

Palaeocene Rhodophycean Algae from the Ninniyur Formation of the Cauvery Basin, southern India

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ABSTRACT

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The sediments of the Ninniyur Formation, Ariyalur are characterised by exceptionally rich assemblages of algae, of which the coralline algae constitute a major component. The present paper documents 32 species of coralline algae, distributed among eleven genera and five unnamed members of sub-family Melobesioideae, from the algal beds of this formation from Ninniyur and the neighbouring areas. An attempt is made to discuss the depositional environment, using actualistic interpretation of the ecological data on the recovered red algae and the associated fossils in conjunction with information on geological aspects gathered from the existing literature. Based on these, it is inferred that the deposits of the Ninniyur Formation were laid down in a transgressing sea within the neritic zone marked by deposition of biogenic accumulations.

Key-words—Rhodophycean algae, Palaeocene, Ninniyur Formation, Cauvery Basin, India.

दक्षिण भारत की कावेरी द्रोणी के निनियूर शैलसमूह से प्राप्त पेलियोसीन युगीन रोडोफाइसी शैवाल
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सारांश

अरियालूर के निनियूर शैलसमूह के अवसाद शैवालों के अत्यधिक सम्पन्न समुच्चयों द्वारा अभिलक्षित हैं, जिनमें प्रवाली शैवालों की प्रधानता है। प्रस्तुत शोध पत्र में प्रवाली शैवालों की उपप्रजातियों का उल्लेख किया गया है, जो निनियूर तथा समीपवर्ती क्षेत्रों के इस शैलसमूह के शैवालीय संस्तरों में ग्यारह वंशों तथा मेलोबीसिआइडी उप कुल के पाँच अनाम सदस्यों के मध्य संवितरित हैं। विद्यमान साहित्य से प्राप्त विभिन्न पारिस्थितिकीय परिप्रेक्ष्यों की सूचना के आलोक में खोजे गए लाल शैवाल तथा सहचारित जीवाश्मों के पारिस्थितिकीय आंकड़ों के वास्तविक निर्वचन की सहायता से निक्षेपणीय पर्यावरण की विवेचना का प्रयास इस शोध पत्र में हुआ है। इनके आधार पर यह अनुमान किया जाता है कि निनियूर शैलसमूह के निक्षेप जीवजनित संचयन के निक्षेपण द्वारा सूचित नेरिटॉचल के भीतर अतिक्रामी समुद्र में शायित थे।

संकेत शब्द—रोडोफाइसी शैवाल, पेलियोसीन, निनियूर शैलसमूह, कावेरी द्रोणी, भारत।

INTRODUCTION

THOUGH carbonate facies is generally poorly developed globally in the Danian successions, the Tiruchirapalli area of the Cauvery Basin has the distinction of preserving some excellent carbonate build-ups of this interval. They are made up mainly of calcareous algae, foraminifera and other organisms which have attracted the attention of the earth scientists for long but have not been studied in sufficient details to make interpretations concerning palaeoenvironment and depositional history. Despite previous efforts of several palaeontologists mentioned below, the taxonomic inventory of the Ninniyur fossil algal forms has largely remained inconclusive and this has resulted in a limited progress of the studies on the stratigraphy and depositional environment of these build-ups. Sustained efforts therefore have to be put in to enlarge the taxonomic database of the algae and the associated fossil forms.

Globally, Johnson (1961-1969), Maslov (1956), Lemoine (1917, 1923, 1939), etc. have given excellent account of Tertiary algae from different parts of world (cf. Wray, 1977). Braga and Martin (1988) have written a field trip guide book on algal reefs in S. Spain. However, in the taxonomy of recent coralline algae some additional vegetative and reproductive characters have been considered significant (Poignant, 1984; Woelkerling, 1988; Braga *et al.*, 1993; Braga & Aguirre, 1995; Aguirre *et al.*, 1996; Rasser & Piller, 1999; Boscence, 1983, 1984, 1991; Bassi 1995a, b, 1997; Basso *et al.*, 1996, 1997). These workers have also revised the previously documented fossil taxa in the light of these taxonomic concepts. Their revision has helped immensely in the understanding of palaeobotanical and palaeogeographical implications of the above thallophytes with respect to their area of occurrence and distribution in various depositional realms.

Rao (1931, 1956, 1958), Rao and Pia (1936) and Varma (1952) described 15 taxa of green and red calcareous algae from the Ninniyur Formation of Tiruchirapalli District. Gowda (1978) mentioned the occurrence of two dasycladeous and two Rhodophycean specimens from the Ninniyur Formation. Three unnamed species belonging to *Sporolithon* (= *Archaeolithothamnium*), *Lithothamnion* and *Mesophyllum* were reported from the Upper Cretaceous of Ariyalur in Tiruchirapalli District by Mamgain *et al.* (1968). Misra and Kumar (1988) described 31 species of Cyanophyceae, Chlorophyceae and Rhodophyceae from the Upper Cretaceous beds of the Varagur area. Rajnikanth (1991) enumerated the calcareous algae from the Ninniyur area of the Cauvery Basin. The ecological implications of Cretaceous-Tertiary algae were discussed by Rajnikanth (1992). Ghosh and Maithy (1995)

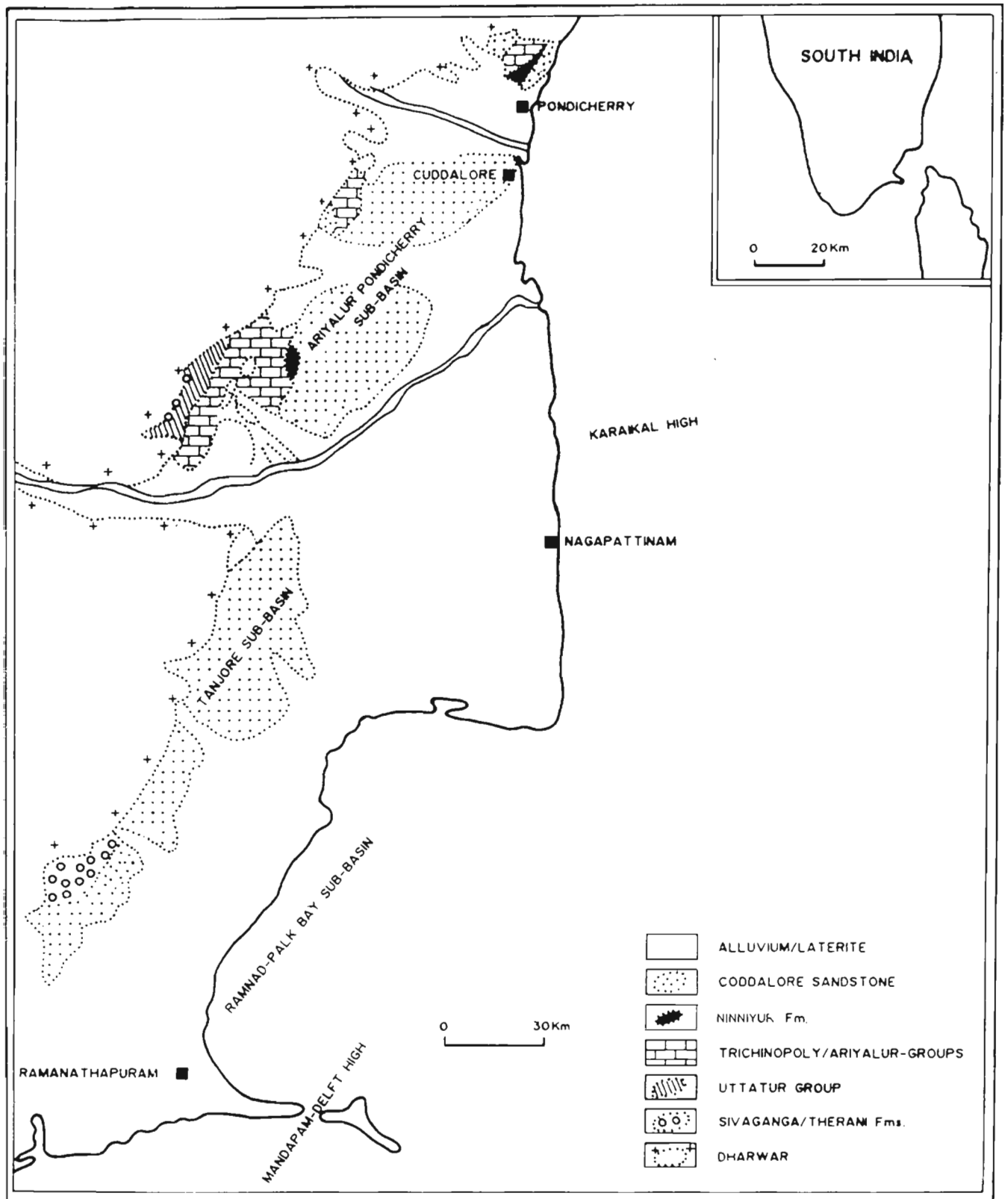
recorded six species of an artificial algal group called the Porostromata from the Cretaceous of Sendurai, Tiruchirapalli District. As the taxonomic contents of these works are based on older morphological criteria, taxonomic observations on the South Indian fossil algal flora need reconsiderations. The present paper is a detailed account of the taxonomic composition of the red algae recovered from the carbonates of the Ninniyur Formation and presents palaeoecological interpretations of the documented taxa and the associated fossil groups in the light of known geological factors.

GEOLOGICAL SETTING

The study area forms a part of the Cauvery Basin which falls in the southernmost portion of the Coromondal shelf regime of India (Fig. 1). The basin, situated 160 to 460 km south of Chennai, covers an area of 25,000 Sq km on land and about 35,000 sq km of the offshore shelf (Gulf of Mannar, Palk Strait and Coromondal Coast between India and Sri Lanka). The basin evolved as a pull-apart basin as a consequence of rifting along the pre-existing fracture zones of eastern continental margin of Indian craton sometime during the Late Jurassic. The basement faults which have given rise to a series of horsts and grabens, trend NE-SW. The grabens and the faulted depressions in the early stages were filled up with the Upper Gondwana sediments. The marine transgression occurred in the Early Cretaceous, initiating a depositional cycle with a paralic environment which was followed by accumulation of dominantly the marine sequences. After the Deccan Trap outpourings, during the early Tertiary, another phase of marine transgression occurred in response to tectonic and oscillatory movements. These resulted in a shift of depocenters to the east during a series of transgressions and regressions in the Cauvery Basin (Kumar, 1983; Govindan *et al.*, 1998; Banerji, 1979; Sastri *et al.*, 1977). The exposed sedimentary sequence includes continental sediments (Sivaganga Formation) overlain by the marine successions of Cretaceous and Palaeocene ages. The latter are followed by the continental deposits referable to the Cuddalore Sandstone which contains lignite deposits at Neyveli.

The part of the basin which includes the study area, has been termed the Ariyalur-Pondicherry Depression. This depression is located in the northern part of the basin and is bounded, on the west, by the granites and gneisses of the Dharwar Supergroup (Archaean) and, on the south-east, by the subsurface ridge, referred to as Kumbhakonam-Shiyali Ridge. The outcrops of the Cretaceous sediments are developed near the western margin of the depression and exhibit facies change from the shelf carbonates near

Fig. 1—The geological map of the Cauvery Basin. The inset shows position of the area in India (after the document VII-Lithostratigraphy of Indian petroliferous basins, Cauvery Basin, 1993 published by O.N.G.C.)



Tiruchirapalli to the shales in the deeper part of the basin. Tertiary sequence is not developed extensively as outcrops but is well represented in the subsurface. During the Tertiary (Palaeocene), extensive carbonate platform environment prevailed because of reduction of clastic supply due to peneplanation of the source area as well as reduced rates of subsidence; in some areas, the fine clastics, however, accumulated alongside the carbonates because of fluctuating conditions of local tectonics (Kumar, 1983).

STRATIGRAPHY

Blanford (1862) was first to study the sedimentary rocks of the Tiruchirapalli area and considered the youngest beds exposed near Sendurai and Ninniyur to be part of the Upper Cretaceous Ariyalur Group. Subsequent work by Rao and Pia (1936) showed that these beds were deposited during an independent transgressive event and hence could be referable to a distinct stratigraphical unit which was designated as the Ninniyur division. Among the subsequent contributions to the stratigraphy of the Tiruchirapalli area, the important ones include Krishnan and Jacob (1959), Banerji (1979), Kumar (1983), Govindan *et al.* (1996), Malarkodi and Nagaraj (1997, 1998) and Govindan *et al.* (1998). Currently, the sequence of fossiliferous marine beds conformably overlying the Kallamedu Formation (Ariyalur Group, Fig. 2) (Upper Cretaceous) is recognised as the Ninniyur Formation. It is well exposed at Sendurai Village (11°15' N : 79°10' E), Adanakkurichchi Village (11°21' N : 79°15' E) and at Periyakurichchi mines (11°17'30" : 79°12') over a NNE-SSW strike between Vellar River in the north and Coleroon River in the south limited between Latitudes 11°08' - 11°22' N and Longitudes 79° 10' - 79° 17' E (Fig. 2).

Fig. 5 gives some stratigraphic details of the Ninniyur Formation. The most distinguishing feature of this formation is its lithology and fossils, especially the rich representation of the fossil algae (Rao, 1958). Three distinct units can be recognised in the Ninniyur Formation: lower fossiliferous limestone; middle subcrystalline shelly limestone; and the upper argillaceous gritty nodular limestone.

