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Late Miocene siliceous endoskeletal dinoflagellates from the Sawai Bay Formation, Neill Island, Andaman Sea, India

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ABSTRACT – Siliceous spicules of endoskeletal dinoflagellates form a very small part of the siliceous microfossil assemblage from Neill Island, Ritchie's Archipelago, Andaman Island and Nicobar Island. They are represented here by a solitary genus, *Actiniscus*, with two species – *Actiniscus pentasterias* and *Actiniscus elongatus*. Light microscopy, supported by scanning electron microscopy, illustrates its remarkable symmetry and geometry. Though biostratigraphically unimportant, this genus has considerable value in deriving palaeoecological interpretations. Their association with age-diagnostic calcareous nannofossil taxa indicates that the glauconitic mudstones of the Sawai Bay Formation of Nipple Hill and East Coast sections are Late Miocene in age, equivalent to the *Discoaster berggrenii* Subzone (Subzone CN9A) corresponding to the lower part of the *Discoaster quinqueramus* Zone (Zone NN11). *J. Micropalaeontol.* **25**(1): 37–44, April 2006.

KEYWORDS: *Endoskeletal dinoflagellates, Actiniscus, Sawai Bay Formation, Neill Island, Late Miocene*

INTRODUCTION

This paper records for the first time the presence of endoskeletal dinoflagellates in the Neogene succession of the Andaman area, India (Fig. 1). Endoskeletal dinoflagellates are a rare group of siliceous microfossils belonging to the family Actiniscaceae Kutzing (1844). The mineralized skeleton of *Actiniscus pentasterias* (known both in fossil and extant form) is found to be composed of opaline silica.

Of considerable interest is the structure shown by the most commonly recorded group of actiniscids. They are characterized by an alveolar structure which pervades their skeleton from the centre to the distal end of the arms. Species with such structures are represented more frequently in the Neogene than in the Palaeogene. A central or apical alveola is surrounded by the first row of 4–6 alveoli and it forms a ring-like or amphora-shaped central alveola with a central opening and a polygonal outline, known as an apical plate (Hovasse, 1932).

Literature on this rare group of microfossils is scarce; Ehrenberg (1840) first described five species of the genus *Actiniscus*. Dumitrica (1968, 1973) gave excellent illustrations and detailed accounts of such microfossils recovered from the Oligocene to Quaternary sediments from the SW Pacific. Perch-Nielsen (1975, 1976) recorded a rich assemblage from the Late Cretaceous to Pleistocene sediments of the Sub-Antarctic, the southwest Pacific and Eocene–Pliocene sediments of the Norwegian Sea. Orr & Conley (1976) recorded the distribution of Miocene to Recent *Actiniscus* from about a dozen sites in the northeast Pacific. Dumitrica (1973) noted the interval from the Middle Miocene to the Early Pliocene to be extraordinarily rich in siliceous dinoflagellates.

The objective of the present study is to document a well-preserved assemblage of endoskeletal dinoflagellates, represented by *Actiniscus*, from the sediments of Late Miocene age from Neill Island, Andaman Sea.

GEOLOGY OF THE AREA

The Andaman and Nicobar Islands lie in the Bay of Bengal and extend N–S for *c*. 850 km between 6°45' N and 13°45' N latitude. This is an island-arc system representing peaks of a prominent oceanic rise, extending from eastern Burma to Sumatra and Java. It comprises an outer (western) non-volcanic arc which contains the major islands of Andaman and Nicobar, and an inner (eastern) volcanic arc representing Narcondum and Barren Islands, which are both mud volcanoes. Two sub-parallel submarine ridges occur to the east and west of the main Andaman and Nicobar belt. This region has been subject to several cycles of deformation during the Mesozoic, Palaeogene and Neogene.

Neill Island is one of the volcanic islands belonging to Ritchie's Archipelago, which have outcrops of Neogene sediments (Fig. 1). These islands owe their origin to Palaeogene uplift. The geology and stratigraphy of Neill Island is discussed by Oldham (1885), Gee (1927), Singh & Vimal (1973) and Srinivasan & Azmi (1976a). The eastern and northeastern part of Neill Island projects as prominent cliffs, comprising glauconitic mudstones of the Sawai Bay Formation (Srinivasan & Azmi, 1976b) and are capped by the hard, fossiliferous Neill West Coast Formation which is characterized by molluscs and larger foraminifera. The latter formation has a heavy influx of clay material in the lower part which then grades into hard limestones. The lithostratigraphic framework is shown in Figure 2. Volcanic glass shards recorded from Neill Island (Rai, unpublished data) are indicative of inorganic silica exuded from the volcanic vents along mid-oceanic ridges during some phase of active tectonics in the Andaman Basin.

