The Middle to Late Cretaceous microbiostratigraphy (foraminifera) and lithostratigraphy of the Cauvery Basin, Southeast India

by

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A thesis submitted to the University of Plymouth in partial fulfilment for the degree of

DOCTOR OF PHILOSOPHY

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June 1996
Abstract

The present research is on the Cretaceous microbio- and litho-stratigraphy of the Cauvery Basin, Southeast India. The planktonic and benthonic foraminifera are used to establish microbiostratigraphic zonations for the mid-Cretaceous succession in the Basin; leading to the first proposal of a benthonic foraminiferal zonation scheme. The schemes are primarily defined for regional application. In the absence of a formal lithostratigraphic classification for the Cretaceous succession in the Basin, a revised lithostratigraphy, in line with standard stratigraphic procedure, is proposed.

The systematic taxonomy of the foraminifera studied is documented and revised in line with Western standards. The study shows that, in contrast to the standard European forms, the fauna from the Cauvery Basin is composed of more robust individuals. The study also shows some interesting differences in the planktonic foraminifera from the standard Tethyan assemblage. Comparative studies indicate a longer time range for some of the "index" species and more ornamented forms in the Cauvery Basin.

The study records two levels, (1) in the late Albian and (2) from the late Cenomanian to mid-Turonian, when anoxic conditions developed in the Basin. These anoxic events record major taxonomic changes in the planktonic foraminiferal assemblage. The study shows that the anoxic events had a major affect on the microfaunal community and that the post anoxic microfaunal population was dominated by more robust and heavily ornamented individuals. The planktonic foraminifera are used to identify the mid-Cretaceous sea-level changes in the Basin. The pattern of evolution and expansion of the planktonic foraminifera suggest a continuously rising sea-level in the mid-Cretaceous; with four periods of major transgressions. These levels are, at the late Albian, mid-Cenomanian, late Cenomanian-early Turonian and mid-Turonian. The pattern of sea-level changes in the Cauvery Basin followed, in general, the global sea-level curve, but has been influenced by local factors particularly tectonics.

A pilot study demonstrates how palaeontology (including ichnology) in conjunction with sedimentology and stratigraphy is used to apply sequence stratigraphy concepts to the late Turonian-Coniacian succession in the Basin. A comprehensive study of Teredolites-infested fossil wood documents the morphological characters of the wood and its palaeoenvironmental significance. The study shows that there exists a close link between the influx of the fossil wood and sea-level dynamics.
Declaration

This is to certify that the work submitted for the Degree of Doctor of Philosophy under the title “The Middle to Late Cretaceous microbiostratigraphy (foraminifera) and lithostratigraphy of the Cauvery Basin, Southeast India” is the result of original work. All authors and works consulted are fully acknowledged. No part of this work has been accepted and/or submitted in substance for any other degree, nor is it being currently submitted for candidature for any other degree.

During the course of this research the following papers have been published or submitted for publication on the results obtained:


Copies of the published papers are bound into this thesis as Appendix 1.

Candidate
Archana Tewari
Archana Tewari

Research Supervisors
Prof. Malcolm B. Hart
Dr Matthew P. Watkinson
to my parents with love
Acknowledgements

This research was conducted as a “Nehru Centenary British Fellowship” holder (December 1992 - June 1996) sponsored by the British Council, at the University of Plymouth under the supervision of Prof. Malcolm B. Hart. During the course of study several people have helped. Whilst it is impossible to mention each individual, the support of all those involved is acknowledged with sincere appreciation.

The author is grateful for the study grant made available from the British Council and the supervision of Prof. Malcolm B. Hart, without the two this research would not have been accomplished. Throughout the course of research the guidance, encouragement and attention given by my supervisor Prof. Hart was overwhelming. The persistent interest, enduring patience and unreserved support of Malcolm helped me through the daunting moments of the course. I thank Dr. Mathew P. Watkinson for co-supervising this research. The stimulating discussions and positive criticism by both the supervisors has added to the quality of this research.

I thank the following scientists and technical staff for their contributions. Their help has been indispensable in the final completion of this work.

Field assistance: Prof. M.B. Hart & Dr. M.P. Watkinson (University of Plymouth); Dr. Govindan, Dr. Pandian & Dr. Ravindran (Oil and Natural Gas Commission); Dr. Venkatachalapathy (Madras University) and Mr. Lakshminarayanan (Dalmia Cement Company).

Macrofossil identification: Dr. M. Thomson of British Antarctic Survey Group & Prof. P. Bengston of Heidelberg University (ammonites); Dr. P. Doyle of Greenwich University (belemnites) and Dr. P. Skelton of Open University (rudist bivalves).

Palynological studies: Paul Dodsworth of Sheffield University.

Thin section foraminiferal study: Prof. M.B. Hart.

Translating French and German text: Prof. M.B. Hart.


Technical assistance: J. Abraham (drafting Figures 2.1, 2.9, 3.2, 5.1, 6.1, 7.1-7.3 and Tables 3.1 & 3.2); M. Ashton (thin sections); M. Grimbly (micro-photography);
A. Smith & D. Griffiths (photography); B. Lakey, R. Moate & J. Green (scanning electron micro-photography); D. Peacock & H. Shi (computer) and J. Brown & Ian Norton (inter-library loan).

The staff of the Department of Geological Sciences, University of Plymouth are thanked for making me feel welcomed. Don Tarling and David Peacock are acknowledged for their advice and encouragement during the course and their honest opinion on the text they read. Jim Griffiths, Marylyn Luscott-Evans and Maureen Loton are thanked for all their favours. Philip Green, Sheila Stubbles, Meriel Fitzpatrick, Peter Bell and the staff at the International Office (University of Plymouth) are thanked for helping me to adjust to the social and the academic life in Plymouth.

Finally I would like to extend my personal gratitude to the people whose silent presence has been of greatest assistance. The warmth and the affection I received from my landlady Maria and the landlord Nicholas have been humbling. I feel privileged to have enjoyed the luxury of parental attention out of home. The personal attention of “The Security” (University of Plymouth) towards my safety, during my out-of-hours working schedule, is very much appreciated. Dr. & Mrs. Saha; Margaret Stevens & family and Carole Wright are thanked for their thoughtfulness. The overwhelming flow of letters, cards and “remembering you” notes from my family and friends in India were always a welcome relief.

Last but not the least I thank my parents. My mother’s trust and my father’s memories are the bedrock of this achievement. During solitary, dark nights of lost confidence their thought has been my only strength. I dedicate this work to my parents.
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Chapter 1

Introduction
1.1 Introduction

The Cretaceous sediments of the Cauvery Basin have been investigated since the mid-nineteenth century. Since then, various workers (see Section 1.4) have contributed to the understanding of the bio- and litho-stratigraphy of the Basin. Despite intensive research, opinions, in general, amongst the workers are divided and the stratigraphy of the Basin, as it stands at the present time, remains much the same as that established in the mid-nineteenth century. A need, therefore, exists to take a fresh look into the existing stratigraphy of the Basin. The present research was directed towards a more comprehensive understanding of the microbio- and litho-stratigraphy of the Basin.

1.2 Scope of the research

The principal objectives of the research were:

1. Systematic taxonomy (in line with Western standards) with a record of relative abundance of the planktonic and benthonic foraminifera, curation of a type collection and the scanning electron photomicrographic record of the species (see Chapter 4).

2. To establish the mid-Cretaceous foraminiferal microbiostratigraphy (foraminifera) for regional application, which can be correlated with other well established schemes (see Chapter 5).

3. To study the affect of the mid-Cretaceous oceanic anoxic events on the planktonic foraminifera and the use of the planktonic foraminifera to identify the mid-Cretaceous sea-level changes in the Cauvery Basin (see Chapter 6).

4. To revise the existing Cretaceous lithostratigraphy of the Basin (see Chapter 3).
The secondary objective of the research was:

1. Application of ichnology to sequence stratigraphy concepts to the late Turonian-Coniacian Garudamangalam Sandstone Formation (see Chapter 7).

1.3 Experimental and analytical procedures

A major part of this research has been carried out on the field sampling of the Cretaceous sediments of the Cauvery Basin. During the course of field work the toposheets used are 58I/16, 58J/13, 58M/3, 58M/4 and 58N/1, published by the Geological Survey of India in 1932. Throughout the study notes were made on lithology, stratigraphy, trace fossil assemblages and macrofauna associated with the different lithostratigraphic units. A systematic photographic record and plotting (using GPS (Global Positioning System)) of sampled localities was made. All the outcropping localities sampled are plotted in Figure 2.9. Micropalaeontological studies on the samples collected in the outcrop and obtained from well sections (see Section 1.3.1) were conducted. The procedure followed during the course of research was as follows:

1.3.1 Sample collection

Since this research is based on the outcrop study it is considered appropriate to mention, briefly, the two major problems encountered in sample collection. Firstly, a general lack of continuity and/or good outcrop sections, together with a poor accessibility to localities are a major hurdle in the field. Many of the previously described localities (e.g., Subbaraman 1968, Srivastava & Tewari 1969, Ravindran 1980, etc.) have been lost to expanding settlements, are permanently water logged or are covered under vegetation. This is especially true for the Upper Cretaceous succession (e.g., outcrops of the Sillakudi Sandstone Formation- Section 3.4.3.(i)), where accessibility to and availability of good outcrop sections is greatly reduced. Complete sections are available only where working and/or abandoned quarries exist.
For most of the study, therefore, spot samples were collected to cover the lithostratigraphic units in the Basin. Absence of motorable roads and public transport adds to the difficulty in reaching the outcrop sections. It is worth mentioning here that, in the paucity of complete maps and proper landmarks, the use of GPS is indispensable. Without a GPS it is impossible to find the exact position of sections in the field and the construction of maps and diagrams. Secondly, tropical weathering (high heat and humidity) associated with these latitudes has contributed to a major disadvantage, especially in palynological studies (see point 5 in Section 1.3.3 for details). The typical tropical climate (hot and humid) has resulted in the development of badlands, e.g., the area occupied by the Karai Clay Formation (see Section 3.4.2.(ii)) represents a monotonous, badland topography.

During two successive field visits in February 1994 and March 1995 respectively, 186 samples representing all lithostratigraphical units in the Basin were collected. In badly weathered localities the surface was dug to reach fresh, unweathered surfaces for sample collection. The field work was carried out in assistance with Prof. Hart & Dr. Watkinson (Plymouth University); Dr. Govindan, Dr. Ravindran & Dr. Pandian (Oil & Natural Gas Commission (O.N.G.C.)) Madras; Dr. Venkatachalapathy (Madras University) and Mr. Lakshminarayanan (Dalmia Cement Company). A further 20 samples, across the Cenomanian-Turonian boundary, from the Karai-Kulakkalnattam traverse (Fig. 2.9), were provided by Dr. Venkatachalapathy, University of Madras (India). Two samples of the Grey Shale Member (see Section 3.4.2.(i.a)) were provided by Dr. Ramasamy (Madras University) and Mr. Lakshminarayanan (Dalmia Cement Company). The core-section from Periya-Patiakkadu (Fig. 2.9) was made available by Mr. Lakshminarayanan to study the Sillakudi-Kallanakuruchchi contact (see Section 3.4.3.(ii)). The outcrop study was complemented with 39 samples obtained from three on-shore, 120 meter deep well sections (Karai wells-3, 4 & 6; Fig. 6.1) provided by the Utrecht University, The Netherlands. The Karai core-samples were curated in the core-library of the Utrecht University by Dr. Raju of O.N.G.C. during his study visit to the Utrecht University in the 1970's.
1.3.2 Sample preparation

Three methods, dictated by the hardness and the ease with which the samples disaggregated, were employed in the present study.

1.3.2.(i) Processing of samples

The soft claystones and unconsolidated or poorly cemented siltstones and sandstones were processed in the following way:

1. Small lumps (average 200 gms of dry sample weight) of the sample were soaked thoroughly in distilled water for a minimum period of twenty-four hours. This generally soaked the sample which then disaggregated on gently rubbing and stirring the sample with finger tips. Where the disaggregation was incomplete the sample was left to soak for another twenty-four hours or more if needed. This ultimately disaggregated the sample.

2. The sample was then washed through a 63 micron sieve to remove the fine material.

3. The residue was then dried in two steps. First the residue was dried at 60°C for approximately 5 to 7 hours till a thick soupy consistency was reached. It (residue) was then transferred to the oven operating at approximately 15°C. Drying the residue in two steps avoided the clays to get hard on drying.

4. The dry residue was sieved through a series of standard size meshes measuring 500, 250, 125 and 63 micron fraction size. The finest material, collected in a basal sieve pan, was retained separately. There are three reasons for selecting the four mesh sizes in the present study:
   (a) The use of 500 micron mesh stopped the very large benthonic foraminifera, dominated by a low diversity and high abundance (99% of the total foraminiferal population) _Lenticulina_ Cushman from entering the 250 micron mesh size. This reduced the otherwise occurring improper representation of benthonic and...
planktonic foraminifera (in the 301 count (see point 5 below) in 250 fraction size) to a minimum.

(b) It is well established, e.g., Hart 1973, Hart & Carter 1975, Bailey 1978, etc. (also observed in the present study), that the adult stages of a majority of foraminiferal species occur within the 250 micron size fraction.

(c) It is observed (e.g., Bailey 1978, Koutsoukos 1989, this study) that several of the stratigraphically significant foraminiferal species occur, however, in finer fractions. The study of foraminiferal assemblages in the 125 and 63 micron fraction size are, therefore, important in biostratigraphical studies.

The selection of four mesh sizes was therefore considered best to meet the objective set for the present research.

5. From each fraction size 301 complete specimens were picked. The specimens were then mounted on a 32 square microfaunal slide for later reference and detailed examination. Where the 301 count was not met the whole fraction was used.

Throughout this procedure (stages 1 to 5) care was taken to ensure that all the equipment used was clean and was not being used for any other laboratory purpose. This was to reduce the risk of contamination to its minimum. The sample and sample fractions were weighed at each stage. This was considered appropriate if, at any stage of this study or for future reference, a quantitative analysis is considered.

1.3.2.(ii) Thin section preparation

As a result of the hardness of compact limestones, well cemented sandstones and fossil wood, thin sections were prepared for microfaunal and petrographic studies. The identification of foraminifera in thin section is a specialised and an independent branch of micropalaeontology. The method (thin section study) has its value, especially where the conventional methods of sample preparation are not viable, as is the case (in part) with this study. In the present study, as a non-specialist in thin section foraminiferal study, only limited observations were possible. The study (identifying foraminifera in
thin section) was done with the help of Prof. M.B. Hart. Thin section of rocks and fossil wood of standard thickness of 0.03 mm were prepared (by Mike Ashton) in the rock cutting laboratory of the Department of Geological Sciences, University of Plymouth. Three mutually perpendicular sections of rock samples and one section of fossil wood were prepared. One thin section each of the rock samples was treated with Dickson’s stain to facilitate petrographic studies.

1.3.2.(iii) Lapped sections

The fossil wood samples were lapped (by Mike Ashton) and coated with varnish in the rock cutting laboratory of the Department of Geological Sciences, University of Plymouth.

1.3.3 Examination and analysis

The following analytical technique has been followed in the present research:

1. Detailed study of the prepared microfaunal slides (see point 5 in Section 1.3.2.(i)) was conducted. This included examining the morphology, keeping a numerical record of the diversity and the abundance of foraminiferal species and recording the first and the last appearances of planktonic and benthonic species. Standard reference slides were subsequently made for each foraminiferal species. Type representatives of each species (including representatives showing any variation in the morphologic characters of species) were picked and mounted on a single-celled microfaunal slide. The standard reference slides form the private collection of the author. A selected standard slides (all planktonic and some benthonic foraminifera) were duplicated and are in the microfossil collection of the Department of Geological Sciences, University of Plymouth.

2. Having made a record of the absolute number of each foraminiferal species, the information was used to compile planktonic:benthonic ratio, agglutinated:calcareous
ratio, planktonic percentage and benthonic diversity graphs (Figures 6.2 & 6.3). Stratigraphic range chart representing relative abundance of the species against the biozonation scheme adopted in the present study was made (Tables 5.3 & 5.4). A comparative study, looking into the general trend (abundance, diversity and morphologic characters) in foraminiferal assemblages before, during and after the mid-Cretaceous oceanic anoxic events was made. The count from the 500 micron fraction size was not used for numerical and graphical analysis but the fauna was examined for the purpose of taxonomy.

3. Thin sections were studied under a petrographic microscope for microfaunal and petrographic information.

4. The macrofauna collected during the field work were sent to the specialists in the respective fields.

5. In a pilot scheme, palynological study (P. Dodsworth pers. comm.) on 40 samples was carried out in the Centre of Palynological Studies, University of Sheffield. Except for some wood fragments (most resistant phytoclasts) the samples were barren of palynomorphs. The rational explanation (K. Dorning & P. Dodsworth pers. comm.) to this could be a high susceptibility of palynomorphs to the tropical weathering associated with these latitudes.