The lowermost unit is exposed at Adanakkurichchi mines, hence called the Adanakkurichchi Limestone. It comprises marl, off-white to yellowish limestone which is moderately compact and richly fossiliferous and noted for the rich miliolid assemblage (Malarkodi & Nagaraj, 1997); however, its algal association is poorly developed (Figs 3, 5). The middle unit is

very well exposed at Periyakurichchi and is a dominantly recrystallized, hard, compact, variegated limestone. It is less fossiliferous as compared to the lower unit so far as the mega-invertebrate fossils are concerned; its fauna is largely disintegrated and characterised by the frequently occurring *Hercoglossa danica* Schlotheim along with gastropods, bivalves, ostracods and foraminifers. However, its algal associations are very rich and highly diversified in comparison to that of the lower and upper units (Figs 3, 5). The uppermost unit outcrops at Sendurai Village (about 1.5 km towards Mattur) in a well cutting located near the 1 km milestone on the right side of the main road leading to Adanakkurichchi mines. It is an argillaceous, fine to gritty nodular limestone with nodules ranging in diameter from 2 to 5 cm. It is richly fossiliferous and contains abundant corals, bivalves and gastropods but has less diversified algal association (Figs 3, 5). It is characterised by numerous irregular voids filled with calcite cement. *Cardita beaumonti* Douvillé is the most common fossil of this unit.

The Ninniyur Formation was assigned to the Danian (early Palaeocene) on the basis of *Hercoglossa danica* Schlotheim considered to be characteristic of this stage (Blanford, 1862; Rao & Pia, 1936; Rao, 1956). Subsequent work revealed the presence of planktic foraminifera in the Ninniyur Formation. Sastry *et al.* (1965) suggested an early Palaeocene age for these beds on the basis of *Globorotalia (Truncorotalia) mossae* Hofker. Malarkodi and Nagaraj (1997, 1998), however, document several species of benthic and planktic foraminifera from different 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 *Thalmanntia* which indicate that it ranges from early to late Palaeocene (Danian to Thanetian) in age. The distribution and significance of these microfossils in the chronobiostatigraphic context have been examined by Misra *et al.* (2000). Based on this information, each of the three units of the Ninniyur Formation can be precisely dated.

The lower unit is characterised by *Acarinina spiralis* Bolli, *Morozovella praecursoria* (Morozova) and *Planorotalites chapmani* (Parr); of these, *A. spiralis* is diagnostic of zone P2, i.e., late Danian (Malarkodi & Nagaraj, 1997). The lower unit, on this basis could be considered to be late Danian (early Palaeocene) in age. The age-diagnostic planktic foraminifera of the middle unit are *Acarinina mckannai* (White) and *Planorotalites pseudomenardii* (Bolli).

PLATE 1

- 1-3, 7, 8. *Kymalithon belgicum*.
- 1, 8. Showing isolated sporangia and mature conceptacles. X 75.
- 2, 3. Conceptacles under low magnification. X 55.
- 4, 5. *Sporolithon* sp. 4.
4. Thallus with sporangia.

5. Magnified view of sporangia. X 30.
6. *Lithophyllum* sp. Johnson & Tafur 1952. X 75.
7. Thallus attached on coral.
9. *Solenopora* sp. X 50.

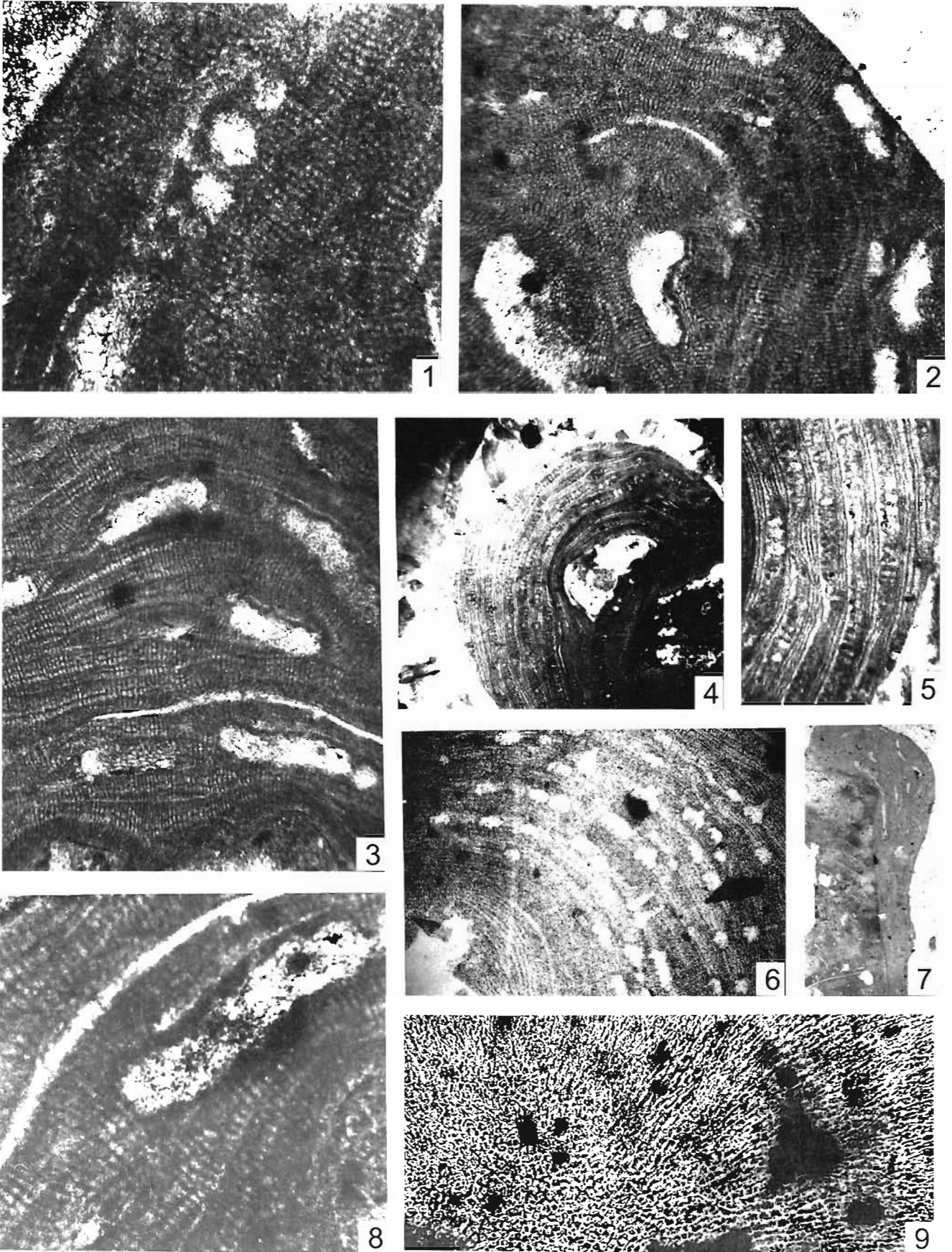


PLATE 1

While *A. mckannai* extends from zone P3 to zone P5, *P. pseudomenardii* is confined to zone P4 (Malarkodi & Nagaraj, 1997). These forms indicate that the middle unit corresponds to zones P3-P4, i.e., Thanetian (late Palaeocene). The upper unit, though marked by the absence of planktic foraminifera, includes some benthic foraminifera, in which *Gavelinella danica*, a Palaeocene marker (Brotzen), is prominent. The upper unit appears to correspond to the Thanetian in view of its position in sequence.

The geological data and sample collections have been made from the following sections.

Adanakkurichchi Section—The lower unit of the Ninniyur Formation is exposed here. However, as compared to its thick subsurface succession, the outcrops are very thin. The studied section exposed at Adanakkurichchi shows a 3-4 m thick sequence of the carbonate rocks with few marly horizons which are characterised by well preserved megafossils (Fig. 5); however, the associated calcareous algae are present only as thin horizontal bands.

Periyakurichchi Section—It represents the middle unit of the Ninniyur Formation and is exposed at Periyakurichchi mines in Ninniyur Village. The measured section is 6-7 m in thickness and comprises subcrystalline to crystalline shelly limestone. The general lithology shows compact, hard limestone at the base which grades into marl beds above. The algal composition of these rocks is rich and varied (Fig. 3).

Mattur Section—This section exposes a sequence which is quite similar to that exposed at the Periyakurichchi mines. However, it is also partly exposed in the well cuttings in and around Ninniyur Village (Fig. 2).

Ninniyur Section—The sequence exposed here is similar to that of the Sendurai Section in general lithology and fossil contents. In this section, the Cuddalore Sandstone overlies the upper unit of the Ninniyur Formation (Fig. 2, 3).

Sendurai Section—This section belongs to the upper unit of the Ninniyur Formation but its exposures are rare and the samples were taken mainly from an unlined well cutting. The exposed surface was only 3.5 to 4.0 m thick. The calcareous algae usually occur as rounded to irregular white patches.

The present investigation has revealed the presence of 32 species grouped under 10 genera of the red alga. The genera recorded in this study are presented in a check-list along with their diagnostic characters. The number of species of these

genera are indicated in parentheses as below : *Parachaetetes* (1), *Solenopora* (1), *Kymalithon* (1), *Sporolithon* (8), *Lithothamnion* (9), *Melobesioideae* gen. et spec. indet (5), *Mesophyllum* (1), *Neogonolithon* (1), *Lithophyllum* (1), *Polystrata* (2), *Thaumatoporella* (1).

All the thin sections and peelings are preserved at the Algalogy Laboratory, Botany Department, University of Lucknow, Lucknow.

SYSTEMATIC DESCRIPTION

Division—RHODOPHYTA Wittstein, 1901

Class—RHODOPHYCEAE Rabenhorst, 1863

Order—CORALLINALES Silva & Johansen, 1986

Family—SOLENOPORACEAE Pia, 1927

Genus—SOLENOPORA Dybowski, 1878

Species—SOLENOPORA sp.

(Pl. 1.9)

Description—Encrusting, nodular masses are common growth forms of this genus. In vertical section, the filaments show radiating walls between them. Septations between cells of filaments are absent. In transverse sections, cells are rounded to polygonal, averaging 30-50 µm in diameter. Reproductive organs not seen.

Sample No.—B/Mt/A3.

Slide No.—M/CB-33.

Locality—Mattur.

Occurrence—Middle Unit, Ninniyur Formation.

Discussion—This genus is known from Cambrian to Miocene. It occurs rarely in the Ninniyur Formation.

Genus—PARACHAETETES Deninger, 1906

PARACHAETETES ASVAPATII Rao & Pia, 1936

(Pl. 3.4; Pl. 4.6; Pl. 6.2, 9)

1936 *Parachaetetes asvapati* Rao & Pia, p. 32, pl. 3, fig. 1.

1982 *Parachaetetes asvapati* Beckmann, p. 138, pl. 15, figs 4-7.

1991 *Parachaetetes asvapati* Kuss & Conrad, p. 877, figs 5.17.

PLATE 2

1. *Sporolithon* sp. 1. X 50.
2. *Sporolithon aschersonii*. X 100.
3. *Sporolithon* sp. 6. X 30.
4. *Sporolithon* sp. 3. X 150.
- 5, 7, 9. *Sporolithon* sp. 7.
5. Thallus with sporangia. X 20.

7. Group of sporangia forming conceptacle-like structure. X 50.
9. Magnified view of conceptacle. X 150.
- 6, 8. *Sporolithon aschersonii*.
6. *Sporolithon aschersonii*. X 150.
8. *Sporolithon aschersonii*. 2 X 50.
10. *Lithothamnion* cf. *caravellense*. X 50.

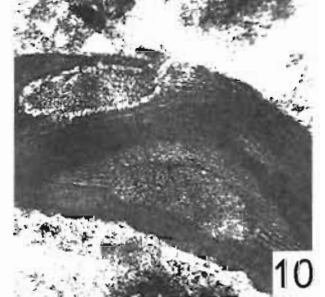
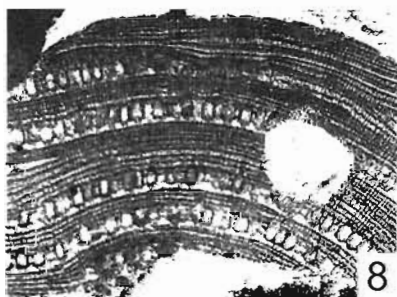
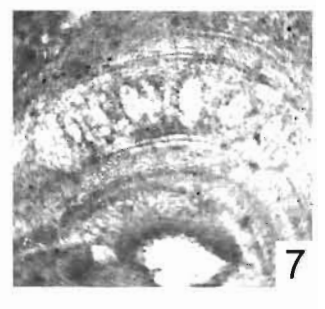
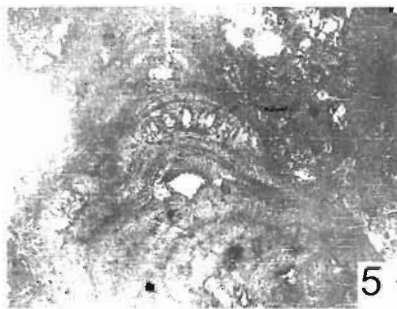
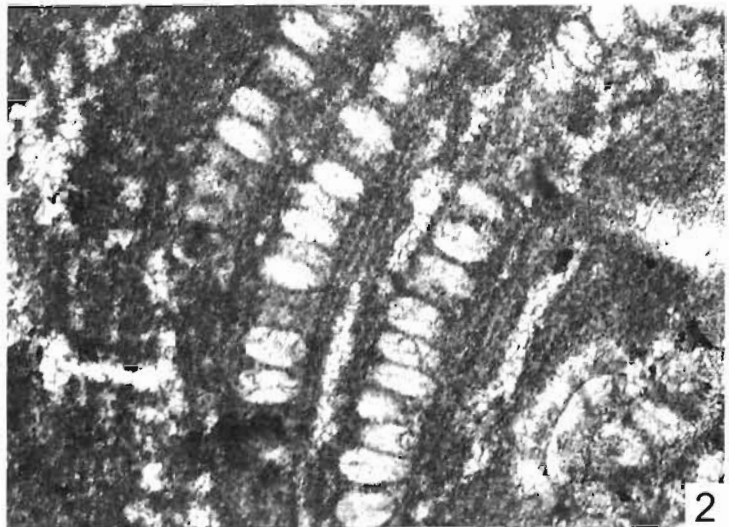


PLATE 2

Description—Thallus encrusting, transparent. Cells are arranged in rows. Cell septations prominent at few places. The diameter of the cells ranges from 40 to 60 μm . The length of the cells vary from 40 to 120 μm .