PALAEONTOLOGY

Neill Island exposes one of the deepest marine sedimentary sequences of Neogene age in India. Precise biozonations using both calcareous and siliceous microfossils have been established from the Sawai Bay Formation (Fig. 2), which also yielded the endoskeletal dinoflagellates recorded. *Actiniscus* is known from the Cretaceous (*fide* Deflandre, 1953); however, all other genera recorded are restricted to younger Tertiary sediments only. The presence of age-diagnostic microfossil groups – foraminifers (Srinivasan & Azmi, 1976a), nannofossils (Singh & Jafar, 1995),

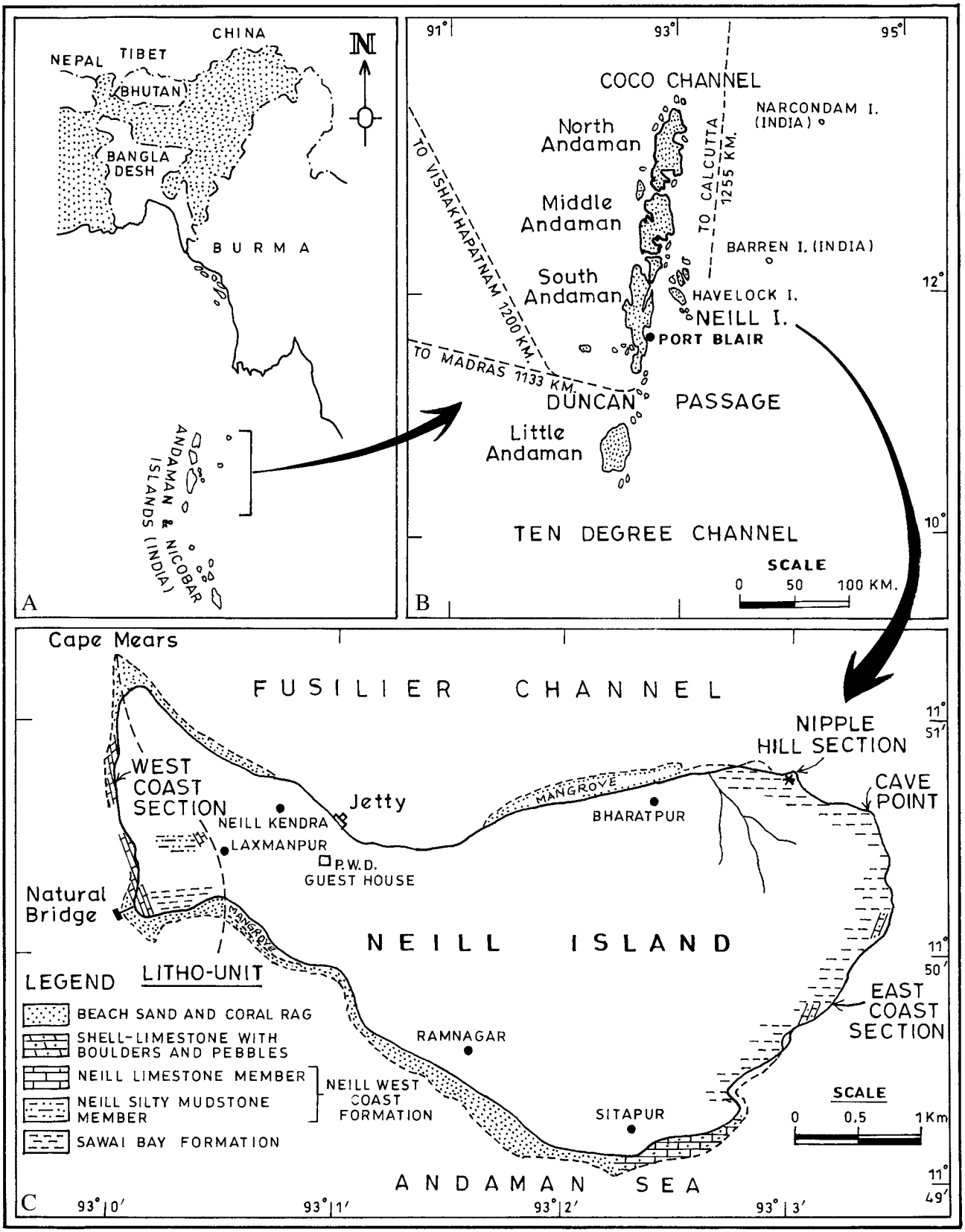


Fig. 1. (**A**) Inset map of part of India. (**B**) Location map of Andaman–Nicobar Islands. (**C**) Geological map of Neill Island showing the locations of the sections examined.

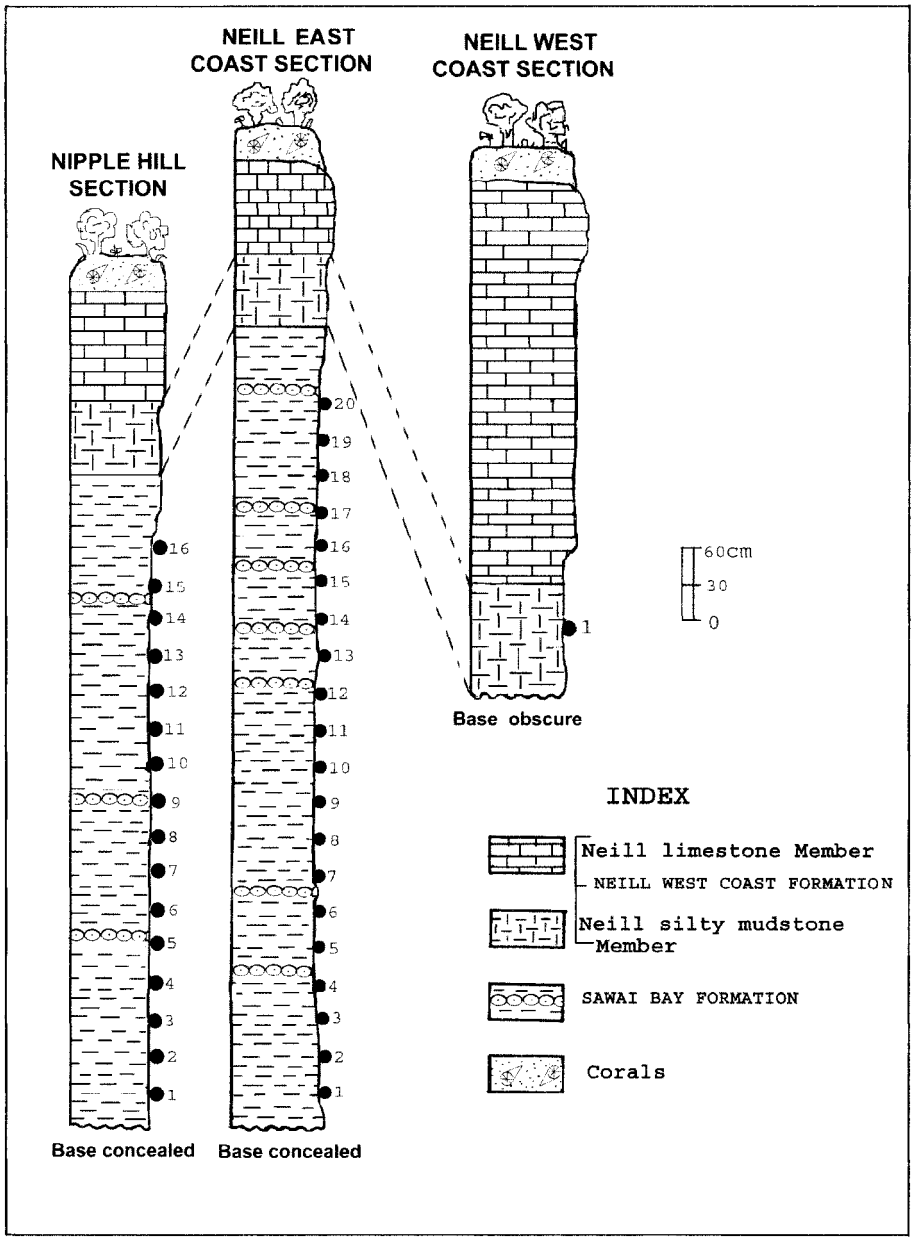


Fig. 2. Lithologs of the sections studied in Neill Island.

diatoms, silicoflagellates and radiolaria (Gupta & Srinivasan, 1992) – from Neill Island confirms their occurrence in Late Miocene sediments (Fig. 3).