1.3.4 Photography

During the course of the research, scanning electron microphotography, thin section photography and macrofossil photography was conducted. Type representatives of each species were photographed with a scanning electron microscope. Selected specimens were mounted on standard copper stubs (initially coated with a double sided sellotape) and shadow coated with approximately $10^6$ A of gold. The specimens were then observed on a JEOL (JSM-5200) SEM, operated at 20 Kv. Thin sections were photographed with an Olympus research microscope using an Olympus photomicrographic system. The macrofossils (including the fossil wood) collected during the course of the field work were systematically photographed by Antony Smith.
and David Griffiths of Media Services, University of Plymouth. This was complemented with the regular photographs taken during the course of field work.

1.4 Previous studies

Chapter 2

Development and architecture of the Cauvery Basin
2.1 Introduction

The break-up of East Gondwanaland (India, Australia and Antarctica) in the late Mesozoic was responsible for the development of the Indian Ocean (Johnson et al. 1976, Powell et al. 1988, Tarling 1988, Moores 1991). Major changes in the plate configuration took place which influenced the Cretaceous palaeogeography of the Indian sub-continent. New sedimentary basins developed and two episodes of widespread flood-basalt extrusions occurred (Acharyya & Lahiri 1991). The Cretaceous basins of the east coast of India cut across the NW-trending, Permian-Triassic Gondwana grabens (Sastri et al. 1973, 1981). They are often precursors of the Tertiary basins and present-day shelves. Others were intra-cratonic basins, occurring as narrow troughs which were later flooded by the Deccan basalts. Figure 2.1 shows the distribution of the Cretaceous rocks in the Indian sub-continent, together with the approximate location of the Cauvery Basin in the enclosed box.

2.2 Break-up of East Gondwanaland and development of the Cauvery Basin

India was joined with Australia and Antarctica until the late Jurassic-early Cretaceous (Fig. 2.2). The break-up of East Gondwanaland, in the late Mesozoic, initiated the opening of Indian Ocean (Johnson et al. 1976, Powell et al. 1988, Tarling 1988, Moores 1991). The late Jurassic-early Cretaceous rifting between India and Australia-Antarctica developed a number of NE-SW trending half grabens in the Indian Precambrian crystalline basement. Powell et al. (1988) suggested a significant amount of continental extension prior to any sea-floor spreading. The reconstructions suggest the break-up of East Gondwanaland, first by continental extension and then by the growth of the Indian Ocean. Unfortunately, geophysical data are incomplete or known only within broad limits, especially along the east coast of India. All attempts by workers (e.g., Johnson et al. 1976, Powell et al. 1988, Tarling 1988, Moores 1991,
Figure 2.1: Distribution of the Cretaceous rocks in the Indian sub-continent (after Acharyya & Lahiri 1991). The approximate position of the Cauvery Basin is shown in the enclosed box.
Figure 2.2: Reconstruction of East Gondwanaland prior to any continental extension (based on Powell et al. 1988).

Figure 2.3: Reconstruction of East Gondwanaland after the onset of continental extension. Small circles and arrows indicate relative rotation directions between pairs of continental fragments. Heavy stipple indicates the amount of continental extension; light stipple shows the continental extension distributed over the entire area (based on Powell et al. 1988).
etc.) at reconstructing East Gondwanaland are, therefore, a compromise, requiring improvement in the future.

2.2.1 Continental extension phase

It is established (Powell et al. 1988, Tarling 1988) that a significant amount of continental lithosphere stretching occurred prior to the onset of any sea-floor spreading between the East Gondwanaland continental fragments. Extension of continental crust by up to 360 km occurred prior to the mid-Cretaceous (96 Ma) onset of sea-floor spreading between Australia and Antarctica. This large amount of continental extension was restricted to the late Jurassic-middle Cretaceous interval. Powell et al. (1988) suggested that this lithosphere stretching occurred in two stages, (1) from 160 to 132.5 Ma and (2) from 132.5 to 96 Ma. This pre-break-up continental extension loosened the fit between the continents and could have produced significant structures in the extended continental crust (Powell et al. 1988).

Figure 2.2 shows the reconstruction of India, Australia and Antarctica, prior to any continental extension. In the first stage of lithospheric stretching, from 160 to 132.5 Ma, India-Australia rotated from Antarctica with continental extension between Australia and Antarctica and largely transform motion between the south-eastern coastal margin of India and the western margin of Antarctica. In the earliest Cretaceous there was continental extension (without any generation of oceanic crust) between India, Australia and Antarctica (Fig. 2.3). Powell et al. (1988) observe a remarkable linear bathymetry between the margins of western Antarctica and south-east coast of India. This fit and approximately close bathymetry between the conjugate margins of Antarctica and India suggest that they formed as a transform boundary. Powell et al. (1988) propose a transform origin to this boundary. In the earliest Cretaceous (132.5 Ma) the southern half of the east coast of India slid along a dextral fault (Fig. 2.3). The transform motion between India and Antarctica developed a number of NE-SW trending half-grabens in the Indian Precambrian crystalline basement. At the same time
it was assumed (Powell et al. 1988) that, between India and Australia, there was a small amount of extension in an E-W direction, normal to the graben boundaries. This led to the development of NE-SW trending east coast basins (including the Cauvery Basin), cut by E-W trending faults, in the late Mesozoic. These Mesozoic basins, along the eastern margin of India, cut across the NW-trending Permian-Triassic Gondwana grabens (Sastri et al. 1981). In the second stage of stretching, from 132.5 to 96 Ma, India rotated away from Australia-Antarctica (Fig. 2.4). This marked the early Cretaceous break-up of India from Australia and Antarctica.

2.2.2 Sea-floor spreading phase

Between 132.5 to 96 Ma, India rotated north-westwards away from Australia-Antarctica (Powell et al. 1988). The break-up of India from Australia and Antarctica occurred a little earlier, at 132.5 Ma. By 118 Ma India was a little less than half way through the first phase of sea-floor spreading while continental stretching continued between Australia and Antarctica (Fig. 2.4). This marks the opening of the Indian Ocean. At the end of the first phase of sea-floor spreading between India and Australia-Antarctica (at 96 Ma), India was probably in a position with suitable orientation to begin its rapid northward movement from Australia and Antarctica (Fig. 2.5). A major change in the spreading pattern occurred in the mid-Cretaceous (Cenomanian). Up to then, India was rotating northwards from Australia-Antarctica, while Australia and Antarctica separated by continental extension. At 96 Ma (Fig. 2.5) India began a rapid northward movement away from Australia-Antarctica with a realignment of the spreading ridges between India and Australia-Antarctica and formation of new spreading ridges between Australia and Antarctica.

2.3 The Cauvery Basin architecture

This is a NE-SW trending, block-faulted basin, with a horst-graben basin architecture (Ramanathan 1968, Sastri et al. 1973, 1981). The Basin covers an area of about
Figure 2.4: Reconstruction of East Gondwanaland at 118 Ma. Symbols as described for Fig. 2.3 (based on Powell et al. 1988).

Figure 2.5: Reconstruction of East Gondwanaland at the end of first phase of spreading in the Indian Ocean and at the end of continental extension between Australia and Antarctica. Symbols as described for Fig. 2.3 (based on Powell et al. 1988).
25,000 km² on land and approximately 17,500 km² off-shore, between Pondicherry in the north and Ramanathapuram in the south (Fig. 2.6). The depth of the crystalline basement does not exceed more than 4.5 km anywhere, but may reach nearly 6 km in certain off-shore parts of the Basin. The Basin is limited to the west by outcrops of the igneous and metamorphic rocks of the Indian Archaean Shield. North of the latitude 10° the Basin opens into the present off-shore area of Bay of Bengal (Sastri et al. 1973, 1981). To the south, it is limited to the east and south-east by the Archaean crystalline massifs of Sri-Lanka and occupies a sizeable area under the waters of Palk-Strait and the north-western part of Sri-Lanka island (Fig. 2.6).

Geophysical surveys and drilling by the Oil and Natural Gas Commission (O.N.G.C.) of India has established that the Basin comprises several depressions or sub-basins (Ramanathan 1968, Sastri et al. 1973, 1981) separated by buried basement ridges, delimited by faults (Fig. 2.7). These ridges are mostly aligned in a NE-SW direction, while a few are somewhat tangential and follow a N-S trend. Tectonically the floors of the depressions (sub-basins) have been subsiding along the marginal synsedimentary faults throughout most of the Cretaceous period. The nomenclature terms for these depressions and ridges, from north to south of the Basin, are as follows (Fig. 2.7):

- Ariyalur-Pondicherry depression.
- Kumbakonam-Shiyali ridge (K-S ridge) and Madanam high.
- Thanjavur depression and Tranquebar depression.
- Karaikal high.
- Tirururaindu depression.
- Thirupunundi-Vedaranniya ridge (T-V ridge).
- Devakottai-Mannargudi ridge (D-M ridge).
- Ramanathpuram depression.
Figure 2.6: Geological map of the Cauvery Basin showing different outcropping areas (after Sastri & Raiverman 1968).
Figure 2.7: Basement configuration map of the Cauvery Basin showing the ridges and depressions (after Sastri et al. 1979).
2.4 The Ariyalur-Pondicherry depression

This is the most northerly depression in the Basin (Fig. 2.7). It is largest in terms of area and is triangular in shape. To its north the depression is bounded by Archaean crystallines and to its south by Kumbakonam-Shiyali ridge (K-S ridge). The depression opens to the present Bay of Bengal to its east. The Ariyalur-Pondicherry depression (Fig. 2.8) contains three important Mesozoic-Tertiary outcrops- at Pondicherry, Vridhanchalam and Ariyalur, as followed from north to south-west (Sastri et al. 1973, 1981). The Cretaceous succession is best exposed in the Ariyalur outcrop (Fig. 2.8).

The present study concentrates on the work carried out on the Ariyalur outcrop (Fig. 2.8) of the Trichinopoly District. Figure 2.9 shows the geological map of the Ariyalur outcrop (based on Sundaram & Rao 1986, Ramasamy & Banerji 1991 and Geological Survey of India) together with the localities studied. The lithostratigraphy is that based on the present study (see Chapter 3 for details).
Figure 2.8: Geological map of Ariyalur-Pondicherry sub-basin showing different outcropping areas (based on Sastry & Rao 1964).
Figure 2.9: Geological map of the Ariyalur outcrop (based on Sundaram & Rao 1986, Ramasamy & Banerji 1991, Geological Survey of India) together with the localities studied. The lithostratigraphy is that based on the present study.
Chapter 3

A revised lithostratigraphic classification for the Cretaceous succession (on-shore part) in the Cauvery Basin.
Stratigraphy is the study and description of rock successions (Hedberg 1976, Holland et al. 1978, Commission A.A.P.G. 1983, Whittaker et al. 1992). The objective of a stratigraphic classification is the understanding of the geometry and the sequence of rock bodies. The classification aims to distinguish a naturally occurring body of rock from the adjoining rock on the basis of some distinguishing features. The properties that characterise a unit include composition, texture, included fossils, magnetic signature, radioactivity, seismic velocity and age. Care should be taken while defining a rock unit. A unit should be described so clearly that a subsequent investigator can recognise the unit unequivocally (Hedberg 1976, Holland et al. 1978, Commission A.A.P.G. 1983, Whittaker et al. 1992). The three principal approaches to stratigraphy are lithostratigraphy, biostratigraphy and chronostratigraphy. Other methods in stratigraphy, e.g., magnetostratigraphy, geophysical log stratigraphy, seismic stratigraphy, etc., augment the stratigraphic practice (Whittaker et al. 1992).

Lithostratigraphy is the description, definition and naming of rock units. "It is fundamental to all other branches of stratigraphy because accuracy in, for example, biostratigraphy and chronostratigraphy relies on the correct recognition of spatial relationships (both vertical and lateral) of rock units", Whittaker et al. (1992, p. 813). A lithostratigraphic unit generally confirms to the law of superposition and is commonly stratified and tabular in form. It is independent of inferred geologic history, depositional environment and biological sequences. A lithostratigraphic unit is distinguished and delimited only on its gross lithological characters and stratigraphic position. Nevertheless, petrography, geochemistry, general fossil content and ichnofossil information can be included as a supplement or even a requisite. Palaeontological information may be valuable during mapping, in distinguishing two lithostratigraphically similar, non-contiguous lithostratigraphic units. The basic hierarchy in a lithostratigraphic classification consists of supergroup, group, formation,
3.2 Justification for a revision of the existing lithostratigraphic classifications in the Cauvery Basin

The Cretaceous succession (on-shore part) of the Cauvery Basin has been the subject of intensive research since the early studies of Blanford 1862 (published in 1865), Stoliczka 1870-1871 and Kossmat 1897. During that time a number of stratigraphic units have become well-established, almost by historical precedent. Since then, various workers (e.g., Rama Rao 1956, Tewari & Srivastava 1965, Bhatia & Jain 1969, Srivastava & Tewari 1969, Sastry & Mamgain 1971, Banerji 1973, 1982, Jain 1976, Sastri et al. 1973, 1977, Nair 1974, Rasheed & Ravindran 1978, Banerji & Sastri 1979, Sundaram & Rao 1979, 1986, Rasheed 1981, Chiplonkar 1985, Ramasamy & Banerji 1991, etc.) have established major lithostratigraphic units for the Cretaceous succession in the Cauvery Basin. A majority of the workers, while proposing new terms and age ranges for these rocks have, however, failed to acknowledge (in most cases) any of the previously published work. Foraminifera (e.g., Sastri et al. 1968, Sastry et al. 1968, Banerji & Mohan 1970, Banerji 1973, Narayanan 1977, Govindan 1978, Rasheed & Ravindran 1978, Ravindran 1980, Venkatachalapathy & Ragothaman 1995, Govindan et al. 1996), ammonites (e.g., Chiplonkar & Phansalkar 1976, Ayyasami & Rao 1978, Phansalkar & Kumar 1983a,b, Ayyasami & Banerji 1984, Chiplonkar 1985, Ayyasami 1990) and nannofossils (Kale & Phansalkar 1992) have been used for the biostratigraphic zonation and the age determination of these rocks. There is, therefore, a plethora of stratigraphic terms in current usage with many authors continuing to use their own classification almost regardless of other work.

Attempts, in the past, have been made, e.g., Sastry & Mamgain 1971, Jain 1976, Rasheed 1981, Chiplonkar 1985, Raju & Mishra 1996, etc., to review the stratigraphy
of the Cauvery Basin. Despite the vast amount of work done, the lithostratigraphy of the Basin, as it stands at the present time, remains much the same as that established by Blanford, 1862 (in 1865). There are three key reasons for this state of affairs. While it is generally appreciated that there are major facies changes in the area there is still a reluctance to recognise this in the lithostratigraphic classifications employed. This has meant that, in some cases, natural lithological groupings have been ignored. In the lower part of the succession, therefore, one has to establish a lithostratigraphy for a more basinal succession (clay and siltstone dominant) together with a more shallow-water succession, largely composed of carbonates, calcareous sandstones and siltstones. The second problem has been the lack of a proper understanding of the mid-Cretaceous faulting seen at numerous localities in the Basin (especially at the western end of the Kovandakuruchchi quarry-2 (Fig. 3.1) where the Archaean basement is in contact with mid-Cretaceous calcareous sandstone and in the Kallakudi quarry-2 (Fig. 3.1) where the shape of the pink limestone outcrop is fault controlled (as discussed later) and not due to its "reefal" structure. Around the margin of the Basin this mid-Cretaceous faulting has generated a large number of massive debris flow deposits, which mainly contain massive blocks of pink limestone (e.g., in Olaipadi, Neykulam and Tiruppattur quarries, Fig. 3.2) together with rare (and smaller) blocks of Archaean basement. In other places, massive conglomerates, composed exclusively of Precambrian clasts, cobbles and boulders (e.g., trench section in Kovandakuruchchi quarry-2, Fig. 3.1) represent an unrelated depositional system. A lack of understanding of the effect the mid-Cretaceous faulting had on the deposition in the Basin has resulted in some gross misinterpretation (as discussed later) of the lithofacies relationships. The third problem which besets the lithostratigraphical classification has been an insufficient sedimentological analysis, including the recognition of different sedimentary architectures and the relevance of many of the trace fossil assemblages. Failure to recognise key sedimentary features for what they are has lead to major errors in interpretation.

