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CALCAREOUS ALGAE (DASYCLADACEANS AND GYMNOCODIACEANS) FROM THE PALAEOCENE DEPOSITS OF THE TIRUCHIRAPALLI (=TRICHINOPALLY) AREA, TAMIL NADU, INDIA

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ABSTRACT

The Palaeocene sediments (Ninniyur Formation) of the Trichy area show exceptionally rich assemblages of fossil algae. Besides the predominant coralline algae, the floristic composition also includes dasycladacean forms. In the present paper, eight species belonging to five genera of calcareous algae are described from the Ninniyur and adjoining areas. Out of these, five species belong to the family Dasycladaceae and three species belong to the family Gymnocodiaceae of the class Rhodophyceae.

The chronological value of the studied dasycladacean elements is examined within a chronostratigraphic framework based on the associated planktic and benthic foraminifera which indicate that the Ninniyur Formation can be correlated with zones P2-P4 of the planktic foraminiferal zonation, corresponding to late Danian-Thanetian.

Because of their low diversity, the dasycladaceans cannot be effectively used for interpreting environment. Their environmental preferences however, can be inferred on the basis of the associated corallines, foraminifera and lithology. Three broad facies can be differentiated, each indicating a distinct palaeoenvironmental setting : lagoonal/restricted platform facies, middle-shelf carbonate shoal facies and landward "reef-margin" facies.

Key words : Calcareous Algae (Dasycladaceae and Gymnocodiaceae), Palaeocene, Ninniyur Formation, Tiruchirapalli, Cauvery Basin.

INTRODUCTION

Palaeocene epoch is a geologically significant time for calcareous algae, as the latter not only recovered from a spell of their general decline in the terminal Cretaceous extinction event but also flourished and achieved the levels of diversity prevalent prior to the extinction event. In spite of this well-documented observation (Barattolo, 1991, 1998), very little progress has been made in the understanding of the fossil algal flora from the Indian Palaeocene successions possibly because of poor development of suitable facies in most of these successions. The Tiruchirapalli area, however, is noted for its richly fossiliferous carbonate beds of this interval that are characterised by the abundance of calcareous algae (Banerji, 1979). The earlier works (cited below) gave a general idea about the algal composition of these beds but did not reveal the true taxonomic composition of the calcareous algae. This possibly hampered the use of this important fossil group for biostratigraphic and palaeo-ecological purposes.

In the last three decades, several studies of early Palaeogene calcareous algae have been carried out (Beckmann and Beckmann, 1966; Beckmann, 1982; Johnson 1962, 1964; Johnson and Kaska, 1965; Barattolo, 1991, 1998; Barattolo, De Castro and Parente, 1993; Barattolo and Bigozzi, 1996; Génot 1980, 1991; Elliott, 1968, 1978; Kuss and Herbig, 1993). These studies give a comprehensive account of morphotaxonomical, stratigraphical and palaeo-ecological aspects of the Tertiary dasycladaceans and coralline algae. But the studies from the equivalent south Indian sequences have been rather inadequate. Rao (1931, 1956, 1958) and Rao and Pia (1936) and Verma (1952) described 15 taxa of dasycladalean and red calcareous algae from the Ninniyur Formation of Tiruchirapalli district. Rajnikanth (1991) enumerated the dasycladalean and red calcareous algae from the Ninniyur area of the Cauvery basin. The ecological implications of Cretaceous-Tertiary algae were discussed by Rajnikanth (1992). Pal (1972) and Pal and Dutta (1979) described some dasycladacean algae from the Tertiary sequences of the Ninniyur and the Meghalaya areas.

In an attempt to fill the existing gap in the knowledge of the algal composition of the

Tiruchirapalli area, the authors (Misra, Jauhri, Chowdhury and Kishore, *in review*) presented, in considerable detail, the taxonomic composition of the calcareous algae from the Ninniyur Formation, documenting 34 species of the red algae. The present paper provides further data on the knowledge of the highly diversified Palaeocene calcareous algae, reporting the occurrence of an assemblage of the dasycladacean group, together with three gymnocodiacean elements in the Ninniyur Formation.

The studied area forms a part of the Cauvery Basin in the southernmost portion of the Coromandal shelf regime of India (fig. 1). The Palaeogene succession in this basin includes the strata of Palaeocene age (Rao and Pia, 1936; Krishnan and Jacob, 1956; Banerji, 1979; Sundaram and Rao, 1986; Govindan, Yadagiri, Ravindran and Kalyansunder, 1996, 1998; Malarkodi and Nagaraja, 1997). Designated as the Ninniyur Formation, it is well exposed as isolated outcrops over the Ariyalur Group along a NNE-SSW strike between Vellar river in the north and Kavanur in the south, for a distance of about 26 km on the northeastern part of the Tiruchirapalli area (fig.1). The lithological details of this formation are outlined in Table 1. Its most distinguishing feature is the occurrence of fossil algae in abundance (Rao, 1958), besides the lithology and the characteristic animal fossils. It is divisible into three units: the lower fossiliferous limestone unit (Adanakkurichchi Limestone); the middle unit (Subcrystalline Shelly Limestone); and upper unit (Argillaceous Gritty Nodular Limestone).