Sample No.—B/Ad/A3, B2; B/Nn/A4; B/Mt/A15; B/Per/A10, B6; B/Sn/A24, B3, C3.

Slide No.—S/CB- 19, 48, 23, 29.

Locality—Adanakkurichchi, Mattur, Sendurai.

Occurrence—Lower, Middle, Upper Unit, Ninniyur Formation.

Discussion—Rao and Pia (1936) have reported segregated specimens of this species from Ninniyur Village which is very close to Sendurai. In the present work, the fragments are associated with coralline algae. Beckmann *et al.* (1982) recorded this taxon from the Palaeocene of the Monte Giglio, Italy. Kuss and Conrad (1991) reported this species, together with other coralline algae, from the Middle-Late Maastrichtian of the Eastern Desert of Egypt.

Family—SPOROLITHACEAE Verheij, 1993

Genus—*Sporolithon* Heydrich 1897

(=*Archaeolithothamnium* Rothpletz ex Foslie, 1898)

(=*Archaeolithothamnium* Rothpletz ex Foslie 1898)

Archaeolithothamnion Rothpletz 1891;
Archaeolithothamnium Rothpletz 1891 ex Foslie 1898a.
Woelkerling (1988, p. 203, 220). Moussavian and Kuss (1990) and Ghosh and Maithy (1996) treated the genus *Archaeolithothamnium* as synonym of *Sporolithon*.

Species—SPOROLITHON ASCHERSONII (Schwager)
Moussavian & Kuss 1990

(Pl. 2.2, 6, 8)

1990 *Sporolithon aschersonii* Moussavian & Kuss, p. 934, pl. 1, figs 1-5.

1995b *Sporolithon aschersonii* Bassi, p. 14, figs 3-5.

1998a *Sporolithon* cf. *aschersonii* Bassi, p. 20, pl. 8, figs 3-6, pl. 9, figs 1-6.

1998b *Sporolithon aschersonii* Bassi pl. 33, figs 2, 3, 5.

Description—Growth form encrusting, with few protuberances; core filaments generally reduced and poorly preserved; peripheral filaments with small cells. Tetrasporangia cylindrical to club-shaped, densely arranged in a zone, separated by 1-3 sterile filaments (paraphyses); fertile tetrasporangia-bearing areas prominently raised. The cells are generally longer than wide, 8-15 μm in length and 6-12 μm in width. Sporangia 120-130 μm in length and 70-85 μm in width. Sporangia usually arise from a basal layer of elongated cells.

Sample No.—B/Per/A8.

Slide No.—P/ CB-18, 76.

Locality—Periyakurichchi.

Occurrence—Middle Unit, Ninniyur Formation.

Discussion—The present specimens are included in *S. aschersonii* on the basis of thallus morphology and prominently raised tetrasporangia-bearing areas, but in the present specimens they are not clearly delimited. Segonzac (1961) described this species as "*A. aschersonii*" from the Thanetian limestone of Pyrenees. Moussavian and Kuss (1990) found it in the Palaeocene limestones of the eastern and western parts of Egypt. Bassi (1995b, 1998a, b) has reported this species from the Eocene of Northern, Italy.

Sporolithon sp. 1

(Pl. 2.1)

Description—Growth form encrusting. Cells of the peripheral filaments 9-14 μm in length and 8-13 μm in width and cells of core filaments not preserved. Cell fusions indistinct. Sporangial conceptacles arranged in sori. Individual sporangial compartments are rectangular with rounded corners, compactly arranged. They are 50-70 μm in length and 35-45 μm in width. Sporangia usually do not arise from a basal layer of elongated cells.

Sample No.—B/Mt/A27.

Slide No.—M/CB-5.

Locality—Mattur.

Occurrence—Middle Unit, Ninniyur Formation.

Discussion—This specimen resembles *Sporolithon batalleri* Lemoine (c.f. Johnson, J.H., 1964a, p. 208, pl. 1, fig. 1) in shape and size of sporangia. However, sporangia are arranged in sori, while in *S. batalleri* they are segregated.

PLATE 3

- | | | | |
|-------|--|--------|--|
| 1 | <i>Sporolithon</i> sp. 8. X 50. | 7 | <i>Polystrata alba</i> . X 25. |
| 2, 11 | <i>Polystrata alba</i> . X 50. | 8. | <i>Mesophyllum</i> sp. X 25. |
| 3. | <i>Melobesioideae</i> gen. et spec. indet. 5. X 10. | 9, 10. | <i>Lithothamnion</i> sp. 2. |
| 4. | <i>Parachaetetes asvapatii</i> . X 25. | 9. | Magnified view of conceptacle. X 125. |
| 5. | <i>Melobesioideae</i> gen. et spec. indet. 4. X 50 Showing immature conceptacle. | 10. | Fragmentary thallus with conceptacles. X 50. |
| 6. | <i>Sporolithon</i> sp. 5. X 50. Thallus with a row of sporangia. | 12. | <i>Neogonolithon</i> sp. X 25. Conceptacle in perithallus. |
| | | 13. | <i>Sporolithon</i> sp. 3. X 100. Showing branching of thallus. |

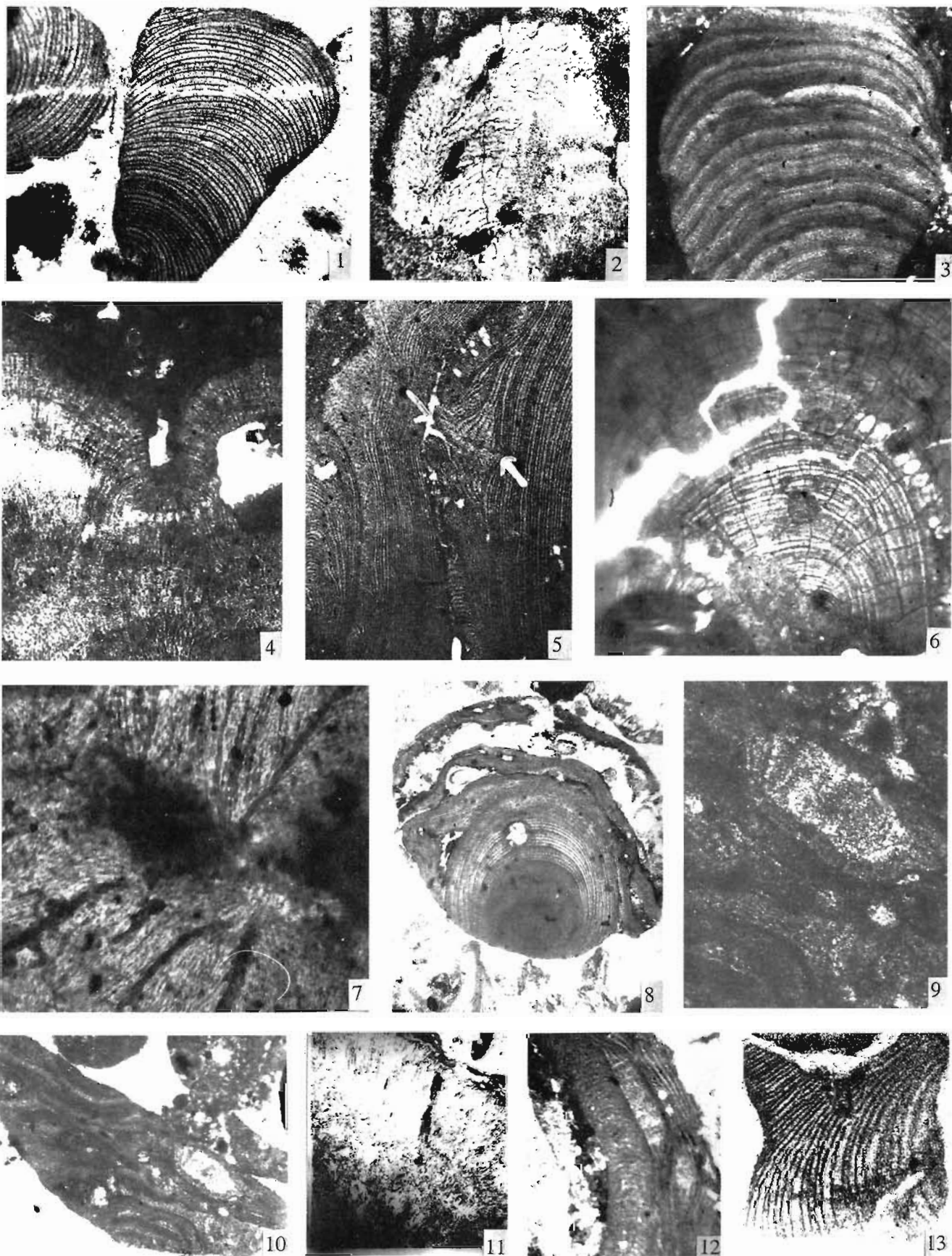


PLATE 3

Sporolithon sp. 2

(Pl. 6.10, 11)

Description—Growth form encrusting to lumpy with short protuberances. Cells of peripheral filaments 15-28 μm in length and 9-12 μm in width. Peripheral filaments regular with thick horizontal partitions forming concentric lines. Filament walls much thinner and not conspicuous. Sporangia arranged in a row, ovoid in shape, 91-108 μm in length and 53-67 μm in width.

Sample No.—B/Ad/B4.

Slide No.—A/CB-69.

Locality—Adanakkurichchi.

Occurrence—Lower Unit, Ninniyur Formation.

Discussion—This species resembles *Sporolithon parisiense* (Gümbel) Lemoine in thallus organisation and shape of sporangia. However, only few sporangia are preserved in our specimen and their outline is not prominent. *Sporolithon parisiense* (Gümbel) Lemoine has been reported by Johnson (1964a) from the Palaeocene beds of Sirwar-Balambo, northern Iraq.

Sporolithon sp. 3

(Pl. 2.4; Pl. 3.13)

Description—Growth form encrusting to lumpy, with thick irregular protuberances or short branches. Core filaments poorly developed or absent. Cells of peripheral filaments are 11-28 μm in length and 8-15 μm in width. Sporangia numerous, normally in well-defined layers or rows, ovoid to spherical in shape, 35-50 μm in diameter, 75-90 μm in height. Sporangia usually arise from a basal layer of elongated cells.

Sample No.—B/Per/A8.

Slide No.—P/CB-76.

Locality—Periyakurichchi.

Occurrence—Middle Unit, Ninniyur Formation.

Discussion—This species is comparable with *Sporolithon nummuliticum* (Gümbel) Rothpletz but differs from the latter in the shape and size of sporangia and cells of peripheral filaments.

Sporolithon sp. 4

(Pl. 1.4, 5)

Description—Growth form encrusting. Peripheral filaments are arranged in regular cell rows and horizontal cell walls are more distinct than vertical ones. The peripheral

filaments have cell dimensions of 10-24 μm in length and 6-8 μm in width. Several concentric rows of sporangia may occur within one thallus and usually they arise from a basal layer of elongated cells. Sporangia are relatively small and narrow, ovoid to oblong, 40-64 μm in length 24-32 μm in diameter.

Sample No.—B/Per/A21.

Slide No.—P/CB-7.

Locality—Periyakurichchi.

Occurrence—Middle Unit, Ninniyur Formation.

Discussion—This algal specimen is comparable with *Sporolithon nongsteinense* Sripada Rao in arrangement and morphology of sporangia. Beckmann *et al.* (1982) reported *Sporolithon nongsteinense* Sripada Rao from the Palaeocene of Monte Giglio, Italy.

Sporolithon sp. 5

(Pl. 3.6)

Description—Growth form encrusting. Core filaments poorly developed and badly preserved. Peripheral filaments fairly regular in some areas, but showing alternate layers of long and short cells in some portions. Horizontal cell walls are more distinct than vertical ones. Cells are 12-14 μm in length and 6-10 μm in width. Sporangia in groups, tightly packed in irregular rows, measuring 75-90 μm in length and 45-60 μm in diameter. Sporangia does not arise from the basal layer of elongated cells.

Sample No.—B/Per/A17.

