



PALAEOCENE (DANIAN-THANETIAN) FORAMINIFERA IN CARBONATE ENVIRONMENT OF THE CAUVERY BASIN, SOUTHERN INDIA

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ABSTRACT

The carbonate environment that developed during the Palaeocene in the study area is well represented in the three units of the Ninniyur Formation. The environment ranged from the shallow inner-ramp to mid- to uppermost outer-ramp environment and was host to several groups of invertebrate and foraminiferal fauna and algal flora. In the studied profiles of the lower, middle and upper units of this formation, it appears that it is the inner-ramp environment and its low-diversity assemblage of fossil forms that persisted throughout the course of deposition. The assemblage consists of foraminifers, represented by miliolids and fewer members of rotaliid and agglutinated groups, and calcareous algae (dasyclads). As this environment had a small habitat-area (ecospace) with limited possibilities of further evolutionary differentiation, it was marked by the persistence of low-diversity biota throughout the Ninniyur succession. However, this continuum was broken when the deposition of the middle unit occurred in deeper mid- to uppermost outer-ramp locations of sea in the Periyakurichchi area. This change resulted in an enlarged habitat-area allowing for multiplication of microhabitats to give rise to high-diversity coralline algal assemblage with some planktic species.

Keywords: Palaeocene foraminifera (miliolids, agglutinated forms, etc.), Ninniyur Formation, Palaeoenvironment, south India

INTRODUCTION

This paper presents the stratigraphic, palaeoenvironmental and brief systematic account of the Palaeocene benthic foraminifera from the Ariyalur area of the Cauvery Basin. These include, apart from the previously reported planktic and some benthic species (Sastry *et al.*, 1965; Malarkodi and Nagaraj, 1997, 1998), the forms belonging to Miliolidae, Rotaliidae and textulariaceans common in the inner-ramp deposits in many areas. Palaeocene carbonates were deposited in inner-ramp to mid-to uppermost outer-ramp environments during the marine transgression in the northern part of this basin following the terminal Cretaceous extinction event (Kishore *et al.*, 2007, *in press*). The planktic and benthic foraminifera described earlier are associated with the rich fossil algal (coralline) assemblages (Misra *et al.*, 2000; 2001; 2003; Kishore *et al.*, 2003; Kishore, 2004; Kishore *et al.*, 2006), while those examined in this note occur in association with the dasyclads and rare fragmented corallines.

The foraminiferal assemblage is studied in random thin sections of the carbonate samples of three members of the Ninniyur Formation exposed in vicinity of the Ariyalur area.

REGIONAL GEOLOGY

The study area is situated in the southern part of the Ariyalur-Pondicherry sub-basin forming the northern part of the Cauvery Basin which constitutes the southernmost portion of the Coromandel shelf regime of India (Fig.1) (Pandey, 1986). Marine transgression occurred in the Cretaceous, which was followed by Deccan volcanism towards the close of the Cretaceous. After the Deccan Trap outpourings, marine transgression occurred during the early Tertiary in response to tectonic and oscillatory movements. 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 succession (Cuddalore Sandstone) containing

lignite deposits at Neyveli. The detailed account of the geological setting of the Cauvery Basin has been discussed in a number of papers (e.g. Sastry *et al.*, 1977; Banerji, 1979; Kumar, 1983; Govindan *et al.*, 1998).

The outcrops of the Cretaceous sediments exhibit facies change from the shelf carbonates at 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 developed because of reduction of clastic supply due to peneplanation of the source area as well as reduced rates of subsidence; in some areas, however, the fine clastics accumulated alongside the carbonates because of fluctuating conditions of local tectonics (Kumar, 1983).

STRATIGRAPHY

The main contributors to the knowledge of the stratigraphy of the Tiruchirapalli area are Blanford (1862), Rao and Pia (1936), 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 the fossiliferous marine beds conformably overlying the Kallandedu Formation (Ariyalur Group, Upper Cretaceous) is recognised as the Ninniyur Formation. It is well exposed at Sendurai, Adanakkurichchi and Periyakurichchi mines over a NNE-SSW strike between Vellar River in the north and Coleroon River in the south.

The characteristic feature of the Ninniyur Formation is its lithology and fossils – the carbonates and the rich representation of the fossil algae (Rao, 1958; Kishore *et al.*, 2003). Three distinct units can be recognised in it (Fig. 2); the lower fossiliferous Limestone (Adanakkurichchi Limestone); the middle Subcrystalline Shelly Limestone; and the upper Argillaceous Gritty Nodular Limestone.