The nannofossil assemblage herein contains *Calcidiscus macintyeri*, *Coccolithus miopelagicus*, *Cyclococcolithus leptoporus*, *Cy. luminis*, *Cy. rotula*, *Cyclicargolithus floridanus*, *Discoaster berggrenii*, *D. brouweri*, *D. calcaris*, *D. challengeri*, *D. druggii*, *D. formosus*, *D. neohamatus*, *D. pentaradiatus*, *D. pseudovariabilis*, *D. quinqueramus*, *D. surculus*, *D. variabilis*, *Helicosphaera carteri*, *H. obliqua*, *H. recta*, *H. scissura*, *H. selli*, *Pontosphaera callosa*, *Reticulofenestra abisecta*, *R. haqii*, *R. minuta*, *R. pseudoumbilica*, *Sphenolithus abies*, *S. moriformis*, *Scyphosphaera* spp., *Thoracosphaera granifera*, *Th. saxea* and *Th. tuberosa*. The assemblage also shows reworking of Cretaceous and Palaeogene forms.

MATERIAL AND METHODS

Sixteen samples from the outcropping cliff sections of Nipple Hill and 20 samples from the Neill East Coast section were collected from the Sawai Bay Formation (Srinivasan & Azmi, 1976b). One sample was also collected from the overlying Neill West Coast Formation (Fig. 2). All samples proved to be productive. Permanent strewn slides were prepared using standard techniques (Perch-Nielsen, 1985). Material was absorbed in distilled water and a drop of the dissolved material was spread

evenly on a slide and dried over a hot plate, which was then mounted in Canada Balsam.

Light microscopic documentation was carried out using oil immersion objective (100 ×) using the single polarizer on a Leitz polarizing microscope. Further material containing siliceous microfossils was crushed, powdered and dispersed in glycerine jelly and then mounted under a coverslip to study the morphological details of the specimens. This revealed orientation pattern of arms, structure of the central body, surface features and the nature of depressions on the rays and ray tips.

For scanning electron microscopy, stubs were prepared by spreading a few drops of suspension and drying over a circular coverslip which was fixed on a stub. Coating was with gold-palladium alloy and the material was examined using a Philips model 505 with 30.0 kV acceleration voltage.

SYSTEMATIC DESCRIPTIONS

Dumitrica (1973) discussed the systematics of endoskeletal dinoflagellate genera recovered from Leg 21 of the southwestern Pacific and assigned them to the family Actiniscidae. He erected several new genera and species and gave a detailed description of species, along with sketches and light micrographs and a synonymy list, showing their relationship and distribution in time and space, thus highlighting their biostratigraphical potential.

Perch-Nielsen (1975), using both light and scanning electron micrographs, illustrated several species of the genera *Actiniscus*, *Foliactiniscus* and *Carduifolia*, with detailed descriptions from the Norwegian Sea, DSDP Leg 29. Perch-Nielsen (1976) additionally illustrated several species of the genera *Actiniscus*, *Foliactiniscus, Carduifolia* and *Calcipedinium* and a few siliceous forms similar to organic-walled dinoflagellates from DSDP Leg 38 of the Sub-Antarctic southwest Pacific.

The present material is restricted to the genus *Actiniscus* represented by the type species *A. pentasterias* with *A. elongatus*. It is noteworthy that these taxa are uniformly distributed in all the samples of the three studied sections of Neill Island. Their distribution ranges from rare to very rare, with only 1–3 specimens generally seen in ten fields of view (100 ×).

Fensome *et al.* (1993) dealt with the details of this group in their catalogue of Dinoflagellates.