Slide No.—P/CB-70.

Locality—Periyakurichchi.

Occurrence—Middle Unit, Ninniyur Formation.

Discussion—The present specimen differs from *Sporolithon* sp. 3 and other species of the genus mainly in the sporangia not originating from the basal layer of thallus. Though broadly similar to *Sporolithon cyrenaicum* Raineri in shape, size and arrangement of its cells and sporangia, this specimen has slightly larger sporangia. Johnson (1964b) reported *S. cyrenaicum* from the Miocene of Lailuk, northern Iraq.

Sporolithon sp. 6

(Pl. 2.3)

Description—Growth form encrusting. Cells of core filaments not measurable due to bad preservation, peripheral filaments with cells 8-11 μm in length and 12-18 μm in width.

PLATE 4

1. *Lithothamnion mannii*. X 125.
2. *Lithothamnion florabracca*. X 35.
3, 5, 7, 8, 9. *Lithothamnion andrusovi*.
3, 7. X 50.

- 5, 8, 9. X 125.
4. *Lithothamnion* sp. 3. X 30.
6. *Parachaetetes asvapatii*. X 15.

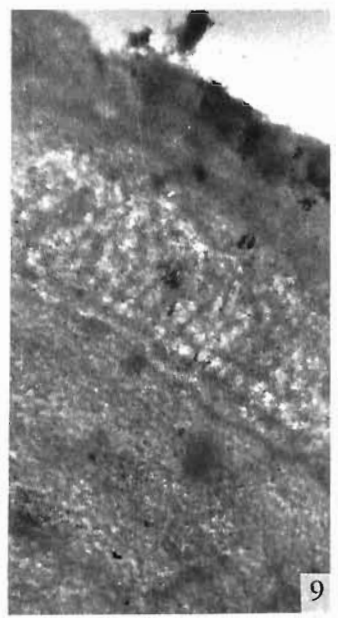
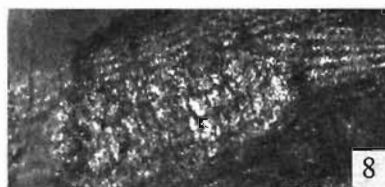
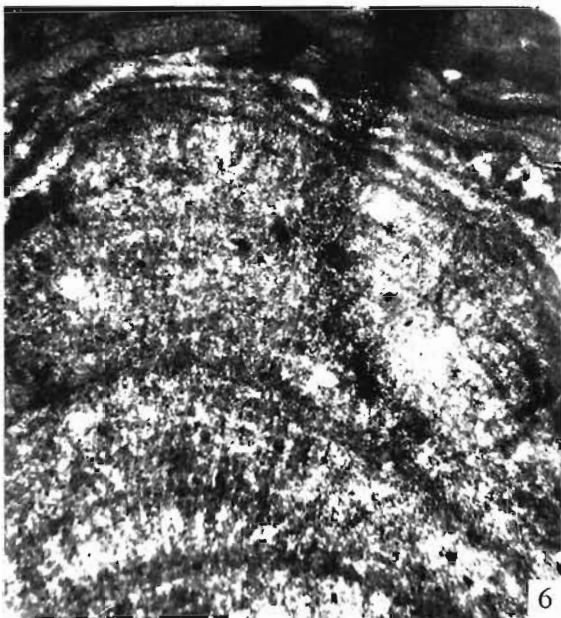
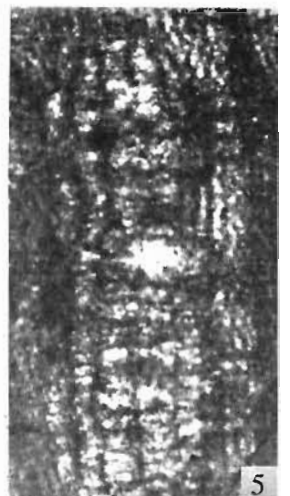
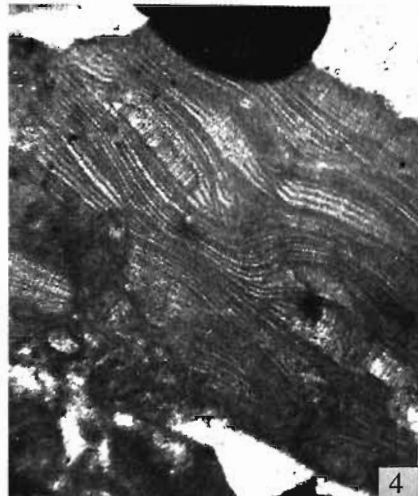
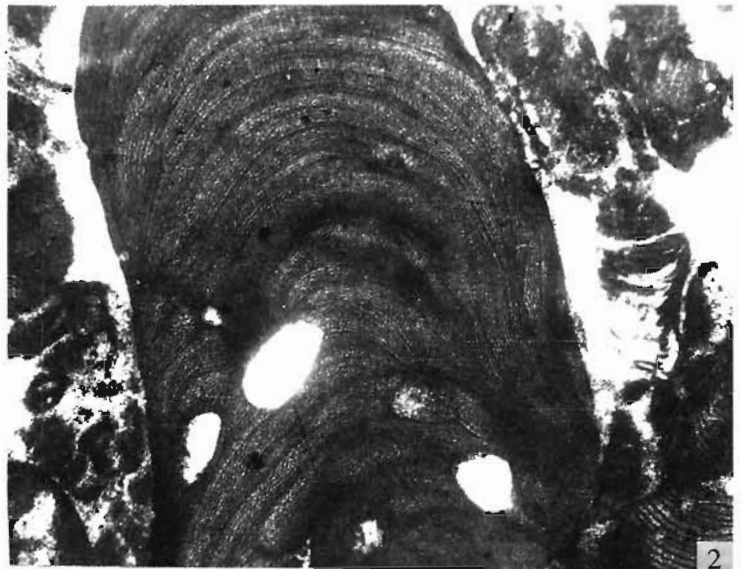


PLATE 4

with rows of oval to elliptical sporangia, 45-50 μm in length and 25-35 μm in diameter.

Sample No.—B/Mt/A5.

Slide No.—M/CB-8.

Locality—Mattur.

Occurrence—Middle Unit, Ninniyur Formation.

Discussion—Only one specimen of this species was found and could not be compared with any known species of the genus *Sporolithon* Heydrich.

Sporolithon sp. 7

(Pl. 2.5, 7, 9)

Description—Growth form encrusting to lumpy with small protuberances of different shapes. Peripheral filaments with concentric growth zones. Peripheral cells 8-12 μm in length and 10-15 μm in width. Core filaments poorly preserved. Sporangia arranged in saucer-shaped clusters (each 40-60 μm in diameter and 90-120 μm in height).

Sample No.—B/Sn/B3.

Slide No.—S/CB- 25.

Locality—Sendurai.

Occurrence—Middle Unit, Ninniyur Formation.

Discussion—The saucer-shaped grouping of sporangia initially appears to be a conceptacle but there is no definite outline of the conceptacle wall and the sporangia are clearly separated from each other. This specimen does not match with any of the known species of the genus *Sporolithon* Heydrich.

Sporolithon sp. 8

(Pl. 3.1)

Description—Thallus encrusting, with curved rows of cells of peripheral filaments. Cells 12-15 μm in length and 8-10 μm in width. Sporangia not preserved.

Sample No.—B/Sn/B6.

Slide No.—S/CB- 59.

Locality—Sendurai.

Occurrence—Upper Unit, Ninniyur Formation.

Discussion—This specimen has narrow-elongated cells. The cells of peripheral filaments resemble that of other species of this genus, but it lacks sporangia, hence the specific identification is not possible.

Family—CORALLINACEAE Lamouroux, 1812

Genus—KYMALITHON Lemoine & Emberger, 1967

KYMALITHON BELGICUM Lemoine & Emberger, 1967

(Pl. 1.1, 2, 3, 7, 8)

1967 *Kymalithon belgicum* Lemoine & Emberger, p. 1-11, pl. 4.

1969 *Kymalithon belgicum* Johnson, p. 10, pl. 6, figs 1-3, pl. 23, figs 1-2, pl. 24, figs 1-2.

Description—Growth form encrusting, thickness of encrusting thalli up to 5.25 mm. Thallus organisation monomerous. Core filaments non-coaxial, core portion 75 μm thick. Cells 16-22 μm in length and 10-15 μm in width. The cells of the peripheral region 20-30 μm long and 12-18 μm wide; cell fusions present. Tetra/bisporangia present in small groups within the outer part of peripheral tissue. At places, sporangia unite to form flat, rectangular conceptacles which are multiporate and contain rounded sporangia in small clusters. Conceptacles 140-160 μm in height and 330-460 μm in diameter.

Sample No.—B/Sn/C3.

Slide No.—S/CB- 6.

Locality—Sendurai.

Occurrence—Upper Unit, Ninniyur Formation.

Discussion—The south Indian specimens are referable to *K. belgicum* Johnson (1969), and Lemoine and Emberger (1967) reported this species from the Lower Cretaceous (Aptian) of Guatemala. The present record of this species from the Palaeocene indicates its probable extension up to early Tertiary period. In the present specimen, sporangial initials develop as a small group and later unite to form a multipored conceptacle. Hence, it differs from the genus *Lithothamnion* and is being referred to *Kymalithon* Lemoine & Emberger.

Subfamily—MELOBESIOIDEAE Bizzozero, 1885

Genus—LITHOTHAMNION Heydrich 1897

Species—LITHOTHAMNION FLOREABRASSICA (Millet) Lemoine 1923

(Pl. 4.2)

1923 *Lithothamnion floreabrassica* Lemoine, 1924, p. 184, fig. 5.

PLATE 5

- | | |
|---|---|
| 1, 2. <i>Melobesioideae</i> gen. et spec. indet. 3. X 50. Vegetative thallus. | 5, 8. <i>Lithothamnion orbiculatum</i> conceptacle with tetrasporangia X 125. |
| 3, 7. <i>Melobesioideae</i> gen. et spec. indet. 2. X 100. | 8. Strap-shaped thallus. X 25. |
| 7. X 30. | 6, 9. <i>Lithothamnion wallisium</i> . X 150. |
| 4. <i>Lithothamnion</i> sp. 3. X 40. Immature conceptacle in peripheral. | 9. <i>Lithothamnion wallisium</i> . X 50. |

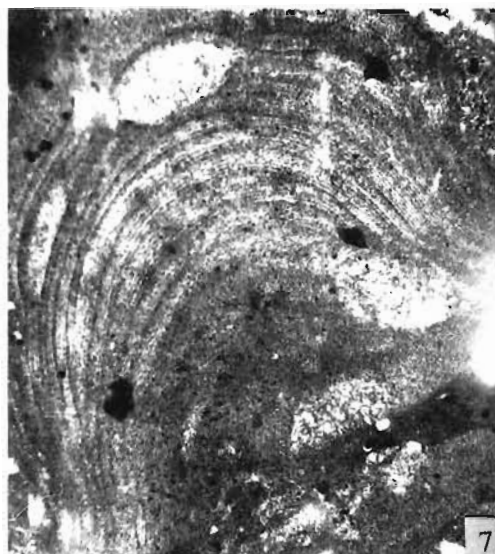
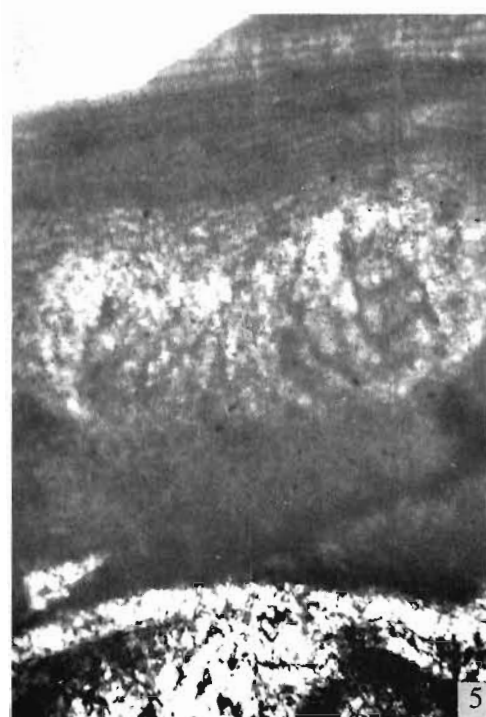
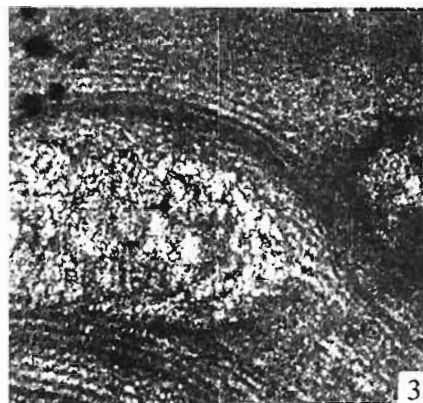
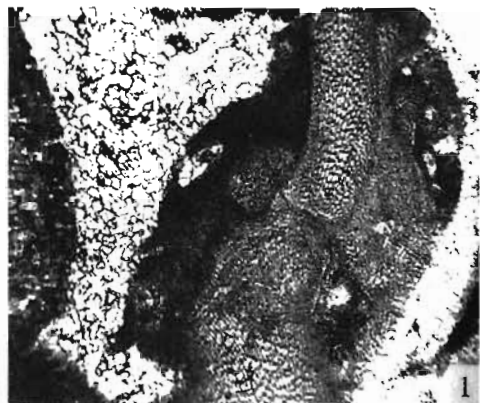


PLATE 5

Description—Growth form encrusting to warty. Thallus organisation monomerous. Core filaments non-coaxial, core portion usually 80-100 μm thick, filaments curved towards the dorsal surface. Filaments show strong irregular growth zones, with a more or less layered structure. Cell size may vary from zone to zone. Cells 14-23 μm in length and 8-14 μm in diameter. Tetra/bisporangial conceptacles 325-375 μm in diameter and 153-225 μm in height.

