Late Miocene discoasters from Sawai Bay Formation, Neill Island, Andaman Sea, India

Om P. Singh & Syed A. Jafar

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Twentyone species of discoasters are documented from the East Coast and Nipple Hill sections of Sawai Bay Formation. *Discoaster pentaperforatus* is proposed as new and three species are described under open nomenclature. *Discoaster berggrenii* and *Discoaster quinqueramus* are the most common forms in the assemblage. The calcareous nannofossil assemblage containing critical *Discoaster* species suggests assignment to *Discoaster berggrenii* Subzone (CN9A) of Okada and Bukry (1980), corresponding to lower part of *Discoaster quinqueramus* zone (NN11) of Martini (1971).

Key-words — Discoasters, Late Miocene, Sawai Bay Formation, Andaman - Nicobar Islands (India).

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साराँश

अन्डमान समुद्र (भारत) में नील द्वीप-समूह में सवाई खाड़ी शैल-समूह से अन्तिम मध्यनूतन कालीन डिस्कोएस्टर

ओम प्रकाश सिंह एवं सैय्यद अब्बास जाफर

सवाई खाड़ी शैल-समूह के निप्पल गिरि खंड एवं पूर्व तट से डिस्कोएस्टरों की 21 जातियाँ अभिलिखित की गई हैं। *डिस्कोएस्टर पर्फोरेटस* एक नया प्ररूप प्रस्तावित किया गया है तथा तीन नई जातियाँ अभिनिर्धारित की गई हैं। इस समुच्चय में *डिस्कोएस्टर बरग्रेनाई* एवं *डि. क्विनक्वेरेमस* नामक जातियाँ अधिकता में मिलती हैं। विशेष डिस्कोएस्टर की जातियों से युक्त इस चूनामय परासूक्ष्म जीवाश्म समुच्चय की ओकाडा एवं बुकरी (1980) के *डिस्कोएस्टर बरग्रेनाई* उपमंडल (सी एन 9 ए) से तुलना की गई है।

THE Andaman-Nicobar Islands have an important place in the history of micropaleontology owing to its uplifted Neogene oceanic sediments with abundant and well preserved calcareous (foraminifera, nannofossils) and siliceous (radiolaria, diatoms, silicoflagellates) microfossils. Classic work of Schwager (1866) on Car Nicobar foraminifera is detailed account of Tertiary microfossils in the Indo-Pacific region. In recent years, a detailed systematic study of Neogene planktonic foraminifera was carried out in this basin by Srinivasan and his co-workers (Srinivasan & Sharma, 1969, 1973, 1974; Srinivasan & Srivastava, 1975; Srinivasan & Azmi, 1976; Srinivasan, 1977, 1978, 1980, 1984, 1988). On account of the abundance of radiolaria and other siliceous microfossils in the sedimentary sequences, a detailed systematic study on radiolaria was carried out (Srinivasan *et al.*, 1983; Sharma & Sharma, 1988, 1989; Gupta & Srinivasan, 1992). Despite rich occurrence of associated calcareous nannofossils, a detailed systematic study on this group was hitherto not attempted, except for publication of a few preliminary reports (Table 1). Therefore, a systematic programme for the study of calcareous nannofossils of Andaman-Nicobar Islands was initiated to evolve an integrated microfossil biostratigraphy for achieving higher resolution and to understand the palaeoceanographic factors influencing the assemblage and appearance and disappearance of critical planktonic microfossil taxa in this basin. A detailed account of calcareous nannofossils, other than discoasters, is being published elsewhere.

Table 1–Previous work on Neogene calcareous nannofossils from Andaman-Nicobar Islands

Author	Locality	Age
Pant & Bandopadhyaya, 1972	Havelock, John Lawrence and Nicholson Island	Early Miocene
Singh *et al.*, 1972	Neill Island	Pliocene
Singh & Vimal, 1973a, 1976a, b	Neill Island	Late Miocene - Early Pliocene
Pant & Misra, 1976	Wilson Island	Early Miocene
Singh, 1979	Neill Island	Early Pliocene
Mathur, 1980	Neill Island	Late Miocene
Wei & Srinivasan, 1984	Colebrook North Passage and Great Nicobar Islands	Early - Middle Miocene

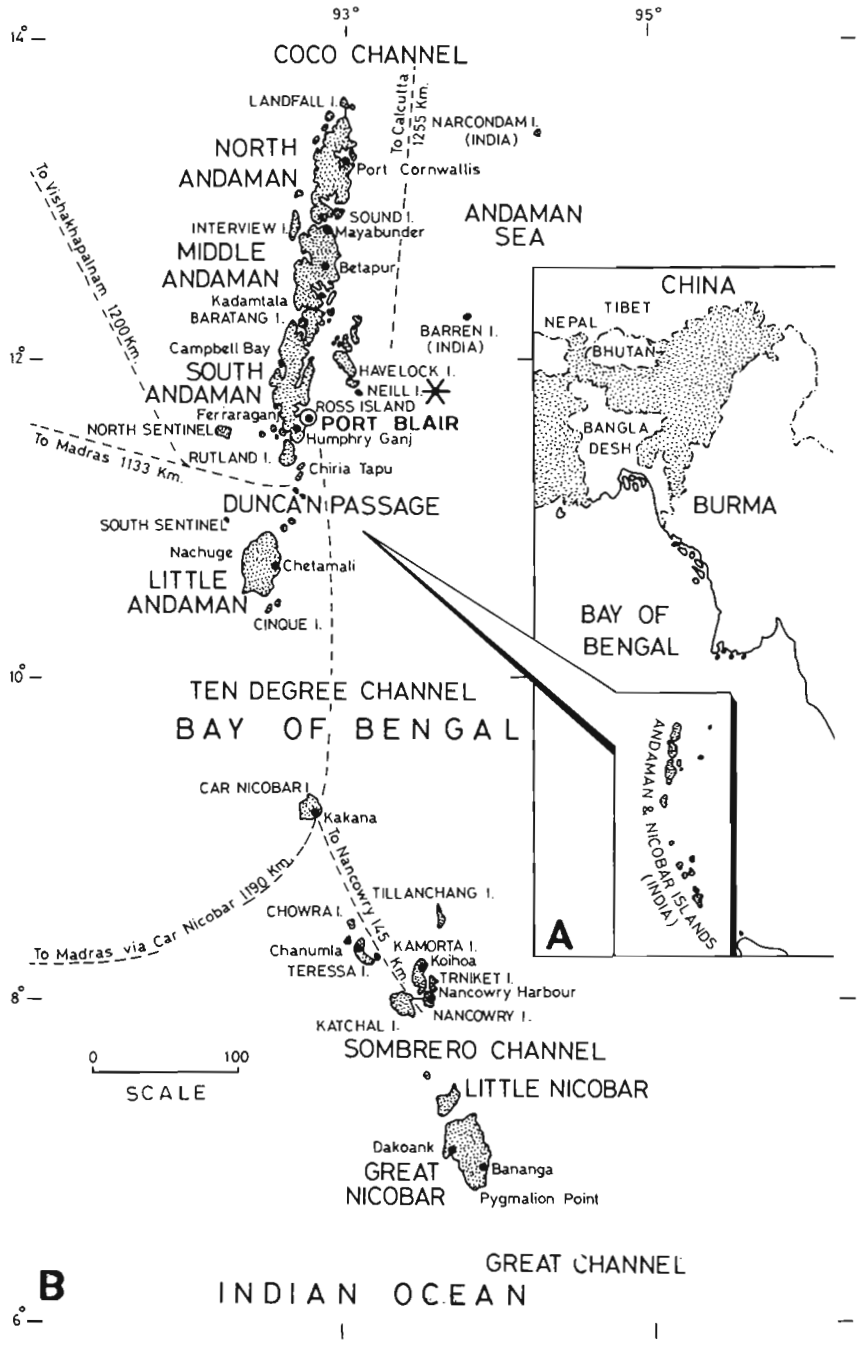
Neill Island, a member of Ritchie's Archipelago, is a small island situated about 32 km northeast of Port, Blair in the Andaman Sea (Text-figures 1-2). This island was selected because of well established foraminiferal (Srinivasan & Azmi, 1976) and radiolarian (Sharma & Sharma, 1988, 1989; Gupta & Srinivasan, 1972) data being available on the same set of samples, being also used in the present study for evolving integrated microfossil biostratigraphy. Preliminary account of the Geology of Neill Island is given by several workers (Oldham, 1885; Gee, 1927; Singh & Vimal, 1973a; Srinivasan & Azmi, 1976). Planktonic foraminifera (Singh & Vimal, 1973b, 1974, 1976; Srinivasan & Azmi, 1976; Mehrotra, 1977), ostracoda (Singh *et al.*, 1972), calcareous nannofossils (Singh *et al.*, 1972; Singh & Vimal, 1973a, 1976a, b; Singh, 1979; Mathur, 1980) and radiolaria (Singh & Sharma, 1988, 1989; Gupta & Srinivasan, 1992) of the Neill Island are already known. Although, Singh *et al.* (1972), Singh and Vimal (1973a, 1976a, b), Singh (1979) and Mathur (1980) gave a preliminary account of the calcareous nannofossils from the Neill Island, a detailed study on this group was undertaken by the present authors on the same set of samples (Text-figures 3, 4), earlier used for studies of planktonic foraminifera by Srinivasan and Azmi (1976), radiolaria by Sharma and Sharma (1988, 1989) and by Gupta and Srinivasan (1972) from the East Coast and Nipple Hill sections of Sawai Bay Formation (Text-figure 2). A rich assemblage of calcareous nannofossils was recorded from 54 samples (Text-figures 1-4) by employing both light– and scanning electron microscope. Discoasters comprising 21 species dominate the assemblage. In view of the importance of discoasters in Neogene biostratigraphy (Perch-Nielsen, 1985), a detailed systematic account of *Discoaster* species is presented in this paper.