An approach for a more comprehensive lithostratigraphic classification of these rocks
Figure 3.1: Sketch map of the area around Dalmiapuram showing the positions of the Kallakudi and the Kovandakuruchchi quarries (modified after Subbaraman 1968).
Figure 3.2: Geological map of the Ariyalur outcrop (based on Sundaram & Rao 1986, Ramasamy & Banerji 1991, Geological Survey of India) together with the localities studied. The lithostratigraphy is that discussed in this Chapter.
was taken by Sundaram & Rao in 1979 (later revised in 1986); but it was Ramasamy & Banerji (1991) who attempted a formal definition of lithological characteristics with reference to type localities/sections in accordance with current practice (Hedberg 1976, Holland et al. 1978, Commission A.A.P.G. 1983, Whittaker et al. 1992). Ramasamy & Banerji's (1991) work is, however, limited to the mid-Cretaceous succession. A need, therefore, exists to revise the present lithostratigraphic classification for the whole of the Cretaceous succession in the Cauvery Basin.

### 3.3 Method

This Chapter presents a revised lithostratigraphic classification for the Cretaceous succession (on-shore part) of the Cauvery Basin. When revising a classification it is necessary to be as precise as possible. It is acknowledged that the stability in a classification is maintained by the use of the rule of priority and by the preservation of established names. This should, however, not prevent a more appropriate designation if the original nomenclature fails to meet the standard. Throughout the process of this revision recommendations provided in the code of stratigraphical procedure (Hedberg 1976, Holland et al. 1978, Commission A.A.P.G. 1983, Whittaker et al. 1992), the rule of priority (as far as it could be traced) of publication and the preservation of established names are complied with. Failure, by a majority of the workers (e.g., Banerji 1973, Jain 1976, Sundaram & Rao 1979, 1986, Ramasamy & Banerji 1991, etc.) to acknowledge previous work has, however, been a major problem (in the present study) in tracing the nomenclatural history. This has also created a series of terms for the same lithostratigraphic unit, with or without any stratigraphic significance. The issue has been addressed in the current process of revision. Attempt has been made to solve the problem without doing injustice to the original author or compromising the standard practice of stratigraphical procedure.
In this study, for most of the work, spot sample collection (see Section 1.3.1 for details on sample collection) has been carried out. This is due to a general lack of continuity and/or good exposures (see Chapter 1) in the outcrop, except where working and/or abandoned quarries exist. Throughout the process of research the toposheets used are 58I/16, 58J/13, 58M/3, 58M/4 and 58N/1, published by the Geological Survey of India in 1932.

3.4 A revised lithostratigraphic classification for the Cretaceous succession (on-shore part) in the Cauvery Basin

In the proposed classification seven lithostratigraphic units of “Formational” status, grouped into three “Groups”, (1) the Gondwana Group- Section 3.4.1, (2) the Uttatur Group- Section 3.4.2 and (3) the Ariyalur Group- Section 3.4.3, are recognised. In the present work the terms Group, Formation and Member have been used, but individual beds rarely have been identified. It must be noted that a Member, which is a distinctive part of a Formation, may or may not extend completely across an outcrop area. It is also unnecessary to divide a Formation (Holland et al. 1978, p. 10) completely into Members. Tables 3.1 and 3.2 (at the end of this Chapter) summarise the revised classification with the lithofacies relationships in the Basin (on-shore part) and a comparison of the proposed classification with some of the existing classifications, respectively.

3.4.1 The Gondwana Group

**Nomenclature (author):** The term “Gondwana” was coined by H.B. Medlicott (in Krishnan 1982, p. 239), in a manuscript report in 1872, after the kingdom of Gonds (an ancient Indian tribe which still inhabits the Central Indian state of Madhya Pradesh). The name “Gondwana” was, however, first formally published by Feistmantel (in Krishnan 1982, p. 239) in 1876.
The Upper Carboniferous-middle Cretaceous Gondwana Sequence (Krishnan 1982, Kumar 1985) represents a 6 to 7 km thick succession of fluviatile and lacustrine deposits, with a glacial deposit at the base. These continental Gondwana sediments are rich in floral remains and extend over a wide geographical area across India (Krishnan 1982, Kumar 1985). From the Cauvery Basin, isolated patches of plant-rich beds (clays and siltstones), e.g., Ootatoor (=Uttatur) plant beds of Blanford 1862 (in 1865), Upper Gondwana beds of Rama Rao 1942, etc., are reported along the western margin of the Basin. These plant beds are identified (e.g., Rama Rao 1942, Sundaram & Rao 1979, 1986, etc.) as representing the Upper Gondwana rocks in the Cauvery Basin.

The Gondwana Group (this study) constitutes a series of conglomerates, siltstones, plant-rich claystones, argillaceous claystones, sandstones and silty-sandstones. In the area studied, the Gondwana Group comprises of one formation, the Sivaganga Sandstone Formation- Section 3.4.1.(i).

3.4.1.(i) Sivaganga Sandstone Formation

**Nomenclature (author):** Banerji (1973), after the type locality Sivaganga (Fig. 2.6).

Banerji (1973, p. 19) established Sivaganga Formation, a conglomerate-claystone succession, in the Sivaganga area (see Fig. 2.6). Detached occurrences of the Formation were reported (Banerji 1973, Banerji & Sastri 1979) from the Ariyalur outcrop. Banerji (1982, pp. 452-453, table I) later divided the Sivaganga Formation (in the type locality- Sivaganga) into three members- Lower, Middle and Upper. The Lower (conglomerate) and the Upper (clay) Members of the Formation were recognised (Banerji 1982, table I) in the Ariyalur outcrop. Later, Ramasamy & Banerji (1991, pp. 589-590) argued that the Sivaganga Formation is not correlatable to the exposures in the Ariyalur outcrop. They (Ramasamy & Banerji 1991) gave three reasons to support this argument. First, that the two areas (Sivaganga and Ariyalur) are geographically widely separated (see Fig. 2.6). Second, the lack of compatibility of
sedimentary characters. The sediments, at these two areas, show different textural characters, e.g., sorting coefficient, skewness, kurtosis, etc. (Banerji 1982, table II). Third, the apparent lack of stratigraphic continuity. In the Sivaganga area the Cretaceous succession is incomplete to absent and the Sivaganga Formation is followed by Mio-Plio-Pliostocene sediments (Ramasamy & Banerji 1991). By contrast, in the Ariyalur area, the exposures are followed by marine Cretaceous rocks. Ramasamy & Banerji (1991, p. 590) argued that due to the geographical distance, stratigraphic gaps and a general lack of compatibility of sedimentary characters, between the outcrops in the Ariyalur and the Sivaganga area, the term “Sivaganga Formation” cannot be applied to the Ariyalur exposures. A new stratigraphic unit, Terani Formation with a Lower Sandstone Member and an Upper Shale Member, was proposed (Ramasamy & Banerji 1991, p. 589), therefore, for the exposures in the Ariyalur outcrop.

Except for the point on geographical distance between the exposures in the Sivaganga and the Ariyalur areas, the other two arguments (lack of compatibility of sediment characters and stratigraphic gap) do not appear convincing, at least as they read in the publications (Banerji 1973, Banerji & Sastri 1979, Banerji 1982, Ramasamy & Banerji 1991). A lithostratigraphic unit should be defined so clearly that a subsequent investigator could identify the unit unequivocally (Commission A.A.P.G. 1983, p. 853, article 9). Textural parameters, e.g., skewness, kurtosis, sorting coefficients, etc., are not the characters which can be used to differentiate two lithostratigraphic units in the field; so the argument of lack of compatibility in sedimentary characters at the two areas (Ariyalur and Sivaganga), as put forward by Ramasamy & Banerji (1991) does not hold good. Second, absence of the immediately next stratigraphic unit (i.e., stratigraphic gap) does not effect the stratigraphic position (time and space) of the underlying unit. When extending and later revising the term Sivaganga Formation in the Ariyalur outcrop, the publications (Banerji 1973, Banerji & Sastri 1979, Banerji 1982, Ramasamy & Banerji 1991) have not strictly followed the standard stratigraphic procedure (Hedberg 1976, Holland et al. 1978, Commission A.A.P.G. 1983, Whittaker et al. 1992). This does not allow a full assessment of the applicability of Ramasamy &
Banerji’s (1991) argument. At this stage of work it is considered best, therefore, to retain the use of the term Sivaganga Formation for the exposures in the Ariyalur outcrop as originally proposed by Banerji (1973, 1982).

The Sivaganga Sandstone Formation (this study) represents the first phase of Cretaceous sedimentation in the Basin. The Formation (this study) is locally divisible into three members, (1) the Kovandakuruchchi Conglomerate Member- Section 3.4.1.(i.a), (2) the Kovandakuruchchi Siltstone Member- Section 3.4.1.(i.a) and (3) the Terani Clay Member- Section 3.4.1.(i.b). While use of the same locality name for two units is discouraged (Whittaker et al. 1992, p. 815) the name Kovandakuruchchi is used here for the Kovandakuruchchi Conglomerate Member and the Kovandakuruchchi Siltstone Member as, (1) there is no other suitable location where the two units are well developed, and (2) the two units grade into each other along the trench section between the Kovandakuruchchi quarries-1 and 2 (at the eastern end of the Kovandakuruchchi quarry-2, see Fig. 3.1).

3.4.1.(i.a) The Kovandakuruchchi Conglomerate Member and the Kovandakuruchchi Siltstone Member

**Nomenclature (author)** (for both Members, as discussed earlier): Proposed names, after the type locality- trench section at the eastern end of the Kovandakuruchchi quarry-2 (Fig. 3.1).

**Lithology**: The Conglomerate Member has a clast-supported fabric (some of the clasts being 1 m in diameter, Photo 3.1) comprising exclusively of pink to buff coloured, sub-rounded to sub-angular boulders and cobbles of the Precambrian gneissic basement rock. It is a cross-bedded, cyclic, coarsening-upward unit. The Conglomerate Member rests on the Archaean basement and grades upwards into the Kovandakuruchchi Siltstone Member. The Siltstone Member is an off-white to grey, fine to medium grained, horizontally bedded, graded, fining-upward, sandstone-siltstone succession.
Photo 3.1: The Kovandakuruchchi Conglomerate Member (Sivaganga Sandstone Formation) at a trench section (type locality), eastern end of the Kovandakuruchchi quarry-2 (Fig. 3.1).

**Type locality** (for both Members): Trench section at the eastern end of the Kovandakuruchchi quarry-2 (Photo 3.1, Fig. 3.1).

**Fossils:** Except for some belemnite guards (not in-situ) no fossils are reported.

**Environment &/or depositional process:** Probably represents sheet flow deposits in a retrogradational alluvial fan or density (gravity) underflows down the face of a submarine fan delta.

**Remarks:** Conglomerate-boulder beds (associated with plant remains) were reported by Blanford, 1862 (in 1865) from all along the western margin of the Cauvery Basin. Blanford, 1862 (in 1865, pp. 47, 66) observed that the boulder bed at Kallakudi (=Cullygoody, in old literature) to be composed exclusively of basement gneissic rocks and containing some marine fossils (belemnites) but no plant remains. This (presence of belemnites and no plant remains) made the conglomerates at Kallakudi different from
other conglomerate beds (discussed under remarks in Section 3.4.2.(i.c)). Blanford, 1862 (in 1865, pp. 47, 66) concluded the conglomerate occurrence at Kallakudi to be of post Ootatoor (Uttatur) plant beds (Terani Clay Member- Section 3.4.1.(i.b), this study) and a local feature. Various workers, e.g., Ramanathan & Rao (1965, table I), Ramanathan (1968, table I), Subbaraman (1968, table 1, map 1), Jain & Subbaraman (1969), Banerji (1973, 1982), Prabhakar & Zutshi (1993, table IV), based on outcrop and/or bore-hole studies have reported the occurrence of a sandstone-conglomerate/conglomerate-boulder bed (Upper Gondwana age) in the Cauvery Basin. Sundaram & Rao (1986, p. 11) appear to have wrongly identified this conglomerate unit as the Lower Conglomerate Member (in part) of the Maruvattur Formation (Table 3.2), a glacial drop-stone facies of post Upper Gondwana age. It was Banerji (1973, 1982), however, who for the first time, formally recognised a Neocomian to Aptian ranging conglomerate-sandstone sequence in the Sivaganga area (south of Trichinopoly) and named it as the Sivaganga Formation. Isolated outcrops of the Sivaganga Formation were also identified (Banerji 1973, 1982) in the Ariyalur outcrop.

The Kovandakuruchchi Conglomerate Member and the Kovandakuruchchi Siltstone Member (this study) are identified as representing parts of the Sivaganga Formation (sensu Banerji 1973, 1982) in the Ariyalur outcrop. The Members, Kovandakuruchchi Conglomerate and Kovandakuruchchi Siltstone (this study), may represent the Lower and Upper Members of the Sivaganga Formation (sensu Banerji 1973, 1982) as originally described by Banerji (1982, table I).

3.4.1.(i.b) Terani Clay Member

In and around Karai, a third, synchronous, but more basinal unit is exposed in the Terani Clay mines (Locality 1 in Fig. 3.2). This is the more argillaceous member, the Terani Clay Member, of the Sivaganga Sandstone Formation. Isolated outcrops of the Member are seen along the western margin of the Basin (Fig. 3.2).

**Lithology:** Dirty yellow to dirty brown and off-white, thin to thickly bedded kaolinitic claystones with subordinate ferruginous sandstone and siltstone beds (Photo 3.2). At the Terani Clay mine the claystones have thin to medium bedded (4-30 cm), coarse-grained sandstone beds with sharp planar to erosive bases and planar upper surfaces. Mudstone rip-up clasts are present at the base of some sandstone beds. Box-like pyrite concretions are also reported in these sandstone beds.

**Type locality:** Terani Clay mine (Locality 1 in Fig. 3.2), 11° 07.030' N - 78° 53.363' E, Photo 3.2.

Photo 3.2: Thickly bedded, dirty yellow to off-white kaolinitic claystones with subordinate ferruginous sandstone and siltstone beds. Terani Clay Member (Sivaganga Sandstone Formation) in the Terani Clay mine (type locality), Locality 1 in Fig. 3.2.
Fossils: The clays are rich in plant fossils and plant impressions and are commonly referred to as Terani plant beds. Palynological studies (P. Dodsworth pers. comm.) show that, except for some black wood fragments (most resistant phytoclasts), the clays are now barren of palynomorphs. Some bioturbation is present in these clays.

Age: Not datable, in the present study. The clays are reported (e.g., Sastri et al. 1977, Ramasamy & Banerji 1991), however, to be of (?) Neocomian-Aptian age although no datable fossils have been recorded, with one exception. Mamgain et al. (1973) report two Upper Neocomian (Barremian) ammonite species, Gymnoplitites cf. simplex Spath and Pascoeites cf. crassus Spath and one ?Inoceramus species along with plant fossils from the plant beds near Terani (11° 06’ N - 78° 52’ E).

Environment &/or depositional process: A low energy, lacustrine environment with little signs of wave or current reworking or (?) a marine basin with periodic deposition from density currents (? turbidites).

Remarks: As discussed earlier (under nomenclature in Section 3.4.1.(i)), Ramasamy & Banerji (1991) arguing the non-applicability of the term “Sivaganga Formation” (sensu Banerji 1973, 1982) to the exposures in the Ariyalur area, established a new term, Terani Formation (sensu Ramasamy & Banerji 1991). The pros and cons of Ramasamy & Banerji’s (1991) arguments (non-applicability of the term “Sivaganga Formation” to Ariyalur outcrop) have been addressed earlier (see nomenclature in Section 3.4.1.(i)).

The Terani Clay Member (this study) is what Ramasamy & Banerji (1991) describe as Upper Shale Member of the Terani Formation (sensu Ramasamy & Banerji 1991). A boulder-conglomerate bed (boulders of Archaean basement rocks in shales and clays of plant beds) at the base of Terani Clays, reported by Blanford, 1862 (in 1865, pp. 40, 45-46) and Ramasamy & Banerji (1991, as Lower Sandstone Member of Terani Formation (sensu Ramasamy & Banerji 1991, p. 589)) have not been seen in the present study (discussed under remarks in Section 3.4.2.(i.c)).

3.4.2 Uttatur Group

Nomenclature (author): Blanford 1862 (in 1865, p. 23) after the village Uttatur
The Uttatur Group, rests on the Archaean basement and/or the Gondwana Group of rocks (Table 3.1). In this study the Group is divided into three formations (Table 3.1). These are, (1) the Dalmiapuram Limestone Formation- Section 3.4.2.(i), (2) the Karai Clay Formation- Section 3.4.2.(ii) and (3) the Garudamangalam Sandstone Formation- Section 3.4.2.(iii).