Division **Dinoflagellata** Fensome *et al*., 1993
Subdivision **Dinokaryota** Fensome *et al*., 1993
Class **Dinophyceae** Pascher, 1914
Subclass **Gymnodiniphycidae** Fensome *et al*., 1993
Order **Gymnodiniales** Apstein, 1909
Suborder **Actiniscineae** (Sournia, 1984) Fensome *et al*., 1993
Family **Actiniscaceae** Kutzing, 1844
Genus *Actiniscus* (Ehrenberg 1840) emend. Ehrenberg, 1843

Type species. *Actiniscus pentasterias* Downie & Sarjeant, 1965

Occurrence. Actiniscaceans are marine planktonic and non-photosynthetic micro-organisms. The marine fossil record of this siliceous skeletal group ranges from the Palaeogene to the Recent and they are at their most diverse during the Late Tertiary. Dumitrica (1973) and Perch-Nielsen (1975, 1976) discussed their palaeoecological importance.

Remarks. The genus *Actiniscus* is the earliest described form; Ehrenberg (1840) proposed *Actiniscus* as a subgenus of the silicoflagellate *Dictyocha*. He described two subspecies, *Dictyocha* (*Actiniscus*) *pentasterias* and *D.* (*Actiniscus*) *sirius* without designating a type for the subgenus *Actiniscus. Actiniscus* was subsequently raised to generic rank by Ehrenberg (1843). The type species of *Actiniscus* was first validly and legitimately designated by Downie & Sarjeant (1965).

Actiniscus pentasterias (Ehrenberg 1840) Downie & Sarjeant, 1965
(Pl. 1, figs 1–4, 6, 7, 9; Pl. 2, figs 1, 3, 4)

1854 *Actiniscus pentasterias* Ehrenberg: pl. 18, fig. 61; pl. 19, fig. 45; pl. 20, fig. 48; pl. 33 (XVII), fig. 1; pl. 35A (XXIII), fig. 1; pl. 36, fig. 36.
1975 *Actiniscus pentasterias* Ehrenberg; Perch-Nielsen: 882, pl. 10, figs 2–10, 16.
1976 *Actiniscus pentasterias* Ehrenberg; Perch-Nielsen: 154, pl. 5, figs 1–7, 9–11; pl. 6, figs 9, 13–16.
1976 *Actiniscus pentasterias* Ehrenberg; Orr & Conley: 92–99, pl. 1, figs 1–11; pl. 2, figs 1–6.

Description. The skeleton consists of opaline silica with a basal concave plate containing five rays and alveolar structures throughout. They show the phenomenon of extinction when seen under crossed nicols. The arms are tricostate, triangular in cross-section, curving down on the ventral side. The tapered arms vary in length and appear pointed at the distal ends. The arms contain alveolar structures and transverse wrinkles as ornamentation on the furrows and between the median and lateral crests. A central amphora-shaped pentagonal alveola is surrounded by five peripheral alveoli.