MATERIAL AND METHODS

Thirtytwo mudstone samples (mf. 507 - 538) from the East Coast section and 22 mudstone samples (mf. 541 - 563) from the Nipple Hill section of Sawai Bay Formation (Srinivasan & Azmi, 1976; Text-figures 2-4) were used in the present work. For the light microscopy, conventional smear slides of each sample were prepared and studied under the Leitz Polarizing Research Microscope by using 100/1.32 oil immersion objective and single polarizer. For preparing stubs for scanning electron-microscopy, a drop or two of the turbid suspension of material obtained by dispersing the sample in distilled and neutral water, was spread over a cover slip. After complete drying, the cover slip containing the material was broken in small pieces to fit within the diameter of the stub, which was fixed on the stub with quick- silver and later coated with Gold-Palladium alloy. The coated stubs were examined and discoasters documented by employing Scanning electron microscope model 505 PHILIPS and using 30.0 Kv accelerating voltage.

SYSTEMATICS

The higher classification of the calcareous nannoplankton adopted in the present study, is after the work of Young (1987). The negative of SEM serves as the Type specimen for the new species. The SEM negative has been deposited in the Museum, Birbal Sahni Institute of Palaeobotany, Lucknow. The slides of the illustrated specimens are available in the Micropalaeontology Lab., Department of Geology, Banaras Hindu University, Varanasi.



Text-figure 1—A, Map showing the position of Andaman-Nicoar Islands in Bay of Bengal; and B. map showing study area.

Family — Discoasteraceae

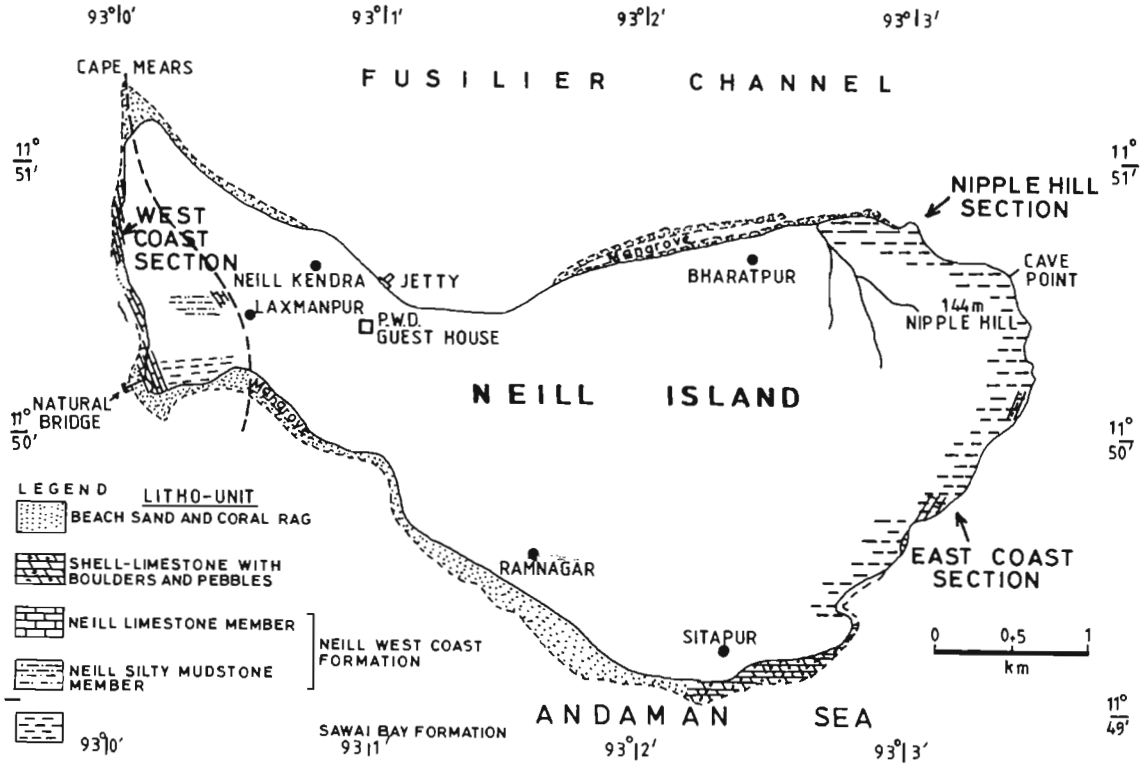
Genus — *Discoaster* Tan 1927

Discoaster adamanteus Bramlette & Wilcoxon 1967.

Pl. 3, fig. 1

1965 *Discoaster* sp. 1 Martini, *Proc. 17th Symp. Colston Res. Soc. London,* p. 405, pl. 36, figs 11-12.

1967 *Discoaster adamanteus* Bramlette & Wilcoxon., W.I. *Tulane Study Geol.* **5**, p. 108, pl. 7, fig. 6.



Text-figure 2 — Geological map of Neill Island showing locations of sections examined (modified after Srinivasan & Azmi, 1976).

1971 *Discoaster adamanteus* Bramlette & Wilcoxon - Martini & Worsley, *Initial Reports of the Deep Sea Drilling Project* **7**(2), p. 1485.

1974 *Discoaster adamanteus* Bramlette & Wilcoxon - Muller, *Initial Reports of the Deep Sea Drilling Project* **25**, p. 612, pl. 9, fig. 4.

1975 *Discoaster adamanteus* Bramlette & Wilcoxon - Edwards & Perch-Nielsen, *Initial Reports of the Deep Sea Drilling Project* **29**, p. 530, pl. 17, fig. 6.

1978 *Discoaster adamanteus* Bramlette & Wilcoxon - Haq & Berggren, *J. Palaeontology* **52**(6), p. 1186, pl. 4, fig. 2.

1980 *Discoaster adamanteus* Bramlette & Wilcoxon - non Mathur & Mathur, *Geosci. J.* **1**(2), p. 54, pl. 1, fig. 31.

1984 *Discoaster adamanteus* Bramlette & Wilcoxon - Wei & Srinivasan, *Revue esp. Micropalaeontology* **16**(1-3), p. 352, pl. 2, fig. 5; pl. 4,? fig. 14.

Remarks — Originally described from Oligocene to Miocene sediments of Central Pacific Ocean. The recorded specimen under SEM is smaller in size (4 µm) than original size range (6-13 µm) published.

Stratigraphic occurrence — Rare in East Coast and Nipple Hill sections.

Known stratigraphic range — Common to rare in Upper Oligocene to Lower Pliocene sediments of several parts of the world (Jafar, 1975).

Discoaster barbadiensis Tan Sin Hok emend. Bramlette & Riedel 1954
Pl. 1, fig. 1

Remarks — It is a rosette-shaped, medium-sized 14 µm) asterolith consisting of ten pointed rays which are joined along most of their length. The large central area has a prominent central stem. Solitary specimen has been found in sample Mf.563. of Nipple Hill section (Text-figure 4). It is a reworked Eocene element in the present assemblage.

Discoaster bergenii Knüttel *et al.* 1989

Pl. 1, figs 4, 5, 8

1972 *Discoaster berggrenii* Bukry - Perch-Nielsen, *Initial Reports of the Deep Sea Drilling Project* **12**, p. 1044, pl. 10, fig. 5.

1973 *Discoaster berggrenii* Bukry-Bukry, *Initial Reports of the Deep Sea Drilling Project* **16**, p. 933, pl. 3, fig. 4.
1980 *Discoaster berggrenii* Bukry - Mathu, Geosci. J. **1**(2), p. 38, pl. 1, fig. 3.
1989 *Discoaster berggreniii* Knüttel *et al.*, *Initial Reports of the Deep Sea Drilling Project* **105**.

Remarks — Five rayed *Discoaster bergenii* can be distinguished from closely related *D. berggrenii* by marked difference in the free length of rays relative to the diameter of the central area. In distal view, the ridges of the central knob characteristically protrude beyond the periphery in the inter-ray area of asterolith.

Stratigraphic occurrence — Rare to few in the East Coast section but absent in Nipple Hill section.

Known stratigraphic range — Known from Late Miocene.