Adanakkurichchi Limestone: This unit, the basal unit of the Cenozoic succession in the area, consists of marl, offwhite

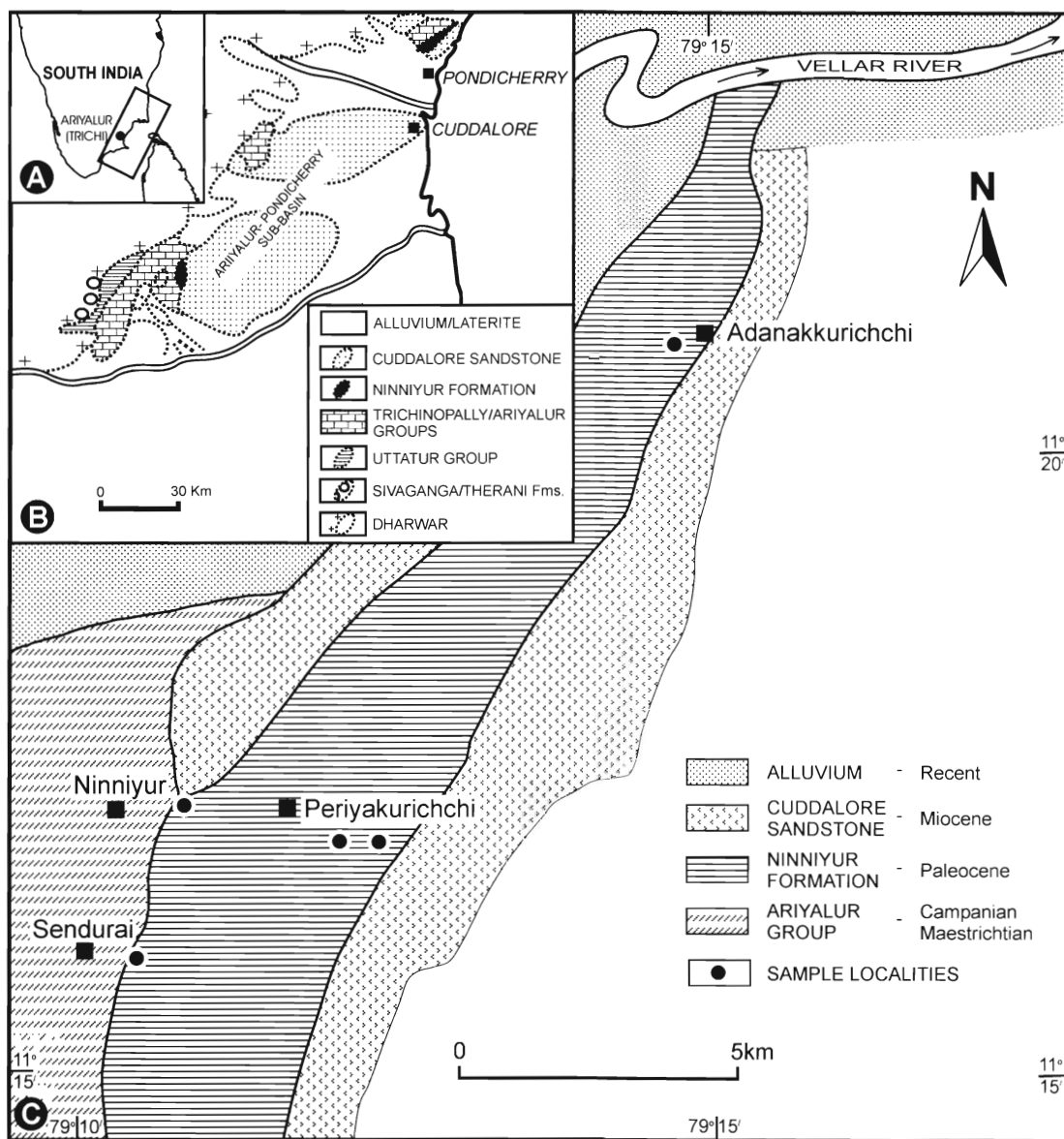


Fig. 1: Location and geological map of the area of study. A. Position of the Cauvery Basin in India (inset) indicated by a rectangle. B. The general geological map of the Cauvery Basin showing distribution of the studied succession in the Ariyalur-Pondicherry sub-basin. C. The geological map of the Ariyalur area showing the sampled localities where the outcrops of the Ninniyur Formation are well exposed (modified after Govidan *et al.*, 1998).

to yellowish, compact, fossiliferous limestone characterised by common megainvertebrates and miliolids but poor algal assemblage. The poor fossil content of this unit represents the early phase of evolution of the Palaeogene marine life after the terminal Cretaceous extinction. Low faunal diversity and less representation of calcareous algae point to gradual regeneration of carbonate platform environments in the early Cenozoic (Misra *et al.*, 2001). Associated planktic foraminiferal species indicate age-equivalence of this unit to zone Zone P2, i.e. late Danian (early Palaeocene; Malarkodi and Nagaraj, 1997).