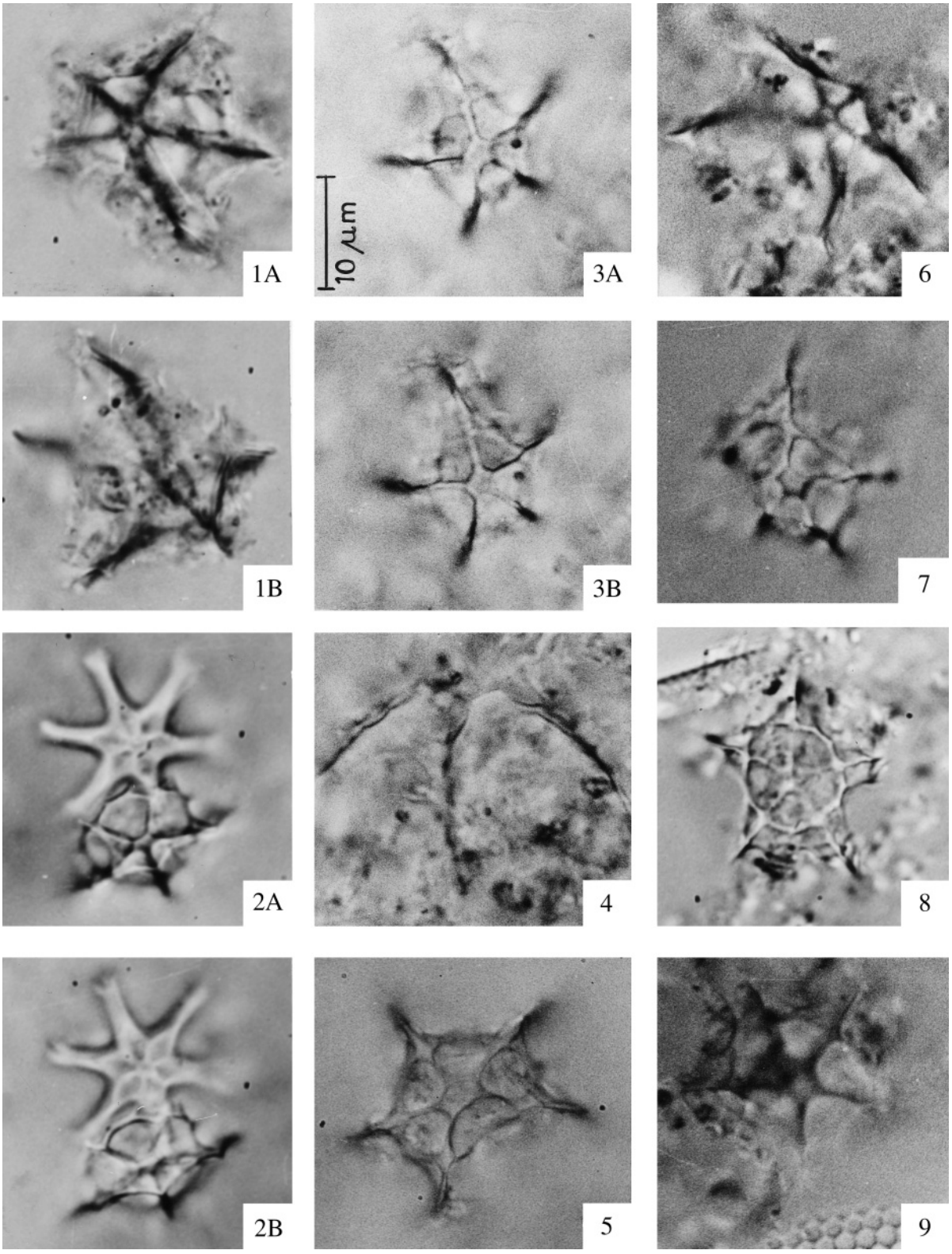
Dimensions. The distance between two arms is between 10 μm and 15 μm.

Stratigraphic range. The known range is Late Eocene to Recent, but it is recorded as the most common siliceous endoskeletal dinoflagellate in most Miocene and Pleistocene samples and is the only representative in the Pleistocene (Perch-Nielsen, 1975, 1976). Orr & Conley (1975) stated that thinner forms were noticed in the Pleistocene whilst robust forms dominated older intervals. This shift from robust to delicate specimens appears to be gradual throughout its distribution.

Remarks. Dumitrica (1973) recorded the variation in the number of arms from 4 to 6. Perch-Nielsen (1975) recorded forms with 5–8 arms. The present material, however, shows only 5-rayed forms. Orr & Conley (1976) also recorded only 5-rayed *A. pentasterias* from the northeast Pacific rim.