Sample No.—B/Nn/A14.

Slide No.—N/CB-53.

Locality—Ninniyur.

Occurrence—Middle Unit, Ninniyur Formation.

Discussion—At few places, the conceptacles appear to be multiporate but pores are not prominent. However, this specimen agrees well with *L. floreabrassica* (Millet) Lemoine in general shape and size.

LITHOTHAMNION MANNI Johnson & Stewart 1953

(Pl. 4.1; Pl. 6.8)

1953 *Lithothamnion manni* Johnson & Stewart, p.133, pl. 15, fig. 4.

1982 *Lithothamnion manni* Beckmann, p. 134, pl. 11, figs 9, 10, 11.

Description—Growth form encrusting, thallus thickness about 870 μm . Thallus organisation monomerous. Core filaments non-coaxial about 105 μm in thickness, with cells 10-15 μm in length and 8-12 μm in width. Peripheral region with cells 8-12 μm in length and 6-10 μm in width. Cell fusions present. Tetra/bisporangia conceptacles multiporate, 190-205 μm in height and 350-375 μm in width.

Sample No.—B/Per/A26.

Slide No.—P/CB-76.

Locality—Periyakurichchi.

Occurrence—Middle Unit, Ninniyur Formation.

Discussion—This specimen differs from *L. floreabrassica* (Millet) Lemoine in the encrusting nature of the growth form and obovoid conceptacles. Thallus organisation and conceptacle morphology of these specimens show resemblance to *L. manni*. Conceptacles in the present specimens are slightly broader than in the type recorded by Beckmann *et al.* (1982) from the Palaeocene of Monte Giglio, Italy; but their size is similar to that reported by Johnson &

Stewart (1953) from the Eocene beds of the Meganos Formation, California.

LITHOTHAMNION ANDRUSOVI Lemoine 1934

(Pl. 4.3, 5, 7, 8, 9)

1934 *Lithothamnion andrusovi* Lemoine, p. 274, fig. 2.

Description—Growth form encrusting to warty. Thallus organisation monomerous. Core filaments non-coaxial, core portion 150-180 μm thick. Cells 10-15 μm in length and 5-12 μm in diameter. Filaments of peripheral region thick, compact, with small cells (8-10 μm in length and 4-7 μm in width). Tetra/bisporangial conceptacles multiporate, 360-450 μm wide and 140-180 μm high.

Sample No.—B/M/A27.

Slide No.—M/CB-68.

Locality—Mattur.

Occurrence—Middle Unit, Ninniyur Formation.

Discussion—The south Indian specimen is referable to *L. andrusovi* Lemoine reported from the Palaeocene to Middle Eocene of Massif of Akros, Massif of Mavrovouni, Massif of Klokova and Massif of Lapithos, Greece (Johnson, 1965). It is also comparable to *Lithothamnion wallisium* (Johnson & Stewart, 1953, p. 134, pl. 16, fig. 1) in general shape, irregular growth zones and arrangement of conceptacles, but the latter can be distinguished by small protuberances and smaller and somewhat oblong conceptacles.

LITHOTHAMNION ORBICULATUM Krivanne Hutter

1961

(Pl. 5.5, 8)

1961 *Lithothamnion orbiculatum* Krivanne Hutter XCI, 4, 432-441.

1989 *Lithothamnion orbiculatum* Bucur, *et al.*, p. 144, pl. 2, figs 5-8.

Description—Growth form encrusting, thallus thickness about 2.1 mm. Thallus organisation monomerous. Core filaments non-coaxial, about 180 μm in thickness, with cells 10-14 μm in length and 8-12 μm in width. Peripheral region with cells 8-12 μm in length and 6-9 μm in width. Cell fusions present. Conceptacles multiporate, 200-240 μm in height and 440-495 μm in width. All conceptacles are buried in the thallus. Conceptacles sunken and elongated with rounded margins,

PLATE 6

- | | | | |
|-------|--|---------|---|
| 1 | <i>Melobesioideae</i> gen. et spec. indet. 1. X 50. | 5. | <i>Thaumatoporella incrustata</i> X 50. Front view. |
| 2, 9. | <i>Parachaetetes asvapatii</i> . X 15. | 6. | <i>Thaumatoporella incrustata</i> X 50. Side view. |
| 9 | X 25. | 8. | <i>Lithothamnion manni</i> . X 50. |
| 3, 7. | <i>Lithothamnion</i> sp. 1. Enlarged view of conceptacles. X 50. | 10, 11. | <i>Sporolithon</i> sp. 3. X 50 |
| 7. | Thallus with coaxial hypothallus and conceptacles. X 15. | 10. | Thallus showing branching and sporangia. X 100. |
| 4. | <i>Polystrata</i> sp. X 50. | | |

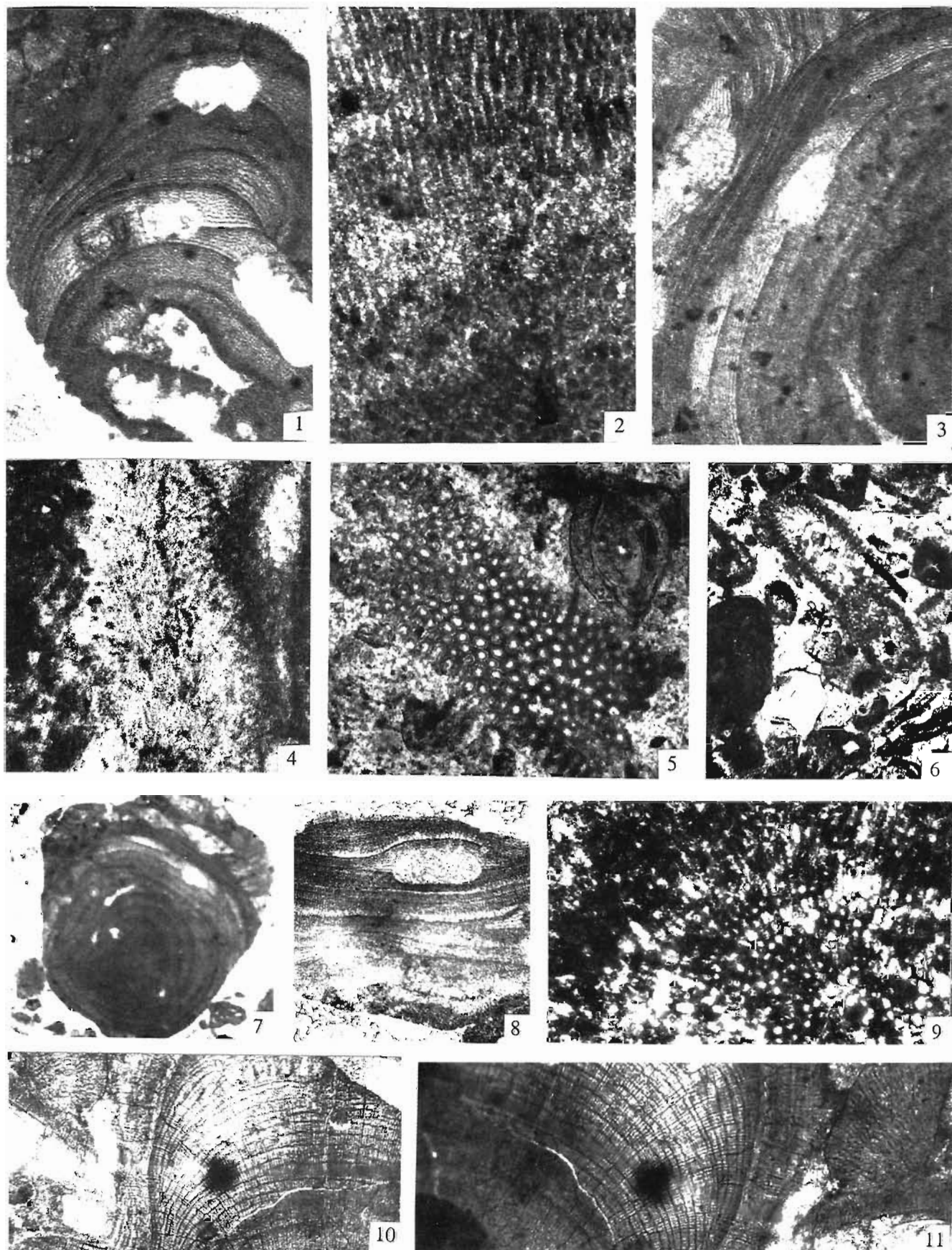


PLATE 6

apparently bisporangiate/tetrasporangiate, each with four tetraspores.

Sample No.—B/Sn/C4.

Slide No.—S/CB-1.

Locality—Sendurai.

Occurrence—Upper Unit, Ninniyur Formation.

Discussion—The present specimen is comparable with *L. orbiculatum* Krivanne on the basis of morphology and conceptacles. However, in the present specimen conceptacles possess zonated tetra/bisporangia, each probably with four tetraspores. However, in the Krivanne's species sporangia have not been reported.

LITHOTHAMNION WALLISIUM Johnson & Tafur
1952

(Pl. 5.6, 9)

1952 *Lithothamnion wallisium* Johnson & Tafur, p. 538, pl. 62, fig. 3.

1953 *Lithothamnion wallisium* Johnson & Stewart, p. 143, pl. 16, fig. 1.

1982 *Lithothamnion wallisium* Beckmann *et al.*, p. 134, pl. 12, figs 3-4.

Description—Growth form encrusting with variable thickness. Thallus organisation monomerous. Core filaments non-coaxial, parallel to the surface, core portion usually 60-110 μm thick, with cells of 10-25 μm in length and 6-10 μm in diameter. The peripheral filaments is distinct but irregularly zoned; its cells are 7-15 μm in length 6-9 μm in diameter. The conceptacles occur in irregular clusters; more or less reniform and measure 185-250 μm in width and 140 μm in height.

Sample No.—B/Per/A11.

Slide No.—P/CB-65.

Locality—Periyakurichchi.

Occurrence—Middle Unit, Ninniyur Formation.

Discussion—The present specimens appear to be identical with the type species in filament organisation and shape of conceptacles, though the type specimens from California and those described from northwestern Peru (Johnson & Tafur, 1952; Johnson & Stewart, 1953) have larger conceptacles. Beckmann *et al.* (1982) reported this species from the Palaeocene of Monte Giglio, Italy.

LITHOTHAMNION CF. L. CARAVELLENSE Lemoine
1939

(Pl. 2.10)

1939 *Lithothamnion cf. L. caravellense* Lemoine, p. 68-69.

1965 *Lithothamnion cf. L. caravellense* Johnson & Kaska, p. 27, pl. 39, figs 2-3.

Description—Growth form encrusting, thallus thickness about 870 μm . Thallus organisation monomerous. Core filaments non-coaxial, about 105 μm in thickness, with cells 8-15 μm in length and 8-12 μm in width. Peripheral region thicker than the core region, with prominent growth zones having cells 12 μm in length and 10 μm in width. Tetra/bisporangia conceptacles apparently multiporate, obovoid to reniform chambers, 410-450 μm in diameter and 140-150 μm in height.

Sample No.—B/Per/B19.

Slide No.—P/CB-36.

Locality—Periyakurichchi.

Occurrence—Middle Unit, Ninniyur Formation.

Discussion—Though broadly similar to *Lithothamnion cf. L. caravellense* reported from the Miocene of Guatemala by Johnson and Kaska (1965), the present specimens have slightly larger conceptacles than those of the Miocene specimens. Moreover, the multipored roof of the conceptacle in the present specimens is indistinct; it is, therefore, presently described as *Lithothamnion cf. L. caravellense* Lemoine.

LITHOTHAMNION sp. 1

(Pl. 6.3, 7)

Description—Growth form encrusting to lumpy. Thallus organisation monomerous. Core filaments not preserved. It is surrounded by the peripheral filaments, whose cells are arranged in layers parallel to the surface and are 25 μm in length and 18 μm in diameter. Tetra/bisporangia conceptacles, usually present in protuberances, and 212-230 μm long and 136-145 μm wide.

Sample No.—B/Nn/A13.

Slide No.—N/CB-8.

Locality—Ninniyur.

Occurrence—Middle Unit, Ninniyur Formation.

Discussion—The growth form and thallus organisation of this specimen resembles that of *L. valens* Foslie as described by Basso *et al.* (1997) who have given a detailed account of morphotaxonomy of *L. valens* and *L. ramosissimum* (Gümbel non Reuss) Conti, 1946.

LITHOTHAMNION sp. 2

(Pl. 3.9, 10)

Description—Growth form encrusting. Core filaments non-coaxial, core portion 70-120 μm thick and has cell dimensions 10-15 μm in length and 8-10 μm in diameter. Cells of peripheral filaments not measurable due to bad preservation of filaments. Conceptacles more or less rectangular or box shaped, pore indistinct, 280-310 μm wide, 110-125 μm high. Sporangia not preserved.