Lithologically, the lowermost unit comprises marl and off-white to yellow limestone which is moderately compact and highly fossiliferous, showing diverse mega-invertebrates and a rich miliolid assemblage along with a few elements of planktic foraminifera (Malarkodi and Nagaraja, 1997); however, its algal association is poor. Occasionally sea urchin spines are seen (Pl. II, fig. 4; Pl. III, fig. 5). The middle unit is a dominantly recrystallized, hard, compact, variegated limestone. As compared to the lower unit, its mega-invertebrate fossils are less diverse; its fauna is largely disintegrated and characterised by the frequently occurring *Hercoglossa danica* Schlotheim (nautiloid) and lucinoid bivalves along with gastropods, other bivalves, ostracods and foraminifers. However, its algal association is more diverse than the lower and upper units. The uppermost unit is an argillaceous, fine to gritty nodular limestone with calcareous nodules ranging in diameter from 2 to 5 cm. It is richly fossiliferous and contains abundant corals, bivalves, gastropods and some echinoid spines (e.g. Pl. II, figs.1, 3), besides the algal components. A few of these spines appear to resemble the sections of dasycladaceous algae (e.g. the fig. 3 of Pl. II seems to compare with *Clypeina* sp.). *Cardita beaumonti* Douvillé is the most important bivalve fossil of this unit.

The geological details and the studied samples of the Ninniyur Formation were collected from the Adanakkurichchi section exposing the lower unit.

Table 1 : Basic composition and lithological subdivision of the Ninniyur Formation in the area of study (modified after Mallikarjuna and Nagaraja, 1996).

	LITHOLOGICAL UNITS	LITHOLOGY	STUDY AREA
CUDDALORE FORMATON			
NINNIYUR FORMATION	Argillaceous Gritty Nodular Limestone	Limestone intercalated with marl and clay, containing calcareous algae, corals, polyzoans, bivalves, gastropods and milioline foraminifera in large numbers (4m).	SENDURAI
	White Compact Subcrystalline Shelly Limestone	Limestone containing broad, rounded patches of calcareous algae with occasional milioline foraminifera, *Hercoglossa danica,* lucinoid bivalves, etc. (6m).	PERIYAKURICHCHI
	Adanakkurichchi Limestone	Argillaceous Limestone with intercalated marl and clay. Large number of small, rounded white bioclasts of calcareous algae present in association with milioline formainifera, polyzoans, etc. (1.5m).	ADANAKKURICHCHI
ARIYALUR GROUP			

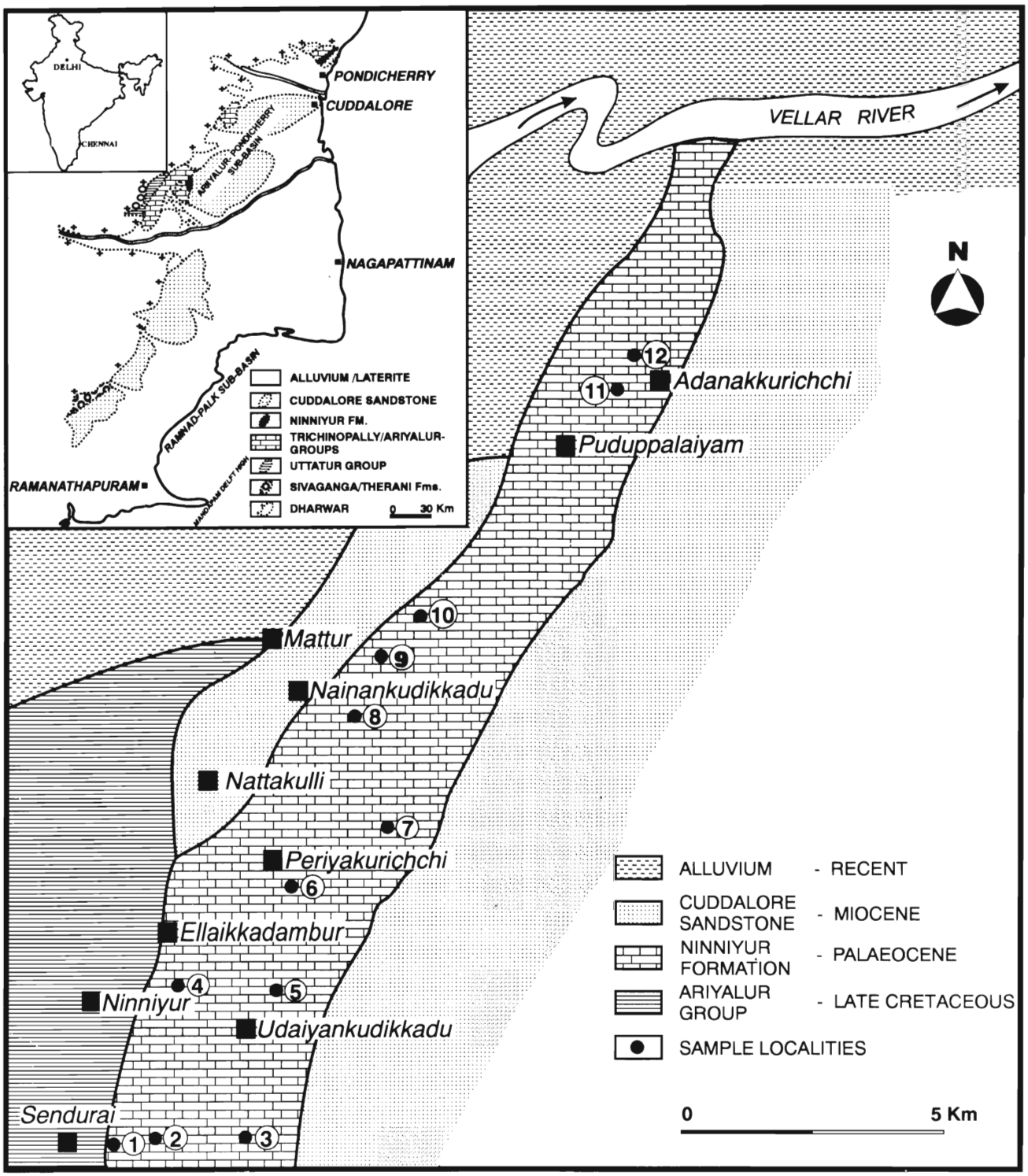

Fig. 1. Location and geological map of the area of study. A. Position of the Cauvery Basin in India (inset) indicated by a rectangle. B. The general geological map of the Cauvery Basin showing distribution of the studied succession in the Ariyalur/Pondicherry sub-basin. C. The geological map of the Tiruchirapalli area showing the sampled localities where the outcrops of the Ninniyur Formation are well exposed.

from the Periyakurichchi, Mattur and the Ninniyur sections showing the exposures of the middle unit; and from the Sendurai section exposing the upper unit (see Misra *et al., in review*).