Discoaster berggrenii Bukry 1971

Pl. 1, figs 2, 3, 6, 7, 9a, b, c, 10a, b; Pl. 3. figs 2-4

1969 *Discoaster quintatus* Bukry & Bramlette (part), *Tulane Study Geol. Palaeont.* **7**(3-4), p. 133, pl. 1, fig. 6.
1969 *Discoaster quinqueramus* Gartner (part), *Gulf Coast Assoc. geol. Soc. Trans.* **19**, p. 598, pl. 1, fig. 7.
1971 *Discoaster berggrenii* Bukry, *Micropalaeontology* **17**(1), p. 45, pl. 2, figs 4-6.
1972 *Discoaster quiqueramus* Gartner- Perch-Nielsen, *Initial Reports of the Deep Sea Drilling Project* **12**, p. 1042, pl. 9, figs 1-2.
1972 *Discoaster berggrenii* Bukry - Perch-Nielsen, *Initial Reports of the Deep Sea Drilling Project* **12**, p. 1044, pl. 10, figs 1-3, 6-7.
1976 *Discoaster berggrenii* Bukry - Singh & Vimal, *J. geol. Soc. India* **17**(1), p. 39, pl. 1, figs 4-5.
1979 *Discoaster berggrenii* Bukry - Singh, *Bull. Indian geol. Assoc.* **12**(2), p. 230, pl. 2, figs 9, 12.
1980 *Discoaster berggrenii* Bukry - Mathur, *Geosci. J.* **1**(2), p. 35, pl. 1, figs 1-2, ?4.

Remarks — It has originally been described from Late Miocene of Gulf of Mexico. It is medium-sized, five-rayed symmetric asterolith. Rays taper towards the tip. Free length of each ray is approximately equal to the diameter of the central area which is occupied by a prominent star-shaped central knob. The tips of the central knob point towards the inter-ray area. Three rayed *D. berggrenii* was also discovered.

Scanning electronmicrographs indicate that in proximal view the tips of the central knob are either aligned with the rays or slightly rotated. In some specimens, there is another star-shaped structure within the five-rayed central knob (Pl. 3, figs 2, 3). In distal view, another five-rayed central knob of different shape is present.

It differs from closely related *Discoaster quinqueramus* by having shorter arms and much stronger central knob and from *Discoaster bergenii* by its longer arms and less prominent central knob.

Stratigraphic occurrence — Frequent in East Coast and Nipple Hill sections and dominating over *Discoaster quinqueramus*.

Known stratigraphic range — *D. berggrenii* appears slightly earlier than *D. quinqueramus* in the Late Miocene (Bukry, 1971) and disappears from the stratigraphic record in the middle of the CN9B *Amaurolithus primus* subzone (Bukry, 1974), still in Late Miocene.

Discoaster blackstockae Bukry 1973

Pl. 1, fig. 11

1969 *Discoaster brouweri* Tan Sin Hok, Takayama (part), *Bull. natn. Sci. Mus. Tokyo* **12**, p. 447, fig. 5.5.
1973 *Discoaster blackstockae* Bukry, *Initial Reports of the Deep Sea Drilling Project* **20**, p. 307, pl. 1, figs 1- 4.

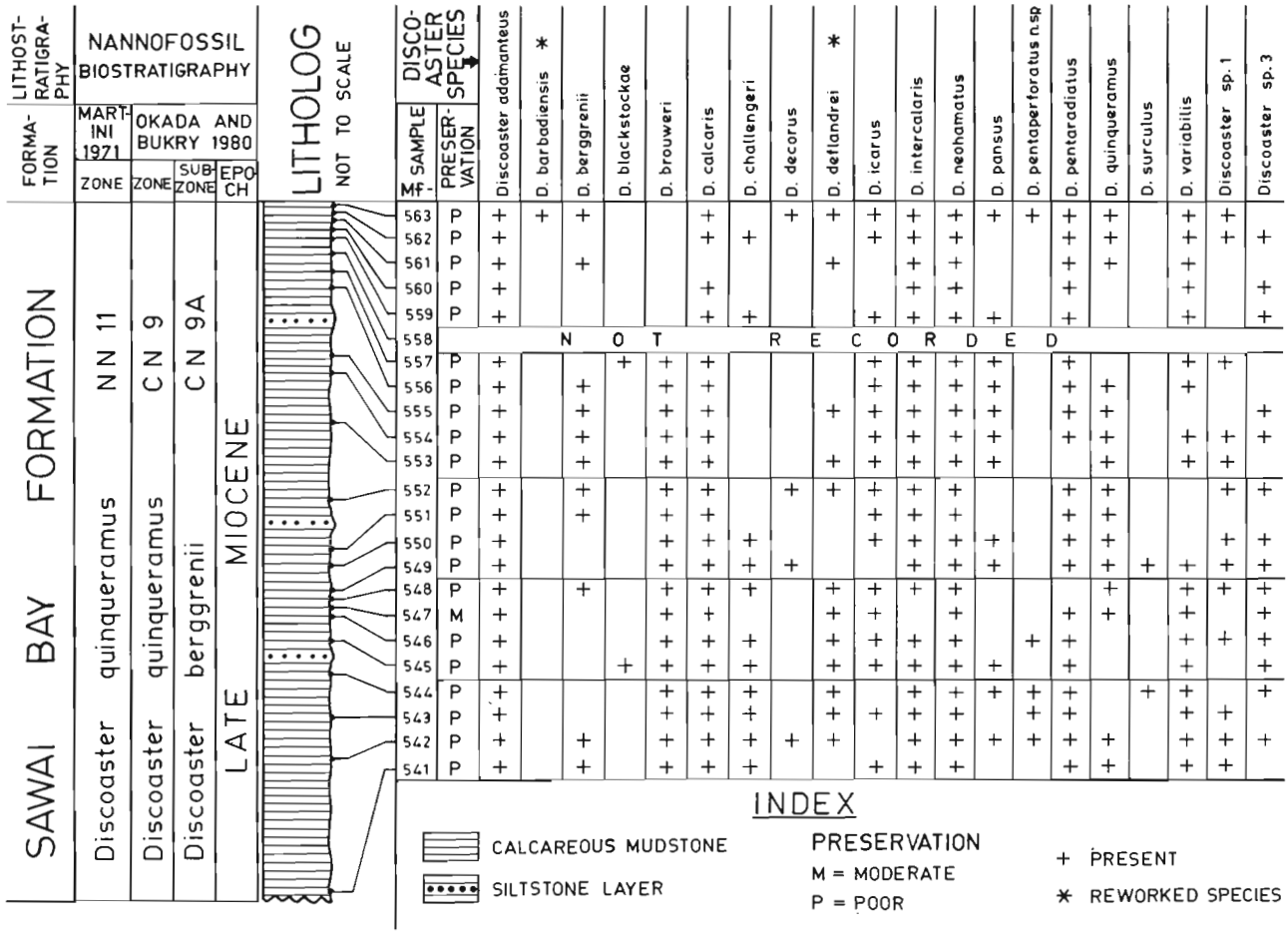
Remarks — Originally described from Latest Miocene to Pliocene sediments of tropical Indian Ocean. It is small-sized asterolith consisting of four simply terminating rays with a small quadrangular central area. It can be distinguished from four-rayed *Discoaster tamalis* by possessing arms making a pair each of obtuse and acute angles.

Stratigraphic occurrence — Rarely in East Coast and Nipple Hill sections.

Known stratigraphic range — Latest Miocene to Pliocene.

Discoaster brouweri Tan Sin Hok emend. Bramlette & Riedel 1954.

Pl. 1, figs 12, 13a, b, 14; Pl. 3, figs 5-6



Text-figure 3 — Range chart showing distribution and preservation of *Discoaster* species recovered from the samples of East Coast section of Sawai Bay Formation, Neill Island. The calcareous nannofossil biostratigraphic zone assigned to the section is also shown against the litholog (for sampling details see Srinivasan & Azmi, 1976).

1954 *Discoaster brouweri* Tan Sin Hok - emend. Bramlette & Riedel, *J. Palaeontology* **28**, p. 402, pl. 39, figs 12,3a-b.

1971 *Discoaster brouweri* Tan Sin Hok - Martini, *Proc. II Planktonic Conf., Roma (1970)* 2, p. 784, pl. 4, fig. 15.

?1972 *Discoaster brouweri* Tan Sin Hok - Pant & Bandopadhyaya, *Indian Minerals* **26**(2), p. 75, pl. 1, figs 2-3, 5, 8.

1974 *Discoaster brouweri* Tan Sin Hok - Müller, *Initial Reports of the Deep Sea Drilling Project* **25**, p. 160, pl. 8, figs 1-3, 4.

1976 *Discoaster brouweri* Tan Sin Hok - Singh & Vimal, *J. geol. Soc. India* **17**(1), p. 39, pl. 1, fig. 3.

1976 *Discoaster brouweri* Tan Sin Hok - Data & Singh, *Proc. 6th Indian Colloq. Micropalaeont. Stratigr., Varanasi*, p. 45, pl. 1, figs 1-3.