Subcrystalline Shelly Limestone: Very well exposed at Ninniyur and Periyakurichchi, it is a dominantly recrystallised, hard, compact, variegated limestone representing a relatively pure carbonate unit marked by disintegrated and less diversified megainvertebrates represented by frequently occurring cephalopod

(*Hercoglossa danica* Schlotheim) in association with bivalves, gastropods and ostracods. The common bivalve species in this unit is *Lucina percrassa*. Its algal flora, however, is much more diversified than that of the lower and upper units. The foraminifera are represented by planktic and benthic species. The latter also include rare miliolids. The miliolids represented by *Idalina sinjarica* and species of *Quinqueloculina*, however, become common in a 4m horizon exposed in a section at the Periyakurichchi mines (Fig. 2). The horizon overlies the succession containing rich algal flora and some planktic species and is represented by pinkish yellow, hard limestone occurring as a second limestone band 10m from the top part of the succession. Planktic foraminifera recorded by Malarkodi and Nagaraj (1997) and presence of *Idalina sinjarica* indicate that this unit corresponds to zones P3-P4, i.e. Thanetian (late Palaeocene).

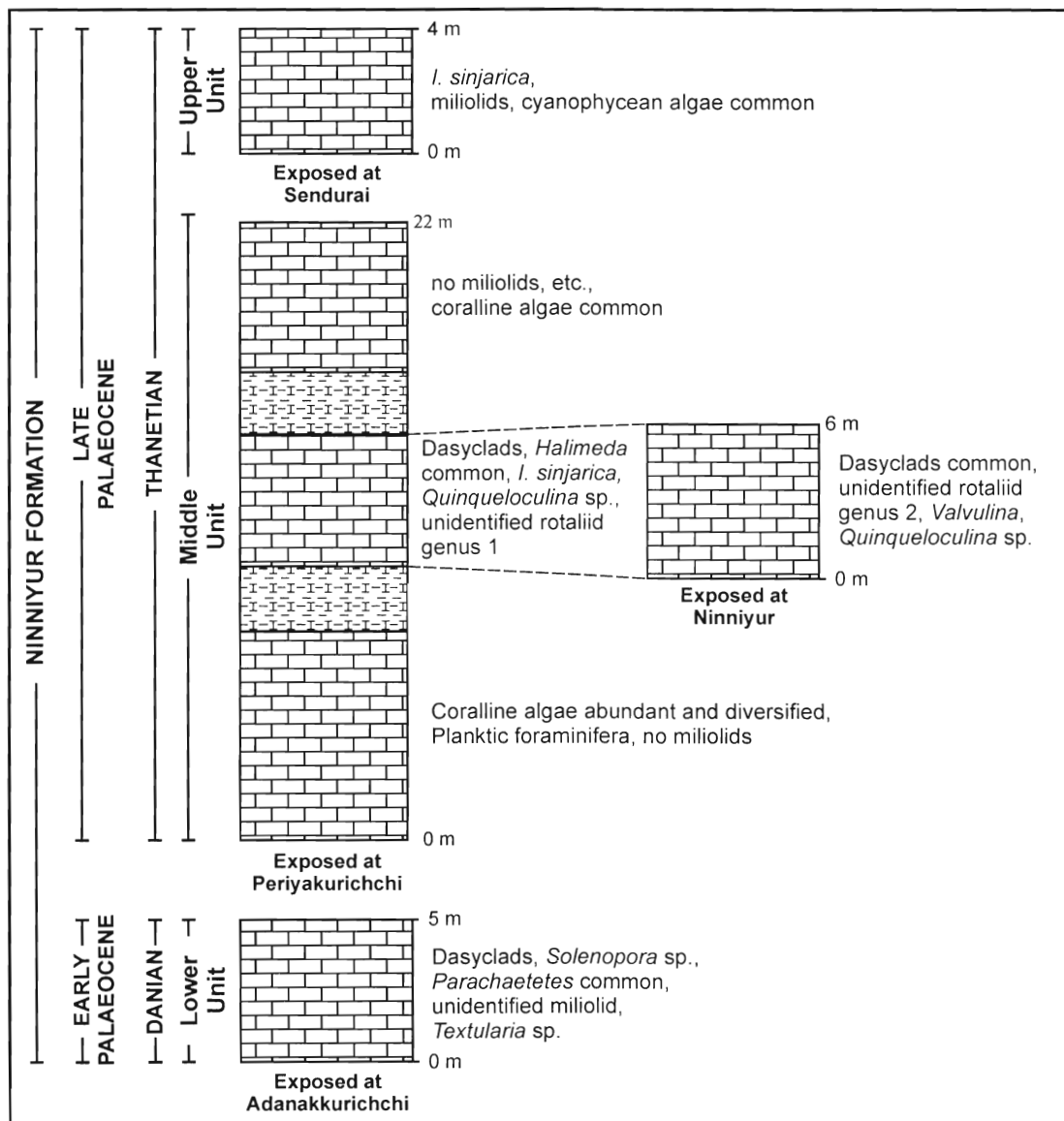


Fig. 2. Distribution of foraminifera and the calcareous algae in the successions of the Ninniyur Formation in the Ariyalur area, southern India.