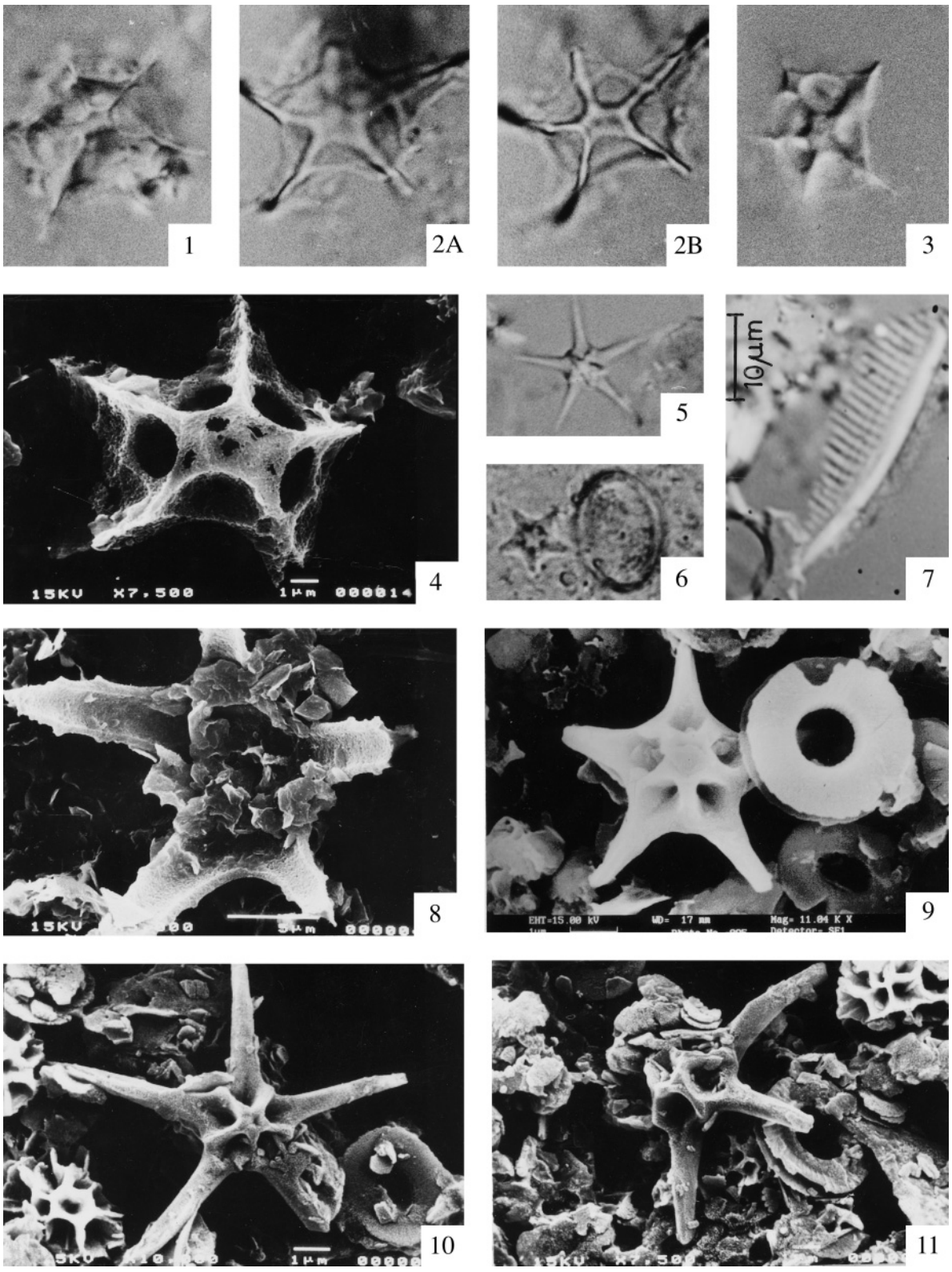
Actiniscus elongatus Dumitrica 1968
(Pl. 1, fig. 5; Pl. 2, figs 2, 8)

1968 *Actiniscus elongatus* Dumitrica: 240, pl. 4, figs 22, 26.
1973 *Actiniscus elongatus* Dumitrica; Dumitrica: pl. 3, figs 6–12; pl. 5, figs 10–11.



Explanation of Plate 1.

fig. 1A, B. *Actiniscus pentasterias* Ehrenberg: (**A**) dorsal view; (**B**) arm tips in focus. **fig. 2A, B.** *Actiniscus pentasterias* Ehrenberg: (**A**) central area in focus; (**B**) lower arms in focus. **fig. 3A, B.** *Actiniscus pentasterias* Ehrenberg: (**A**) central area in focus; (**B**) arms in focus. **fig. 4.** *Actiniscus pentasterias* Ehrenberg displaying highly curved nature of rays. **fig. 5.** *Actiniscus elongatus* Dumitrica, dorsal view. **fig. 6.** *Actiniscus pentasterias* Ehrenberg showing tricostate ray tips. **fig. 7.** *Actiniscus pentasterias* Ehrenberg, central area and two rays in focus. **fig. 8.** *Actiniscus pentasterias* Ehrenberg, dorsal view. **fig. 9.** *Actiniscus pentasterias* Ehrenberg Dorsal view. Each figure is 2000×.