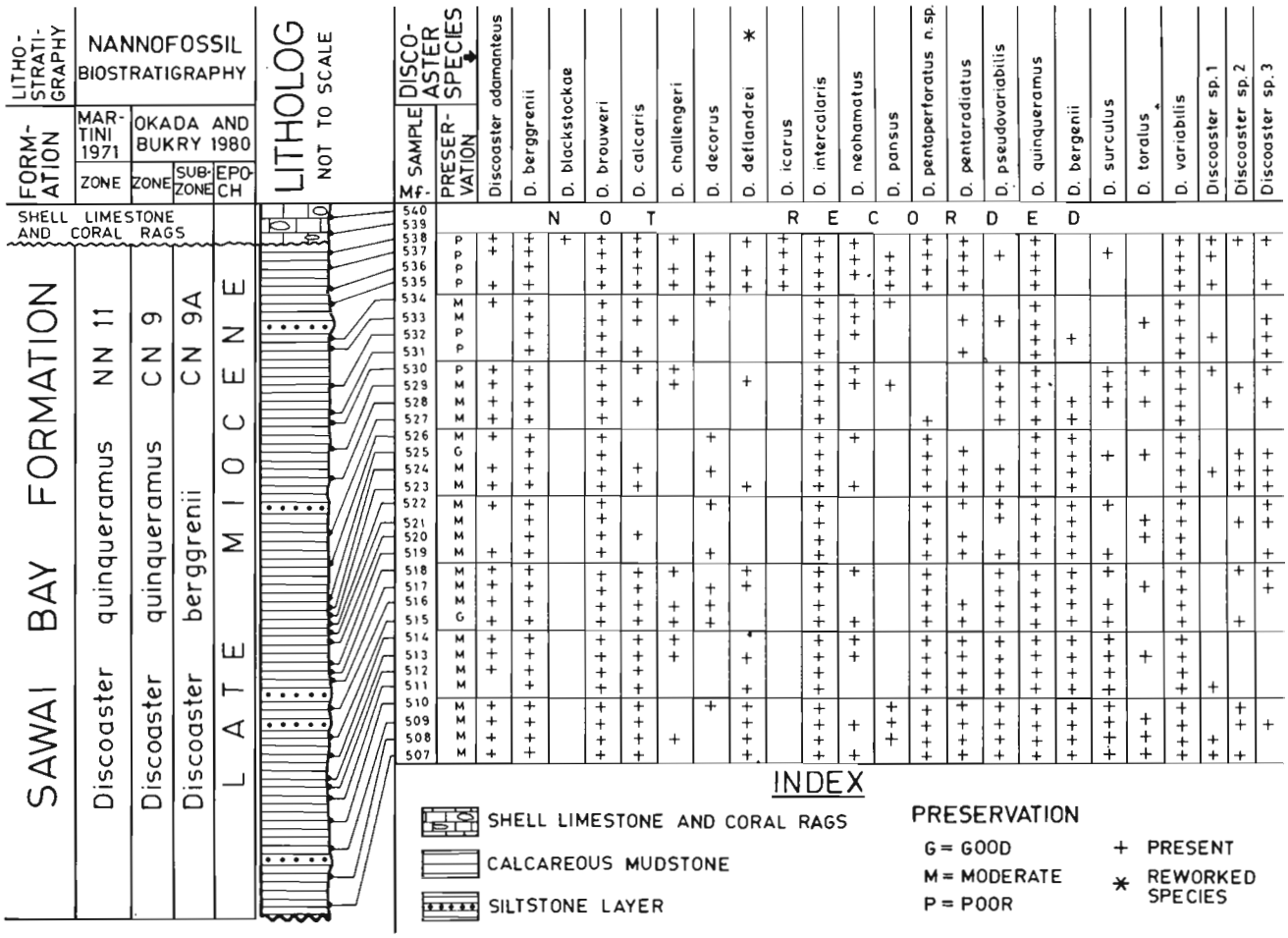
1979 *Discoaster brouweri* Tan Sin Hok - Singh, *Bull. Indian Geol. Assoc.* **12**(2), p. 230, pl. 2, fig. 4.

1980 *Discoaster braarudii* Bukry - Mathur, *Geosci. J.* **1**(2), p. 36, pl. 1, figs 13-14.

1980 *Discoaster brouweri* Tan Sin Hok - Singh, *Geosci. J.* **1**(1), p. 39, pl. 1, figs 18-19.

?1984 *Discoaster brouweri* Tan Sin Hok-Wei & Srinivasan, *Rev. esp. Micropalaeontology* **16**(1-3), p. 352, pl. 2, fig. 2.

1986 non *Discoaster brouweri* Tan Sin Hok - Takayama & Sato, *Initial Reports of the Deep Sea Drilling Project* **94**, p. 700, pl. 6, fig. 6.



Text-figure 4 — Range chart showing distribution and preservation of *Discoaster* species recovered from the samples of Nipple Hill section of Sawai Bay Formation, Neill Island. The calcareous nannofossil biostratigraphic zone assigned to the section is also shown against the litholog (for sampling details see Srinivasan & Azmi, 1976).

Remarks — Originally reported from the Tertiary Limestone of Bebalain, Rotti Island (Tan, 1927; Jafar, 1975). Medium to large-sized asterolith consisting of commonly six (rarely five-three) long rays. Many specimens clearly show moderate umbrella-rib bending. The free length of each ray is much greater than the diameter of central area in most of the specimens. The central area may have a stellate central knob.

Stratigraphic occurrence — Rare in East Coast and Nipple Hill sections.

Known stratigraphic range — Middle Miocene to Late Pliocene (NN5-NN18).

Discoaster calcaris Gartner 1967

Pl. 1, fig. 15a, b

1967 *Discoaster calcaris* Gartner, Univ. Kansas, *Palaeont. Contr.* **29**, p. 2, pl. 2, figs 1-3.

1969 *Discoaster calcaris* Gartner - Martini, *Neues Jb. geol. palaeont. Abh.* **132**(3), p. 292, pl. 28, figs 4-6.

1971 *Discoaster calcaris* Gartner - Martini, *Proc. II Planktonic Conference, Roma (1970)* **2**, p. 784, pl. 4, fig. 2.

1971 *Discoaster calcaris* Gartner - Martini & Worsley, *Initial Reports of the Deep Sea Drilling Project* **7**(2), p. 1485.

1974 *Discoaster calcaris* Gartner - Müller, *Initial Reports of the Deep Sea Drilling Project* **25**, p. 608, pl. 7, fig. 8.

1980 *Discoaster calcaris* Gartner - Singh, *Geosci. J.* **1**(1), p. 39, pl. 1, fig. 20.

Remarks — Originally described from Middle Miocene sediments of Lengua Formation, Trinidad. It is a medium to large sized asterolith having six long taper-

ing rays. Rays are slightly bifurcated unequally at their tips. Some forms exhibit slight bending in their arms. The central area is much smaller than the free length of the individual ray. Central area has a small stellate knob.

Stratigraphic occurrence — Rare in East Coast and Nipple Hill sections.

Known stratigraphic range — First appears in the upper part of Zone NN8 (=Late Middle Miocene) and makes its last appearance in the middle part of the Zone NN 11 (=Late Miocene; Martini, 1971). The LAD of this taxon is useful in dividing the long NN11 Zone (=*Discoaster quinqueramus* Zone; Martini & Worsley, 1971).

Discoaster challengeri Bramlette & Riedel 1954

Pl. 1, figs 16, 17, 18

1954 *Discoaster challengeri* Bramlette & Riedel, *J. Palaeont.* **28**, p. 401, pl. 39, fig. 10.
1967 *Discoaster challengeri* Bramlette & Riedel - Bramlette & Wilcoxon W.I. *Tulane Study Geol.* **5**, p. 109, pl. 8, fig. 2.
1972 *Discoaster challengeri* Bramlette & Riedel - Pant & Bandhopadhyaya, *Indian Minerals* **26**(2), p. 75, pl. 1, fig. 7.
1976 *Discoaster challengeri* Bramlette & Riedel - Pant & Misra, *Proc. 6th Indian Colloq. Micropalaeontology Stratigr., Varanasi,* p. 209-210, pl. 1, figs 4-5.
1976 *Discoaster challengeri neillensis* Singh & Vimal, *J. geol. Soc. India* **17**(1), p. 39-40, pl. 4, figs 3-6, ?7.
1979 non *Discoaster challengeri neillensis* Singh & Vimal - Singh, *Bull. indian Geol. Assoc.* **12**(2), p. 230, pl. 2, figs 6-7.
1980 non *Discoaster challengeri* Bramlette & Riedel- Singh, *Geosci. J.* **1**(1), p. 44, pl. 1, figs 21-22.
1984 *Discoaster challengeri* Bramlette & Riedel - Wei & Srinivasan, *Revue esp. Micropalaeontology* **16**(1-3), p. 352, pl. 4, fig. 12.
1984 *Discoaster exilis* Martini & Bramlette-Wei & Srinivasan, *Revue esp. Micropalaeontology* **16**(1-3), p. 353, pl. 4, fig. 10.

Remarks — Originally described from Miocene sediments of Trinidad. It is six rayed asterolith. The rays are parallel sided and bifurcated at their tips. Central area is smaller than the free length of the ray. and has a central knob.

It can be distinguished from *D. variabilis* and *D. exilis* by its smaller central area diameter and parallel sided rays. *Discoaster challengeri neillensis* proposed as a new subspecies by Singh and Vimal (1976a) is considered here as variant of *D. challengeri.*

Stratigraphic Occurrence — Rare in East Coast and Nipple Hill sections.

Known stratigraphic range — *D. challengeri* ranges from NN6 to NN17 (Middle Miocene to Late Pliocene).

Discoaster decorus (Bukry) Bukry 1973

Pl. 1, figs 19, 20, 21

1971 *Discoaster variabilis decorus* Bukry, *Micropalaeontology* **17**(1), p. 48, pl. 3, figs 5-6.
1973 *Discoaster decorus* (Bukry) Bukry, *Initial Reports of the Deep Sea Drilling Project* **16**, p. 677, pl. 2, figs 8-9; pl. 4, fig. 11.
1973 *Discoaster decorus* Bukry - Cita *et al., Rev. ital. Palaeont. Stratigr.,* **79**(3), p. 438, pl. 42, figs 11-12.
1976 *Discoaster indica* Singh & Vimal, *J. geol. Soc. India* **17**(1), p. 41-42, pl. 4, figs 1-2.
1976 *Discoaster* sp. Singh & Vimal, *J. geol. Soc. India* **17**(1), pl. 2, fig. 10.