Sample No.—B/Per/B15.

Slide No.—P/CB-21.

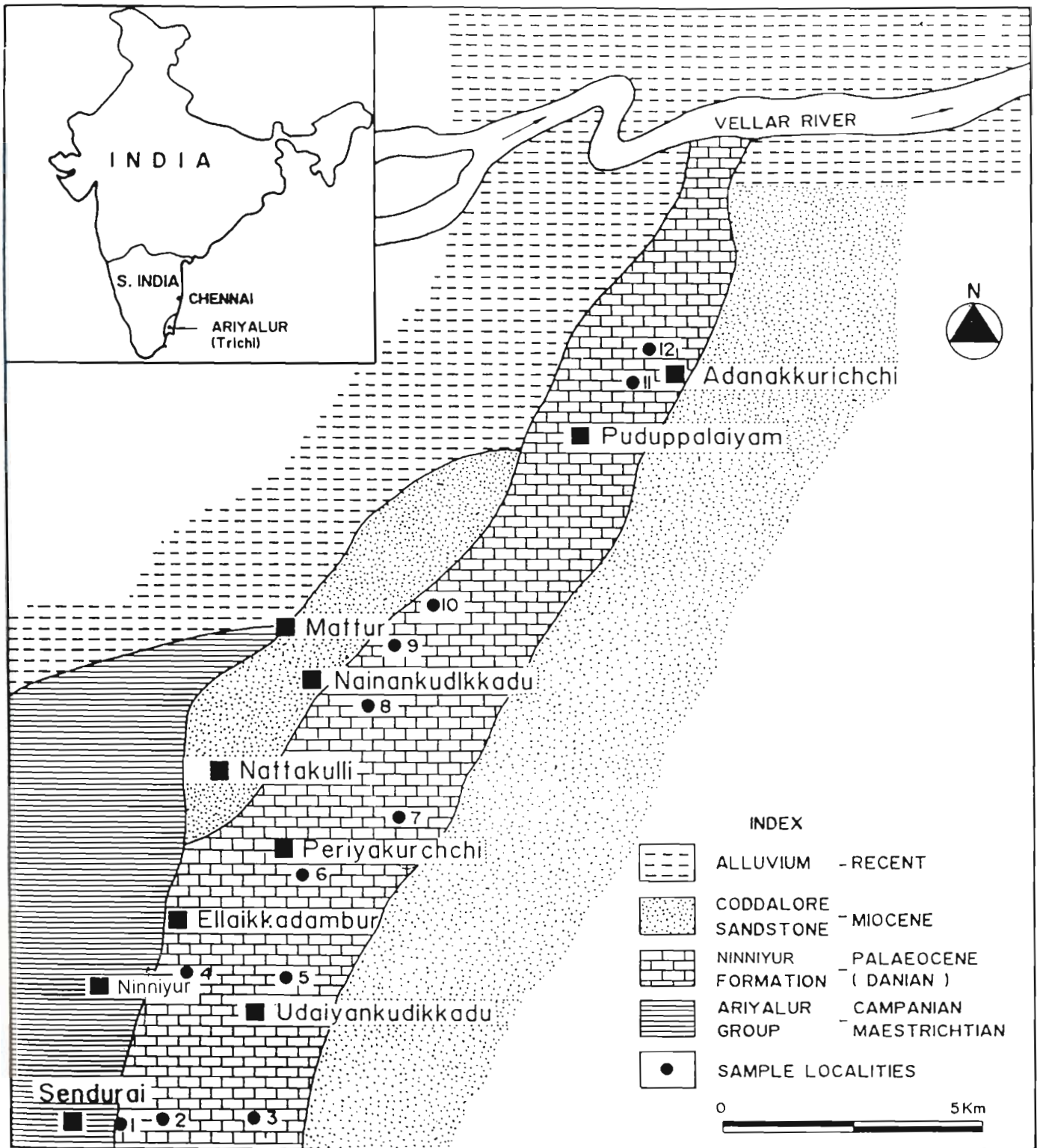


Fig. 2—The geological map of the Ninniyur area, Cauvery Basin, Tamil Nadu (modified after Malarkodi & Nagaraj, 1997).

Locality—Periyakurichchi.

Occurrence—Middle Unit, Ninniyur Formation.

Discussion—This species differs from the *Lithothamnion wallisium* Johnson and Tafur in shape and size of conceptacles. It does not show presence of sporangia. The morphological variation of conceptacles may be due to sectioning of thallus through different planes; but bands of thallus are distinct and the shape of conceptacles appears to be definite.

LITHOTHAMNION sp. 3

(Pl. 4.4; Pl. 5.4)

Description—Growth form encrusting. Thallus organisation monomerous. Core filament non-coaxial, core portion usually 0.16 mm thick, cell fusions occur. Cell tissues 12-20 μm in length and 7-10 μm in width. Peripheral cells rectangular or squarish, distinct, arranged in somewhat undulating rows, about 12-14 in length and 6-10 μm in width. In the peripheral region, the horizontal walls are more distinct than the vertical ones. Conceptacles immature, showing various developmental stages, sunken, 160-210 μm wide, 70-100 μm high.

Sample No.—B/Per/A30.

Slide No.—P/CB-52.

Locality—Periyakurichchi.

Occurrence—Middle Unit, Ninniyur Formation.

Discussion—This specimen is comparable with *Palaeothamnium archaeotypum* Conti in the immature conceptacles. Basso *et al.* (1997) reported morphologically similar specimens from the Miocene of Leithakalk and assigned them to *Palaeothamnium archaeotypum* on the basis of developmental stages of conceptacles. Aguirre *et al.* (1996) and Basso (1997) recommended that identification of different species of the genus *Palaeothamnium* Conti be made not only on the basis of developmental stages of conceptacles but also on the growth form, flat epithallial cells, long subepithallial initials and peripheral region. However, the majority of the workers still give due importance to the developmental stages of conceptacles (c.f. Moussavian, 1991). Aguirre *et al.* (1996) have considered the genus *Palaeothamnium* Conti as the younger heterotypic synonym of the genus *Lithothamnion* Heydrich. Hence, the Ninniyur specimen is being considered here under the genus *Lithothamnion*.

Subfamily—MELOBESIOIDEAE Bizzozero, 1885

MELOBESIOIDEAE gen. et spec. indet. 1

(Pl. 6.1)

Description—Growth form encrusting. Thallus organisation monomerous. Core filaments non-coaxial, core portion usually 140-180 μm thick, filaments curved towards the dorsal surface. Cells 13-20 μm in length and 9-17 μm in width. The peripheral filaments consist of irregular zones composed of rectangular cells. The cells measure 25-32 μm in length and 7-10 μm in width. Numerous large conceptacles occur irregularly through the tissue. They are 300 μm in width and 150 μm in height. The roof is pierced by numerous openings.

Sample No.—B/Per/B16.

Slide No.—P/CB-43.

Locality—Periyakurichchi.

Occurrence—Middle Unit, Ninniyur Formation.

Discussion—The core filaments of this specimen are non-coaxial and epithallial cells are not preserved. Hence, it can be referred either to the genus *Lithothamnion* or to the genus *Phymatolithon*. The taxonomic concept of this form is based on the work of Rasser and Piller (1999) from the Austrian Molasse zone.

MELOBESIOIDEAE gen. et spec. indet. 2

(Pl. 5.3, 7)

Description—Growth form encrusting, with short, slender protuberances. Thallus organisation monomerous. Ventral core filaments poorly developed, non-coaxial, core portion usually 100-140 μm thick, filaments curved towards the dorsal surface. Cells rectangular, measuring 15 μm in length and 12 μm in width. Conceptacles large and prominent, measuring 440-570 μm in diameter and 190-285 μm in height. Roof apparently multiporate.

Sample No.—B/Per/A30.

Slide No.—P/CB-52.

Locality—Periyakurichchi.

Occurrence—Middle Unit, Ninniyur Formation.

Discussion—The core filaments of this specimen are non-coaxial and epithallial cells are not preserved. Hence, it can be referred either to the genus *Lithothamnion* or to the genus *Phymatolithon*. The taxonomic concept of this form is based on the work of Rasser and Piller (1999) from the Austrian Molasse zone.

MELOBESIOIDEAE gen. et spec. indet. 3

(Pl. 5.1, 2)

Description—Growth form encrusting, which maintains a fairly constant thickness. Thallus organisation monomerous. Core filaments non-coaxial, 160-250 μm in thickness, with cells 18-24 μm in length and 6-12 μm in width, cell fusions

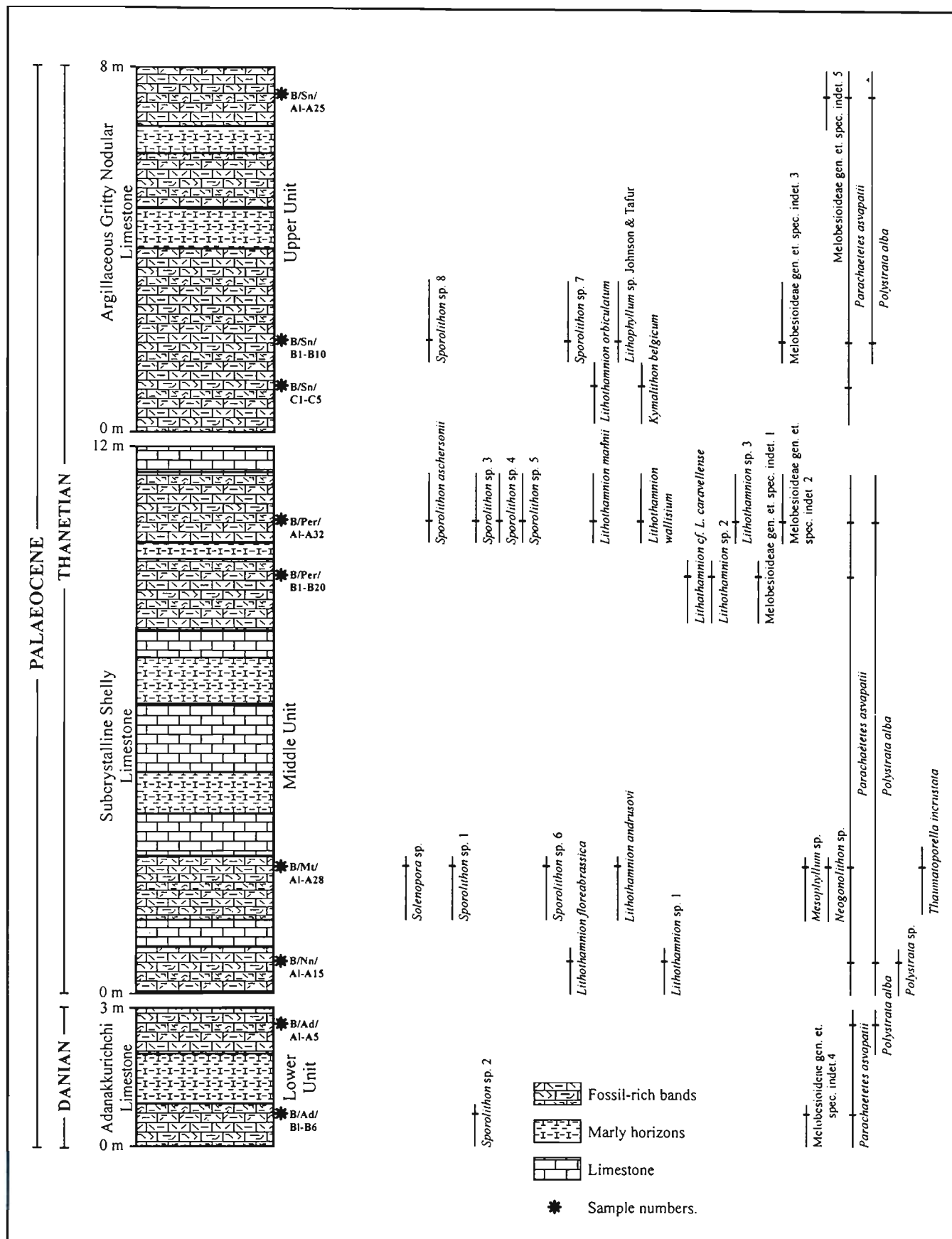


Fig. 3

present. Peripheral region with cells 7-12 μm in length and 6-9 μm in width, the thickness of peripheral cells variable and its cells are arranged in horizontal layers. Cell fusions present. Tetra/bisporangial conceptacles not present.

Sample No.—B/Sn/B5.

Slide No.—S/CB-75.

Locality—Sendurai.

Occurrence—Upper Unit, Ninniyur Formation.

Discussion—Thallus morphology does not resemble any known genus of family Corallinaceae. In the absence of conceptacles, the generic identification of this specimen is not possible. The presence of cell fusions in the thallus and non-coaxial core filaments suggests its relationship with subfamily Melobesioideae.

MELOBESIOIDEAE gen. et spec. indet. 4

(Pl. 3.5)

Description—Growth form encrusting. Thallus organisation monomerous. Core filaments, coaxial, and its cell dimensions 16-26 μm in length and 12-18 μm in width. Peripheral filaments consist of very thin regular rows of long rectangular cells. Cells 15-17 μm in length and 18-25 μm in width. There is a slight alteration of cells near conceptacles; they are smaller and more irregular. Cell fusions not observed. Tetra/bisporangial conceptacles immature.