The Ninniyur Formation was dated as the Danian (early Palaeocene) on the basis of *Hercoglossa danica* Schlotheim earlier considered to be characteristic of the Danian stage (Blanford, 1962; Rao and Pia, 1936; Rao, 1956). Subsequent work revealed the presence of planktic foraminifera in the Ninniyur formation. Sastry *et al.* (1965) suggested an early Palaeocene (Danian) age for these beds on the basis of *Globorotalia* (*Truncorotalia*) *mossae* Hofker. Malarkodi and Nagaraja (1997, 1998) document several species of benthic and planktic foraminifera from different litho-units of the Ninniyur Formation. The age-diagnostic taxa in their assemblage include *Morozovella praecursoria* (Morozova), *Acarinina spiralis* Bolli, *A. mckannai* (White) and the species of *Thalmannita* which together indicate that the Ninniyur Formation ranges in age from early to late Palaeocene (fig. 2).

In the present paper, eight species of calcareous algae belonging to five genera are being described. Five species of the present assemblage belong to the family Dasycladaceae and three species represent the family Gymnocodiaceae of the class Rhodophyceae. Except *Indopolia satyavanti* Rao & Pia, all species are kept in open nomenclature because of the problems of comparison and preservation of morphological characters. The recorded genera are *Indopolia, "Neomeris", Dissocladella, Cymopolia* and *Permocalculus;* the last of these being reported for the first time from the Palaeocene of India.

SYSTEMATIC DESCRIPTION

Order **Dasycladales** Pascher, 1931

Family **Acetabulariaceae** (Endlicher) Hauck, 1885

Tribe **Dasycladeae** Pia, 1920

Genus ***Cymopolia*** Lamouroux, 1816

Cympolia sp.
(Pl. I, fig. 3)

Slide No. : S/CB-16.

Locality : Sendurai.

Horizon : Upper Unit.

Diagnosis : Thallus 835μm in diameter. Primary branches perpendicular to the axis of the thallus, 55-62 μm long and divided into 3-4 secondary branches. Secondary branches longer than primary branches, 88-95 μm long. Large solitary spherical sporangia, 55-60 μm in diameter, present at the junction of primary and secondary branches. Longitudinal section not seen.

Remarks : This specimen was observed in a cross-section, in which secondary branches are not prominent; therefore, its specific identification is not possible.

Tribe **Dissocladelleae** Elliott, 1977

Genus ***Dissocladella*** Pia in Rao & Pia, 1936

Dissocladella sp.
(Pl. III, fig. 3)

Slide No. : Slide No. : P/CB-94.

Locality : Periyakurichchi.

Horizon : Middle Unit.

Diagnosis : Thallus fragmented, 492 μm in diameter. Branches loose, straight widening abruptly and distally, primary branches divided into two or more secondary branches. Secondary branches 75-90 μm long; central cavity 265-275 μm in diameter. Sporangia indistinct.

Remarks : The cross-section of this species resembles *D. savitrie* reported from the Ninniyur area (Rao and Pia, 1936). This species has also been recorded from the Palaeocene-lower Eocene successions of Iraq (Elliott, 1968). In view of the absence of longitudinal sections of thallus and indistinct sporangia, the present specimen is kept in open nomenclature.

Genus ***Indopolia*** Pia in Rao & Pia, 1936

Indopolia satyavanti Rao & Pia, 1936
(Pl. I, figs. 1-2; Pl. II, figs. 2, 5)

Indopolia satyavanti Pia in Rao & Pia, 1936, p., 20 pl. 1. fig. 5-13.- Eliott, 1968, p. 52-53, pl. 12, fig. 2.- Yu Jing, 1976, p. 443, pl. 7, figs.

1-5.-Deloffre, Fleury & Mavrikas, 1991, p. 525, figs. 4-7.

Cymopolia satyavanti (Pia)-Radoicic, 1998, p. 349, figs. 1-7.

Slide No. : S/CB-23, M/CB-14, D/CB-2F.

Locality : Sendurai, Mattur, Adanakkuruchchi

Horizon : Upper, Middle and Lower Units.

Diagnosis : Thallus cylindrical, gradually broadening from base (230 μm) towards apex (510 μm), thallus 4.65 mm long, 1.23 mm wide. Width of the cavity 450 μm. Primary branches emerge at an angle of 30°-40° and usually marked in oblique section. Each primary branch bears two sporangia. The sporangia are spherical or somewhat pear-shaped, 40-50 μm in diameter. Primary branches 30-40 μm long, secondary branches 315-360-280 μm long.

Remarks : The comparison shows that the present material resembles the type specimens considerably; however, the thallus in the latter is uniformly broad from base towards apex, while that of the present material is sometimes tapering from the mid-region to base. Radoicic (1998) treated *Indopolia* Pia as a junior synonym of *Cymopolia* Lamouroux, 1816 and was of the opinion that the former could be a morphological variant of the latter. The distinguishing feature of *Indopolia* is the presence of twin ampullae in the primaries, a character which separates it from *Cymopolia*. According to Radoicic (1998), it is not a constant character and some forms may also show cylindrical primaries. The present authors, however, are of the view that the forms of *Cymopolia* Lamouroux with ampullae could be retained under *Indopolia* Pia until a detailed study of related fossils from other regions has been carried out.