PLATE 1 ⟶

All light micrographs x 2000

1. *Discoaster barbadiensis* Tan Sin Hok emended Bramlette & Riedel 1954, mf-563.
2,3,6,7 *Discoaster berggrenii* Bukry 1971, 2, mf.-511; 3, mf.-517; 6, mf-523; 7, mf-520.
4,5,8. *Discoaster berggrenii* Knüttel *et al.* 1989, 4, mf- 522; 5.8 mf-524.
9a,b,c. Diminutive-sized species closely resembling *Discoaster berggrenii* Bukry 1971, mf-525.
10a,b. Three-rayed form of *Discoaster berggrenii* Bukry 1971, mf- 519.
11 *Discoaster blackstockae* Bukry 1973, mf-545.
12,13a,b,14. *Discoaster brouweri* Tan Sin Hok emend. Bramlette & Riededl 1954, 12, mf-509; 13,mf-507; 14, mf-511
15a,b. *Discoaster calcaris* Gartner 1967, mf-519.
16,17,18. *Discoaster challengeri* Bramlette & Riedel 1954, 16, mf-536; 17, mf-541; 18, mf-562.
19,20,21. *Discoaster decorus* (Bukry) Bukry 1973, 19, mf.-517; 20, mf-536; 21, mf-535.

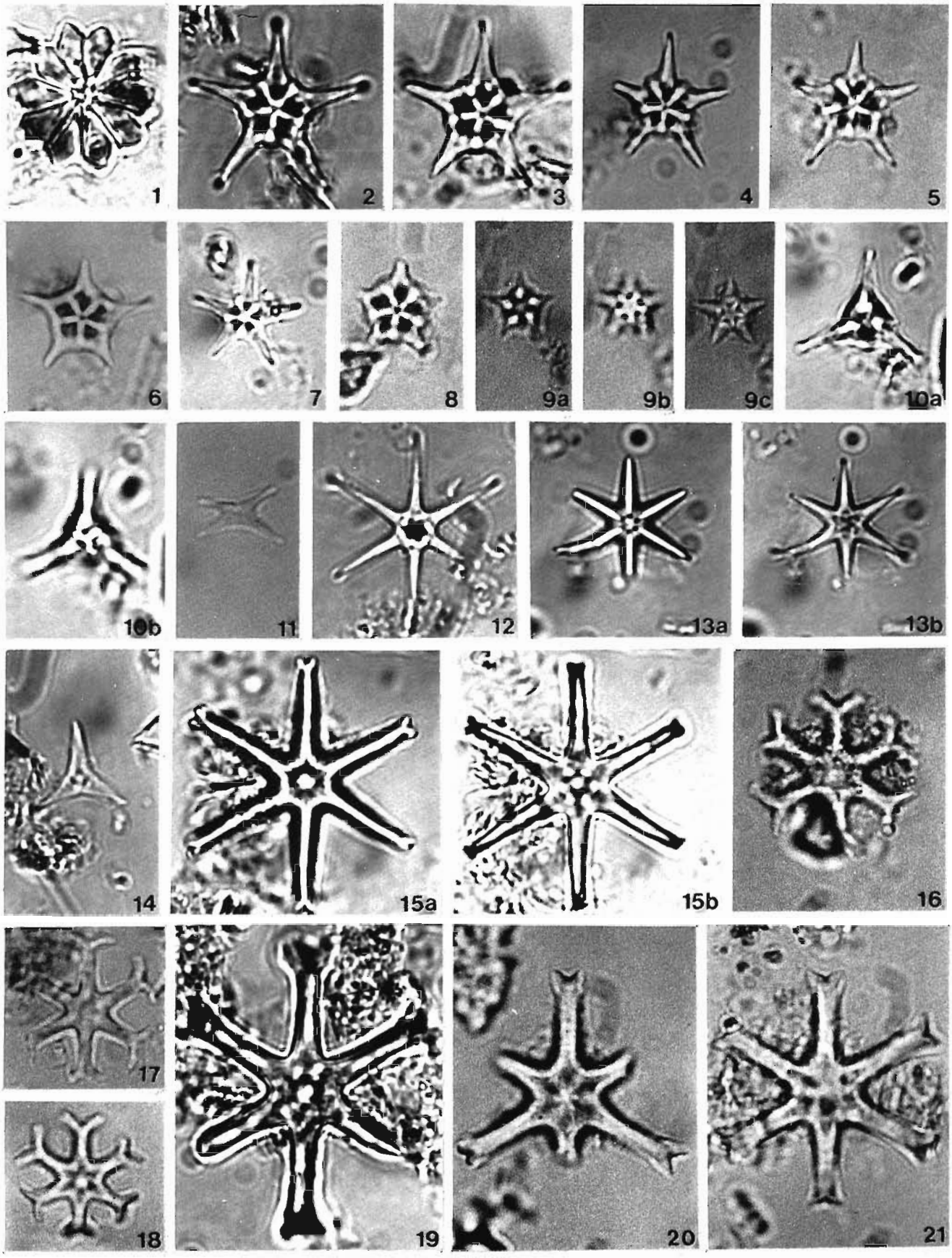

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PLATE 1

1980 *D. variabilis* Martini & Bramlette - Singh, *Geosci. J.* **1**(1), pl. 2, figs 11,13-14.

Remarks — Originally described from Early to Middle Pliocene sediments of Pacific Ocean. It is a medium to large-sized asterolith consisting of six long and broad rays which are narrowly bifurcated at their tips. The central area diameter is less than the free length of individual ray and consists of a stellate central knob. In few specimens, the rays are widely bifurcated at their tips and central area diameter is more or less equal to the free length of each ray and they are very much similar to the paratype (Bukry, 1971, 1973a,b).

Discoaster indica n. sp. by Singh and Vimal (1976a) is a variant of *Discoaster decorus* both in size as well as in morphology. It can be distinguished from *Discoaster variabilis* by its much larger size, smaller central area and characteristic bifurcated ray tips.

Stratigraphic occurrence — Rare in East Coast and Nipple Hill sections.

Known stratigraphic range — Ranges from Late Miocene to Late Pliocene.

Discoaster deflandrei Bramlette & Riedel 1954

Pl. 2, fig. 1

Remakrs — Originally described from Late Oligocene sediments of Cipero Formation, Trinidad. Medium-sized asterolith displays much variation and consists of six broadly bifurcated rays. Central area diameter is slightly greater than the free length of individual ray. It is interpreted as reworked Eocene element in the Neill Island assemblage.

Discoaster icarus Stradner 1973

Pl. 2, fig. 2

1973 *Discoaster icarus* Stradner, *Initial Reports of the Deep Sea Drilling Project* **13**(2), p. 1138, pl. 41, figs 10-11; pl. 42, fig. 5.

1973 *Discoaster icarus* Stradner - Cita *et al., Rev. ital. palaeont. Stratigr.* **79**(3), p. 426, pl. 36, fig. 12; p. 432, pl. 39, figs 8-9; p. 436, pl. 41, figs 4-7.

1981 *Discoaster icarus* Stradner - Stradner & Allram, *Initial Reports of the Deep Sea Drilling Project* **66**, p. 628, pl. 17, figs 3-4.

1984 *Discoaster icarus* Stradner — Steinmetz & Stradner, *Initial Reports of the Deep Sea Drilling Project* **75**, p. 716, pl. 17. fig. 3; p. 721, pl. 22, fig. 4; p. 722, pl. 23, fig. 10.

Remarks — Originally described from Late Miocene (Messinian) sediments of Mediterranean. It is a large-sized asterolith consisting of six sturdy rays. The rays are widely bifurcated containing characteristic "flap" - like extension. This is the first record from the Indian subcontinent.

Stratigraphic occurrence — Rare in the uppermost part of the East Coast section and throughout in the Nipple Hill section.

Known stratigraphic range — Late Miocene.

Discoaster intercalaris Bukry 1971

Pl. 2, fig. 3

1961 *Discoaster brouweri* Tan Sin Hok, of Stradner & Papp (partim), *Geol. Jb. Bundesanst. Wien. Sonderband* **7**, p. 85, pl. 20, fig. 6.

1971 *Discoaster intercalaris* Bukry, *San Diego Soc. Nat. Hist. Trans.* **16**(14), p. 315, pl. 3, fig. 12; pl. 4, figs 1-2.

?1976 *Discoaster intercalaris* Bukry - Singh & Vimal, *J. geol. Soc. India* **17**(1), p. 42, pl. 2, figs 1-3.

1976 *Discoaster andamanensis* Singh & Vimal, *J. geol. Soc. India* **17**(1), p. 38 pl. 1, figs 1-2.

PLATE 2 ⟶

All light micrographs x 2000.

