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

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ABSTRACT


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.
INTRODUCTION

TAlthough 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 (1971, 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 algalaya 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 dasycladalean 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
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 Celeron 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 mioloid 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* Douville 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 *Thalmanta* 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 foraminifer of the middle unit are *Acarinina mckannai* (White) and *Planorotalites pseudomenardii* (Bolli).
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.


All the thin sections and peelings are preserved at the Algalology 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 JA3.

Slide No. — M/ICB-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** — PARACHAELETES Deninger, 1906

**PARACHAELETES ASVAPATII** Rao & Pia, 1936

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

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

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


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**PLATE 2**

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

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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/Mi/A15; B/Per/A10, B6; B/Sn/A24, B3, C3.

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)


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.

(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/Mi/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.

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**PLATE 3**

1. **Sporolithon** sp. 8. X 50.
2. **Polystrata alba**. X 50.
3. **Melobesia irides** gen. et spec. indet. 5. X 10.
4. **Parachaetetes asparagi**. X 25.
5. **Melobesioda** gen. et spec. indet. 4. X 50 Showing immature conceptacle.
6. **Sporolithon** sp. 5. X 50. Thallus with a row of sporangia.
7. **Polystrata alba**. X 25.
8. **Mesophyllum** sp. X 25.
9. **Lithothamnion** sp. 2.
11. Fragmentary thallus with conceptacles. X 50.
13. **Sporolithon** sp. 3. X 100. Showing branching of thallus.
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 (Gumbel) Lemoine in thallus organisation and shape of sporangia. However, only few sporangia are preserved in our specimen and their outline is not prominent.

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 (Gumbel) 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, oval 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. Lithothamnium manuoi. X 125.
2. Lithothamnion floribrassica. X 35.
4. Lithothamnion sp. 3. X 30.
5, 8, 9. X 125.
with rows of oval to elliptical sporangia, 45-50 μm in length and 25-35 μm in diameter.

**Sample No.** — B/MV/A5.
**Slide No.** — M/CB-8.
**Locality** — Mattur.
**Occurrence** — Middle Unit, Ninnyur 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, Ninnyur 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, Ninnyur 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.

**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. 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, Ninnyur 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 floreabrazzica* (Millet) Lemoine 1923

*(Pl. 4.2)*

1923 *Lithothamnion floreabrazzica* Lemoine, 1924, p. 184, fig. 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/Mn/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 mm. 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 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 Laphitos, Greece (Johnson, 1965) 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 protruberances and smaller and somewhat oblong conceptacles.

**LITHOTHAMNION ORBICULATUM** Krivanne Hutter 1961

(Pl. 5.5, 8)

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

**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.
apparently bisporangiate/tetraspoangiate, 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 Krivann 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/Perl/19.
Slide No.—P/CB-65.
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 WALLISIUM Lemoine 1939
(Pl. 2.10)

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 monomorous. Core filaments non-coaxial, about 105 µm in thickness, with cells 8.5-15 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 multipartate, obovoid to reniform chambers, 410-450 µm in diameter and 140-150 µm in height.

Sample No.—B/Perl/19.
Slide No.—P/CB-36.
Locality—Periyakurichchi.
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. 1
(Pl. 6.3, 7)

Description—Growth form encrusting to lumpy. Thallus organisation monomorous. 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 measureable 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/Perl/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

*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/Pet/A30.
*Slide No.*—P/CB-52.
*Locality*—Periyakurichchi.
*Occurrence*—Middle Unit, Ninniyur Formation.
*Discussion*—This specimen is comparable with *Palaeothamnium archeaetypum* Conti in the immature conceptacles. Basso et al. (1997) reported morphologically similar specimens from the Miocene of Leithakalk and assigned them to *Palaeothamnium archeaetypum* 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. 2

*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 multporate.

*Sample No.*—B/Pet/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

*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

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Fig. 3—The lithobiostratigraphic representation of the Ninniyur Formation in the Tiruchirapalli area showing position of fossil-yielding samples.
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 Melobesioidae.

MELOBESIOIDEAE gen. et spec. indet. 4

(Pl. 3.5)

Description—Growth form encrusting. Thallus organisation monomorous. 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—Adanakkurichi.
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 Melobesioidae.

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

Subfamily—LITHOPHYLLOIDEAE, Satchell, 1943

Genus—LITHOPHYLLUM, Phillipi, 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/Ad/JB5.
Slide No.—SC/B-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 (Calcari 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) INCURSTATA 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 Elliott, 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

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<td>NINNIYUR FORMATION</td>
<td>Argillaceous gritty nodular Limestone (Upper)</td>
<td>Limestone intercalated with marl and clay, containing calcareous algae, corals, polyzoans, bivalves, gastropods and milioline foraminifera in large numbers (8 m).</td>
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<td>White Compact Subcrystalline shelly Limestone (Middle)</td>
<td>Limestone containing broad, rounded patches of calcareous algae with occasional milioline foraminifera, <em>Hercoglossadonta</em>, lucinoid bivalves, etc. (12 m).</td>
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<td>Adanakkurichchi Limestone (Lower)</td>
<td>Argillaceous Limestone with intercalated marl and clay. Large number of small, rounded white bioclasis of calcareous algae present in association with milioline, foraminifera, polyzoans, etc (3 m).</td>
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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 Melobesioidae. 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, monomorous, or both dimerous and monomorous. 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 plumbosely 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., Kynalithon 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 litho units 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 palaeoecological 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, Parachaeetes, 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). Dasyycladacean elements referable to *Indopollia satyavanti* Rao & Pia are present in noticeable numbers. *Indopollia* 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 (Racz, 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 megavertebrate 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, Parachaeetes* 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 acervulid 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; Racz, 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 subcrustaceous 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 beaumontii* 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 megavertebrates, foraminifera, etc.

Among the microfaunal elements, ostracods are predominant in comparison to foraminifera. Three common genera of foraminifera noticed in this unit are *Gavelinella* (referred 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 *Parachaeetes*. 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., Indopodia savitgae Rao & Pia, Indopodia 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 Kacz (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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