The present species has previously been reported from the Thanetian sections (Klokova and Skolis) of Greece (Deloffre, Fleury and Mavrikas, 1991), Ras Al Hamra, Oman (Rácz, 1979) and the Palaeocene-lower Eocene successions of Iraq (Elliott, 1968). Radoicic (1998) has recorded *I. satyavanti* Pia (as *Cympolia satyavanti*) from the Palaeocene of western Slovenia.

Indopolia sp.
(Pl. III, fig. 2)

Slide No. : S/CB-23.

Locality : Sendurai.

Horizon : Upper Unit.

Diagnosis : Thallus broad in cross-section, 1.35 mm in diameter. Primary branches 45-70 μm long, secondary branches 90-120 μm long, branches straight or oblique, wide. Central cavity 880-910 mm wide. Sporangia indistinct.

Remarks : The cross-section of this species is somewhat oblique and the central cavity of thallus is wider than that of *I. satyavanti* Rao & Pia. Sporangia are not clearly seen; hence, it is being described here as an unnamed species of genus *Indopolia* Pia.

Genus **Neomeris** Lamouroux, 1816

"*Neomeris*" sp.
(Pl. I. fig. 5)

Slide No. : S/CB-20.

Locality : Sendurai.

Horizon : Upper Unit.

Diagnosis : Cross-section circular, 455 μm in diameter, central axis 115-125 μm broad, bearing a whorl of considerably elongated primary branches; primary branches 30-40 μm long and divided into secondary branches (95-110 μm long); secondary branches overlap or lie close to each other; sporangia, present at the junction of primary and secondary branches, oblong or subspherical, 30-35 μm.

Remarks : *Neomeris* is an extant genus. Calcification surrounds the sporangia and secondary branches, but the thallus is essentially uncalcified around the central stem and primary branches. This specimen is comparable with *Neomeris fragilis* (Defrance) Morellet in branching pattern and outline of the cross-section but differs in its oblong or subspherical sporangia; in *N. fragilis* sporangia are spherical and stalked. Génot (1980) reported *Neomeris fragilis* (Defrance) Morellet from the lower Eocene of Paris, France.

Family **Gymnocodiaceae** Elliot, 1965

Genus **Permocalculus** Elliot, 1955

Permocalculus sp. A
(Pl. III, fig. 4)

Slide No. : P/CB-94.

Locality : Periyakurichchi.

Horizon : Middle unit.

Diagnosis : Thallus segmented, with elongated to almost cylindrical segments, often strongly calcified; fine pores are best visible near the cortical zones. 1.47 mm long and 930 μm wide. Walls perforated by pores which radiate obliquely. Pores small and numerous. At the surface they may expand into funnel- or tulip-shaped openings. Calcification variable, ranging from thin irregular, outer crust to complete thallus.

Remarks : The fertile structures (sporangia) are not preserved here; hence, it is not possible to determine its specific status.

Permocalculus sp. B
(Pl. III, fig. 1)

Slide No. : P/CB-195.

Locality : Periyakurichchi.

Horizon : Middle Unit.

Diagnosis : Segments keg shaped to ovoid, 945 μm long, 536 μm wide. Sporangia not distinct, numerous small pores are present.

Remarks : This specimen appears to be comparable with *P. tenellus* Pia (Johnson and Kaska, 1965) reported from the Upper Permian of Guatemala. However, absence of sporangia and insufficient material preclude specific determination of this form.

Permocalculus sp. C
(Pl. I, fig. 4)

Slide No. : P/CB-101.

Locality : Periyakurichchi

Horizon : Middle Unit.

Diagnosis : Thallus segmented, 934 μm long, 625 μm wide. A few segments with poorly preserved internal structure; sporangia indistinct, numerous small pores present.

Remarks : In view of indistinct sporangia, segmented thallus and poor preservation, the specific identification of the forms under study is not possible.

DISCUSSION

The studied assemblage of the dasycladaceans and gymnocodiaceans are distributed through the sequence into three associations (fig. 2). However, their chronologic value can be deduced by their reference to the associated planktic and benthic foraminifera (Malarkodi and Nagaraja, 1997) which are used here as chronostratigraphic indices (Toumarkine and Luterbacher, 1986).

(a) The lower unit association comprises only one dasycladacean species – *Indopolia satyavanti* Rao & Pia – which occurs in a shale- and marl-dominated Adanakkurichchi Limestone Unit. The age-diagnostic planktic foraminifera of this unit are *Acarinina spiralis* Bolli, *Morozovella praecursoria* (Morozova) and *Planorotalites chapmanni* (Parr) as reported by Malarkodi and Nagaraja (1997). *M. praecursoria* ranges from Zone P2 to Zone P3; *Planorotalites chapmanni* is distributed from Zone P3 to Zone P6; and *Acarinina spiralis* is confined to Zone P2. The latter species suggests that the lower unit has an age equivalence to Zone P2, i.e. late Danian (early Palaeocene).

(b) The association present in the middle unit consists of two dasycladacean species (*Dissocladella* sp. and *Indopolia satyavanti* Rao & Pia) and three gymnocodiacean species (*Permocalculus* sp. A, *P.* sp. B and *P.* sp. C.) The associated planktic foraminifera include *Acarinina mckannai* (White) and *Planorotalites pseudomenardii* (Bolli); *A. mckannai* extends from Zone P3 to Zone P5 and *P. pseudomenardii* is characteristic of Zone P4 (Malarkodi and Nagaraja, 1997). These markers indicate that the middle unit is equivalent of a stratigraphic interval corresponding to Zones P3-P4, i.e. Thanetian (late Palaeocene).