1 *Discoaster deflandrei* Bramlette & Riedel 1954, mf-563.
2. *Discoaster icarus* Stradner 1973, mf-563.
3. *Discoaster intercalaris* Bukry 1971, mf-524.
4. *Discoaster neohamatus* Bukry & Bramlette 1969, mf-509.
5. *Discoaster pansus* (Bukry & percival) Bukry 1973, mf-563.
6,7. *Discoaster pentaradiatus* Tan Sin Hok 1927, 6, mf-543; 7, mf-525.
8,9,10. *Discoaster quinqueramus* Gartner 1969, 8, mf-509; 9,10 mf-563.
11,12a,12b. *Discoaster pseudovariabilis* Martini & Worsley 1971, 11, mf-507; 12, mf-511
13. *Discoaster surculus* Martini & Bramlette 1963, mf-529.
14. *Discoaster toralus* Ellis, Lohmann & Wray 1972, mf-517.
15a,b,16,17. *Discoaster variabilis* Martini & Bramlette 1963, 15, 16 mf-563; 17, mf-559.
18. *Discoaster* sp. 2, mf-525.
19a,b. *Discoaster* sp.3, mf-507.

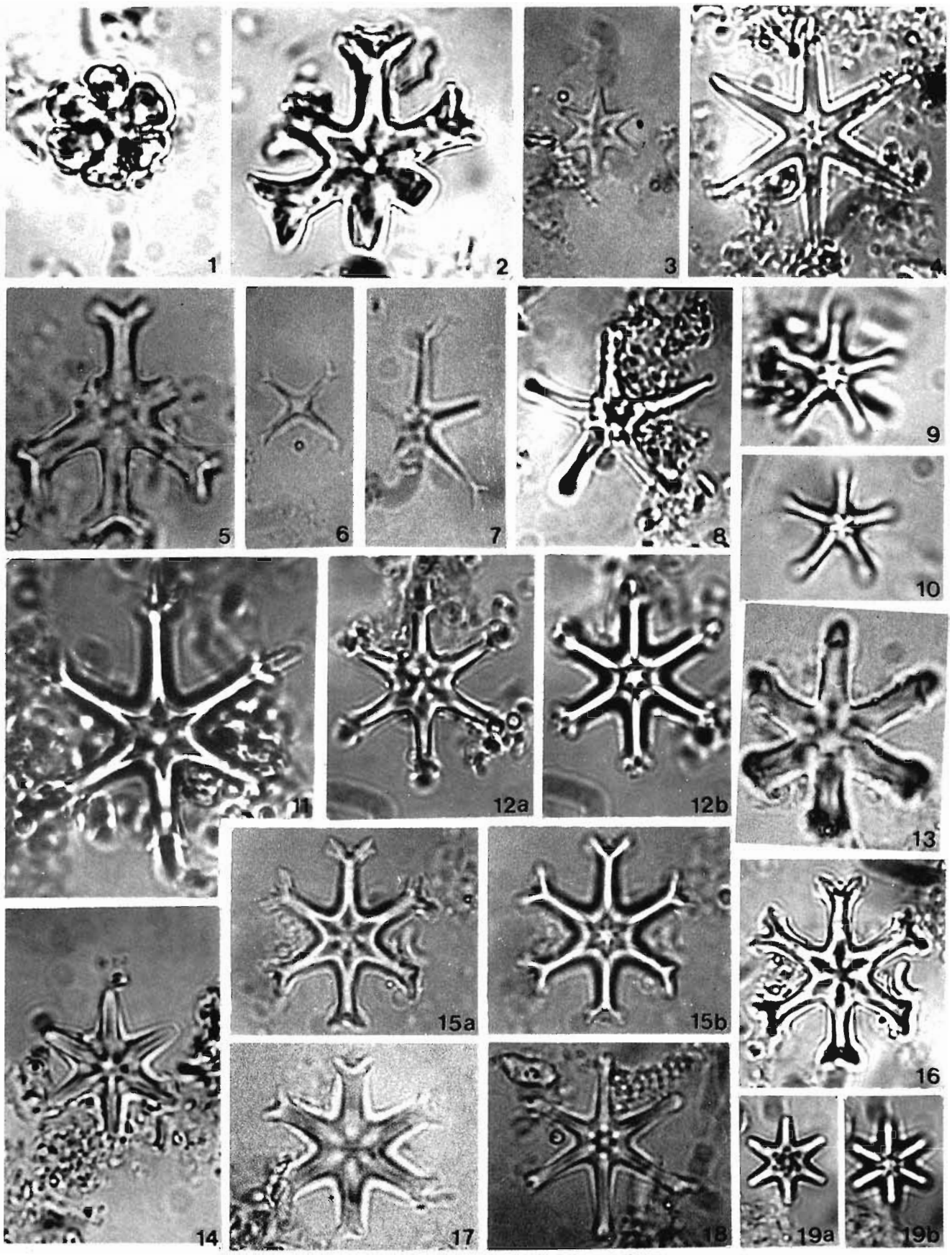

PLATE 2

1976 *Discoaster raoi* Singh & Vimal (Partim), *J. geol. Soc. India* **17**(1) pl. 2, figs 6-7.

?1976 *Discoaster intercalaris* Bukry - Pant & Misra, *Proc. 6th Indian Colloq. Micropalaeontology Stratigr., Varanasi*, p. 209, pl. 1, fig. 3.

1980 *Discoaster intercalaris* Bukry-Singh, *Geosci. J.* **1**(1), p. 40, pl. 1, fig. 28.

1984 *Discoaster intercalaris* Bukry - Wei & Srinivasan, *Revue esp. Micropalaeontology* **16**(1-3), p. 353-354, pl. 4, fig. 13.

Remarks — Originally described from Late Miocene to Late Pliocene DSDP cores of Northeastern Pacific Ocean. It is a small-sized six-rayed asterolith with simple rounded tips and consists of large central area with a stellate central knob.

Stratigraphic occurrence — Rare in East Coast and Nipple Hill sections.

Known stratigraphic range — Ranges from Middle Miocene to Late Pliocene. It is a cool water element (Bukry, 1971).

Discoaster neohamatus Bukry & Bramlette 1969

Pl. 2, fig. 4

1969 *Discoaster neohamatus* Bukry & Bramlette, *Tulane Study Geol. Palaeont.* **7**(3-4), p. 133, pl. 1, figs 4-5.

1979 *Discoaster neohamatus* Bukry & Bramlette, -Ellis & Lohmann, *Marine Micropalaeontology* **4**(1), pl. 12, fig. 10.

Remarks — Originally described from Late Miocene sediments of Blake Plateau, Altantic Ocean. It is a large-sized asterolith having six long slender rays with characteristic bend of ray tips in the plane of asterolith. Differs from similar and older *D. hamatus* in possessing six instead of five rays. Recorded for the first time from the Indian subcontinent.

Stratigraphic occurrence — Rare in East Coast and Nipple Hill sections.

Known stratigraphic range — Middle to Late Miocene.

Discoaster pansus (Bukry & Percival) Bukry 1973

Pl. 2, fig. 5

1963 *Discoaster* aff. *D. variabilis* Martini & Bramlette, *J. Palaeontology* 37, pl. 104, fig. 9.

1971 *Discoaster variabilis pansus* Bukry & Percival, *Tulane Study Geol. Palaeont.* **8**(3), p. 129, pl. 3, figs 8-9.

1973 *Discoaster pansus* (Bukry & Percival) Bukry, *Initial Reports of the Deep Sea Drilling Project* **16**, p. 678, pl. 4, fig. 25.

1973 *Discoaster pansus* Bukry - Cita *et al., Rev. ital. palaeont. Stratigr.* **79**(3), p. 432, pl. 39, figs 11-12, p. 438, pl. 42, fig. 5.

1977 *Discoaster variabilis pansus* Bukry & Percival-Perch- Nielsen, *Initial Reports of the Deep Sea Drilling Project* **39**, p. 772, pl. 15, fig. 17.

1980 *Discoaster variabilis* Martini & Bramlette-Singh, *Geosci. J.* **1**(1), pl. 2, figs 10-12.

Remarks — Originally described from Late Miocene to Early Pliocene sediments of Shatsky Rise, Pacific Ocean. It is a large-sized asterolith consisting of six sturdy widely bifurcated rays. Bifurcated branches are nearly perpendicular to the rays. The free length of the ray is approximately equal to the diameter of the central area with a central knob. It can be distinguished from *Discoaster decorus* by its widely bifurcated ray tips which are nearly perpendicular to the rays and from *Discoaster variabilis* by its large size, sturdier arms and widely bifurcated ray tips.

Stratigraphic occurrence — Rare in East Coast and Nipple Hill sections.

Known stratigraphic range — Middle Miocene to Early Pliocene.

Discoaster pentaperforatus n. sp.

Pl. 3, figs 7, 8

Holotype — Pl. 3, fig. 7; Sample no. Mf/511, BSIP Museum no. 3089/91.

Type locality — East Coast section, Neill Island, Andaman Sea, India.

Type level — Late Miocene, Sawai Bay Formation. *Discoaster quinqueramus* Zone (=NN11 Martini, 1971); *Discoaster berggrenii* Subzone (=CN 9A Okada & Bukry, 1980).

Diagnosis — Small 4-5 μm large *Discoaster pentaperforatus* has five short tapering rays. The free length of the rays is nearly half or less than the diameter of the central area. In distal view, the central area of the holotype displays strong stellate knob with thick arms pointing toward inter ray area, thus, leaving five rhomboidal pores aligned to the rays of the asterolith.