Argillaceous Gritty Nodular Limestone: This unit is exposed at Sendurai village, consisting of argillaceous gritty limestone characterised by nodules ranging in size from 2 to 5 cm. It is richly fossiliferous and is characterised by abundant bivalves, gastropods and corals but contains less diversified algal flora. *Cardita beaumonti* is the most common fossil of this unit. In comparison to the other two units, it has thinner fossil content due to influence of terrigenous clastic material. Though marked by absence of planktic foraminifera, this unit appears to correspond to the Thanetian in view of its position in sequence and the presence of *Idalina sinjarica* Grimsdale (this paper) which is known from Thanetian to early Ilerdian.

BIOSTRATIGRAPHIC SIGNIFICANCE

The foraminifera recovered in random thin sections from Adanakkurichchi, Sendurai, Ninniyur and Periyakurichchi are almost all long-ranging benthic forms,

most of which are identifiable up to generic level; and a few are referable to their families only. They have, therefore, little value for biostratigraphic correlation. However, the foraminiferal association is comparable with those from the Palaeocene of the Ordu region of Turkey (Sirel, *personal communication*). *Idalina sinjarica* Grimsdale, for example, is characteristic of the Thanetian of Turkey (Sirel, 1998), the Palaeocene of Jebel, Sinjar, north-west Iraq (Grimsdale, 1952, p. 230) and the Thanetian-early Ilerdian of Yugoslavia (Drobne, 1974). Its biostratigraphic range, according to Serra-Kiel *et al.* (1998), is from SBZ3 to SBZ 6, i.e. Zones P4-P5 (Thanetian to early Ilerdian). An indeterminate rotaliid genus (Pl. I, figs. 7-8) resembles the Palaeocene "unidentified rotaliid genus" of Sirel (1998). These taxa therefore indicate Palaeocene age, corresponding to the Thanetian stage. The associated biostratigraphic indices in the three units (Malarkodi and Nagaraj, 1997, 1998) provide age constraint to the benthic fauna reported herein.

Based on these, the present fauna is dated as Danian-Thanelian, i.e. Zone P2-P4 on planktic foraminifera zonation (Blow, 1969, 1979).

PALAEOENVIRONMENTAL ASPECTS

Low-energy, shallow (lagoonal) inner-ramp environments, preserved in the lower argillaceous limestone unit at Adanakuruchchi (Kishore *et al.*, 2007, *in press*), are characterised mainly by miliolids (e.g. unidentified miliolid, Pl. II, figs. 1-2) and a few textulariaceans, e.g. *Textularia* (Pl. II, fig. 3). The algal flora of this unit is dominated by dasyclads referable to *Cymopolia satyavantii* (Pia) Radoicic. The red algae have limited representation, usually occurring as fragments of *Sporolithon*, *Solenopora* (Pl. II, fig. 4), *Parachaetetes* and *Lithophyllum*.

High energy, very shallow inner-ramp environments (<5m) are represented by the outcrops at Ninniyur which are referable to the middle unit (Kishore *et al.*, 2007, *in press*); they have yielded some miliolids (represented by *Quinqueloculina* sp. (Pl. I, fig. 6), *Valvulina* (Pl. I, fig. 9) and an unidentified rotaliid genus 2 (Pl. I, fig. 3). Associated algal taxa commonly include dasyclads and few corallines with columnar and massive growth forms.

The equivalent middle unit outcrops at Periyakurichchi representing relatively the deeper mid- to uppermost outer-ramp environments with reduced energy conditions (moderate to low), show absence of miliolids, rotaliids, etc. and dasyclads but are characterized by abundant corallines usually occurring as branching and laminar growth forms (Kishore *et al.*, 2007, *in press*). They are accompanied by some planktic foraminiferal species (Sastry *et al.*, 1965; Malarkodi and Nagaraj, 1997, 1998). However, the miliolid-dominated assemblage comprising *Idalina sinjarica* Grimsdale (Pl. I, fig. 5), *Quinqueloculina* sp. (Pl. I, figs. 4, 11), and an unidentified rotaliid genus 1 (Pl. I, figs. 7-8) reappears in an overlying 4m thick horizon of the middle unit, indicating return of shallow inner-ramp environment at Periyakurichchi (Fig. 2). The algal forms common in this horizon include *Halimeda* sp., and some dasyclads (*Cymopolia satyavantii* (Pia) Radoicic, *Dissocladella longijansis* Mu & Wang and *Gyroporella* sp., Pl. II, figs. 5-8). Stratigraphically, the horizon lies 10m below the topmost bed of the middle unit in the Periyakurichchi section and is immediately overlain by a 2m thick marl bed (Fig. 2).