(c) The association of the upper unit includes four identifiable dasycladacean elements (*Cymopolia* sp, *Indopolia satyavanti* Rao & Pia, *Indopolia* sp. and *"Neomeris"* sp.). Though marked by abundant megafossil remains, *Cardita beaumonti* Douvillé appears to be stratigraphically most significant. The microfossil assemblage reported by Malarkodi and Nagaraja (1997), however, is distinguished by the absence of planktic foraminifera. The important

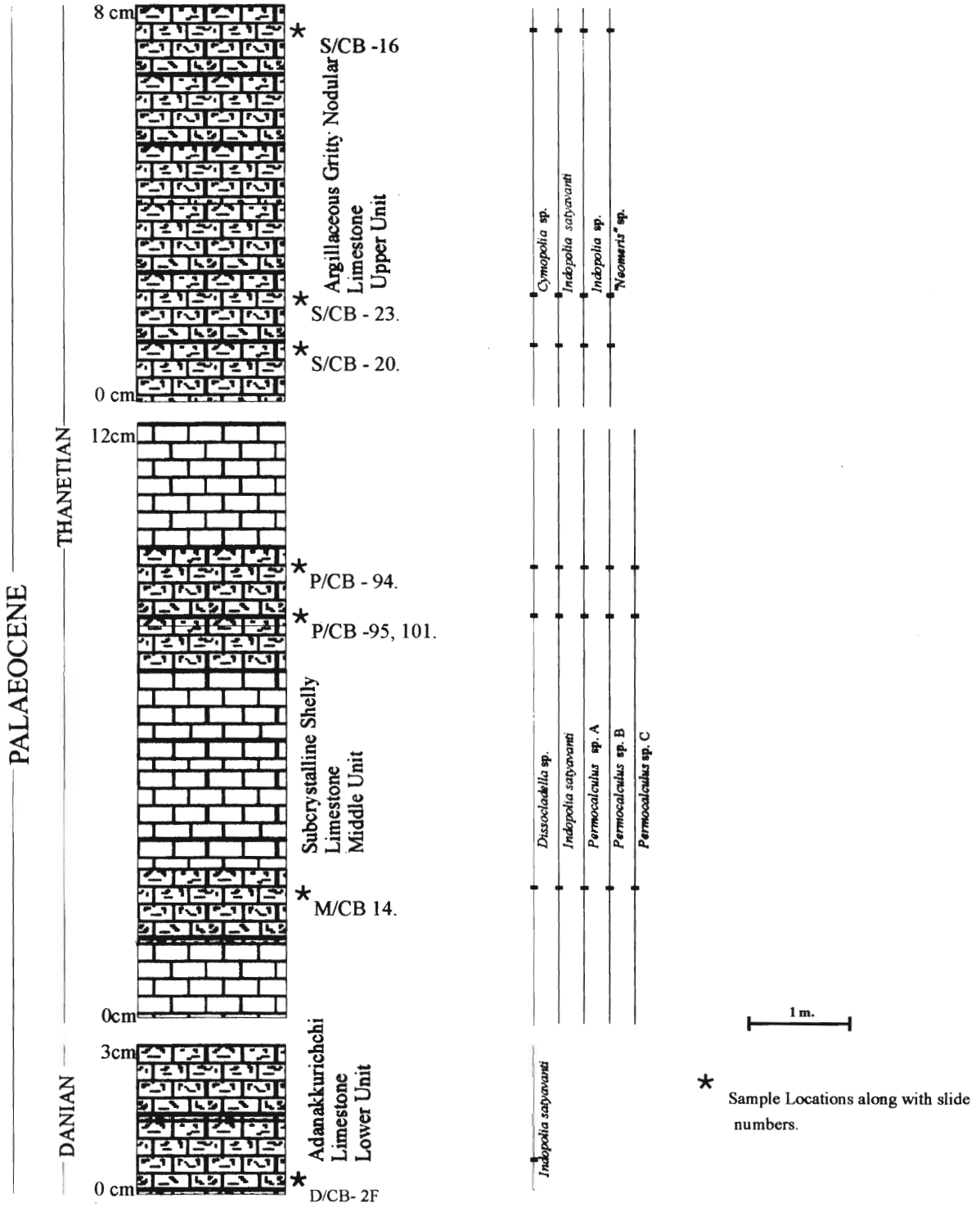

Fig. 2. The litho-biostratigraphic representation of the Ninniyur Formation in the Tiruchirapalli area showing position of the fossil-yielding samples (indicated by star*) as well as the stratigraphic ranges of the species of calcaresous algae based on the present study (indicated by vertical line). The horizontal bar (-) marks the actual occurrence of the algal species.

benthic foraminifera are *Protelphidium brotzeni* (Hofker) and *Gavelinella danica* (Brotzen). *G. danica* is a widely distributed Palaeocene marker. Berggren and Aubert (1975) report that it is a common component of the foraminiferal shelf assemblages of lower and upper Palaeocene deposits in the Tethyan and extra-Tethyan regions. The upper unit seems to be referable to the Thanetian in view of its position in sequence, i.e. above the middle unit dated here as the Thanetian on the basis of the planktic microfossils.

The dasycladaceans of the Ninniyur Formation constitute a low percentage of the total algal flora and it is not presently possible to use them for the interpretation of palaeoenvironment. Their environmental adaptations, however, can be inferred from the associated red algae, foraminifera and animal fossils which occur in abundance and show varied populations in the sequence. Ecological data on living Dasycladales indicate their adaptations to shallow marine, tropical-subtropical environments; they occur in abundance in low-energy regimes, either below wave base or in the quiet-water areas in sheltered situations, and extend from just below the low tide to about 30 m. They are known to colonise sand and mud bottoms, though some are found attaching their rhizoids to firm objects such as shells, etc. on the bottom (Wray, 1977; Génot, 1991; Elliott, 1978. 1984).