3.4.2.(i) Dalmiapuram Limestone Formation


The Dalmiapuram Limestone Formation (this study) has a somewhat chequered nomenclature history. The confusion is mainly due to the failure (knowingly or not) of acknowledgement by workers of any of the previously published works. The term Dalmiapuram Formation (after the town Dalmiapuram, Fig. 3.1) was first published in 1969 (Bhatia & Jain 1969, p. 106) for a grey shale unit occurring below the Uttatur succession of rocks (base of limestone) in the Kallakudi quarry-2 (Fig. 3.1). Later, Banerji (1971a, 1972b) proposed (first proposed by Banerji in 1968 in an unpublished report, as referred to in Banerji 1972b, p. 36) the name Dalmiapuram Formation, with two members, a lower shale member and an upper limestone member for the reef limestones and associated rocks (shales, clays, marls, etc.) in the Kallakudi quarry-2. Banerji’s (1971a, 1972b) lower shale member (lower member in the Dalmiapuram Formation as proposed by Banerji 1971a, 1972b) is same as what Bhatia & Jain (1969) described as the Dalmiapuram Formation. Some confusion is also created by the fact that the names Kallakudi and Dalmiapuram (town near Kallakudi, Fig. 3.1) have, quite often, been used as synonyms. Workers used (and published) casual, descriptive terms to serve their purpose. This has created a plethora of terms and has resulted in ambiguity as to what they mean in time and space. The literature (e.g., Gowda 1964, Sastry & Sastri 1968, Banerji 1971a, 1972b, Jain 1977, Ramasamy & Banerji 1991, etc.) is, therefore, full of terms, e.g., Kallakudi limestones, Dalmiapuram limestone,
Dalmiapuram Formation, limestones from Kallakudi, limestones from Dalmiapuram, etc., without making it clear what these terms mean in a stratigraphic terminology.

The procedure on naming and establishing a geologic unit requires publication of the proposed nomenclature in a recognised scientific medium (Commission A.A.P.G. 1983, p. 851, articles 3 and 4). The term Dalmiapuram Formation was first published in 1969 (Bhatia & Jain 1969, p. 106) for a grey shale bed in the Kallakudi quarry-2. The name was first proposed in 1968 (as cited in Banerji 1972b, p. 36), but in an unpublished report, for the grey shales and reef limestones. The credit is, therefore, given to Bhatia & Jain (1969) for proposing the term “Dalmiapuram”. Banerji’s (1971a, 1972b) definition, of extending the name Dalmiapuram Formation to include the shale unit with argillaceous limestone beds and the limestone unit is, however, upheld in this study. Throughout the present work the names Dalmiapuram and Kallakudi are used separately.

In the proposed classification five members, of which three are new, are recognised in the Dalmiapuram Limestone Formation. These are, (1) the Grey Siltstone Member- Section 3.4.2.(i.a), (2) the Dalmiapuram Limestone Member- Section 3.4.2.(i.b), (3) the Olaipadi Conglomerate Member- Section 3.4.2.(i.c), (4) the Kallakudi Sandstone Member- Section 3.4.2.(i.d) and (5) the Kallakudi Siltstone Member- Section 3.4.2.(i.e). The Kallakudi Sandstone and the Kallakudi Siltstone Members (as is the case with the Kovandakuruchchi Conglomerate and Kovandakuruchchi Siltstone Members) are best represented at the Kallakudi quarries-2 and 1 respectively, forcing the repetition of the name Kallakudi.

3.4.2.(i.a) Grey Siltstone Member

This is the lowermost member in the Dalmiapuram Limestone Formation. The Member is not exposed anywhere in the outcrop. The part of the Kallakudi quarry-2 where the grey shale bed was previously exposed (Subbaraman 1968, see Fig. 3.1), along a fault,
is now water-logged. Two samples of the grey shales were provided, for the present study, by S. Lakshminarayanan (from the Kallakudi quarry-2, Fig. 3.1) and S. Ramasamy (from Perali, Fig. 3.2).


Ramanathan & Rao (1965), for the first time, reported the occurrence of a black carbonaceous shale bed at the base of Uttatur succession (base of limestones). The black shale bed was observed (Ramanathan & Rao 1965, table I) in a bore-hole near Odiyam (Fig. 3.2) and in the Kallakudi quarry-2. Ramanathan & Rao (1965) and Ramanathan (1968) reported that the grey shale lay conformably below the Uttatur succession (base of limestones). Later Subbaraman (1966, 1968) reported that the grey shale lay conformably below the Uttatur succession (base of limestones). Later Subbaraman (1966, 1968) reported the presence of a grey shale bed, lying unconformably below the Uttatur succession (base of limestones), in the Kallakudi quarry-2 (see Fig. 3.1). Grey shales were also recorded (Subbaraman 1968) from the bore-holes between Alundalippur and Garudamangalam villages. Bhatia & Jain (1969) named these grey shales as Dalmiapuram Formation, after the town of Dalmiapuram. Later Banerji (1971a, 1972b) grouped the grey shales and the overlying limestones into Dalmiapuram Formation (as discussed earlier), with a lower shale member and an upper limestone member. Subsequent workers (e.g., Phansalkar & Kumar 1983, Sundaram & Rao 1986, Ramasamy & Banerji 1991, Kale & Phansalkar 1992, Prabhakar & Zutshi 1993, etc.) have more or less followed the nomenclature grey shale. The term “grey shale” has since become well established, overriding Bhatia & Jain’s (1969) proposal to call these grey shales the Dalmiapuram Formation. Following the rule of priority of publication “Grey shale” (Ramanathan & Rao 1965, Subbaraman 1968) gets preference over Bhatia & Jain’s (1969) “Dalmiapuram Formation”. The argument in favour of Bhatia & Jain (1969) is that they (Bhatia & Jain 1969) proposed a formal name, Dalmiapuram Formation, for the black/grey shale bed reported by Ramanathan & Rao (1965) and Subbaraman (1968). This should, however, not override the well established (the rule of preservation of well
established names) term “Grey Shale”. Informal it may have been but the term black/grey shale (Ramanathan & Rao 1965, Subbaraman 1968) was proposed and published before the term Dalmiapuram Formation (Bhatia & Jain 1969) and subsequently became well established. In the present study it is observed that the so-called “Grey Shale Member” (e.g., Sundaram & Rao 1986, Ramasamy & Banerji 1991, etc.) is a siltstone. Redefining the member as “Grey Siltstone” allows a proper lithologic representation of the Member.

**Lithology:** Dark grey, fine-grained siltstones with some pyrite and mica.

**Type locality:** The Member is not exposed anywhere in the outcrop. The part of the Kallakudi quarry-2 where the grey shale bed was previously exposed (Subbaraman 1968, see Fig. 3.1), along a fault, is now water-logged.

**Fossils:** An impoverished foraminifera and palynomorph (P. Dodsworth pers. comm.) assemblage along with some ostracod valves and fragments of gastropod and bryozoa are reported. The foraminiferal population is dominated by poorly preserved *Hoeglundina* Brotzen species (90% of the total foraminiferal population) with rare occurrences of *Epistomaroides* Uchio, *Gavelinella* Brotzen, *Gyroidinoides* Brotzen, *Ammodiscus cretaceous* (Reuss) and *Haplophragmoides* Cushman species. The palynological study (P. Dodsworth pers. comm.) on the sample from Kallakudi quarry-2 records a cosmopolitan palynomorph assemblage. The sample was dominated by black and, to a lesser extent, brown wood fragments. An impoverished, organic-walled microfossil assemblage is reported. Relatively thick-walled sphaeromorph acritarchs and terrestrially-derived spores are preferentially better preserved to dinoflagellate cysts, which are sparse in number (about 4 specimens per gramme).

**Age:** The limited palaeontological evidence from these siltstones suggest a probable Barremian to Albian and a possible Aptian age.

**Remarks:** Jain (1977) observed 3-4 bands of argillaceous limestones in the grey shale unit of the Dalmiapuram Formation (*sensu* Bhatia & Jain 1969, lower shale member in the Dalmiapuram Formation of Banerji 1971a, 1972b). The more calcareous beds (interbedded with the grey shales) reported by Jain (1977, p. 170) have not been seen,
but this is probably due to the absence of any of the previously exposed sections. The work on the palynology (P. Dodsworth pers. comm.) of these siltstones, however, agrees with much of that reported by Jain (1977). An impoverished foraminifera and palynomorph assemblage (P. Dodsworth pers. comm.) suggests that by this time marginal marine conditions were established in the Basin.

It is difficult to prove at this stage of work, but the Grey Siltstone Member (this study) may grade downwards into the Kovandakuruchchi Siltstone Member (this study). The lack of exposed sections (in the area studied) does not allow to observe the stratigraphic relationship between the two Members. The Grey Siltstones report a Barremian to Albian ranging, impoverished foraminiferal and palynomorph assemblage (as discussed above). In the present study no fossils are recorded from the Kovandakuruchchi Siltstone Member. Banerji & Sastri (1979) and Banerji (1982) report, however, a Neocomian-Aptian ranging, impoverished, agglutinated foraminiferal assemblage from the clayey unit (=Kovandakuruchchi Siltstone Member, this study) of the Sivaganga Formation (sensu Banerji 1973, 1982). From the limited fossil record and lithological evidence available, a transition between the Grey Siltstones and Kovandakuruchchi Siltstones is speculated.

### 3.4.2.(i.b) Dalmiapuram Limestone Member

**Nomenclature (author):** Bhatia & Jain (1969) and Banerji (1971a, 1972b), after the town Dalmiapuram.

These limestones have been identified (e.g., Rasheed 1962a, 1962b, Gowda 1964, Jain 1976, etc.) as the Kallakudi (or Cullygoody) limestones. The nomenclature Dalmiapuram, however, gets priority over the nomenclature Kallakudi limestone. This is because Banerji (1972b), for the first time, formally extended (as discussed earlier under nomenclature in Section 3.4.2.(i)) the nomenclature Dalmiapuram for the limestones exposed along the western margin of the Basin. The previous workers (e.g.,
Rasheed 1962a, 1962b, Gowda 1964, etc.) have used the term “Kallakudi limestone” while simply describing the limestones exposed in the Kallakudi quarry-2 and not as a formal lithostratigraphic term.  

**Lithology:** The in-situ, massive, pink to off-white/grey limestones (Photo 3.3) are bioclastic to arenaceous bioclastic mudstone-wackestone-packstone-grainstone combinations with isolated boundstone fabric. The grainstone and wackestone fabric is dominant. Arenaceous content, mainly quartz with some feldspar, is between 2-10 percent. The limestones are characterised by dissolution vugs and cavities, geopetal structures, internal sedimentation and show small scale grading. Isolated clasts of Archaean basement rock and less frequently, lithified carbonate clasts, embedded in these limestones are observed.

Photo 3.3: The in-situ massive, pink limestone (lowest bench) of the Dalmiapuram Limestone Member overlain by the bedded Kallakudi Sandstone Member (middle bench) of the Dalmiapuram Limestone Formation. Kallakudi quarry-2 (type locality, Fig. 3.1), 10° 59.412’ N - 78° 56.756’ E.
Type locality: Kallakudi quarry-2 (Photo 3.3, Fig. 3.1), 10° 59.412' N - 78° 56.756' E.

Reference localities: The Member is exposed along the western margin of the Basin at Varaguppadi, Sirukanpur, Olaipadi and Govindrajpatnam (Fig. 3.2) quarries.

Fossils: The limestones are mainly composed of red algae and bryozoa. Other bioclasts consist of echinoid spines and plates, bivalve and grastropod fragments, brachiopods, ostracods, foraminifera, calcareous sponges and fragments of scleractinian corals. The palynological study (P. Dodsworth pers. comm.) show that except of some black wood fragments the limestones are now barren of palynomorphs.

Age: The limestones have been reported to be of Albian age (e.g., Sundaram & Rao 1986, Ramasamy & Banerji 1991, etc.) although no datable fossils have been reported in the present study.

Remarks: The distinctive reefal structures which are associated with reeal bodies, are absent in the Dalmiapuram Limestones. The mid-Cretaceous faulting (see remarks under Section 3.4.2.(i.c)) appears to be the major cause for the loss of the original reefal structures. In thin section and in the outcrop the limestones show isolated reefal fabric (texture not structure). The limestones because of their typical pink colour and incorrectly identified (discussed under remarks in Section 3.4.2.(i.c)) reefal structure are commonly referred (e.g., Gundu Rao 1970, Nair & Vijayam 1981, etc.) to as pink limestones or pink-reefal limestones. There is, however, one exception. Blanford, 1862 (in 1865, p. 70) while calling these limestones “coral reef limestones” clearly pointed out that the original reef structure is no longer recognisable in these limestones.

3.4.2.(i.c) Olaipadi Conglomerate Member

Nomenclature (author): Proposed name, after the village Olaipadi (Fig. 3.2).

Lithology: Massive and chaotic beds with boulders of already lithified carbonates (some of which are several meters across, Photo 3.4) and/or basement rocks with fine- to coarse-grained, poorly sorted, clayey siliciclastic matrix. Associated with the boulder blocks are smaller fragments of Archaean basement and lithified carbonate together with brown, deeply-weathered silty claystones (with plant fragments) of
unknown age and origin. Palynological study (P. Dodsworth pers. comm.) on these silty claystones show that except for some black wood fragments (the most resistant phytoclasts) the claystones are now barren of palynomorphs. The clays, however, appear to be very similar to the (?) Terani Clays, but at this stage it is very difficult to prove this. It is also difficult to comprehend how the Terani Clays can be so intimately associated with these massive conglomerates. Relative proportion of the clasts (carbonate and Archaean basement) varies from location to location, e.g., predominantly basement clasts at the western end of the Olaipadi quarry and in the Kovandakuruchchi quarry-2 (Photo 3.5), while massive carbonate boulders in the E and NE side of the Olaipadi quarry (Photo 3.4) and totally carbonate and quartzite clasts at Neykulam. Evidence of reworking comes from the mixture of basement and carbonate boulders, overturned geopetal structures and upside down fossils within the boulders.

**Type locality:** Olaipadi quarry, 11° 19.063' N - 79° 04.763' E.

**Reference localities:** Tiruppattur, Neykulam, Kovandakuruchchi quarry-2 and Kallakudi quarry-2 (Figs 3.1 & 3.2).

**Environment &/or depositional process:** A rapid deposition from massive submarine debris flows or talus deposits at the foot of eroding fault scarps.

**Remarks:** The chaotic accumulation of boulder-conglomerates (carbonates and Archaean basement blocks) in the Olaipadi Conglomerate Member relates to the mid-Cretaceous faulting. The Kallakudi and Kovandakuruchchi quarries are clearly affected by two sets of roughly E-W and NNE-SSW trending normal fault systems (Fig. 3.1). Minor, localised, faulting is witnessed all along the western margin of the Basin. These faults operated during, or just after, the lithification of the Dalmiapuram Limestone Member. This destroyed the original reef structure of the Dalmiapuram Limestone and generated intraformational, boulder-conglomerate flows. Whether the mid-Cretaceous faulting was responsible for the intimately associated silty-claystones (?) Terani Clays) with the conglomerates is not clear. The fault controlled, chaotic accumulation of massive, redeposited, carbonate blocks in the Olaipadi Conglomerate Member has been confused (e.g., Gundu Rao 1970, Nair & Vijayam 1981, Ramasamy 1986).
Photo 3.4: Massive boulders, some of which are several meters across, of lithified carbonates in the Olaipadi Conglomerate Member (Dalmiapuram Limestone Formation), Olaipadi quarry (type locality), 11° 19.063' N - 79° 04.763' E.

Photo 3.5: Chaotic accumulation of boulder-conglomerates of predominantly Archaean basement clasts in the Olaipadi Conglomerate Member (Dalmiapuram Limestone Formation), Kovandakuruchchi quarry-2 (see Fig. 3.1).
& Banerji 1991, etc.) with a mound shaped, non-bedded architecture associated with
“reef” bodies with Ramasamy & Banerji (1991) reporting them as “bioherms”. It
appears that Blanford, 1862 (in 1865, pp. 54, 59, fig. 3) has described, at least at two
places (east of Tiruppattur and north of Olaipadi), this chaotic accumulation of
limestones as small, isolated masses of limestones calling them “bosses of coral reef”. Blanford, 1862 (in 1865, p. 70) has, however, made it clear that the original reef
structure is not preserved in these limestones.