The upper argillaceous gritty nodular limestone unit,

representing a very shallow, very high-energy, inner-ramp environment (seaward of beach barrier facies) at Sendurai (Kishore *et al.*, 2007, *in press*), contains fauna and flora of much lower abundance and diversity. The foraminiferal fauna consists mainly of miliolids represented by *I. sinjarica* Grimsdale (Pl. I, fig. 1), *Quinqueloculina* sp. (Pl. I, fig. 2) and fragments of miliolids. The algal flora is characterised by few fragmented forms of corallines (such as *Sporolithon* and melobesioids) and abundant cyanophycean algal forms. e.g. *Rivularia* sp. (Pl. I, fig. 10).

CONCLUSIONS

The palaeontological studies of the preserved successions (lower, middle and upper) of the Ninniyur Formation by Misra *et al.* (2001) and Kishore *et al.* (2007, *in press*) indicate that their depositional environment ranged from shallow inner-ramp (seaward of beach barrier facies) to mid- uppermost outer-ramp due to fluctuating eustacy conditions, causing differentiation of faunal and algal communities. The sediments are believed to have been fine to medium-sized, forming soft to firm substrates, and the energy conditions may have varied from low through moderate and high to very high. The most obvious difference noticed between the inner-ramp and mid- to uppermost outer-ramp fossil assemblages is in the composition and dominance of foraminifera and calcareous algae and their growth-forms. Miliolids, textulariaceans, etc. and dasyclads and rare corallines characterise the deposits laid down in inner ramp (lagoonal) profiles, while the large number of coralline taxa and some planktic species are characteristic of the sediments interpreted to have been deposited in seaward locations (mid- to uppermost outer-ramp).

In the studied profiles, it is the miliolids and the associated fauna and flora that mainly constitute the fossil biota in all the three units of the Ninniyur Formation, and throughout the succession the inner-ramp environment appears to have been the common feature of sedimentation. As this environment was spatially restricted, it covered a small habitat-area (ecospace) showing only few possibilities of evolutionary diversification. Such an ecological setting resulted in a low-diversity biota which remained a dominant feature of evolution of benthic communities throughout the Ninniyur succession. It was during the accumulation of a part of the middle unit in the Periyakurichchi area (Fig. 2), however, that the depositional environment became deeper and shifted to mid- to uppermost

EXPLANATION OF PLATE I

1, 5. *Idalina sinjarica* Grimsdale

1, A-form, slightly oblique longitudinal section, Upper Unit, Sendurai (Sample No. Sen/5; Slide No. Y-15); 5, A-form, non centered longitudinal section showing embryonic apparatus, Middle Unit, Periyakurichchi (Sample No. Per/6; Slide No. Y-100).

3. **Unidentified rotaliid genus 2**, equatorial section showing trochospirally coiled form with thickened, canaliculate, radial, curved septa, and prominent umbilical flaps, Middle Unit, Ninniyur (Sample No. Nin/4; Slide No. Y-33).

2, 4, 6, 11. *Quinqueloculina* sp.

2, B-form ?, transverse section, Upper Unit, Sendurai (Sample No. Sen/14; Slide No. Y-174); 4, B-form ?, transverse section, Middle Unit, Periyakurichchi (Sample No. Per/5; Slide No. Y-