The authors (Misra *et al. in review*), while studying the red algae of the Ninniyur Formation, recognise three algal associations which along with their associated fossil assemblages and lithology indicate three broad facies, each indicating a distinct palaeoenvironmental setting :

(i) *Lagoonal/Restricted platform facies :* The coralline algal association of this facies shows only limited development of *Lithophyllum* and *Sporolithon*. Ecological data on *Lithophyllum* indicate a near-shore, shallow lagoonal environment (Fravega, Piazza and Vannucci, 1994). Such an environment is characterised by low-energy conditions. Presence of clastic material and miliolids in large amounts supports such an interpretation (Rácz, 1979).

Dasycladacean forms observed in this facies are referable to *Indopolia satyavanti* Rao & Pia. *Indopolia* is a common constituent of the shallow shelf facies (back-reef) of Greece (Deloffre *et al.*, 1991), Ras Al Hamra, Oman (Rácz, 1979) and Iraq (Elliott, 1968).

(ii) *Middle-shelf carbonate shoal facies :* This facies of relatively pure carbonates exhibits a predominance of red algae dominated by crustose corallines such as *Sporolithon, Lithothamnion, Mesophyllum* along with a fair representation of *Polystrata* (*Ethelia*) *alba* (Pfender) Denizot. The presence of these forms, low amounts of miliolids and carbonate mud indicate a shallow middle-shelf (30-50 m) environment. It seems that the abundant red algal flora and the associated organisms were possibly the principal contributors to the organic matter of the sediment consumed by deposit-feeding, burrowing lucinoid bivalves (commonly distributed in this unit). These bivalves bury themselves completely below the seabed and suck detritus through mucus-lined tubes (Sellwood, B.W. in McKerrow, 1978, p. 211). Their burrowing and detritus feeding habits suggest soft but firm substrates with low rates of deposition and relatively low-water energy conditions, possibly below wave base. Such an environment, though suitable for the luxuriant growth of red algae and accumulation of organogenic build-ups (carbonate shoals), does not promote dasycladalean elements as most of them live on sandy and muddy bottoms of lagoonal and restricted platform environments.

Only two dasycladacean genera (*Indopolia* and *Dissocladella*) are observed in this facies. *Indopolia* commonly occurs in the subtidal Thanetian deposits in Greece (Deloffre *et al.*, 1991), Oman (Rácz, 1979) and Iraq (Elliott, 1968). *Dissocladella* is known from the platform deposits of the Thanetian of Iraq (Elliott, 1968). Associated planktic foraminifera suggest occasional influence of open ocean conditions.

(iii) *Landward "reef-margin" facies :* The carbonates of this facies are relatively impure in view of the presence of terrigenous clastic material in large amounts. They show thinner populations of fossil mega-invertebrates, foraminifera, etc. Ostracodes show dominance over foraminifera and the latter

commonly include the species of *Gavelinella, Textularia* and *Rosalina* which usually flourish in an environment marked by high input of clastic material (Berggren and Aubert, 1975). Though the red algal association is not as abundant and varied as in the middle unit of the Ninniyur Formation, the common occurrence of *Sporolithon, Lithothamnion* and *Lithophyllum* indicates deposition at depths ranging from 20-30 m, in close proximity to lagoonal or tidal environment (Rácz, 1979).

The associated dasycladaceans, though poorly developed in comparison to red algae, are represented by *Cymopolia* sp., *Indopolia satyavanti* Rao & Pia, *Indopolia* sp. and "*Neomeris*" sp. These forms have generally been documented as the main constituents of lagoonal and restricted platform deposits in Europe and the Middle East (Barattolo, 1998). The genera *Cymopolia* and *Neomeris* occur as the characteristic forms of the Kuss and Herbig's (1993) II facies belt of the Thanetian deposits of Egypt. The latter corresponds to the carbonate shoals formed in a lagoon in close proximity to tidal flat (Kuss and Herbig, 1993).

CONCLUSIONS

A study of the calcareous algae from the Ninniyur Formation of the Tiruchirapalli area shows presence of five dasycladacean elements and three species of gymnocodiaceans. The studied algal elements can be grouped into three assemblages corresponding to the three units of the Ninniyur Formation.

Though most of the documented dasycladacean elements have been found to characterise the Palaeocene-lower Eocene successions of the Tethys, their precise age can be established by means of the associated planktic and benthic foraminifera described previously by Malarkodi and Nagaraja (1997, 1998). Based on the foraminiferal association, the Ninniyur assemblages of the calcareous algae can be referred to a stratigraphic interval ranging from Zone P2 to Zone P4 of the planktic foraminiferal zonation, corresponding to the late Danian to Thanetian (early to late Palaeocene).

Algal assemblages, associated foraminifera and mega-invertebrates and lithology indicate three broad facies, each indicating a distinct palaeohabitat on a shallow shelf setting : Lagoonal/restricted platform facies, middle-shelf carbonate shoal facies and landward "reef-margin" facies.