Explanation of Plate 2.

fig. 1. *Actiniscus pentasterias* Ehrenberg, dorsal view. **fig. 2A, B.** *Actiniscus elongatus* Dumitrica, dorsal view. **fig. 3.** *Actiniscus pentasterias* Ehrenberg, dorsal view. **fig. 4.** *Actiniscus pentasterias* Ehrenberg, dorsal view. **fig. 5.** *Discoaster quinqueramus* Gartner. **fig. 6.** *Discoaster berggrenii* Bukry. **fig. 7.** *Triquetrorhabdulus rugosus* Lipps. **fig. 8.** *Actiniscus elongatus* Dumitrica, ventral view. **fig. 9.** *Discoaster berggrenii* Bukry, dorsal view. **fig. 10.** *Discoaster berggrenii* Bukry/*Discoaster quinqueramus* Gartner (intermediate form). **fig. 11.** *Discoaster berggrenii* Bukry, side view.

1975 *Actiniscus elongatus* Dumitrica; Perch-Nielsen: 882, pl. 10, figs 11–13.
1976 *Actiniscus elongatus* Dumitrica; Perch-Nielsen: 154, pl. 5, figs 13–14.

Description. A star-like skeleton which consists of an elongate, pentagonal plate with bilateral symmetry. Five arcuate arms depart from the corners of this pentagonal plate; two of these arms are situated at one extremity whilst the three arms are present at the opposite extremity. The median crests of the arms join together apically and outline the elongate pentagon with a concave surface.

Dimensions. In the longitudinal dimension the span of the skeleton is 10–15 μm.

Stratigraphic range. Dumitrica (1976) recorded *A. elegans* from the Middle Miocene to Early Pliocene, but Perch-Nielsen (1975) found it from the Late Eocene to the ?Early Pliocene, and indicated it was rarely present in the Miocene (Perch-Nielsen, 1976). It is also rarely found in the present material.

Remarks. The central area appears simple in the present material and not divided by one or two wrinkles, as discussed by Dumitrica (1968). The arms indicate the presence of transverse wrinkles in the present specimens and are not smooth.

AGE OF THE ASSEMBLAGE

Srinivasan & Azmi (1976) have identified *Globorotalia plesiotumida*, *G. tumida tumida* and *Sphaeriidinella dehiscens* planktic foraminiferal zones in ascending order from Sawai Bay and Neill West Coast formations and assigned Late Miocene to Early Pliocene age. Gupta & Srinivasan (1992) identified *Didymocyrtis antepenultima*, *D. penultima* and *Stichocorys peregrina* radiolarian Zones of Late Miocene to Early Pliocene age for the same set of samples. Singh & Vimal (1973) provided an Early Pliocene age on preliminary study of foraminifer and nannofossils from grey mudstone of the East Coast section. However, Singh & Jafar (1995), after studying calcareous nannofossils from Neill Island, assigned NN 11=CN9A for the Sawai Bay Formation but did not comment upon the age of the overlying Neill Limestone Formation.

The presence of the nannofossil markers *Discoaster berggrenii* and *Discoaster quinqueramus* in all the samples from Nipple Hill and the Nipple East Coast Section of the Sawai Bay Formation, Neill Island, indicate that the assemblage lies in the *Discoaster berggrenii* Subzone CN9A of Okada & Bukry (1980), corresponding to the lower part of the *Discoaster quinqueramus* (NN11) Zone of Martini (1971).

D. berggrenii and *D. quinqueramus* are poorly preserved both in diversity and frequency amongst the entire discoaster assemblage from the Neill West Coast section. The presence of *Triquetrorhabdulus rugosus* further restricts the age to a slightly younger (CN 9B) zonal attribution and within NN11 Zone.

CONCLUSIONS

1. Rare occurrences of siliceous dinoflagellates represented by the genus *Actiniscus* are recorded from Late Miocene sediments of Neill Island, India.
2. These siliceous dinoflagellates occur in association with rich and datable calcareous (planktonic foraminifers and calcareous nannofossils) and siliceous (diatoms, radiolaria) microfossils.
3. The siliceous dinoflagellates occur within the nannofossil *D. quinqueramus* (NN11) Zone of Martini (1971), corresponding with CN9 Zone of Okada & Bukry (1980). The Sawai Bay Formation belongs to the (CN9A) *D. berggrenii* Zone, while the Neill West Coast Formation is assigned to the (CN9B) *T. rugosus* Zone, both of which occur within the NN11 Zone of Late Miocene age.

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