Sample No.—B/Ad/B1.

Slide No.—A/CB-11.

Locality—Adanakkurichchi.

Occurrence—Lower Unit, Ninniyur Formation.

Discussion—The present specimen possesses immature conceptacles which makes its identification difficult at generic level. Due to the presence of coaxial core filaments, this form seems to be comparable with the genus *Mesophyllum* Lemoine. Since pores of conceptacles are not clear, the present specimen is being placed under subfamily Melobesioideae.

MELOBESIOIDEAE gen. et spec. indet. 5

(Pl. 3.3)

Description—Thallus encrusting. The differentiation of core and peripheral filaments not distinct. Cells 11-16 μm in length and 6-8.5 μm in width. Tetra/bisporangial conceptacles not present.

Sample No.—B/Sn/A19.

Slide No.—S/CB-76.

Locality—Sendurai.

Occurrence—Upper Unit, Ninniyur Formation.

Discussion—Since this vegetative specimen possesses an encrusting growth form and lacks erect or articulated morphology, it is being placed under sub-family Melobesioideae in this study.

Genus—MESOPHYLLUM Lemoine 1928

MESOPHYLLUM sp.

(Pl. 3.8)

Description—Growth form encrusting, formed by more or less well-defined “layers” of cells, showing irregular growth zones. Thallus organisation monomerous. Core filaments coaxial about 75 μm in thickness. Cells 15-20 μm in length and 10-15 μm in width. The layers vary in thickness. The cells of different zones vary considerably in size. Peripheral region with cells 8-12 μm in length and 6-10 μm in width. Tetra/bisporangial conceptacles not preserved.

Sample No.—B/Mt/A23.

Slide No.—M/CB-22.

Locality—Mattur.

Occurrence—Middle Unit, Ninniyur Formation.

Discussion—The present specimen is without reproductive structures but growth form and coaxial nature of core filaments indicate its affinity with *Mesophyllum varians* Johnson (1965) reported from the Palaeocene of Massif of Akros, Greece.

Subfamily—MASTOPHOROIDEAE Setchell, 1943

Genus—NEOGONOLITHON Setchell & Mason, 1943

Species—NEOGONOLITHON sp.

(Pl. 3.12)

Description—Growth form encrusting, thallus 450 μm in thickness. Thallus monomerous. Core filaments coaxial, about 180 μm in thickness, with cells 15-30 μm in length and 8-12 μm in width. Peripheral region with cells 14-20 μm in length and 12-22 μm in width. Cell fusions present. Tetra/bisporangial conceptacle pore indistinct, 380-460 μm wide, 80-95 μm long.

Sample No.—B/Mt/A24.

Slide No.—M/CB-10.

Locality—Mattur.

Occurrence—Middle Unit, Ninniyur Formation.

Discussion—Rasser and Piller (1999) recognised the possibly with similar features as *Neogonolithon* on the basis of uniporate nature of conceptacle and coaxial core filaments. Following these authors, the present specimen is described here as *Neogonolithon* in view of its coaxial core filaments and apparently uniporate nature of conceptacles. Hence, it is being treated as unnamed species of the genus *Neogonolithon* Setchell & Mason. Rasser & Piller (1999) reported *Neogonolithon* sp. from the late Eocene of the Austrian Molasse Zone.

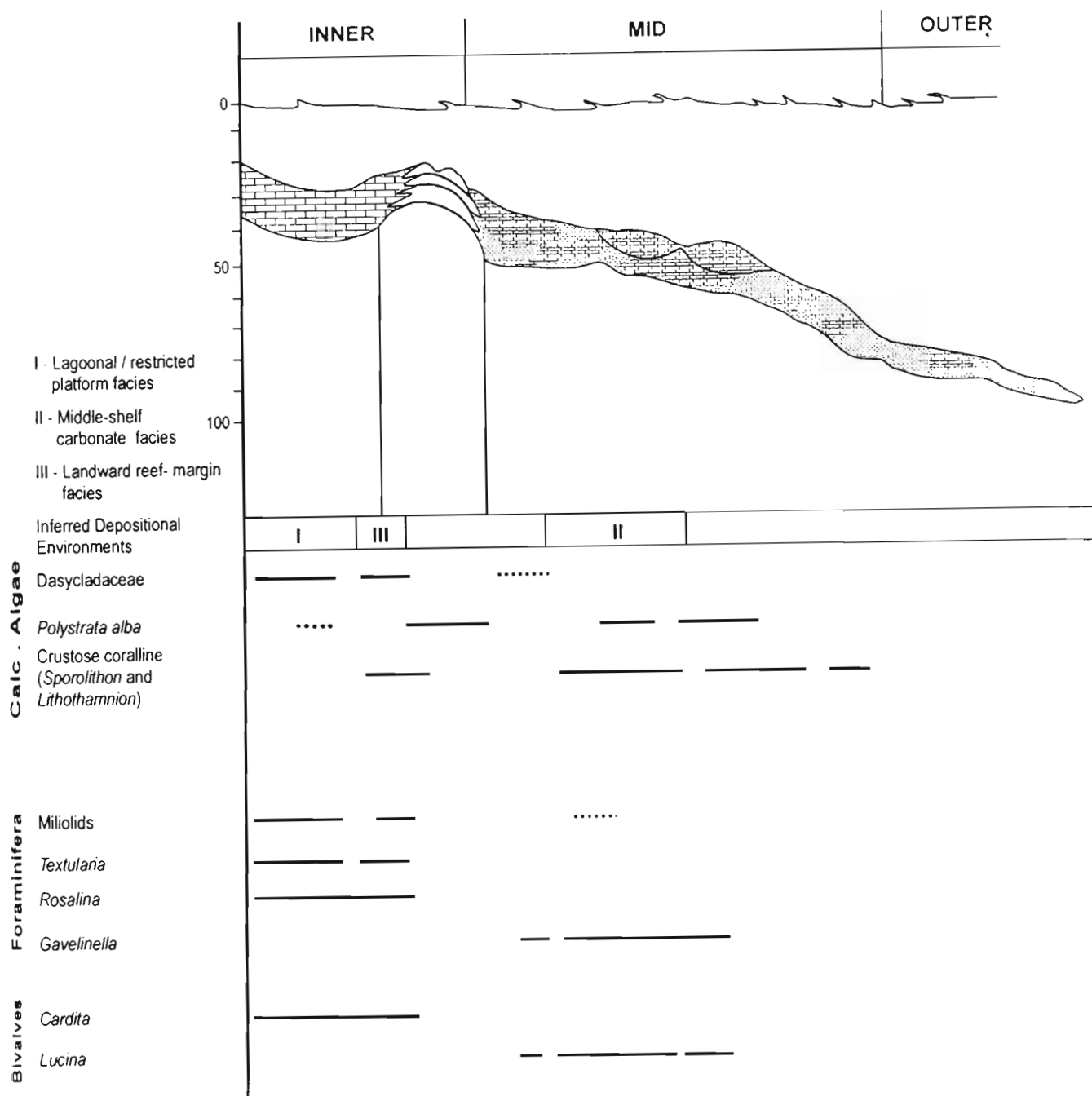


Fig. 4—Conceptual depositional framework of the environmental setting during accumulation on the Ninniyur Formation.

Subfamily—LITHOPHYLLOIDEAE Setchell, 1943

Genus—LITHOPHYLLUM Phillippi, 1837

Species—LITHOPHYLLUM sp. Johnson & Tafur, 1952

(Pl. 1.6)

Description—Growth form encrusting. Core filaments poorly developed. peripheral filaments thin and cells 14-20 μm in length and 16-25 μm in width. Tetra/bisporangial conceptacles small. ovoid or more or less triangular, uniporate, shape variable, 40-70 μm in height and 45-54 μm in width.

Sample No.—B/Sn/B5.

Slide No.—S/CB-75.

Locality—Sendurai.

Occurrence—Upper Unit, Ninniyur Formation.

Discussion—The Ninniyur specimen agrees well with an unnamed species, *Lithophyllum* sp. Phillippi 1837 reported by Johnson and Tafur (1952) from the Atascadero Limestone (Eocene). The present specimen shows poorly developed core filaments, but the nature of uniporate conceptacle and its smaller size suggest its closeness with the Atascadero form.

Family—PEYSSONNELIACEAE Denizot, 1968

Genus—POLYSTRATA Heydrich, 1905

Species—POLYSTRATA ALBA (Pfender) Denizot, 1968

(Pl. 3, figs 2, 7, 11)

1936 *Pseudolithothamnium album* nov. gen. nov. sp.

Pfender, p. 304-308; pl. 19, figs 1-5.

1968 *Polystrata alba* (Pfender); Denizot, p. 475-476; pl. 9, fig. 4.

1965 *Ethelia alba* Johnson & Kaska, p. 69, pl. 15, figs 1, 2.

1997 *Polystrata alba* (Pfender); Denizot, Bassi, p. 311-316; figs 1-4b.

Description—Thallus filamentous, strap or ribbon shaped, consisting of a central part formed by elongated cells which give rise to branched filaments radiating outwards. These filaments are curved outwards and form postigenous tissue. Sporangia not seen. Length of cells 35-40 µm; diameter of cells 20-25 µm.

Sample No.—B/Ad/B4; B/Nn/A13; B/Per/A7; B/Sn/A10, B4.

Slide No.—N/CB-48.

Locality—Adanakkurichchi, Ninniyur, Sendurai.

Occurrence—Lower, Middle, Upper units, Ninniyur Formation.

Discussion—As cited in Bassi (1997), *P. alba* is a widely occurring species in the Eocene limestone of Europe. Bassi (1997) re-examined and redescribed the material from the type section (Calcare di Nago Formation, Southern Alps) and pointed out its anatomical analogies with non-geniculate corallines. In the study area, it usually occurs as crusts in association with other corallines such as *Sporolithon*, *Lithothamnion*, etc.

POLYSTRATA sp.

(Pl. 6.4)

Description—Thallus blade-like, bilateral, comprising large elongated cells at the centre, slightly bending outwards,

to form postigenous filaments. Sporangia not preserved. Length of cells 55-70 µm width of cells 30-45 µm.

Sample No.—B/Nn/A10.

Slide No.—N/CB-35.

Locality—Ninniyur.

Occurrence—Middle Unit, Ninniyur Formation.

Discussion—In this species, the thallus is blade-like and has longer cells, while that of *P. alba* is ribbon-shaped and comprises relatively shorter cells. Hence, this specimen is being described as *Polystrata* sp.

Incertae Sedis

Genus—THAUMATOPORELLA Pia, 1927

Species—THAUMATOPORELLA (POLYGONELLA) INCRUSTATA Elliott, 1957

(Pl. 6.5, 6)

1927 *Thaumatoporella parvovesiculifera* (Raineri) Pia, p. 69.

1957 *Lithoporella elliotti* Emberger, p. 625, 629, pl. 32.

1957 *Polygonella incrustata* Elliot, p. 230, pl. 1, figs 11-12.

1965 *Thaumatoporella (Polygonella) incrustata* Johnson & Kaska, p. 59, pl. 16, fig. 2.

Description—Thallus thin, encrusting, a single layer of long polygonal prismatic cells about 55-112 µm in length, 20-40 µm in width.

Sample No.—B/Mt/A2.

Slide No.—M/CB-14, 17.

Locality—Mattur.

Occurrence—Middle Unit, Ninniyur Formation.

Discussion—De Castro (1990) described the genus *Thaumatoporella* Pia as a member of the family Thaumatoporellaceae of the order Thaumatoporellales, apparently a green algal form. However, we do not find any convincing reason to assign this genus to green algae because it lacks their typical branching pattern. In the present study, it is described as a form under *Incertae Sedis*.

ANNOTATED CHECK LIST OF GENERA

Genus—SOLENOPORA Dybowski 1878

Thallus encrusting with more or less radiating filaments. cross-partitions are widely spaced or absent in this genus. If the partitions are present, they are considerably thinner than the vertical cell walls. Conceptacles unknown.

Genus—PARACHAETETES Deninger, 1906

Thallus in the form of thin crust with small protuberances. The genus is characterised by strong, numerous, regularly

spaced cross-partitions that give the tissue a gird-like appearance in longitudinal section. Conceptacles unknown.

Genus—SPOROLITHON Heydrich 1897

Epithallial cells with flattened and flared cells and tetrasporangial conceptacles separated by interspersed calcified filaments (paraphyses) (Woelkerling, 1988); conceptacles arranged in sori (Verheij, 1993).

Genus—KYMALITHON Lemoine & Emberger 1967

Growth form encrusting. Crustose portion composed of a core of non-coaxial filaments and a peripheral region where distal portions of core filaments or their derivatives curve outwards towards the thallus surface. The core filaments are similar with narrow flexible undulating threads of cells with thin walls. There is no suggestion of a regular horizontal layering of the cells. The peripheral filaments in both the basal crust and around the branches show a well-developed "layering" of the cells with thin continuous partition walls. Sporangia develop in the outer part of the peripheral region, in small groups, often containing rounded spores, each sporangium having an individual canal extending to the surface for the discharge of spores. A few examples of sexual conceptacles have been observed.

Genus—LITHOTHAMNION Heydrich 1897

Growth form warty to fruticose. Thallus monomerous; peripheral region is well developed with distinct zonation. Filaments radially organised inside the protuberances, cell fusions conspicuous. Tetra/bisporangial conceptacles multiporate.