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EXPLANATION OF PLATES

Plate I

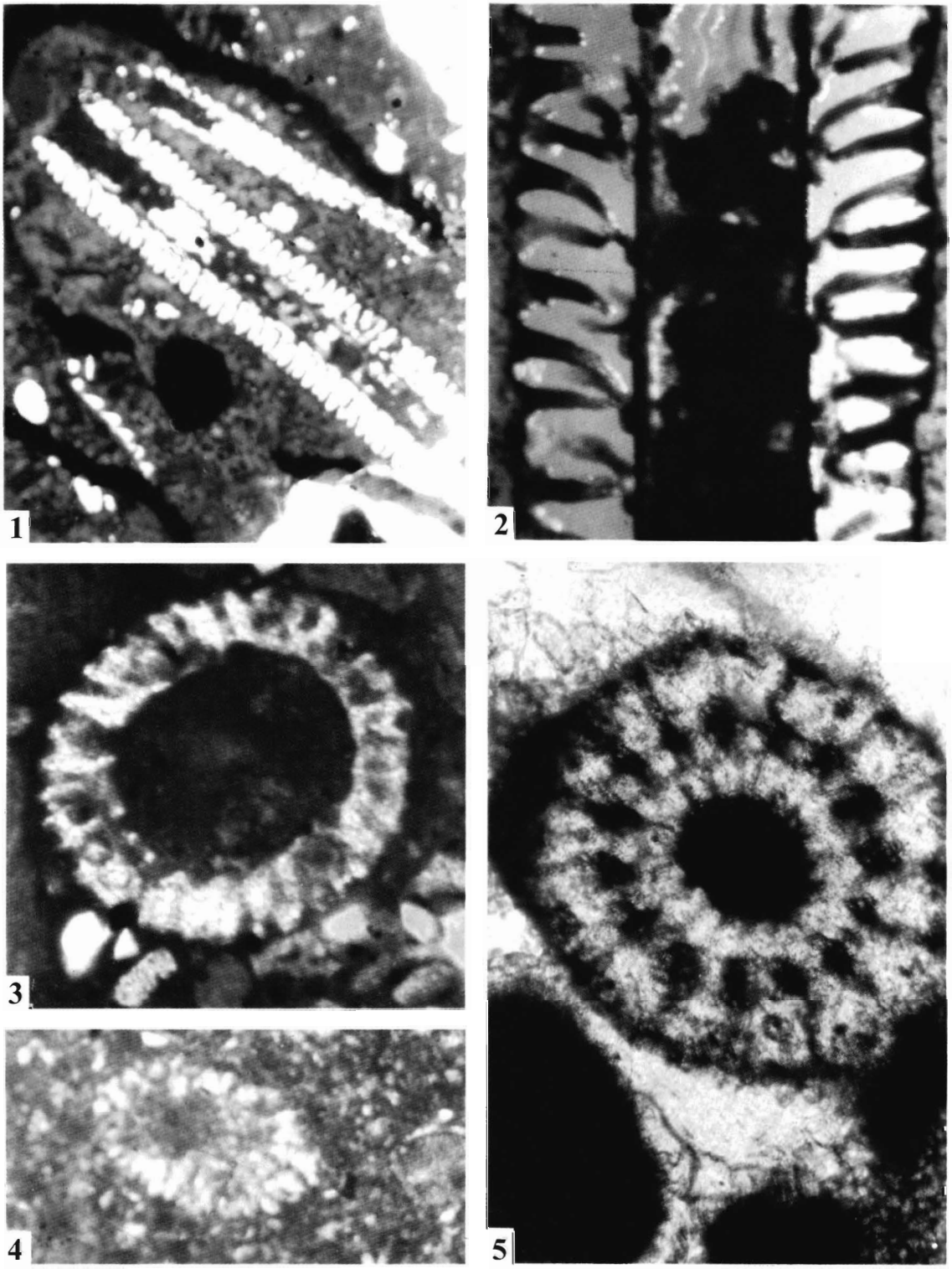
1. *Indopolia satyavanti* Rao & Pia (Sl. No. P/CB-14/MN-33) X 15;
2. *Indopolia satyavanti* Rao & Pia (Sl.No.P/CB-14/MN-33) X 60;
3. *Cymopolia* sp. (Sl. No. S/CB-16/Sen-9) X 70;
4. *Permocalculus* sp. C (Sl. No. P/CB-101/MN-28) X 40;
5. "*Neomeris*" sp. (Sl. No. S/CB-20/Sen-10) X 160.

Plate II

1. Sea urchin spine - Upper Unit (Sl. No. S/CB-175/Sen-6) X 70;
2. *Indopolia satyavanti* Rao & Pia (Sl. No. D/CB-2F) X 110;
3. Sea urchin spine - Upper Unit (Sl. No. S/CB-178/Sen-1) X 35;
4. Sea urchin spine - Lower Unit (Sl. No. D/CB-2F) X 150;
5. *Indopolia satyavanti* Rao & Pia (Sl. No. S/CB-20/Sen-10) X 70

Plate III

1. *Permocalculus* sp. B (Sl. No. P/CB-195/MN-3) X 60;
2. *Indopolia* sp. (Sl. No. S/CB-23/Sen-12) X 70;
3. *Dissocladella* sp. (Sl. No. P/CB-94/MN-18) X 60;
4. *Permocalculus* sp. A (Sl. No. P/CB-94/MN-1) X 60;
5. Sea urchin spine - Lower Unit (Sl. No. D/CB-2F) X 150.



