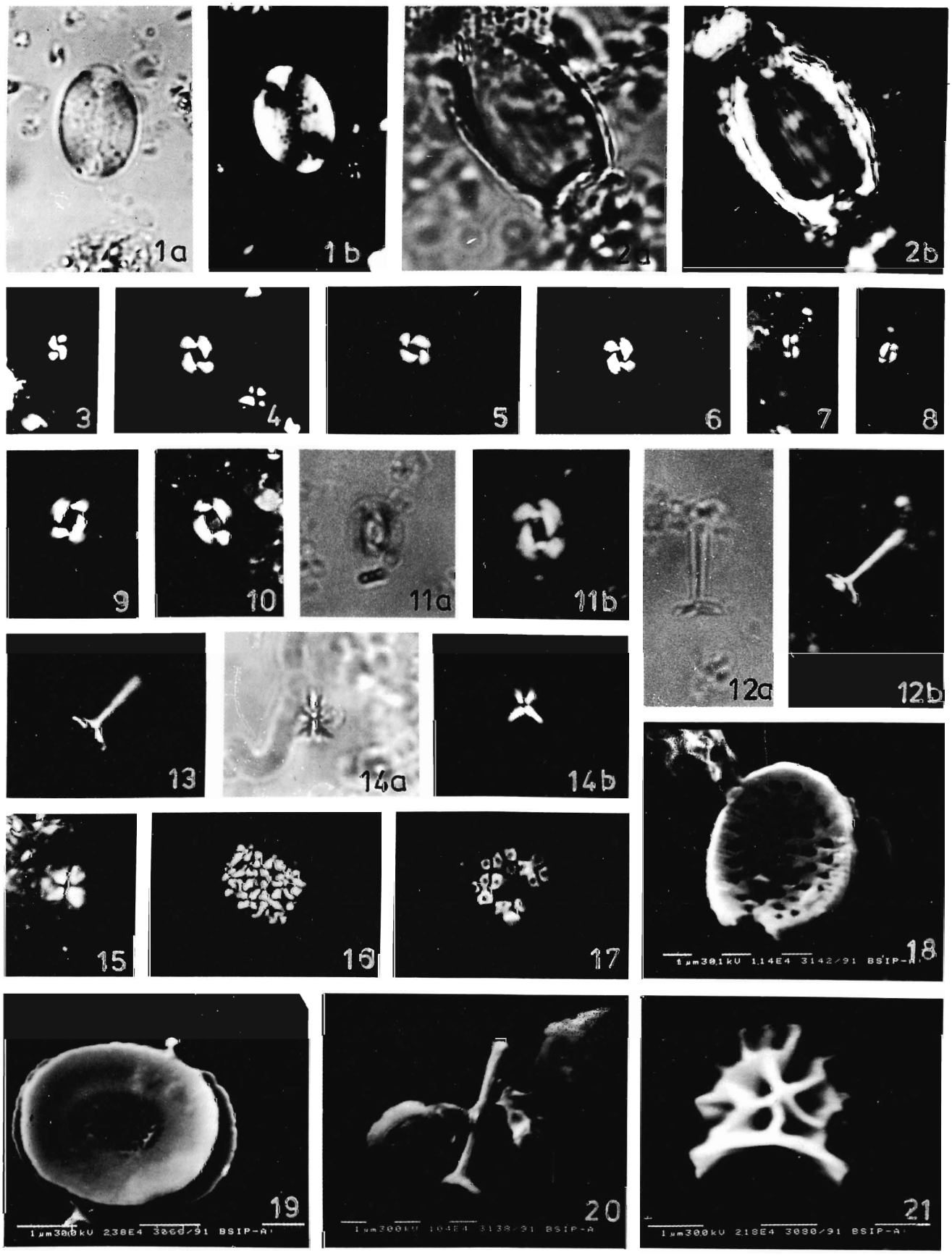
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