Remarks — *Discoaster pentaperforatus* can be distinguished from *D. berggrenii* by its compact nature, much larger central area as compared to the free length of the ray and its smaller size. It is also distinguishable from closely related *Discoaster bergenii* by its smaller size and the presence of five rhomboidal openings. In *Discoaster pentaperforatus* the ridges of the central knob do not protrude beyond the periphery of inter ray area. The name has been derived after five rhomboidal openings in the asterolith.

Stratigraphic occurrence — Rare in East Coast and Nipple Hill sections.

Stratigraphic range — Late Miocene.

Discoaster pentaradiatus Tan Sin Hok 1927

Pl. 2, figs 6,7; Pl. 3, fig. 9

1927 *Discoaster pentaradiatus* Tan Sin Hok, *Proc. Sect. Sci. K. Akad. Wet. Amsterdam* **30** p. 120, text-fig. II, fig. 14.

1954 *Discoaster pentaradiatus* Tan Sin Hok - emended Bramlette & Riedel, *J. Palaeontology* **28**, p. 401, pl. 39, fig. 11, text-fig. 2a-b.

1973 *Discoaster pentaradiatus* Tan Sin Hok - Roth, *Initial Reports of the Deep Sea Drilling Project* **17**, p. 736, pl. 5, fig. 1; pl. 6, fig. 1.

1976 *Discoaster pentaradiatus* Tan Sin Hok - Singh & Vimal, *J. geol. Soc. India* **17**(1), p. 42, pl. 1, fig. 10.

1979 *Discoaster pentaradiatus* Tan Sin Hok - Singh, *Bull. Indian Geol. Assoc.* **12**(2), p. 224.

1980 *Discoaster pentaradiatus* Tan Sin Hok - Singh, *Geosci. J.* **1**(1), p. 40-41, pl. 1, fig. 31.

1980 *Discoaster pentaradiatus* Tan Sin Hok - Mathur, *Geosci. J.* **1**(2), p. 36, pl. 1, fig. 17.

Remarks — Originally described from Miocene sediments of Rotti Island, Indonesia (Jafar, 1975). It is medium to large-sized asterolith with four to five rays. Rays are bifurcated at their tips and show proximal bending. One branch of bifurcation is larger than the other. Small central areas have central knob. *D. pentaradiatus* at younger levels of the sections shows more curvature of the arms. It differs from similar looking *D. prepentaradiatus* Bukry & Percival 1971, in displaying proximal curvature of the rays. Near Miocene Pliocene boundary, the asteroliths of this species show more curvature of rays and much longer ray-tip bifurcations.

Stratigraphic occurrence — Rare in East Coast and Nipple Hill sections.

Known stratigraphic range — Middle Miocene to Late Pliocene.

Discoaster pseudovariabilis Martini & Worsley 1971

Pl. 2, figs 11, 12a, b

1971 *Discoaster pseudovariabilis* Martini & Worsley, *Initial Reports of the Deep Sea Drilling Project* **7**(2), p. 1500, pl. 3, figs 2-8.

1973 *Discoaster pseudovariabilis* Martini & Worsley - Cita *et al., Rev ital. palaeont. Stratigr.* **79**(3), p. 438, pl. 42, figs 8-9.

1980 *Discoaster surculus* Martini & Bramlette. Mathur, *Geosci. J.* **1**(2), p. 35, pl. 1, fig. 6.

Remarks — Originally described from Miocene (NN8-NN9) DSDP core of western equatorial Pacific Ocean. It is medium to large-sized asterolith consisting of five to six bifurcated rays. Each ray-tip has a characteristic tongue-like projection between the bifurcation. Diameter of the central area is either smaller or more or less equal to the free length of the ray. Central area has a star-shaped central knob, the tips of which are aligned along the rays. This species is recorded for the first time from the Indian subcontinent.

Stratigraphic occurrence — Rare in East Coast section and not observed in Nipple Hill section.

Known stratigraphic range — *D. pseudovariabilis* ranges from Middle to Late Miocene (NN6-NN11 nannofossil zones) of several regions including Indo-Pacific realm. The last appearance of this species is within NN11, hence it is stratigraphically useful.

Discoaster quinqueramus Gartner 1969

Pl. 2, figs 8, 9, 10; Pl. 3, fig. 10

1969 *Discoaster quinqueramus* Gartner, *Gulf Coast Assoc. Geol. Soc. Trans.* **19**, p. 598, pl. 1, figs 6-7.

1969 *Discoaster quintatus* Bukry & Bramlette (part), *Tulane Study Geol. Palaeont.* **7**(3-4), p. 133, pl. 1, figs 7-8.

1971 *Discoaster quinqueramus* Gartner - Martini, *Proc. II Planktonic Conference, Roma (1970)* **2**, p. 784, pl. 4, fig. 6.

1979 *Discoaster asymmetricus* Gartner-Singh, *Bull. Indian Geol. Assoc.* **12**(2), p. 230, pl. 2, figs 2-3.

1980 *Discoaster quinqueramus* Gartner - Singh, *Geosci. J.* **1**(1), p. 41, pl. 1, figs 32-33.

1986 *Discoaster quinqueramus* Gartner - Takayama & Sato, *Initial Reports of the Deep Sea Drilling Project* **94**, p. 691, pl. 6, fig. 11.

Remarks — Originally described from Late Miocene sediments of Gulf of California. It is a medium-sized asterolith having five tapering rays bent proximally. The free length of the individual ray is greater than the diameter of central area which has a five sided raised central knob on the proximal side. In distal view, the arms of the star-shaped central knob bisect the inter-ray area. The scanning electronmicrographs exhibit more clearly that the rays are bent sharply. In proximal view, the tips of the stellate central knob are either aligned along the rays or slightly rotated. It can be distinguished from closely related *D. berggrenii* and *Discoaster bergenii* by its longer rays and much smaller central area diameter than the free length of each ray.

Stratigraphic occurrence — Rare in East Coast and Nipple Hill sections.

Known stratigraphic range — The total life span of *Discoaster quinqueramus* encompasses NN11 (*D. quinqueramus* Zone of Martini, 1971) of Late Miocene.

Discoaster surculus Martini & Bramlette 1963

Pl. 2, fig. 13; Pl. 3, fig. 11

1961 *Discoaster brouweri* Tan Sin Hok - Stradner, *Erdöl-Z* **77**, pl. 20, figs 2-3, 6.

1963 *Discoaster surculus* Martini & Bramlette, *J. Palaeont.* **37**, p. 854, pl. 104, figs 10-12.

1973 *Discoaster surculus* Martini & Bramlette - Cita *et al., Rev. ital. palaeont. Stratigr.* **79**(3), p. 440, pl. 43, figs 5-6.

1977 *Discoaster surculus* Martini & Bramlette - Perch-Nielsen, *Initial Reports of the Deep Sea Drilling Project*, **39**, p. 772, pl. 15, figs 1-2, 5-6, 10.

?1979 *Discoaster variabilis* Martini & Bramlette - Singh, *Bull. Indian Geol. Assoc.* **12**(2), p. 230, pl. 2, fig. 15.

1980 non *Discoaster surculus* Martini & Bramlette. Mathur, *Geosci. J.* **1**(2), p. 35, pl. 1, figs 5-7.

Remarks — Originally described from the Late Miocene to Pliocene sediments of Haiti. It is medium to large-sized asterolith having six broad rays which are bifurcated at their ends. Between the bifurcation each ray has a conspicuous spine extending beyond the bifurcation. Central area has a stellate knob. The tips of central knob point toward rays. Scanning electron micrographs exhibit that the central area has small ridges extending out from the stellate central knob and running parallel to the rays. This is the first genuine record of this species from the Indian subcontinent.

Stratigraphic occurrence — Rare in East Coast and Nipple Hill sections.

Known stratigraphic range — Late Miocene to Late Pliocene (upper NN10 to upper NN16) nannofossil zone.

Discoaster toralus Ellis, Lohmann & Wray 1972

Pl. 2, fig. 14

1972 *Discoaster toralus* Ellis, Lohmann & Wray, *Colorado School Mines* **67**(3), p. 53, pl. 16, figs 2-6.

1984 *Discoaster toralus* Ellis, Lohmann & Wray - Steinmetz & Stradner, *Initial Reports of the Deep Sea Drilling Project* **75**, p. 717, pl. 18, figs 1-2.

Remarks — Originally described from Late Miocene-Early Pliocene sediments of Gulf of Mexico. It is six-rayed medium-sized asterolith. Interray areas possess membraneous extensions. The central area diameter is greater than free length of the individual ray. Central area has a stellate knob. Six ridges extend out from the central area, each running parallel to the length of ray.

Stratigraphic occurrence — Rare in East Coast section.

Known stratigraphic range — Late Miocene to Early Pliocene.

Discoaster variabilis Martini & Bramlette 1963

Pl. 2, figs 15a, b, 16, 17

1959 *Discoaster challengeri* Bramlette & Riedel - Stradner, *Proc. 5th World Petrol Congr., New York* **1**, p. 1087, fig. 26.

1963 *Discoaster variabilis* Martini & Bramlette, *J. Palaeont.* **37**, p. 854, pl. 104, figs 4-9.

1976 *Discoaster variabilis* Martini & Bramlette - Singh & Vimal, *J. geol. Soc. India* **17**(1), p. 43, pl. 3, figs 5-7.