Genus—MESOPHYLLUM Lemoine 1928

Growth form crustose to fruticose, composed of flattened lamellae or cylindrical to compressed protuberances. Filaments each consisting of a terminal or subepithallial initial which can produce epithallial cells outwardly at the thallus surface and additional vegetative cells inwardly; palisade cells lacking. Some but not all cells of contiguous filaments joined by cell fusions. Tetra/bisporangial conceptacles multiporate, tetra/bisporangia with mucilaginous plugs. Except for the occurrence of mucilaginous plugs, all these characters can be preserved and observed in fossil specimens. However, according to Woelkerling and Harvey (1992, 1993) *Mesophyllum* is delimited from other genera of Melobesioideae by a combination of eight features, four of which concern the formation of the spermatangial conceptacles and other spermatangial characters, which cannot be observed in the fossils in which the thallus contains a core of coaxial filaments. However, the remaining four characters (haustoria absent, internal construction monomerous; outermost walls

	LITHOLOGICAL UNITS	LITHOLOGY	STUDY AREA
CUDDALORE FORMATION			
NINNIYUR FORMATION	Argillaceous gritty nodular Limestone (Upper)	Limestone intercalated with marl and clay, containing calcareous algae, corals, polyzoans, bivalves, gastropods and milioline foraminifera in large numbers (8 m).	SENDURAI
	White Compact Subcrystalline shelly Limestone (Middle)	Limestone containing broad, rounded patches of calcareous algae with occasional milioline foraminifera, <i>Hercoglossadanica</i> , lucinoid bivalves, etc. (12 m).	PERIYARKURICHCHI
	Adanakkurichchi Limestone (Lower)	Argillaceous Limestone with intercalated marl and clay. Large number of small, rounded white bioclasts of calcareous algae present in association with milioline, foraminifera, polyzoans, etc (3 m).	ADANAKKURICHCHI
ARIYALUR GROUP			

Fig. 5—Showing the succession of the Ninniyur Formation in the area of study (modified after Mallikarjuna & Nagaraj, 1996).

of epithallial cells rounded or flattened but not flared; vegetative initials usually longer than cells immediately subtending them), though observable in fossils, are not sufficient to delimit *Mesophyllum* from other genera of Melobesioideae. Therefore, it is necessary to use a combination of the above-mentioned characters, together with a predominantly coaxial morphology of the ventral core of cell filaments, to identify fossil specimens of *Mesophyllum*.

Genus—NEOGONOLITHON Setchell & Mason, 1943

Thallus non-endophytic, lacking haustoria and palisade cells; core filaments coaxial (Woelkerling, 1988; Braga *et al.*, 1993). Some cells of contiguous filaments joined by cell fusions. Tetra/bisporangial conceptacles uniporate and clearly delimited.

Genus—LITHOPHYLLUM Phillippi 1837

Growth form crustose to fruticose composed entirely of protuberances. Crustose portion of plants and lamellae dorsiventral and dimerous, monomerous, or both dimerous and monomerous. Cell fusions unknown. Tetra/bisporangial conceptacles uniporate and clearly delimited.

Genus—POLYSTRATA Heydrich 1905

Plant growth epigenous, consisting of thin lamellae forming variously shaped thalli lacking in protuberances. The thallus is pseudoparenchymatous, composed of filaments and organised in a bilateral-radial manner. In longitudinal section, each thallus consists of a single eccentric row of primigenous filaments. Postigenous filaments arise plumosely from the outer surface of the cells of primigenous filaments both upward and downward. Within a primigenous filaments, all the successive cells are joined by primary pit-connections. Successive cells of postigenous filaments are not joined by primary pit-connections (Bassi, 1997).

Genus—THAUMATOPORELLA Pia 1927

Thallus crustose or encrusting, consisting of a single layer of large polygonal cells which may be prismatic in shape. Fertile structures not seen.

STRATIGRAPHIC SIGNIFICANCE

Of 32 taxa of the red algae identified in the present material from the Palaeocene rocks of the Ninniyur Formation, seven species are known from the Palaeocene deposits of other parts of the world, and two are known to extend from the Palaeocene to the Eocene. However, this study extends the stratigraphic ranges of a few younger (Oligocene–Miocene, Pleistocene) forms to the Palaeocene (e.g., *Lithothamnion orbiculatum*) and documents for the first time some Jurassic

and Middle-Upper Cretaceous taxa (e.g., *Kymalithon belgicum*, *Thaumatoporella* sp., etc.) from the geologically younger Ninniyur Formation. Among the Ninniyur forms, those which are restricted to the Palaeocene outnumber others and support the Palaeocene age for the Ninniyur Formation.

PALAEOECOLOGY

The fossil assemblages of the Ninniyur Formation show presence in abundance of the fossil algae, foraminifera, ostracods and mega-invertebrates which can be used as a means to interpret the depositional environment in which the three lithounits of this formation were deposited. The foraminifera and the invertebrates have been used in the previous studies for this purpose, but the ecological potential of the fossil calcareous algae, as indicated in Wray (1978), has not been effectively realised for palaeoenvironmental interpretations because the taxonomic database of the coralline algae from the area of study is inadequate. The present study shows that the taxonomic composition of the calcareous algae of the Ninniyur Formation is varied and quite useful for palaeo-ecological interpretations.

Among the various biotic groups, coralline algae constitute the major components of the assemblage of fossils of the Ninniyur Formation. The majority of red algae from the Ninniyur Formation are of crustose type and crusts are usually thick and only few thalli show branches. However, the composition of the coralline algal taxa is not uniform in the sequence and shows variation in their distribution in the three units of the formation (Fig. 3).

Adanakkurichchi Limestone Unit

An argillaceous limestone unit dominated by shale and marl, it is characterised by poor development of calcareous algae and other fossil groups. It is the basalmost unit of the Cenozoic succession in the area following the unfossiliferous Kallamedu Formation of the terminal Cretaceous. The not-so well-developed fossil forms of this unit possibly represent the early phase of evolution of the Palaeogene marine life after the terminal extinction event of the Late Cretaceous. Poor diversity and limited development of the algal flora of the lower unit could be explained in terms of gradual regeneration of carbonate platform environments in the post-Cretaceous times. The recovery of benthic communities in the Cenozoic was not quick and did not occur until the stable, stress-free, warmer, oligotrophic environments became available following the climatic warming, high sea-level, low influx of terrigenous supply, reduced upwelling, etc. during the Thanetian (Keller, 1988; Hottinger, 1987; Jauhri, 1997). The signatures of such environments are seen in the middle unit where the different animal and floral groups appear in very high diversities and show extensive development.

The red algae are represented only by fragments of *Sporolithon*, *Parachaetetes*, *Polystrata* which are not significant. Their limited development seems to be due to influx of clastic material received from the coast, as indicated by presence of fine clastic sediment and dominance of miliolids. The latter are known to thrive in near-shore environment (Malarkodi & Nagaraj, 1997). Dasycladacean elements referable to *Indopolia satyavanti* Rao & Pia are present in noticeable numbers. *Indopolia* is indicative of shallow shelf facies (back-reef) as it has been reported from the deposits of lagoonal/restricted platform facies of Greece (Deloffre *et al.*, 1991), Ras Al Hamra, Oman (Rácz, 1979) and Iraq (Elliott, 1968). Occasional episodes of storms have washed in elements of relatively deeper-water (middle-shelf) planktic foraminiferal species which are present in some horizons of this unit (Malarkodi & Nagaraj, 1997). From the above facts, it is suggested that Adanakkurichchi unit represents a shallow “back-reef” (lagoonal/restricted platform) facies (Fig. 4) possibly laid down during a gradually transgressing sea within the near-shore, inner-neritic zone characterised by relatively low-energy conditions.

Subcrystalline shelly Limestone Unit

It is a relatively pure carbonate unit characterised by abundant bivalve and gastropod shells and foraminifera. The dominant megainvertebrate fossil species is *Lucina percrassa*. The algal group shows maximum representation of crustose type of coralline and other red algae which are dominated by *Sporolithon* and *Lithothamnion*. *Polystrata*, *Parachaetetes* and some indeterminate elements of Melobesioideae also occur in this unit.

The algal crusts appear to be the commonest growth form in the Ninniyur algal flora of the middle unit except for a few lumpy forms with protuberances. The encrusting forms were the sediment binders and might have produced the algal boundstones commonly seen in this unit. The dominance of algal crusts, high algal diversity, presence of sporolithaceans and melobesids in abundance and coarse bioclastic sediment with some carbonate mud all point to a relatively deeper environment of open shelf comparable to that of the algal Rhodolith pavement and Rhodolith mounds facies of Bassi (1998b). The *Sporolithon*-rich flora in association with acervulinid foraminifers has been found to be characteristic of the depth range 20-40 m in the northern Red sea, Egypt (Rasser & Piller, 1997). Previous records of *Sporolithon* and *Lithothamnion* have been made from the deposits interpreted to be representative of reef-margin conditions and deeper parts of middle shelf carbonate environment (Scheibner, 1968; Ghose, 1977; Rácz, 1979).

Another important feature of the coralline algal facies of the middle unit of the Ninniyur Formation is the association of *Polystrata* in appreciable number. Bassi (1998b) reports that *Polystrata* forms encrustations on hard or soft substrates,

“...either alone or in consortium of non-geniculate corallines and encrusting foraminifera ...” in the mid and the uppermost outer ramp environments of the Lessini Shelf characterised by low-energy conditions present below normal wave base and normal storm wave base. The studied samples of the middle unit show low amount of miliolids and presence of carbonate mud supporting a relatively deeper environment of low-energy conditions.

In the present context, the ecological information on the lucinoid bivalves predominant in this unit is very significant. They are detritus feeders which burrow relatively deeply and suck organic matter accumulated on the sediment surface by means of mucus-lined tubes. Their occurrence in abundance in this unit gives indications of soft but firm substrates where the organic matter would settle on sediment surfaces due to low-water energy and low rates of sedimentation because of very little influx of clastic material.

From the above discussion, it appears that the subcrystalline shelly limestone was deposited in a middle-shelf, low-energy carbonate environment which promoted the formation of patch-reefal organogenic accumulations referred to as “bank” by Banerji (1979) (Fig. 4).

Argillaceous gritty nodular limestone Unit

Among the numerous mega-invertebrate fossils such as corals, bivalves and gastropods, *Cardita beaumonti* is one of the most common forms of this unit. This unit shows influence of terrigenous clastic material during its deposition. The carbonate deposits of this part of the succession, therefore, are comparatively impure and show relatively thinner populations of megainvertebrates, foraminifera, etc.

Among the microfaunal elements, ostracods are predominant in comparison to foraminifera. Three common genera of foraminifera noticed in this unit are *Gavelinella* (referable to *G. danica*), *Textularia* and *Rosalina* (Malarkodi & Nagaraj, 1997). *Gavelinella* is a common component of Palaeocene benthic shelf assemblages with textularids and *Rosalina*. These forms usually flourish in an environment marked by high input of clastic material (Berggren & Aubert, 1975).

The red algal association is not as abundant and diversified as that of the preceding unit and is not helpful in providing precise information about palaeo-environmental reconstruction. The genera present in this unit are *Sporolithon*, *Lithothamnion*, *Polystrata*, *Lithophyllum* and *Parachaetetes*. However, the algal association broadly indicates deposition in patch-reefal environment in close proximity to near-shore, lagoonal to tidal, medium energy environment. This interpretation is supported by ecological data on the associated foraminifera (e.g., *Gavelinella*, *Rosalina* and *Textularia*) which indicate deposition of this lithounit in the presence of clastic material received from the shore.

The associated dasycladaceans, better represented in this unit than the lower and the middle, include *Cymopolia* sp., *Indopolia savitrae* Rao & Pia, *Indopolia* sp. and "*Neomeris*" sp. (Misra *et al.*, 2000) which have usually been reported from the lagoonal and restricted platform deposits of Europe and the Middle East (Barattolo, 1998). They support the interpretations based on red algal forms and foraminifera. This depositional environment seems to be similar to the landward reef-margin facies of Rácz (1979); see Text-fig. 4.

CONCLUSION

The algal assemblage studied here is distinguishable into three algal associations in the Ninniyur Formation. These associations allow to interpret the depositional environment which prevailed during the Palaeocene in the Ninniyur area.

Thirty two taxa of the red algae have been recognised (Fig. 3); of these, seven species are characteristic of the Palaeocene deposits in different parts of the world and two extend from the Palaeocene to Eocene. Others are long ranging and are known either from the geologically older or younger successions. The most common genera are *Sporolithon*, *Lithothamnion* and *Melobesioideae* gen. et. spec. indet.

The Ninniyur Formation represents a progradational cycle of the post-Cretaceous transgression which extended from early to late Palaeocene. It was deposited in a carbonate environment with the facies mosaic comparable to that of the Palaeocene deposits of other areas in the Tethys (e.g., Iraq, Oman). The deposits of the Ninniyur Formation are characterized by three depositional facies: a near-shore, lagoonal facies with moderate influence of clastic sedimentation; the middle-shelf low-energy carbonate facies with abundant algal flora and the associated fauna promoting patch-reefal build-ups; and the landward "reef-margin" facies marking deposition in inner-shelf environment having access to near-shore to tidal conditions and influence of terrigenous clastic deposition. The latter points to the regressive phase of sea in the study area.

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