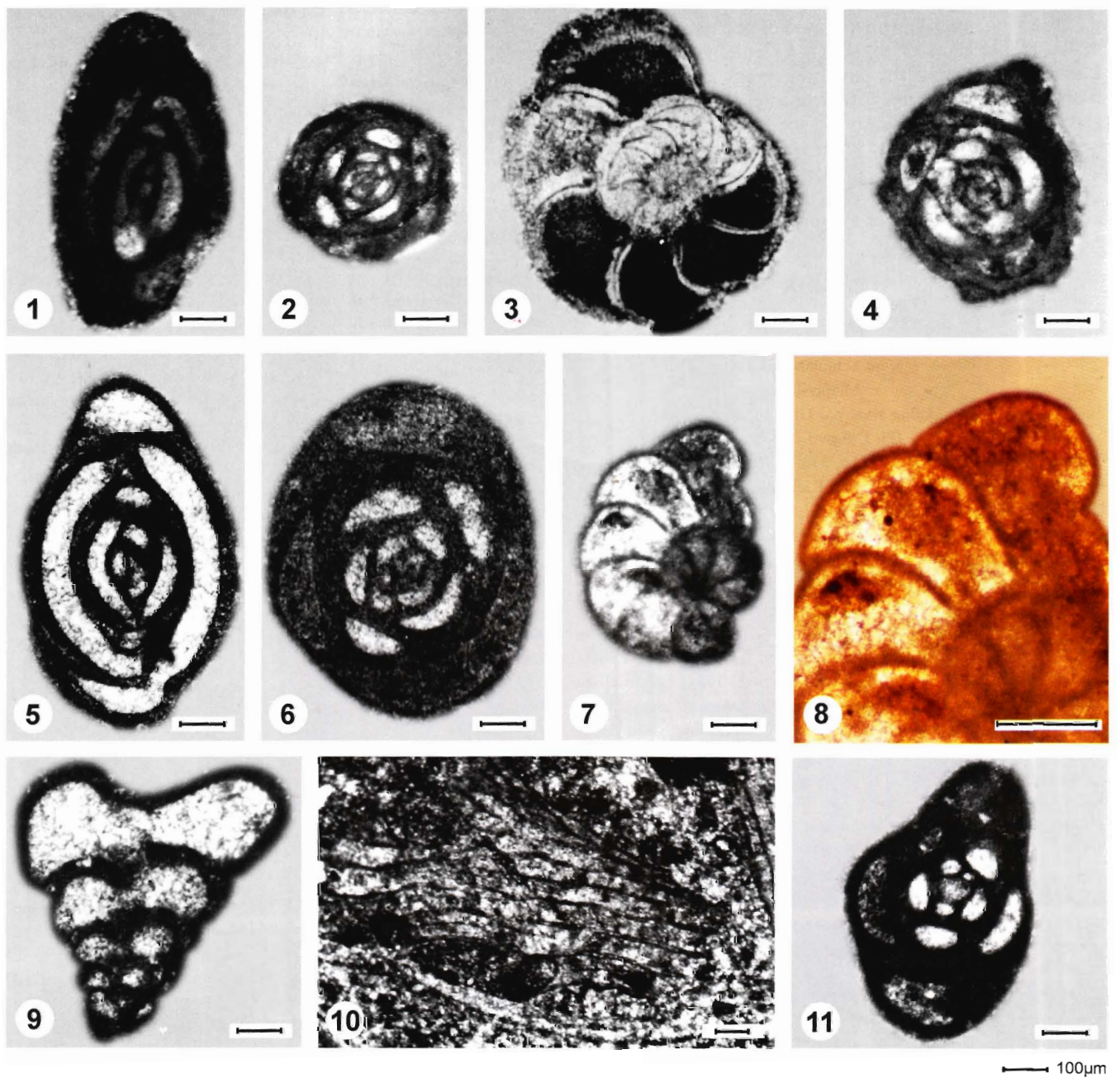
32); 6, B-form, oblique transverse sections, Middle Unit, Ninniyur (Sample No. Nin/7; Slide No. Y-11); 11, A-form, transverse section, Middle Unit, Periyakurichchi (Sample No. Per/5.6; Slide No. Y-34, 104).

7-8. **Unidentified rotaliid genus 1**

7, equatorial section showing spiral side of a low trochospirally coiled form showing radial septa bent backwards near the periphery, Middle Unit, Periyakurichchi (Sample No. Per /6; Slide No. Y-53/A); 8, Enlarged view of fig. 7 showing last three chambers and radial septa.

9. *Valvulina* sp., longitudinal section, Middle Unit, Ninniyur (Sample No. Per/5; Slide No. Y-56/PC).

10. **Cyanophycean algae** (*Rivularia* sp.) showing tubular structure Upper Unit, Sendurai (Sample No. Sen/8; Slide No. Y- 19).



outer-ramp locations of the sea. The resulting bathymetric change increased the ecospace which caused multiplication of microhabitats to give rise to the rich assemblages of coralline taxa and planktic species providing useful data for age determination and palaeoenvironmental interpretations.

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APPENDIX

Taxonomic Notes

Family **Hauerinidae** Schwager, 1876

Genus **Idalina** Schlumberger and

Munier-Chalmas, 1884

Idalina sinjarica Grimsdale

(Pl. I, figs. 1, 5)

Idalina sinjarica Grimsdale, 1952, p. 230, pl. 20, figs. 11-14. – Drobnc, 1974, p. 25, figs. 1-3, 6-13. – Serra-Kiel *et al.*, 1998, fig. 6. – Sirel, 1998, p. 55, 56, pl. 17, figs. 1-22.

Remarks: The megalospheric generation has an elongated ovoid test with maximum length of 0.70 mm and maximum width of 0.50 mm. The chambers are arranged bilocularly throughout ontogeny. The megalosphere and aperture have not been observed.

The material illustrated in Pl. I, figs. 1, 5 from south India compares with the forms described as *I. sinjarica* from the Palaeocene-Eocene (Thanctian-early Elerdian) of Yugoslavia (Drobnc, 1974) and from the Thanctian of Turkey (Sirel, 1998) in the arrangement of chambers.

Horizon: Ninniyur Formation, present in the middle and upper units (Palaeocene).