1976 *Discoaster variabilis sastrii* Singh & Vimal, *J. geol. Soc. India* **17**(1), p. 43, pl. 3, figs 3-4.

1976 *Discoaster variabilis* Martini & Bramlette. Pant & Misra, *Proc. 6th Indian Colloq. Micropalaeont. Stratigr., Varanasi*, p. 209, pl. 1, figs 1-2.

1979 *Discoaster variabilis* Martini & Bramlette - Singh, *Bull. Indian Geol. Assoc.* **12**(2), p. 230, pl. 2, fig. 13.

1980 *Discoaster variabilis* Martini & Bramlette. Mathur, *Geosci. J.* **1**(2), p. 36, pl. 1, figs 8-12.

1981 *Discoaster variabilis* Martini & Bramlette - Driever, *Proc. Kon. Ned. Akad. Wetensch.* **84**(4), pl. 1, figs 4-6.

1984 *Discoaster variabilis* Martini & Bramlette - Wei & Srinivasan, *Rev. Esp. Micropalaeont.* **16** (1-3), p. 355, pl. 4, fig. 11.

Remarks — Originally described from Middle to Late Miocene sediments of Rio Mazzapiedi section near Tortona, Italy. It is a medium-sized asterolith having commonly six and rarely five rays. The rays are bifurcated at their outer ends. In few specimens, the rays have double bifurcation at their ends. Central area has a stellate knob. In proximal view, the tips of the central knob extend along the ray and in distal view, the tips of the stellate central knob extend toward the mid point of the inter-ray area. A considerable variation has been observed in the central area diameter, free length and sturdiness of the rays and the angle of bifurcation in the present study of Neill Island assemblage. *Discoaster variabilis sastrii* (Singh & Vimal, 1976a, pl. 3, fig. 3.) is quite similar to the paratype of *Discoaster variabilis* (Martini & Bramlette, 1963, pl. 104, fig. 6). Therefore, the *Discoaster variabilis sastrii* is considered here a synonym of *Discoaster variabilis*.

Stratigraphic occurrence — Rare in East Coast and Nipple Hill sections.

Known stratigraphic range — Early Miocene to Late Pliocene.

Discoaster sp. 1

Pl. 3, fig. 12

Remarks — It is small-sized asterolith having six short pointed rays. Large central area has a characteristic circular depression. Under SEM each ray of the asterolith consists of a sharp edge.

Stratigraphic occurrence — Rare in East Coast and Nipple Hill sections.

Known stratigraphic range — Late Miocene.

Discoaster sp. 2

Pl. 2, fig. 18

Remarks — It is a six rayed medium-sized asterolith. The rays are more or less straight sided and charcteristically notched or bifurcated at their tips. Central area diameter is less than the free length of the individual ray. Central area has a stellate knob, the tips of which are aligned along the mid point of the inter ray area. Each ray possesses characteristic ridges running parallel to the length of the rays and in this aspect some resemblance is shown with *D. surculus* and *D. toralus*. This may prove to be an independent species after recovery of more specimens.

Stratigraphic occurrence — Rare in East Coast section and not observed in Nipple Hill section.

Known stratigraphic range — Late Miocene.

Discoaster sp. 3

Pl. 3, figs 19a, b

Remarks — It is a small-sized, six rayed asterolith. Rays are slightly tapering and terminate in a simple rounded point. The free length of the individual ray is nearly half of the central area diameter which has a characteristic stellate knob. The rays of the stellate central knob are aligned along the inter ray region.

Stratigraphic occurrence — Rare in East Coast and Nipple Hill sections.

Known stratigraphic range — Late Miocene.

PLATE 3 ⟶

Scanning electron micrographs : magnification indicated by scale- bars.

1. *Discoaster adamanteus* Bramlette & Wilcoxon 1967, distal view.
2,3,4. *Discoaster berggrenii* Bukry 1971, 2,3, proximal view; 4, distal view.
5,6. *Discoaster brouweri* Tan Sin Hok emend. Bramlette & Riedel 1954, 5, distal view; 6, proximal view.
7,8. *Discoaster pentaradiatus* n. sp., 7, holotype, distal view; 8, distal view.
9. *Discoaster pentaradiatus* Tan Sin Hok 1927, proximal view.
10. *Discoaster quinqueramus* Gartner 1969, proximal view.
11. *Discoaster surculus* Martini & Bramlette 1963, proximal view.
12. *Discoaster* sp. 1; distal view.


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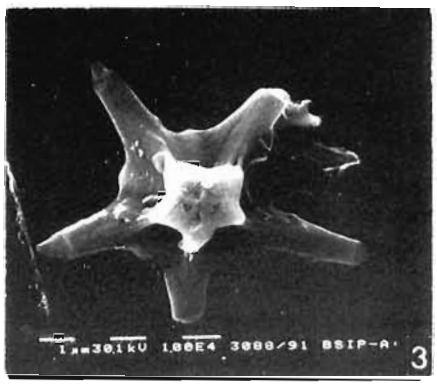
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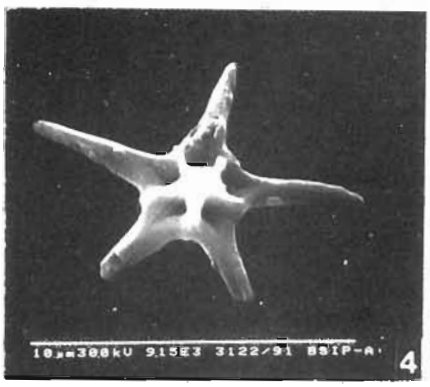
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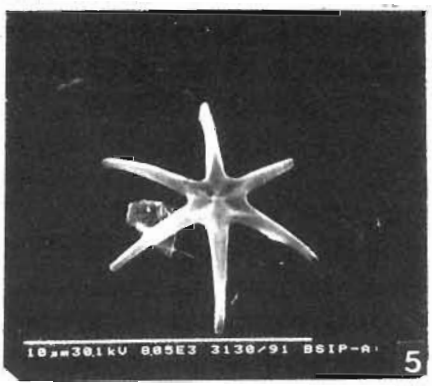
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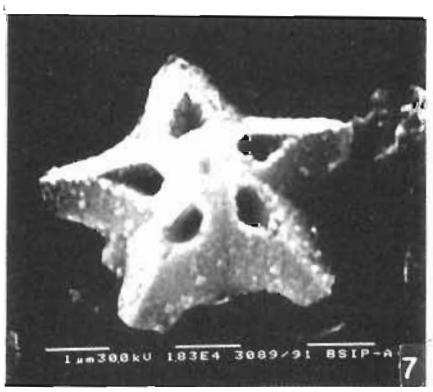
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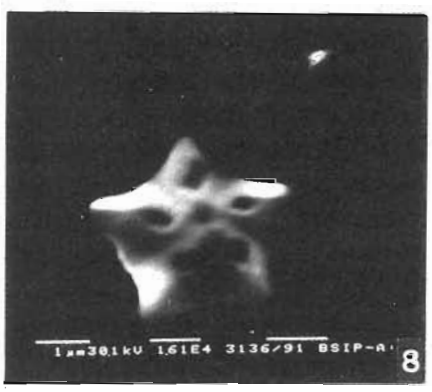
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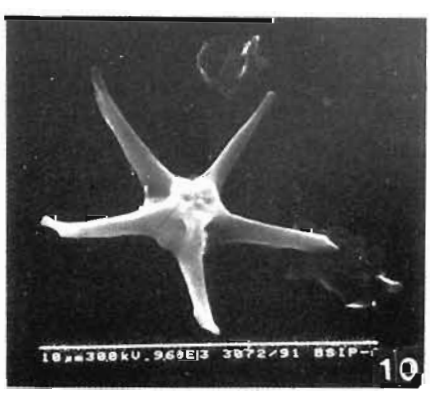
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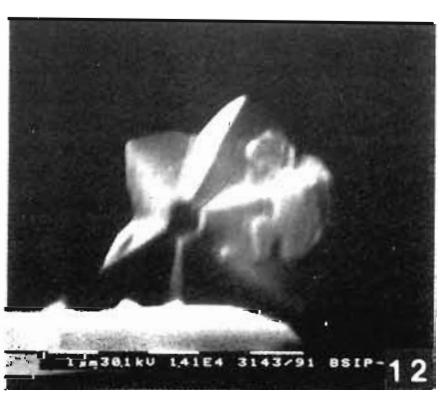
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12

PLATE 3

AGE OF THE ASSEMBLAGE

Recovery of well-preserved specimens of *Discoaster quinqueramus* and *Discoaster berggrenii* in all the samples of East Coast and Nipple Hill sections of Sawai Bay Formation, Neill Island, suggests that the assemblage can be assigned to *Discoaster berggrenii* Subzone: CN9A of Okada and Bukry 1980, corresponding to the lower part of *Discoaster quinqueramus* Zone: NN 11 of Martini (1971). As a result of the present study, extended upper range of the following species of *Discoaster* is recorded as per the known data (Perch-Nielsen, 1985) : *Discoaster adamanteus, Discoaster calcaris, Discoaster pseudovariabilis*. Extended lower range of *Discoaster* species is recorded for: *Discoaster blackstockae, D. decorus* and *D. icarus*.

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