From the western margin of the Basin, Blanford 1862 (in 1865, pp. 40, 45-46, 54-56,
59) has reported three types of conglomerate-boulder beds. These boulder beds differ
in composition and stratigraphic position. Blanford, 1862 (in 1865) observed that the
conglomerates at Uttatur (=Ootatoor), Kudikkadu (=Coodicaud) and Kalpadi
(=Cullpaudy) are composed of weathered basement gneissic rocks and are associated
with plant remains and shales and clays of Ootatoor plant beds (Terani Clay
Member- Section 3.4.1.(i.b), this study). Blanford, 1862 (in 1865) observed that these
conglomerates lay stratigraphically below the Ootatoor plant beds (Terani Clay
Member, this study) and concluded that the boulder-beds were associated and were
probably coeval with the Ootatoor plant beds (Terani Clay Member, this study). These
boulder-beds (lying below the plant beds) have not been observed in the present study
(as discussed under remarks in Section 3.4.1.(i.b)). The second set, of completely
different conglomerate-boulder beds, was reported (Blanford (1862) in 1865,
pp. 54-56, 59) from Tiruppattur (=Tripatoor), Neykulam (=Naicolom), north of
Maruvattur (=Maravattor) and Paravay (=Purawoy). These conglomerate beds were
observed (Blanford 1862, in 1865) to be composed of blocks of basement rocks and
reef-limestones with smaller pebbles of quartzite and reef-limestones. Blanford, 1862
(in 1865) concluded that this set of boulder beds were stratigraphically younger, lying
above the Ootatoor plant beds (Terani Clay Member, this study) and were followed by
the Ootatoor Group (Karai Clay Formation- Section 3.4.2.(ii), this study). The third
type of boulder-conglomerate bed (composed exclusively of basement gneiss and
belemnite fossils, but no plant remains) reported from the Kallakudi quarry (Blanford

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(1862) in 1865, pp. 47, 66) has already been discussed under the Kovandakuruchchi Conglomerate Member (see remarks in Section 3.4.1.(i.a)).

In this study it is observed that the relative proportion of clasts (carbonate and basement rocks) has varied at different localities (as discussed earlier) and the silty-claystones (with plant fragments) are associated with conglomerate beds at each of the studied localities. In all the cases the conglomerate-boulder beds were observed to be stratigraphically younger than the Terani Clay Member (Ootatoor plant beds of Blanford (1862) in 1865).

3.4.2.(i.d) Kallakudi Sandstone Member

**Nomenclature (author):** Proposed name, after the type locality- Kallakudi quarry-2.

**Lithology:** It is a medium- to coarse-grained, glauconite-rich, thick to thinly bedded calcareous sandstone with alternating marl and limestone beds (Photos 3.6 & 3.7) with pebbles of Precambrian basement rock. Sharp based, 10-60 cm thick beds of sandy, bioclastic grainstones interbedded (contact sharp or gradational) with marl and sandy claystones. In some beds the siliciclastic component dominates. The fresh glauconite gives the sandstone a green to grey colour; when weathered, however, the colour changes to orange-brown. Shallow (0.4 m wide), N-S trending channels showing normal (rarely reverse) grading with rare basement clasts occur. Large channels (N-S trending) also occur within the interbedded sandy grainstones and marls. These channels reach 30 m in width and are several meters deep. The tops of the channel fills appear very flat and the infill is very coarse, pebbly arenites with some basement boulders up to 80 cm across. The channels contain little bioclastic material. There are lateral variations with coarse shell-rich sandstone beds, graded beds, channel deposits, alternating massive to bedded nature with rare cross bedding; features which suggest a mode of formation closely related to turbidity currents. At the Olaipadi quarry the thick massive, coarse-grained sandy grainstones pass into very coarse bioclastic arenites with lenses of very coarse grainstones containing reworked rudists and serpulids.
Photo 3.6: Thinly bedded clacareous sandstone and limestone beds in the Kallakudi Sandstone Member (Dalmiapuram Limestone Formation), Kovandakuruchchi quarry-2 (Fig. 3.1).

Photo 3.7: Alternating marl and limestone beds in the Kallakudi Sandstone Member (Dalmiapuram Limestone Formation), Kallakudi quarry-2 (type locality, Fig. 3.1).
Type locality: Kallakudi quarry-2, 10° 59.412′ N - 78° 56.756′ E (Fig. 3.1).
Reference localities: Kovandakuruchchi quarry-1 and Olaipadi quarry (Figs 3.1 & 3.2).

Fossils: The marl beds contain a rich fossil assemblage. Foraminiferal population of the Rotalipora appenninica (Renz)-Planomalina buxtorfi (Gandolfi)-R. ticinensis (Gandolfi) Concurrent Range Biozone to R. reicheli Monrod-cushmani (Morrow) Interval Range Sub-biozone (see Chapter 5 for details), ranging from the late Albian to the late Cenomanian age, are reported. Amongst the macro-fauna Aptian to Albian ranging belemnite species (P. Doyle pers. comm.), Tetrabelus seclusus (Blanford), Parahebolites blanfordi (Spengler) and Neohebolites species and an early to mid-Cretaceous phyloceratid ammonite (M. Thomson pers. comm.) along with shell debris containing Exogyra, Ostrea, Alectronia/Lopha, echinoids and bryozoa fragments.

3.4.2.(i.e) Kallakudi Siltstone Member

Nomenclature (author): Proposed name, after the type locality- Kallakudi quarry-1 (Fig. 3.1).
Lithology: It is an alternating succession of siltstone and calcareous sandstone (Photo 3.8) with varying proportions of glauconite and chert. Sharp based, thin to medium bedded, coarse pebbly sandstone (commonly containing pebbles of quartz and gneiss) interbedded with beds of white silty claystones. Bases of sandstone are sharp, planar to erosional and commonly display load structures. The tops of the beds rapidly grade up into mudstones. More frequent channel flows (Photo 3.9), reverse and normal grading, Bouma divisions and rare low angle cross laminations.
Fossils: Thalassinoides, belemnite species (not in-situ).

Type locality: Kallakudi quarry-1 (abandoned quarry, Photo 3.9), Fig. 3.1.
Reference localities: Tiruppattur and Neykulam quarries, Fig. 3.2.
Environment &/or depositional process (for both Kallakudi Sandstone Member and Kallakudi Siltstone Member): Deposition from high concentration turbidity currents.
Photo 3.8: Alternating succession of thin bedded (beds getting thicker and massive towards the top) siltstones and calcareous sandstones in the Kallakudi Siltstone Member (Dalmiapuram Limestone Member), Kallakudi quarry-1 (abandoned quarry, type locality, Fig. 3.1).

Photo 3.9: The Kallakudi Siltstone Member (Dalmiapuram Limestone Formation) with large channel flows, Kallakudi quarry-1 (abandoned quarry, type locality), Fig. 3.1.
Most likely a ramp-like slope developed over the massive debris/talus flows shed from fault bounded basement/carbonate platform blocks. Talus platform created a steep-sloped turbiditic apron, fed by carbonate sands and eroded siliciclastics, to be funnelled offshore as turbidity current by-passed narrow shelf. Some turbidity currents eroded down into slope deposits to form shallow to deep channels. These channels were then infilled by deposits of high density turbidity currents as they rapidly lost competence. This resulted in the deposition of mixed carbonate and clastic turbidites on a prograding, apron like slope with occasional by-passing of turbidity currents within channels. Consistent channel orientation suggests slope orientation was EW with flows to north or south.

Remarks (for both Kallakudi Sandstone Member and Kallakudi Siltstone Member): Blanford, 1862 (in 1865, pp. 62-64, fig. 5), while failing to explain the mechanism involved, observed distinct bedded nature (with great protruding hummocks) in the limestones at Kallakudi (=Cullygoody). Blanford, 1862 (in 1865, p. 64) reported that the bedded structure in the limestones is so well marked and regular that it could be easily confused for a regularly stratified deposit, which was not the case. It appears that the large channel flows (see Photo 3.9) present in the turbidite deposits (Kallakudi Sandstone and Siltstone Members, this study) are what Blanford, 1862 (in 1865, p. 63) referred to as great protruding hummocks in the bedded limestones. The Kallakudi Sandstone and Kallakudi Siltstone Members with their regularly interbedded nature, characteristic of the turbidite beds, have been mistaken (as cautioned by Blanford 1862 (in 1865), p. 64) for “biostromal” reefal deposits (e.g., Nair & Vijayam 1981, Ramasamy & Banerji, 1991).

The in-situ carbonates of Dalmiapuram Limestone Member, boulder-conglomerates of Olaipadi Conglomerate Member and the interbedded clastic-carbonate sequence of Kallakudi Sandstone and Kallakudi Siltstone Members (this study) have been identified as “reefal” carbonates, with distinct reefal-structure (biothermal and biostromal) by previous workers (e.g., Gundu Rao 1970, Nair & Vijayam 1981, Sundaram & Rao 1986, Ramasamy & Banerji 1991, etc.). The four Members have been grouped
together, in past literature, under one lithostratigraphic unit, Dalmiapuram Limestone Member (e.g., Banerji 1971a, 1972b, Ramasamy & Banerji 1991) or Kallakudi (=Cullygoody) Limestones (e.g., Rasheed 1962a, 1962b, Gowda 1964, Gundu Rao 1970, Nair & Vijayam 1981).

3.4.2.(ii) Karai Clay Formation


The Uttatur Group of Blanford, 1862 (in 1865) (=Uttatur Formation of Banerji 1973, Ramasamy & Banerji 1991) is renamed as the Karai Clay Formation (Karai Formation of Sundaram & Rao 1986). A formation name usually consists of a geographic name, from where the unit is described, followed by a lithic designation or by the word “formation” or both (Commission A.A.P.G. 1983, p. 859). The so-called Uttatur Formation (e.g., Banerji 1973, Ramasamy & Banerji 1991) comprises predominantly clays. The Uttatur village, after which the name was given (Blanford (1862) in 1865), rests on the Archaean basement. The clays have been described from Karai and adjacent villages (Fig. 3.2). This makes it appropriate to rename the Uttatur Formation as the Karai Clay Formation. It is an argillaceous unit with a local development (near Odiyam and Kunnam RF) of an arenaceous facies.

**Lithology:** Dirty brown to rust yellow clays, silty clays and sandy clays (Photos 3.10, 3.11); glauconite- and organic-rich in places. Tropical weathering (high heat and humidity) has resulted in superficial gypsum concentrations. This post-depositional, gypsum concentration has been confused by some workers (e.g., Krishnan 1982, p. 308; Sundaram & Rao 1986, p. 11) for a distinct lithology and raised to a lithostratigraphic unit (e.g., Odiyam Member of Sundaram & Rao 1986). The area occupied by the Karai Clay Formation displays a typical badland topography (Photo 3.11).
Photo 3.10: Dirty brown clays of the Karai Clay Formation in the Karai-Kulakkalnattam traverse. The white streaks and persistent bands seen in the photograph are the superficial gypsum concentrations; a post-depositional, weathering phenomenon.

Photo 3.11: Yellow, silty-sands of the Odiyam Sandstone Member (Karai Clay Formation), 2.5 km west of Kunnam (11° 14.525' N - 79° 00.416' E, Locality 2 in Fig. 3.2). The area occupied by the Karai Clay Formation shows a typical badland topography.
**Type locality:** Karai-Kulakkalnattam traverse (Fig. 3.2).

**Fossils:** The clays are rich in foraminifera. Foraminiferal assemblages belonging to the *R. subticinensis* (Gandolfi) Interval Range Biozone to the *Praeglobotruncana helvetica* (Bolli) Interval Range Biozone are identified (see Chapter 5 for details). Palynological studies (P. Dodsworth pers. comm.) on 20 surface samples show that the clays are now barren of palynomorphs. A rational explanation of this could be a high susceptibility of organic-walled palynomorphs to the tropical weathering associated with these latitudes (K. Dorning & P. Dodsworth pers. comm.).

**Age:** Late-middle Albian to latest mid-Turonian.

**Remarks:** The world-wide reported mid-Cretaceous oceanic anoxic events (OAEs) (Arthur & Schlanger 1979, Jenkyns 1980, Arthur et al. 1987, 1988, Schlanger et al. 1987, Thurow et al. 1988, Peryt et al. 1994, Holser et al. 1996, Kauffman & Hart 1996) are reported in the Cauvery Basin (see Chapter 6). Planktonic foraminiferal studies record two levels, (1) the latest Albian/Albian-Cenomanian and (2) the late Cenomanian-Turonian, when sharp rises in the planktonic:benthonic ratios (P:B ratio) are reported. The high P:B ratio levels are associated with a reduction in the benthonic diversity (see Tewari et al. 1996a & Chapter 6). The study shows that these levels coincide with the late Albian Briestroffer OAE-1c and the late Cenomanian-early Turonian Bonarelli OAE-3 oceanic anoxic events (OAEs). These anoxic events had a major affect on the planktonic foraminiferal population of the Basin (see Tewari et al. 1996a & Chapter 6 for details). The top of the Karai Clay Formation is cut by a rapid regression. In the on-shore part this latest-mid/earliest late Turonian regression is marked by a sudden and sharp fall in the planktonic foraminifera, being completely replaced by a low diversity agglutinated foraminiferal assemblage (see Chapters 5, 6 & 7 for details).
3.4.2.(ii.a) Odiyam Sandstone Member

To the north of the Basin, near Odiyam and Kunnam RF, a locally developed arenaceous unit, the Odiyam Sandstone Member, is recognised in the otherwise argillaceous Karai Clay Formation.

**Nomenclature (author):** Sundaram & Rao (1979), after the village Odiyam (Fig. 3.2).

Sundaram & Rao (1986) divided the Karai Formation into two, locally developed (to the north of the Basin) members; a lower Odiyam Member conformably overlain by the Kunnam Member. In the 1986 (Sundaram & Rao 1986) publication, the Odiyam and Kunnam Formations (Sundaram & Rao 1979) were reduced to member status. The Odiyam unit (of Sundaram & Rao 1979, 1986) includes gypseous clays and shales and the Kunnam unit (of Sundaram & Rao 1979, 1986) includes argillaceous sands and silts. The gypsum in these clays is a post-depositional, weathering phenomenon and Sundaram & Rao (1979, 1986) have wrongly identified it as a lithostatigraphic unit. In the absence of any distinctive lithological change observed (in the present study) between the Odiyam and Kunnam units (of Sundaram & Rao 1979, 1986) and gypsum being a superficial, post-depositional phenomenon, only one member, Odiyam Sandstone Member, is recognised in this study.

The name “Odiyam” is preferred over “Kunnam” for two main reasons. Firstly, in Sundaram & Rao’s (1979, 1986) classification the Odiyam unit is the lower unit, hence, proposed before the Kunnam unit. The rule of priority to publication allows, therefore, the retention of the name Odiyam. Secondly, in the area studied there are two political divisions; Kunnam RF and Kunnam. Kunnam RF is a regional division (toposheet 58I/16, Geological Survey of India 1932) covering an area between Odiyam and Maruvattur with a “panchayat” (the smallest judicial unit in the Indian Judicial System which operates in rural India). The region of Kunnam RF displays lithology of the Odiyam Sandstone Member (this study). The other Kunnam is a village/settlement...
(toposheet 58M/4, Geological Survey of India 1932, Fig. 3.2) and is the famous locality for the next stratigraphic unit; Garudamangalam Sandstone Formation. To maintain clarity in the nomenclature (Commission A.A.P.G. 1983, pp. 852-853, 859; articles 7 & 30k), avoidance of any confusion arising from the repetition of names (or misuse of names) is encouraged. The name Odiyam, therefore, gets priority over Kunnam.

**Lithology:** Yellow, friable, silty-sands (Photo 3.11) with thin impersistant beds of compact-grey calcareous sandstones, yellow, silty clays and calcareous clays.

**Reference locality:** 2.5 km west of Kunnam, 11° 14.525' N - 79° 00.416' E (Locality 2 in Fig. 3.2).

**Fossils:** A late Cenomanian-early Turonian foraminiferal assemblage of Whiteinella archaeocretacea (Pessagno) Partial Range Biozone, ammonites of (?) mid-Cenomanian age (or younger, M. Thomson pers comm.) along with abundant tubular and spiral serpulids, *Thalassinoides*, *Pecten*, *Exogyra*, *Alectronia/Lopha*.

**Age:** Late Cenomanian-early Turonian.

### 3.4.2.(iii) Garudamangalam Sandstone Formation


The so-described Trichinopoly Group (Blanford (1862) in 1865) is exposed in Garudamangalam and adjacent villages. The Trichinopoly District, after which the name was given (Blanford (1862) in 1865) rests on the Archaean rocks. Rama Rao (1956, p. 199) considering the name "Trichinopoly" a misnomer renamed the Trichinopoly Group of Blanford, 1862 (in 1865) as Garudamangalam. While all successive workers, up to the present date, have continued using the term "Trichinopoly", Banerji (1973) re-inforced the use of "Garudamangalam". Banerji (1973, p. 22) has, however, given Kossmat (1897) the credit for renaming the "Trichinopoly Group" of Blanford 1862 (in 1865) to "Garudamangalam". Kossmat
(1897) studied the Cretaceous deposits in the Pondicherry outcrop (see Chapter 2, Figs 2.6 & 2.8) of the Cauvery Basin and correlated them with Blanford’s, 1862 (in 1865) work in the Ariyalur outcrop. Kossmat (1897) reported (Kossmat 1897, pp. 54, 66) a mollusc sandstone unit in the Pondicherry outcrop bearing resemblance with the calcareous, shell-sandstone of Garudamangalam (described as “Trichinopoly marble” by Blanford (1862) in 1865, p. 116) in the Ariyalur outcrop. Kossmat (1897), however, nowhere suggested that the name “Trichinopoly Group” of Blanford 1862 (in 1865) is a misnomer and that “Garudamangalam” is a more appropriate choice. It was Rama Rao (1956, p.199) who, for the first time, mentioned this problem and proposed renaming the Trichinopoly Group as Garudamangalam.