Locality: Sendurai and Periyakurichchi, Ariyalur district, Cauvery Basin, south India.

Genus **Quinqueloculina** d'Orbigny, 1826

Quinqueloculina sp.

(Pl. I, figs. 2, 4, 6, 11)

Remarks: The test is represented by oblique equatorial, longitudinal sections. Oblique equatorial section nearly circular to elongate in outline, 4.8 mm to 7.5 mm in diameter, A to B form; longitudinal section elongate oval, A form, with longer diameter 8 mm and shorter diameter 5 mm; chambers quinqueloculine.

Horizon: Ninniyur Formation, Middle and Upper Units, Subcrystalline Shelly Limestone (late Palaeocene, Thanctian).

Locality: Periyakurichchi, Ninniyur village and Sendurai, Ariyalur district, Cauvery Basin, south India.

Unidentified miliolid

(Pl. II, figs. 1-2)

Remarks: The test, with length between 0.44 mm and 0.56 mm and breadth between 0.25 mm and 0.30 mm, is large, narrow, elongate, fusiform. The chambers are quinqueloculine, two per whorl and one-half coil in length. The faintly visible aperture is terminal, cribrate.

Horizon: Ninniyur Formation, Lower Unit, Adanakkurichchi Limestone (early Palaeocene, Danian).

Locality: Adanakkurichchi, Ariyalur district, Cauvery Basin, south India.

Superfamily **Textulariacea** Ehrenberg, 1838

Family **Valvulinidae** Berthelin, 1880

Genus **Valvulina** d'Orbigny, 1826

Valvulina sp.

(Pl. I, fig. 9)

Remarks: The test is elongated, conical, with chambers trochospirally arranged in early stage, later becoming triserial. The last and the last-but-one whorls rapidly increase in size. The maximum length and breadth are 0.64 mm and 0.62 mm respectively. The wall is thick, agglutinated. The aperture is not visible.

Horizon: Ninniyur Formation, Middle Unit, Subcrystalline Shelly Limestone (late Palaeocene, Thanctian).

Locality: Ninniyur village, Ariyalur district, Cauvery Basin, south India.

Family **Textulariidae** Ehrenberg, 1880

Genus **Textularia** DeFrance, 1824

Textularia sp.

(Pl. II, fig. 3)

Remarks: The test is large, measuring 1.18 mm and 0.60 mm in length and breadth respectively. The wall is agglutinated and canalliculate. The initial stage is trochospiral, followed throughout by biserial stage. The aperture is not observed.

Horizon: Ninniyur Formation, Lower Unit, Adanakkurichchi Limestone (early Palaeocene, Danian).

Locality: Adanakkurichchi, Ariyalur district, Cauvery Basin, south India.