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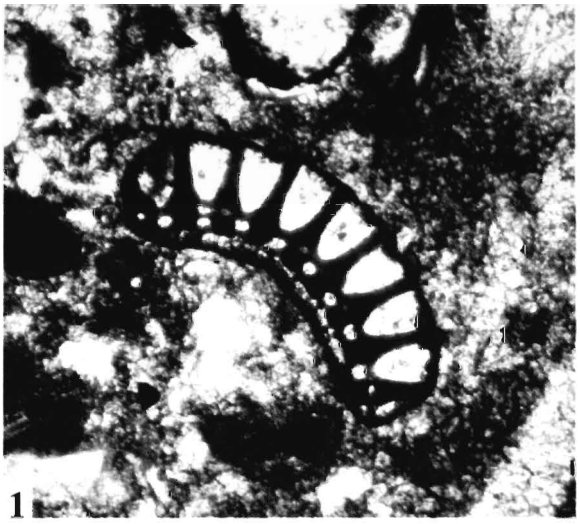
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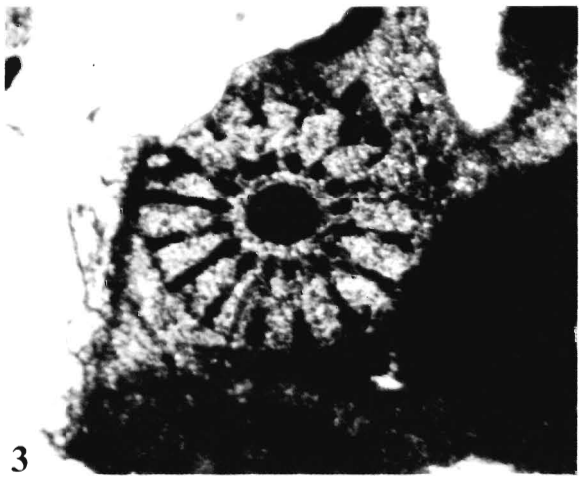
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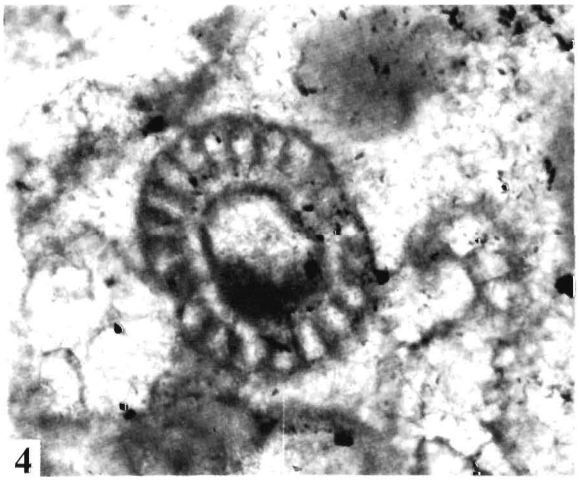
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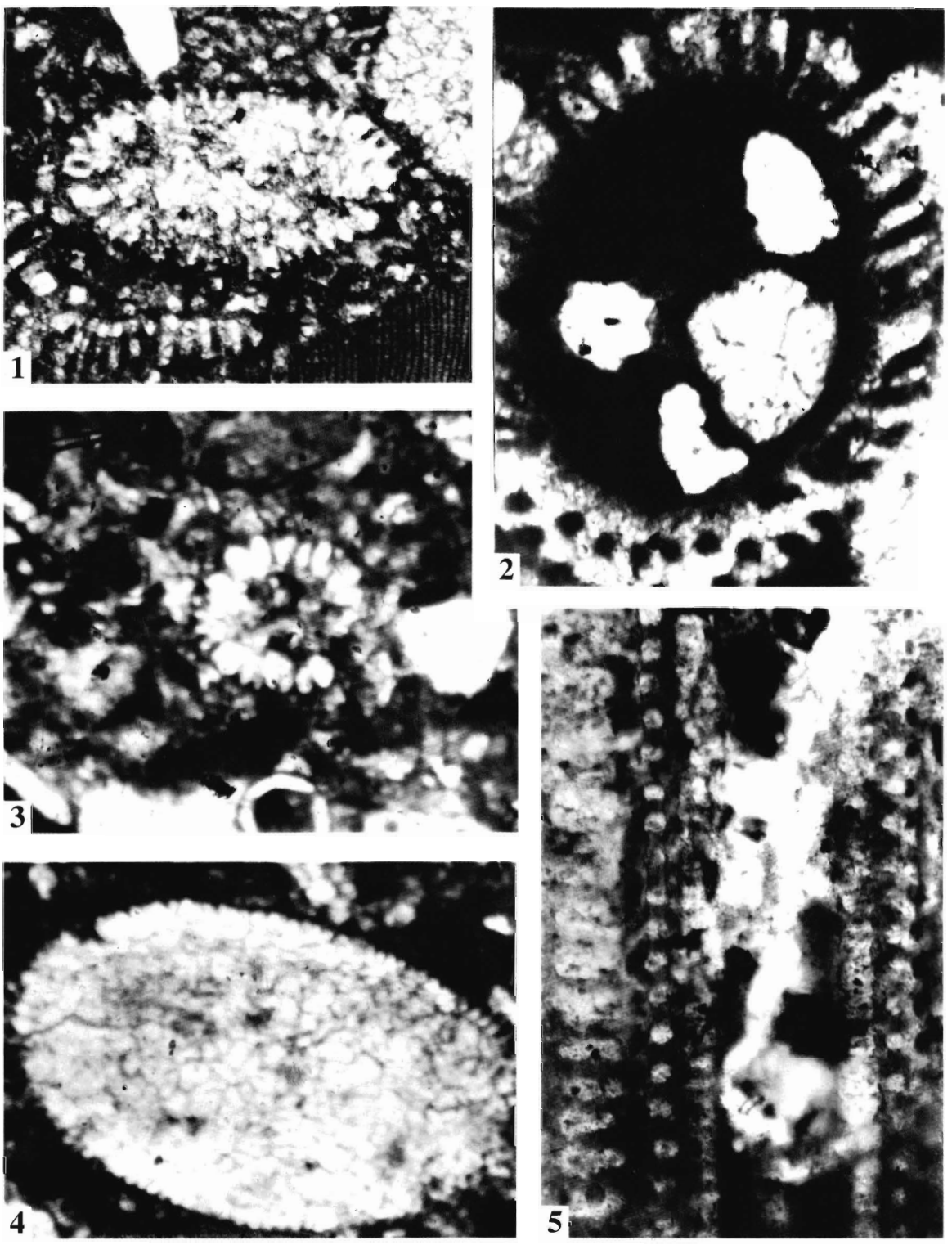

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