Sundaram & Rao (1979, 1986) recognised the Garudamangalam Sandstone Formation (this study) as the Trichinopoly Group with two formations; (1) Kulakkalnattam Formation and (2) Anaipadi Formation. Banerji (1973) recognised the same unit as the Garudamangalam Formation (Garudamangalam nom. correct of Rama Rao 1956). Later Ramasamy & Banerji (1991) divided the Garudamangalam Formation (Banerji 1973) into three members; Kottarai, Anaipadi, Kulathoor, in stratigraphic order. The code on the exact location of type sections (Whittaker et al. 1992, p. 814) allows the use of term “Garudamangalam” (as revised by Rama Rao 1956 and followed by Banerji 1973) instead of “Trichinopoly” (of Blanford (1862) in 1865). While the rule of priority in publication and preservation of established names (Commission 1983, p. 853) permits the retention of nomenclature, for the Members in the unit, as proposed by Sundaram & Rao (1979, 1986) to that proposed by Ramasamy & Banerji (1991). The “group” status of the unit (e.g., Garudamangalam Group of Rama Rao 1956, Trichinopoly Group of Sundaram & Rao 1979, 1986) is reduced to a “formation” and included in the Uttatur Group (this study). Raising a sediment starved, condensed, sandstone unit (see Chapter 7 for details) to “group” status is not justifiable. The Garudamangalam Sandstone Formation (this study) is divided into a lower Kulakkalnattam Sandstone Member- Section 3.4.2.(iii.a) and an upper Anaipadi Sandstone Member- Section 3.4.2.(iii.b). In the absence of any distinctive lithological
change between the Anaipadi Member and Kulathoor Member (of Ramasamy & Banerji 1991) only the Anaipadi Sandstone Member is being recognised in the present study.

3.4.2.(iii.a) Kulakkalnattam Sandstone Member

**Nomenclature (author):** Sundaram & Rao (1979), after the village Kulakkalnattam.

**Lithology:** Fine to coarse calcareous sandstones with distinct layers of carbonate concretions, shell-rich sandstones, silty sandstones, ferruginous sands, argillaceous siltstones, pebbly sandstones. Near the power line at Kulakkalnattam village (Locality 3 in Fig. 3.2, 11° 06.976' N - 78° 56.391' E), 2 km north of Garudamangalam village (Locality 4 in Fig. 3.2, 11° 05.630' N - 78° 55.751' E) and between Alundalippur and Garudamangalam villages (Locality 5 in Fig. 3.2, 11° 03.856' N - 78° 54.963' E) is a fine- to coarse-grained, well cemented, ferruginous sandstone unit. These sandstones are massive to cross- and planar-laminated containing a distinct layer (double layer in some cases, e.g., near the power line at Kulakkalnattam (Locality 3 in Fig. 3.2), 11° 06.976' N - 78° 56.391' E), of large carbonate concretions (up to 1.5 m in diameter) with vertical burrows (including *Teredolites*). Two km north of Garudamangalam (Locality 4 in Fig. 3.2, 11° 05.630' N - 78° 55.751' E) a carbonate concretion layer (Photo 3.12), with concretions up to 1.5 meters in diameter is followed by a cannon-ball, nodule layer (Photo 3.13). These carbonate nodules have fossil fragments in their nuclei. This nodular-concretionary unit has been reported (e.g., Jain 1976, Nair & Vijayam 1981, Sundaram & Rao 1986, etc.) as a conglomerate bed, being used to identify a major unconformity between the underlying Karai Clay Formation and the overlying Garudamangalam Sandstone Formation. These are, however, carbonate concretions (see Chapter 7 for details) which formed during a transgressive phase. The Karai Clay Formation is therefore followed, conformably in places (see Chapter 7 for details), by the Garudamangalam Sandstone Formation. The less well indurated sandstones are highly bioturbated by feeding traces (e.g.,
Photo 3.12: Distinct layer of carbonate concretions (upto 1.5 m in diameter), base of the Kulakkalnattam Sandstone Member (Garudamangalam Sandstone Formation). Two km north of Garudamangalam (11° 05.630' N - 78° 55.751' E), Locality 4 in Figure 3.2.

Photo 3.13: A Cannon-ball, nodular layer of concretions, in the Kulakkalnattam Sandstone Member (Garudamangalam Sandstone Formation). Two km north of Garudamangalam (11° 05.630' N - 78° 55.751' E), Locality 4 in Figure 3.2.
Cross-bedding appears to occur within shallow channels (1 meter or so) above a coarse pebble (pebbles include basement quartzite, garnet gneisses and quartz) and oyster fragment lag base. This facies appears to cut into planar horizontal laminated, medium-grained sandstones with abundant fine bioclastic material. At Garudamangalam (11° 04.562' N - 78° 55.534' E), south of Kunnam (Locality 6 in Fig. 3.2, 11° 13.018' N - 79° 00.754' E) and Mungalpari (11° 12.235' N - 79° 00.520' E) there are 1-2 meters thick, compact, grey, shell-rich sandstone beds (Photo 3.14) with pockets of pyrite concretions and characterised by the presence of mono-specific molluscan shell banks, a typical near shore or estuarine facies. The unit is a fine- to medium-grained, shell-rich sandstone. When fresh these shell-rich sandstones are dark- to light-grey in colour. When weathered, the colour changes to dirty yellow (due to the oxidation of glauconite into limonite). There are small scale lateral variations in shell concentration, planar- and cross- laminations, load structures (lenses), normal grading and massive beds. On a larger scale a lateral variation in fossil content is
observed. At Garudamangalam the shells are mainly of gastropods while at Kunnam and Mungalpari, bivalve shells dominate. In the past this mollusc-rich unit has been identified (e.g., Blanford 1862 (in 1865), Jain 1976, Nair & Vijayam 1981, Sundaram & Rao 1986, Ramasamy & Banerji 1991, etc.) as shell limestone with one exception. Kossmat (1897) while correlating the Cretaceous deposits in the Pondicherry outcrop (see Figs 2.6 & 2.8) with the Ariyalur outcrop has described (Kossmat 1897, pp. 54, 66) these beds as calcareous shell-sandstones of Garudamangalam. The shell-rich sandstones are followed by a pebbly sandstone bed. Along the stream sections between Sattanur and Mungalpari (11° 10.280' N - 78° 58.878' E), west of Saradamangalam (Locality 8 in Fig. 3.2, 11° 03.346' N - 78° 55.912' E), and stream sections near Kulakkalnattam is a very coarse- to coarse-grained, pebbly, bioclastic sandstone bed with silty sandstones and argillaceous siltstones. The bed contains pyrite, reworked clasts of shelly sandstones (up to 10 cm diameter), basement gneiss and clay pebbles.

**Type locality:** Beneath the power line near Kulakkalnattam (Locality 3 in Fig. 3.2, 11° 06.976' N - 78° 56.391' E) for concretionary sandstone bed; Garudamangalam, (11° 04.562' N - 78° 55.534' E) for grey, shell-rich sandstone bed; stream sections near Kulakkalnattam (for pebbly sandstone bed).

**Reference localities:** Two km north of Garudamangalam (Locality 4 in Fig. 3.2, 11° 05.630' N - 78° 55.751' E) and between Alundalippur and Garudamangalam villages (Locality 5 in Fig. 3.2, 11° 03.856' N - 78° 54.963' E) for concretionary sandstone bed; Kunnam and Mungalpari villages for shell-rich sandstone bed; stream section between Sattanur and Mungalpari villages (Locality 7 in Fig. 3.2, 11° 10.280' N - 78° 58.878' E) and west of Saradamangalam (Locality 8 in Fig. 3.2, 11° 03.346' N - 78° 55.912' E) for pebbly sandstone bed.

**Fossils:** Abundant wood fragments encrusted with oysters and completely bored by bivalves (Hart et al. 1996, Tewari et al. in review), molluscs, Pinna (not in-situ), Thalassinoides, Diplocraterion and Ophiomorpha. In the present study a more comprehensive work on these fossil wood, including morphological characteristics, palaeoenvironmental and sequence stratigraphic significance of these wood fragments,
has been done. It is considered un-necessary to repeat that work in this Chapter. For full account on these fossil wood see Hart et al. 1996 and Tewari et al. in review, (both papers enclosed in Appendix 1).

**Age:** (?) Latest Turonian to earliest Coniacian.

**Environment &/or depositional process:** The sandstone unit (with carbonate concretions) suggests an intertidal to shallow subtidal sandflats or possible foreshore setting. Several flooding events eroded the coastal woodland areas introducing xylic-material to the shallow marine shelf, led to the concretion growth, boring, etc., (see Chapter 7 for details). The drowning led to subtidal, burrowed sands or erosive ravinement surface formation. The mollusc-rich sandstone unit represents a restricted marine environment, formed by rapid deposition from supratidal currents (suggested by loading, graded beds and planar horizontal beddings). An overbank of distributary channels or a high discharge or a washover event into a lagoonal or tidal sandflat environment was probably responsible for these mollusc-rich sandstones. The pebbly sandstone bed appears to be a reworking (perhaps during transgression) of cemented sandstones and rarely basement rocks. The facies most likely represents some form of inlet or channel in delta plain, estuarine or within a barrier succession.

### 3.4.2.(iii.b) Anaipadi Sandstone Member

**Nomenclature (author):** Sundaram & Rao (1979), after the village Anaipadi.

**Lithology:** Dirty yellow, medium- to coarse-grained, hard calcareous sandstone and fine- to medium-grained silts and silty-sandstones.

**Reference localities:** Two km Northwest of Kulattur (Locality 9 in Fig. 3.2, 11° 06.882' N - 78° 58.042' E), one km north of Kulattur and near Kottur (Locality 10 in Fig. 3.2).

**Fossils:** A rich assemblage of Coniacian ammonites, some of which are 1 m in diameter (especially 2 km Northwest of Kulattur, Locality 9 in Fig. 3.2), represented by *Kosmaticeras gr. theobaldianum* Stoliczka, *Kosmaticeras theobaldianum* var. *crassicostata* Colligon, *Puzosia* sp., *Damesites* aff. *sugata* (Forbes) (M. Thomson 64
pers. comm.) along with abundant brachiopods (especially near Kottur, Locality 10 in Fig. 3.2, 11° 09.610′ N - 78° 00.543′ E). Associated with them are nautiloids, molluscs and bored wood with encrusting oysters. The most famous locality is Sattanur where an 18 m long tree trunk is preserved as national monument.

**Age:** Coniacian.

**Remarks:** In the area studied, no complete sections of the Anaipadi Member are present. Isolated exposures of the Member were reported from three localities (see reference localities). Only limited information is, therefore, recorded for the Member.

### 3.4.3 The Ariyalur Group

The Ariyalur Group (**nomenclature:** Blanford (1862) in 1865, p.23) is divided into three formations, (1) the Sillakudi Sandstone Formation- Section 3.4.3.(i), (2) the Kallanakuruchchi Limestone Formation- Section 3.4.3.(ii) and (3) the Kallamedu Sandstone Formation- Section 3.4.3.(iii). Accessibility to and availability of good outcrop sections, for the Ariyalur Group, is greatly reduced. Many of the previously described localities (e.g., Srivastava & Tewari 1969, Rasheed & Ravindran 1978, Ravindran 1980, etc.,) are now lost due to expanding settlement or are covered under vegetation. Only limited outcrop sections are available for study for the Ariyalur Group, except where working quarries exist.

#### 3.4.3.(i) Sillakudi Sandstone Formation

A major unconformity, spanning (?) post-Coniacian to late Santonian, is present between the Garudamangalam Sandstone Formation and the Sillakudi Sandstone Formation. During this period the Basin appears to be under erosive and/or fluvial influence. At a stream section, north of Saturbhagam (11° 03.188′ N - 78° 57.954′ E, Locality 11 in Fig. 3.2), fluvial sandstones and silty-sandstones (Photo 3.15) with reworked, mud, fresh feldspar pebbles and sandstone cobbles (up to 30 cm diameter)
Photo 3.15: Fluvial sandstones and silty-sandstones with reworked, mud, fresh feldspar pebbles and sandstone cobbles. At a stream section, north of Saturbhagam (11° 03.188' N - 78° 57.954' E), Locality 11 in Figure 3.2.

Photo 3.16: Friable calcareous sands followed by a hard calcareous sandstone bed (Sillakudi Sandstone Formation) at the Sillakudi railway cutting (Locality 14 in Fig. 3.2).
are exposed. Very large scale trough cross-beds with sets upto 3 m wide (pale grey siltstone drape some foreset surfaces) occur in the unit. This is probably a fluvial channel fill. Mud drapes may indicate some marine tidal influence although this may also be the result of seasonal changes in discharge. The Sillakudi Sandstone Formation has the largest areal extent (Fig. 3.2) in comparison to any other formations in the outcrop. This, however, is due to the near horizontal nature of the Formation and should not be confused for a greater thickness of the unit.

**Nomenclature (author):** Srivastava & Tewari (1969), after the village Sillakudi.

**Lithology:** Medium to coarse, off-white to grey, calcareous friable sands and hard, calcareous sandstones (Photo 3.16). There is a local development of carbonate facies (discussed later), however, in an otherwise clastic Sillakudi Sandstone Formation.

**Petrography:** Medium to coarse, moderate- to poorly-sorted grains with fine-grained, carbonate mud matrix. The grains constitute 70% to 80% of the rock. The principal grain types are subangular to subrounded quartz (constituting 80%) and feldspar (15%), including perthite intergrowth. Some biotite and glauconite, together with rare inoceramid prisms and mollusc fragments form the remainder 5% of the grains. The rock is mineralogically mature (80% of the grains are quartz) and texturally mature to submature (moderate to poor sorting, subangular to subrounded grains and matrix forming approximately 30% of the rock).

**Reference locality:** Sillakudi railway cutting; 11° 04.887' N - 79° 01.966' E, Locality 14 in Fig. 3.2.

**Fossils:** Except for a few inoceramid prisms and foraminifera, the sandstones are very poor in fossils. The only datable foraminiferid present is *Globotruncana arca* (Cushman), suggesting a Campanian age.

**Age:** Probable Campanian.

**Remarks:** In the present study no good outcrop sections were found. Previously reported (Ravindran 1980) sections are lost either due to expanding settlement or are now covered under vegetation. Srivastava & Tewari (1969), Rasheed & Ravindran
(1978) and Ravindran (1980), Govindan et al. 1996 have reported a rich foraminiferal assemblage from surface and subsurface material of the Sillakudi Sandstone Formation.

3.4.3.(i.a) Kilpalvur Grainstone Member

A new (locally developed around Kilpalvur, Fig. 3.2) member, the Kilpalvur Grainstone Member is proposed for the base of the Sillakudi Sandstone Formation.

**Nomenclature (author)**: Proposed name, after the type locality Kilpalvur (Fig. 3.2).

**Lithology**: White to off-white, coarse-grained, bioclastic, oolitic grainstone-packstone with oolites (probably chamosite) constituting 90% of the allochems.

**Petrography**: The rock is coarse-grained, moderately sorted, grain-supported (allochems comprising at least 60% or more of the rock) with carbonate mud sediment in the matrix and ferroan calcite cement. Oolites constitute 90% of the allochem (Photo 3.17). The oolites are oval to elongate, indicating that the allochem (oolites) are strained. The remainder 10% of the allochem are bioclasts (foraminifera, inoceramid prisms, rare bivalve and echinoid fragments). The inoceramid prisms are bored, with the borings filled with oolites and/or micrite and microspar (Photo 3.18). The micrite (carbonate mud) shows neomorphism to microspar. Although the spar calcite cement and microspar are mainly blue-stained ferroan calcite, there are tints of pink-stained non-ferroan calcite. Reducing conditions must have existed to incorporate any ferrous iron into the calcite lattice to produce ferroan calcite. This is also supported by the fact that the oolites are composed of chamosite. Some oxidising conditions must have existed, however, allowing the ferrous iron to oxidise to ferric iron and precipitate as iron hydroxide (Photo 3.17). The oolites also show the oxidising effect, where the chamosite is oxidised to limonite. The rock has a grainstone-packstone fabric.