Family **Rotaliidae** Ehrenberg, 1952

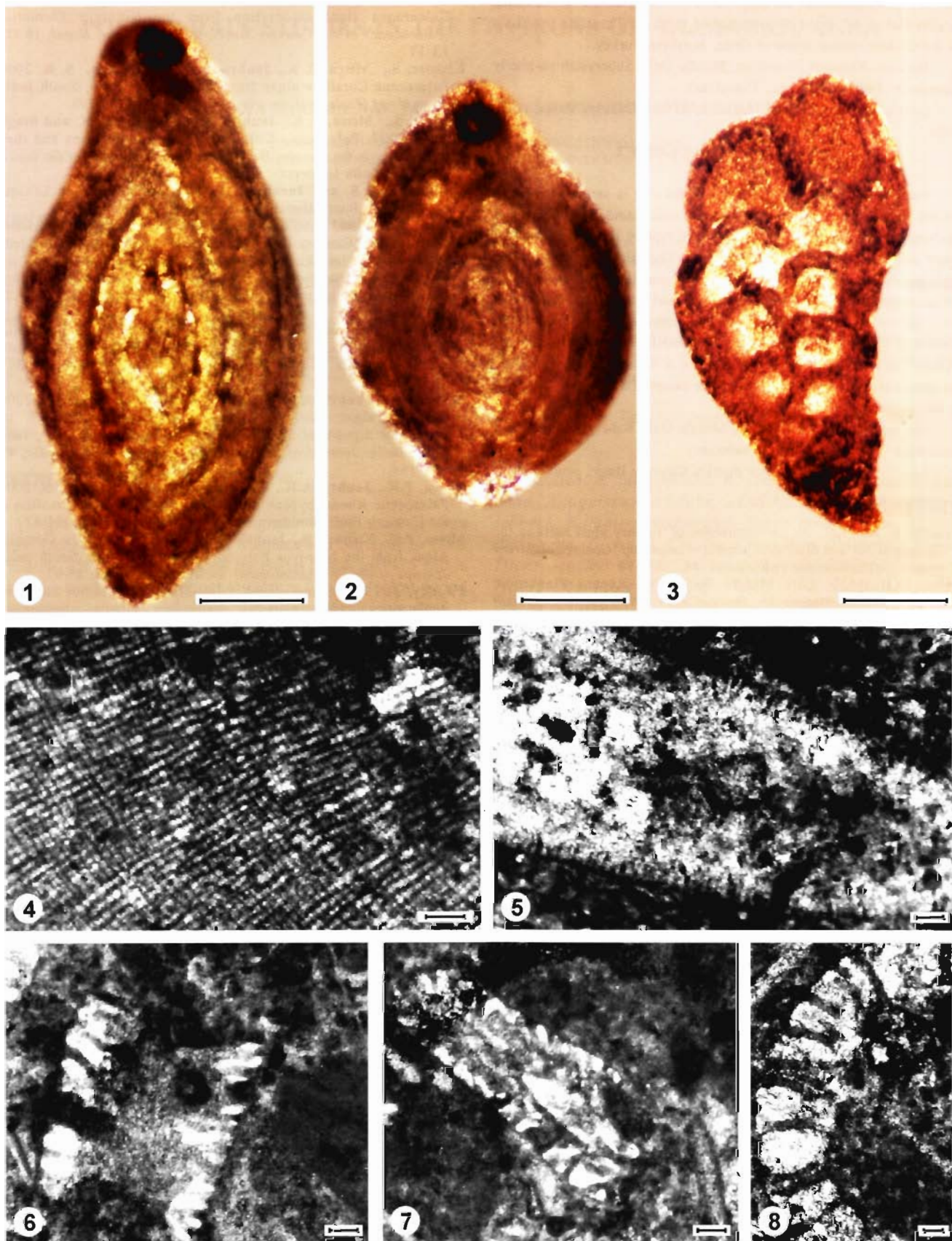
Unidentified rotaliid Genus 1

(Pl. I, figs. 7-8)

Remarks: The equatorial section of this form shows spiral side. It is characterised by small, low trochospirally coiled, discoidal test measuring 0.55 mm in length and 0.42 mm in breadth. The whorls rapidly increase in size with last three chambers of the last whorl enlarging rapidly. The last whorl contains higher than long chambers, the last chamber being 0.12 mm in length and 0.2 mm in height. The septa are radial and curved backwards near the periphery. The wall is calcareous, thin, finely perforate. The aperture is not clear, possibly a small slit at the base of the septum.

EXPLANATION OF PLATE II

- 1-2. **Unidentified miliolid**, longitudinal sections showing terminal, cribrate aperture, Lower Unit, Adanakkurichchi (Sample No. Ad/15; Slide No. Y-22).
3. **Textularia** sp., longitudinal section showing a large agglutinated test, canalliculated wall and the large, curved, thick septa, Lower Unit, Adanakkurichchi (Sample No. Ad/15; Slide No. Y-22).
4. **Solenopora** sp., Lower Unit, Adanakkurichchi (Sample No. Ad/6; Slide No. Y-99).
5. **Aalimeda** sp., Middle Unit, Periyakurichchi (Sample No. Per/5; Slide No. Y-87). 1985.
6. **Dissocladdella longijansis** Mu & Wang, Middle Unit, Periyakurichchi (Sample No. Per/6; Slide No. Y-33). 1998.
7. **Cymopolia satyavantii** (Pia) Radoicic, Middle Unit, Periyakurichchi (Sample No. Per/4; Slide No. Y-28).
8. **Gyroporella** sp., Middle Unit, Periyakurichchi (Sample No. Per/5; Slide No. Y-97).



It closely resembles the figs. 4,9,14 of Pl. 63 of the "unidentified rotaliid Genus" of Sirel (1998) described from the Thanctian limestone of the Gököy section south of Ordu, Northern Turkey.

Horizon: Ninniyur Formation, Middle Unit, Subcrystalline Shelly Limestone (late Palaeocene, Thanctian).

Locality: Periyakurichchi, Ariyalur district, Cauvery Basin, south India.

Unidentified rotaliid Genus 2

(Pl. I, fig. 3)

Remarks: The equatorial section of the test is small, circular in outline measuring 0.75 mm in diameter, with rounded periphery and trochospiral coiling. The whorls increase rapidly in size, with about seven inflated chambers in the last whorl. The thickened, canalliculate septa are radial, strongly curved; the septal canals are connected with the spiral canals of the chambers of the final whorl. Umbilical flaps cover the umbilical region. The wall is calcareous, bilamellar, radially fibrous in character. The aperture is a small slit at the base of the septum. The form appears to be a new taxon of foraminifera in possessing the umbilical flaps; but due to inadequate material it cannot be assigned to any genus.

Horizon: Ninniyur Formation, Middle Unit, Subcrystalline Shelly Limestone (late Palaeocene, Thanctian).

Locality: Ninniyur, Ariyalur district, Cauvery Basin, south India.

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