**Type Locality**: Well sections north of Kilpalvur (Locality 12 in Fig. 3.2); 11° 04.045′ N - 79° 04.585′ E.

**Fossils**: Foraminifera, inoceramid prisms and rare bivalve and echinoid fragments. Amongst the foraminifera, tiny, *Globigerinelloides* Cushman & ten Dam dominate.
Photo 3.17: Field of view: ~3.3 mm. The Kilpalvur Grainstone Member (Sillakudi Sandstone Formation) with oolites (scale: x 40) constituting the dominant part of the allochem. The rock shows a grainstone fabric with blue ferroan calcite cement. Most of the oolites are elongate, suggesting some straining. The blue ferroan calcite with tints of pink non-ferroan calcite (top right) and the brown iron hydroxide (bottom left) suggest some oxidising conditions were present.

Photo 3.18: Field of view: ~3.3 mm. A longitudinal section of an inoceramid prism (Scale: x 40) in the Kilpalvur Grainstone Member (Sillakudi Sandstone Formation). The prism is bored, with the boring now filled with micrite, spar calcite and oolites.
Rare occurrences of *Marginotruncana marginata* (Reuss), *Globotruncana* Cushman, *Whiteinella baltica* Douglas & Rankin and *Archaeoglobigerina* Pessagno are reported.

**Age:** Late Santonian.

**Remarks:** The Kilpalvur Grainstone Member is exposed only in well sections, where it is seen resting on the Archaean basement and/or Dalmiapuram Limestone Member and followed by the Kallanakuruchchi Limestone Formation. Full access to these wells is not possible. The Member may, however, have a more extensive distribution, exposed on the eastern side of the Kilpalvur Ridge not yet investigated in the present study.

### 3.4.3.(ii) Kallanakuruchchi Limestone Formation

**Nomenclature (author):** Srivastava & Tewari (1969), after the village Kallanakuruchchi (Fig. 3.2), nom. amend. Kallanakuruchchi Yellow Marls of Tewari & Srivastava (1965).

The Sillakudi Sandstone Formation is followed unconformably by the Kallanakuruchchi Limestone Formation. At a stream section, near Kallar (11° 08.246' N - 79° 06.965' E, Locality 13 in Fig. 3.2), orange-yellow, pebbly grainstone (Kallanakuruchchi Limestone) with abundant subangular to angular, pink to white quartz and feldspar pebbles to cobbles, some of which are 10 cm in diameter is exposed. Three core sections, (112, 113 and 114), from the well PK3/95 at Periya-Patiakkadu (11° 01' N - 79° 09' E, Fig. 3.2), were made available for study (Dalmia Cement Co. pers. comm.). In PK3/95 at a depth of 34.20 m (Section 114) Sillakudi Sandstone is present. At 34.10 m (Section 113) a 5-10 cm thick gradational unit is followed by a 25 cm thick conglomerate unit (at 33.75 m, Section 112). Dark-grey sandstone pebbles, approximately 3x2 cm² (clasts are reworked pebbles of the underlying Sillakudi Sandstone Formation) are present in orange-yellow limestone; above which the Kallanakuruchchi Limestones start. The Limestones are first located at a depth of 30 m (Lakshminarayanan pers. comm.). Drilling was stopped at 35 m. The presence of a
conglomerate bed (at Kallar stream section (Locality 13 in Fig. 3.2) and in PK3/95 well) between the Sillakudi Sandstone Formation and Kallanakuruchchi Limestone Formation indicates a break in the deposition in the (?) mid-Campanian. Based on the study of drilled material from Tancem, Tamin and Dalmia mines, Radulovic & Ramamoorthy (1992, pp. 78-79, text-fig. 2) report an approximate 1 to 5 m thick conglomerate bed at the base of the Kallanakuruchchi Limestones. This conglomerate unit (Radulovic & Ramamoorthy 1992) is, however, not exposed in any of these mines.

The Kallanakuruchchi Limestone Formation is a clastic dominated-carbonate sequence. Three new members; (1) the Tancem Limestone Member- Section 3.4.3.(ii.a), (2) the Dalmia Biostromal Member- Section 3.4.3.(ii.b) and (3) the Dherani Limestone Member- Section 3.4.3.(ii.c), are proposed in the Kallanakuruchchi Formation. All facies appear to extend laterally over several hundred meters with little lateral variation. The succession represents a retrograding (transgressive) carbonate ramp setting.

3.4.3.(ii.a) Tancem Limestone Member

**Nomenclature (author):** Proposed name, after the type locality Tancem.

**Lithology:** Hard, orange-yellow (Photo 3.19), red in places (due to weathering and oxidation of iron-oxides), coarse- to very coarse-grained, massive to thick bedded (200 to 50 cm) with some beds coarsening up, bioclastic to sandy bioclastic packstone-grainstone, composed mainly of larger foraminifera, bryozoa and rudist bivalves. A lateral variation in the fossil content is seen. At Tancem mines 80-90% of the bioclasts comprise larger foraminifera (Photo 3.20), with bryozoa and rudist bivalves reduced to less than 10%. On the contrary, at the Dalmia (or Fixit) mine 80-90% of the bioclasts constitute bryozoa and rudist bivalves (Photo 3.21) in nearly equal percentage, with larger foraminifera greatly reduced.

**Petrography:** Grain-supported fabric (allochem comprising 70-80% of the rocks, Photos 3.20 & 3.21) with fine to medium sparite cement and/or fine carbonate mud
matrix. The spar cement is pink, non-ferroan calcite with thin zones of mauve-blue ferroan calcite. The ferrous iron present is oxidised and precipitated as ferric hydroxide. The allochems are bioclasts, mainly larger foraminifera (Lepidorbitoides Silvestri and Siderolites Lamark), bryozoa and bivalves (including rudist bivalve- oysters and inoceramid), comprising 80-90% of the allochem (Photos 3.20 & 3.21). Smaller foraminifera, red algae, ostracod and echinoid spines and plates comprise the remainder of the bioclasts. Rudist bivalves are bored to a greater or lesser extent. The borings are filled with spar calcite, carbonate mud and other bioclasts. Terrigenous clastic grains (mainly quartz and feldspar (including perthite intergrowths) and rare glauconite and mica flakes) range from as low as 1/2% to as high as 15/20%. The rock has a

**Type locality:** Tancem mine, 11° 04.887' N - 79° 06.590' E (Fig. 3.2).

**Reference localities:** Dalmia and Dherani mines (Fig. 3.2).

**Fossils:** Larger foraminifera, *Lepidorbitoides* sp. cf. *L. socialis* Leymerie, *Siderolites calcitrapoides* Lamark together with bryozoans, rudist bivalve (oyster shells and
Inoceramus prisms), some red algae, ostracod valves and echinoid fragments (many of which are bored).

**Age:** Late Campanian-Maastrichtian.

**Remarks:** The unique feature of these limestones (Tancem Limestone Member) is the absence of Omphalocyclus Bronn, a Maastrichtian larger foraminifera. In European and Middle Eastern Maastrichtian rocks, the Lepidorbitoides are usually associated with Omphalocyclus (M.B. Hart pers. comm.).

3.4.3.(ii.b) Dalmia Biostromal Member

**Nomenclature (author):** Proposed name, after the type locality Dalmia.

**Lithology:** At Dalmia (or Fixit) mine the Tancem Limestone Member is followed by an orange-yellow, laterally extensive biostromal limestone (Photo 3.22). The limestones are sandy rudstones (characterised by large Gryphaea, terebratulids, Alectronia/Lopha and shell-fragments of approximately 10-12 cm in size) with a coarse to very coarse, bioclastic grainstone matrix (similar to the Tancem Limestone Member).

**Type locality:** Dalmia or (Fixit) mine, 11° 07.997' N - 79° 08.288' E (Photo 3.22).

**Fossils:** Gryphaea, Alectronia/Lopha, terebratulids (many of which are bored and partially encrusted by serpulids, bryozoans and sponges), larger foraminifera, e.g., Lepidorbitoides sp. cf socialis, Siderolites calcitrapoides, Goupillaudini daguini Marie.

**Age:** Late Campanian-Maastrichtian.

**Remarks:** Radulović & Ramamoorthy (1992) have described the brachiopods occurring in these limestones.

3.4.3.(ii.c) Dherani Limestone Member

**Nomenclature (author):** Proposed name, after the type locality Dherani quarry.

**Lithology:** The Dherani Limestone Member comprises of massive, orange-yellow, coarse-grained, friable, orbitoid-rich grainstone/orbitoid-rich sands (Photo 3.23).
Photo 3.22: Dalmia Biostromal Member (Kallanakuruchchi Formation), Dalmia mine (type locality). Orange-yellow (fresh surface, to the right of the photograph), biostromal limestone. The white specks seen in the limestone are the large Gryphaea, terebratulids, Alectronia/Lopha and shell fragments, that pack the rock.

Photo 3.23: The Dherani Limestone Member (Kallanakuruchchi Limestone Formation), Dherani quarry (type locality). Massive, orange-yellow, friable, coarse-grained, orbitoid-rich grainstone sands.
**Type locality:** Dherani quarry, 11° 04.006' N - 79° 09.078' E (Fig. 3.2).

**Fossils:** Larger foraminifera, e.g., *Lepidorbitoides* sp. cf. *L. socialis*, *Siderolites calcitrapoides*, disseminated bivalves (inoceramid, *Gryphaea*) and some whole, large terebratulids.

**Remarks:** At Dherani quarry the Tancem Limestone Member is followed by an approximately 3-4 m of friable, orbitoid-rich sands. Drilling in the quarry is still in progress and 18 m of orbitoid sand has been encountered so far (Quarry manager pers. comm.).

### 3.4.3.(iii) Kallamedu Sandstone Formation

The Kallamedu Sandstone Formation marked an end to the Cretaceous sedimentation in the Basin. The Formation has a locally developed, Ottakovil Sandstone Member-Section 3.4.3.(iii.a).

**Nomenclature (author):** Srivastava & Tewari (1969), after the village Kallamedu (=Cullmood in old literature).

**Lithology:** Red to green/grey variegated claystones (Photo 3.24) overlain by channels of white to pale grey, well to poorly cemented, texturally mature, fine- to medium-grained sandstone. Channel bases contain horizontal planar laminations overlain by sets of low angle planar, cross bedding. A small vertical burrow (present in one foreset) and calcite cement suggests (?) some marine influence.

**Type locality:** Kallamedu, 11° 11.890' N - 79° 08.014' E (Fig. 3.2).

**Environment &/or depositional process:** Variegated clays suggest soil formation in overbank muds with channelised sands showing high degree of maturity and yet appearing to indicate a rapid, shallow deposition in shallow channels. May indicate flash fluvial, flood plain to coastal plain environment with minor marine influence.
3.24: Pale grey to off-white, fine-to medium-grained, sandstones with horizontal planar laminations of the Kallamedu Sandstone Formation, Kallamedu (type locality).

3.4.3.(iii.a) Ottakovil Sandstone Member


The formational status of the Ottakovil Sandstone (Ottakovil Formation of Sastry & Mamgain 1971) is not recognised here as it is not a mappable unit. Also in a lithostratigraphic classification separating the post-Kallanakuruchchi sandstones and unconsolidated sands as Ottakovil Formation and Kallamedu Formation (Sastry & Mamgain 1971) respectively is not justifiable. The Ottakovil Sandstone is a locally developed, regressive marine sandstone and the Kallamedu Sandstone is a fluvial sandstone, but depositional process is not a criterion in lithostratigraphic classification (Commission A.A.P.G. 1983, p. 856). The Ottakovil Sandstone and the Kallamedu Sandstone are, therefore, included as the Kallamedu Sandstone Formation (in this study) with a locally developed, lower Ottakovil Sandstone Member.
**Lithology:** A locally developed Member comprising of grey, dirty-yellow to off-white, cross-bedded (beds unclear to medium bedded), medium to coarse, micaceous (predominantly biotite), friable sand and well cemented, fine- to medium-grained sandstone. Trough cross bedding present at one horizon, sets from 15 to 20 cm thick (at one place cross sets 25 cm thick, 150 cm across).

**Petrography:** Terrigenous grains (quartz, feldspar, biotite and glauconite) comprising 30-40% of the rock in a mauve-pink, non-ferroan, fine carbonate mud matrix with tints of blue ferroan matrix. Medium to coarse, moderately sorted, subangular to subrounded terrigenous grains. Samples from the upstream side of the Ottakovil stream section (type locality) have 20-30% of biotite, 10-12% quartz and feldspar grains and 10-20% of bioclasts. The bioclasts comprise of foraminifera (constituting for about 80% of the bioclasts), echinoid spines and plates, bivalves (with both calcite and originally aragonite shell composition), some bryozoa, red algae fragments and ostracod shells. The bioclasts are very similar to that reported from the Kallanakuruchchi Limestones, with the exception of larger foraminifera (Lepidorbitoides and Siderolites), which are rare to virtually absent. Samples from the downstream side of the Ottakovil stream section (type locality) have a higher percentage of quartz grains (90% of the terrigenous grains) with some feldspar, biotite and glauconite grains. The bioclasts (constituting only of echinoid and bivalve fragments) are significantly reduced, forming <1% of the rock.

**Type locality:** Two km north (at a stream section) of Ottakovil (Fig. 3.2), 11° 11.910' N - 79° 06.850' E.

**Fossils:** In the upstream section the sandstones are associated with echinoids (mainly Stigmatophygus), rare larger foraminifera, together with the trace fossils Thalassinoides, Ophiomorpha, (?) Dactyloidites. Higher up in the stratigraphic section (in the downstream side) the sandstones record frequently occurring Stigmatophygus together with nautilus, Durania mutabilis (Stoliczka) a (?) Maastrichtian rudist bivalve (P. Skelton pers. comm.), Gunnarites kalika (Stoliczka) a Maastrichtian ammonite (M. Thomson pers. comm.) and Alectronia/Lopha.

**Age:** Maastrichtian.
**Environment &/or depositional process:** A relatively low energy, open marine, lower-upper shore face environment. Trough sets of limited lateral extent may represent rip or long shore troughs/channels. The trace fossil assemblage indicate a marginal marine, reduced sedimentation environment of deposition. The associated ammonites are suggestive of more open marine conditions (locally developed) in an otherwise shallowing Basin.

### 3.5 Summary

Investigation of the Cretaceous rocks of Trichinopoly District has lead to a revision of the existing lithostratigraphy. Throughout the study the code of stratigraphical procedure, rule of priority of publication and the preservation of established names are practised. A revised lithostratigraphic classification, dividing the Cretaceous rocks (on-shore part) into three Groups, seven Formations and seventeen Members (of which nine are new), is established.
### Table 3.1: The revised lithostratigraphic classification and facies relationships of the Cretaceous rocks in the Aryalur outcrop, Cauvery Basin

<table>
<thead>
<tr>
<th>STAGE</th>
<th>FACIES RELATIONSHIPS</th>
<th>PROPOSED LITHOSTRATIGRAPHIC CLASSIFICATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>MA++</td>
<td>shallow water &lt; basinal [continental]</td>
<td>Kallamedu Sst. Fm.</td>
</tr>
<tr>
<td>CAMP</td>
<td>? ? ?</td>
<td>Dharani Sandstone Member</td>
</tr>
<tr>
<td>SAN</td>
<td>? ? ?</td>
<td>Dalmia Biosmoral Member</td>
</tr>
<tr>
<td>CO.</td>
<td>? ? ?</td>
<td>Tancen Limestone Member</td>
</tr>
<tr>
<td>TUR.</td>
<td>?</td>
<td>Kilipalvur Grainstone Mbr.</td>
</tr>
<tr>
<td>CEN.</td>
<td>?</td>
<td>Sillakudi Sandstone Formation</td>
</tr>
<tr>
<td>APTIAN</td>
<td>?</td>
<td>Kallakuruchi Cherty Limestone Formation</td>
</tr>
<tr>
<td>ALBIAN</td>
<td>?</td>
<td>Kulakkainittam Sandstone Member</td>
</tr>
<tr>
<td>ARYA</td>
<td></td>
<td>Anaiyadi Sandstone Member</td>
</tr>
<tr>
<td>UTTI</td>
<td></td>
<td>Garudamangalam Sandstone Formation</td>
</tr>
<tr>
<td>CONDWA</td>
<td></td>
<td>Odiyam Sandstone Member</td>
</tr>
<tr>
<td>ARCHAEN</td>
<td></td>
<td>Karai Clay Formation</td>
</tr>
</tbody>
</table>

### Proposed Lithostratigraphic Classification

<table>
<thead>
<tr>
<th>MEMBERS</th>
<th>FORMATION</th>
<th>GROUP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kallamedu Sst. Fm.</td>
<td>Kallamedu Group</td>
<td></td>
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<tr>
<td>Dharani Sandstone Member</td>
<td>Dharani Group</td>
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<tr>
<td>Dalmia Biosmoral Member</td>
<td>Dalmia Group</td>
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<tr>
<td>Tancen Limestone Member</td>
<td>Tancen Group</td>
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<tr>
<td>Kilipalvur Grainstone Mbr.</td>
<td>Kilipalvur Group</td>
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<tr>
<td>Sillakudi Sandstone Formation</td>
<td>Sillakudi Group</td>
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<tr>
<td>Kallakuruchi Cherty Limestone Formation</td>
<td>Kallakuruchi Group</td>
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<tr>
<td>Kulakkainittam Sandstone Member</td>
<td>Kulakkainittam Group</td>
<td></td>
</tr>
<tr>
<td>Anaiyadi Sandstone Member</td>
<td>Anaiyadi Group</td>
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<tr>
<td>Garudamangalam Sandstone Formation</td>
<td>Garudamangalam Group</td>
<td></td>
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<tr>
<td>Odiyam Sandstone Member</td>
<td>Odiyam Group</td>
<td></td>
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<tr>
<td>Karai Clay Formation</td>
<td>Karai Group</td>
<td></td>
</tr>
<tr>
<td>Terani Clay Member</td>
<td>Terani Group</td>
<td></td>
</tr>
<tr>
<td>Sivaganga Formation</td>
<td>Sivaganga Group</td>
<td></td>
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<tr>
<td>Kallakuruchi Cherty Limestone Formation</td>
<td>Kallakuruchi Group</td>
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<td>Kulakkainittam Sandstone Member</td>
<td>Kulakkainittam Group</td>
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<td>Anaiyadi Sandstone Member</td>
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<tr>
<td>Garudamangalam Sandstone Formation</td>
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<tr>
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<tr>
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<tr>
<td>Terani Clay Member</td>
<td>Terani Group</td>
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<tr>
<td>Sivaganga Formation</td>
<td>Sivaganga Group</td>
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<td>Kallakuruchi Cherty Limestone Formation</td>
<td>Kallakuruchi Group</td>
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<tr>
<td>Kulakkainittam Sandstone Member</td>
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<tr>
<td>Anaiyadi Sandstone Member</td>
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<td>Terani Clay Member</td>
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<tr>
<td>Terani Clay Member</td>
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<tr>
<td>Sivaganga Formation</td>
<td>Sivaganga Group</td>
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</tbody>
</table>

**Note:** The facies relationships and lithostratigraphic classification are simplified representations based on the given data.
### Table 3.2: Correlation of the proposed lithostratigraphic classification with some of the existing classifications in the Cauvery Basin.

<table>
<thead>
<tr>
<th>GROUPS</th>
<th>FORMATIONS</th>
<th>MEMBERS</th>
<th>PROPOSED LITHOSTRATIGRAPHIC CLASSIFICATION</th>
<th>CORRELATION WITH EXISTING LITHOSTRATIGRAPHIC CLASSIFICATION</th>
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</thead>
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<tr>
<td><strong>ARYALUR</strong></td>
<td>Kallamedu Sst. Fm.</td>
<td></td>
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<td>Sundaram &amp; Rao (1988)</td>
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<tr>
<td></td>
<td>Kallankuruchchi Limestone Formation</td>
<td></td>
<td></td>
<td>Banerji (1982); Ramasamy &amp; Banerji (1991)</td>
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<tr>
<td></td>
<td>Siltakudi Sandstone Formation</td>
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<tr>
<td><strong>UTTATUR</strong></td>
<td>Kallakudi Sandstone Member</td>
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<td></td>
<td>Kallamedu Sst. Fm.</td>
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<td>Kallakudi Formation</td>
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<td>Odiyam Sandstone Mbr.</td>
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<td><strong>CONDWANAI</strong></td>
<td>Sivaganga Formation</td>
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<td><strong>ARCHAEOAN</strong></td>
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![Diagram](image-url)
Chapter 4

Systematic palaeontology
4.1 Introduction

This Chapter presents a systematic record of the planktonic and the benthonic foraminifera reported from the Aptian-Maastrichtian succession of the Cauvery Basin. The classification followed is that outlined by Loeblich & Tappan (1988). The generic definitions used for the benthonic foraminifera are according to Loeblich & Tappan (1988) and for the planktonic foraminifera by Robaszynski & Caron (1979), Robaszynski et al. (1984) and Caron (1985), except where stated otherwise. During the course of this study 300 species, belonging to 91 genera, have been recognised. Significant variations (in morphology and stratigraphic range) in the planktonic foraminifera assemblage from the Cauvery Basin are described for the first time.

In the present study a complete synonymy and/or reference list of foraminiferal species is not attempted. For each species the references are restricted to the first original description of the species and subsequent references that include relevant information on stratigraphy and/or taxonomic change. All the references are listed according to their year of publication; giving the author, date, plate and figure numbers. The taxonomic descriptions are kept brief, restricted only to the distinctive and diagnostic morphological features. More extensive morphological descriptions are made for the species where significant variation is observed. During the process of speciation some of the foraminifera could be identified only at their generic level and were given a cardinal number. As the work progressed, some of these (foraminifera with a cardinal number) could be identified at their species level. This did not affect, however, the numerical order. The number assigned to a specimen, at the time of its original description, was retained throughout the record. No readjustments were made to fill in the missing numbers arising from subsequent nomenclature of the previously unspeciated specimens. The biochronostratigraphic range and frequency (abundance) of foraminiferal species are also reported. The terms used to define the frequency (absolute numbers in the total count) are as follows: very rare (1-3), rare (4-10), common (11-25), frequent (26-75), abundant (76-100) and very abundant (>101).
Each species is illustrated by scanning electron microphotographs using the specimens forming the curated type collection. The Plates, numbered 1 to 27, are enclosed at the end of the thesis (see Appendix 2).

4.2 Foraminifera

Phylum PROTOZOA
Subphylum SARCODINA
Class RHIZOPODEA
Subclass GRANULORETICULOSIA
Order FORAMINIFERIDA

Suborder TEXTULARIINA Delage & Herouard, 1896
Superfamily ASTRORHIZACEA Brady, 1881
Family BATHYSIPHONIDAE Avnimelech, 1881
Genus BATHYSIPHON Sars, 1872
Type species: Bathysiphon filiformis Sars, 1872

Bathysiphon ex gr. vitta Nauss
(Pl. 1, Figs 1-2)

Bathysiphon vitta Nauss, 1947, p. 334, pl. 48, fig. 4 (fide Koutsoukos 1989).

Diagnosis: Morphotypes assigned to this species-group occur as fragments of unilocular, unbranched, compressed, tubular, straight or slightly curved tests, open at both ends; test surface is finely agglutinated and smooth.

Range: Upper Albian to Middle Turonian.

Occurrence: Very rare to rare.
Family **RHABDAMMINIDAE** Brady, 1884  
Subfamily **RHABDAMMININAE** Brady, 1884  
Genus **RHABDAMMINA** Sars, 1869  
Type species: *Rhabdammina abyssorum* Sars, in Carpenter, 1869

**Rhabdammina sp. 1**  
(Pl. 1, Fig. 3)

**Diagnosis:** Short, rarely branched, straight to slightly constricted tubular fragments, coarsely agglutinated, aperture terminal and slit.  
**Range:** Upper Albian to Lower Turonian.  
**Occurrence:** Very rare to rare.

Genus **RHIZAMMINA** Brady, 1879  
Type species: *Rhizammina agaeformis* Brady, 1879

**Rhizammina ex gr. indivisa** Brady  
(Pl. 1, Fig. 4)

*Rhizammina indivisa* Brady, 1884, p. 277, pl. 29, figs 5-7 (*fide* Koutsoukos 1989).  

**Diagnosis:** Morphotypes are characterised by unilocular, elongate, cylindrical to sinusoidal, flattened tests; moderately coarsely agglutinated; aperture is terminal and slit.  
**Range:** Upper Albian to Lower Turonian.  
**Occurrence:** Very rare.

Genus **SACCAMMINA** Carpenter, 1869  
Type species: *Sacammina sphaerica* Brady, 1871
Saccammina alexanderi (Loeblich & Tappan)
(Pl. 1, Fig. 5)

Proteonina alexanderi Loeblich & Tappan, 1950, p. 5, pl. 1, figs 1,2.

**Diagnosis:** Sac-shaped, slightly compressed test; aperture terminal, slit-like (probably due to post-mortem compaction), on a produced neck.

**Range:** Upper Albian.

**Occurrence:** Very rare to rare.

Superfamily HIPPOCREPINACEA Rhumbler, 1895
Family HIPPOCREPINIDAE Rhumbler, 1895
Genus HYPERAMMINA Brady, 1878
Type species: Hyperammina elongata Brady, 1878

Hyperammina ex gr. gaultina ten Dam
(Pl. 1, Fig. 6)

Hyperammina gaultina ten Dam, 1950, p. 5, pl., fig. 8 (*fide* Koutsoukos 1985).
Hyperammina gaultina ten Dam. Bartenstein, 1974, p. 685, pl. 1, figs 5-30, 35-36; pl. 2, figs 1-4.
Hyperammina sp. 1 Bartenstein, 1974, p. 685, pl. 2, figs 5-14.

**Diagnosis:** Hyperammina ex gr. gaultina morphotypes are characterised by slightly compressed, tubular, unbranching tests, medium to moderately coarsely grained agglutinated surface, tests are slightly flattened due to compression.
Remarks: Hyperammina ex gr. gaultina and Bathysiphon ex gr. vitta Nauss morphotypes are closely related and it is not always possible to differentiate between the two.

Range: Upper Albian to Lower Turonian.

Occurrence: Very rare to rare.

Superfamily AMMODISCACEA Reuss, 1862
Family AMMODISCIDAE Reuss, 1862
Subfamily AMMODISCINAE Reuss, 1862
Genus AMMODISCUS Reuss, 1862
Type species: Ammodiscus infimus Bornemann, 1874

Ammodiscus cretaceus (Reuss)
(Pl. 1, Fig. 7)

Operculina cretacea Reuss, 1845, p. 35, figs 64-65 (fide Koutsoukos 1989).
Ammodiscus cretaceus (Reuss). Cushman, 1946, p. 17, pl. 1, fig. 35.
Ammodiscus cretaceus (Reuss). Koutsoukos, 1989, p. 38, pl. 1, fig. 21.

Diagnosis: An undivided, evolute, planispiral, tubular test, circular to slightly ovate in outline, finely agglutinated with a smooth surface.

Range: Upper Albian to Lower Turonian.

Occurrence: Very rare to common.

Subfamily AMMOVERTELLININAE Saidova, 1981
Genus GLOMOSPIRA Rzehak, 1885
Type species: Trocharmina squamata Jones & Parker var. gordialis Jones & Parker, 1860
**Glomospira charoides** (Jones & Parker)  
(Pl. 1, Figs 19-20)

_Trochammina squamata_ var. _charoides_ Jones & Parker, 1860, p. 304 (fide Koutsoukos 1989).

_Glomospira charoides_ (Jones & Parker) var. _corona_ Cushman & Jarvis, 1928, p. 89, pl. 12, figs 9-11.


**Diagnosis:** The species is characterised by an undivided tubular chamber; the forms are completely coiled forming a conical or bell shaped test, where the coiling is incomplete a globular shaped test is seen; finely agglutinated surface.

**Range:** Upper Albian to Upper Cenomanian.

**Occurrence:** Very rare to rare.

**Glomospira sp. aff. G. gordialis** (Jones & Parker)  
(Pl. 1, Fig. 21)


_Gordialis gordialis_ Jones & Parker. Bartenstein, 1974, p. 686, pl. 2, figs 51-53 (not fig. 54; pl. 3, figs 1-3).


**Diagnosis:** _G. gordialis_ is characterised by an undivided, tubular chamber, coiled irregularly, finely agglutinated.

**Range:** Upper Albian.

**Occurrence:** Very rare.
Genus **GLOMOSPIRELLA** Plummer, 1945  
Type species: **Glomospira umbilicata** Cushman & Waters, 1927

**Glomospirella gaultina** (Berthelin)  
(Pl. 1, Fig. 8)

*Ammodiscus gaultinus* Berthelin, 1880, p. 19, pl. 1, fig. 3a-b (*fide* Koutsoukos 1989).  
*Glomospira gordialis* Jones & Parker. Bartenstein, 1974, p. 686, pl. 2, fig. 54; pl. 3, figs 1-3.  

**Diagnosis:** An undivided, tubular chamber, initial streptospiral coil which later becomes planispirally coiled, test flat and discoidal; aperture at the end of the tube.  
**Range:** Upper Albian and Upper Cenomanian to Lower Turonian.  
**Occurrence:** Very rare to rare.

Superfamily **RZEHAKINACEA** Cushman, 1933  
Family **RZEHAKINIDAE** Cushman, 1933  
Genus **SILICOSIGMOILINA** Cushman & Church, 1929  
Type species: **Silicosigmoidina californica** Cushman & Church, 1929

**Silicosigmoidina** sp. 1  
(Pl. 1, Fig. 9)

**Diagnosis:** Spindle shaped test with sigmoidal chambers arranged in miliolid fashion; aperture terminal and round without a tooth; surface smooth and finely agglutinated.  
**Range:** Upper Cenomanian to Lower Turonian.  
**Occurrence:** Very rare.
Superfamily HORMOSINACEA Haeckel, 1894
Family HORMOSINIDAE Haeckel, 1894
Subfamily REOPHACINAE Cushman, 1910
Genus REOPHAX de Montfort, 1808
Type species: Reophax scorpiurus de Montfort, 1808


Reophax sp. cf. R. ampullacea (Brady)
(Pl. 1, Fig. 10)

Reophax ampullacea Brady (fide Neagu 1965).
Proteonina cf. ampullacea (Brady). Neagu, 1965, p. 3, pl. 1, fig. 11.
Proteonina sp. Bartenstein, 1972, p. 685, pl. 2, fig. 36 (not fig. 37).

Diagnosis: A flat to semi-globular, sac-shaped test; surface coarse-grained and rough; aperture on an open end of the extended neck.
Range: Upper Albian.
Occurrence: Very rare.

Reophax scorpiurus Montfort
(Pl. 1, Fig. 12)

Reophax scorpiurus Montfort. Neagu, 1965, p. 4, pl. 1, fig. 12.

Remarks: A sac-shaped, coarsely agglutinated test; aperture terminal on a produced neck.
Range: Upper Albian.

Occurrence: Very rare.

**Reophax sp. 1**

(Pl. 1, Fig. 11)

**Diagnosis:** An inflated, unilocular, flask-shaped test; surface finely agglutinated; aperture terminal, round and at both ends of the extended chamber.

Range: Upper Albian.

Occurrence: Very rare.

Subfamily **HORMOSININAE** Haeckel, 1984

Genus **HORMOSINA** Brady, 1879

Type species: **Hormosina globulifera** Brady, 1879

**Hormosina crassa** Geroch

(Pl. 1, Fig. 14)

**Hormosina ovulum crassa** Geroch 1966, p. 439, pl. 6, figs 19, 21-26; pl. 7, figs 21-23.

**Hormosina crassa** Geroch. Moullade et al., 1988, p. 364, pl. 2, figs 4-6.

**Hormosina crassa** Geroch. Malata & Oszczypko, 1990, p. 516, pl. 1, fig. 7.

**Remarks:** A compressed, spindle-shaped test, drawn out at both ends; aperture terminal.

**Range:** Upper Albian to Middle Cenomanian.

**Occurrence:** Very rare.
Hormosina ovulum (Grzybowski)
(Pl. 1, Fig. 15)


Hormosina ovulum (Grzybowski). Malata & Oszczypko, 1990, p. 516, pl. 1, fig. 5.

**Diagnosis:** A globular or drop-like chamber; wall smooth and aperture terminal, on a produced neck.

**Range:** Lower to Middle Cenomanian.

**Occurrence:** Rare.

Family **Cribratinidae** Loeblich & Tappan, 1964
Genus **Cribrata** Sample, 1932
Type species: *Nodosaria texana* Conrad, in Emory, 1857

Cribrata sp. 1
(Pl. 1, Fig. 13)

**Diagnosis:** A uniserial, rectilinear, partly compressed test; sutures appear to be straight and horizontal; medium to moderately coarse-grained; aperture terminal and cribate with multiple, irregular openings.

**Range:** Upper Cenomanian to Lower Turonian.

**Occurrence:** Very rare.

Superfamily **Lituolacea** de Blainville, 1827
Family **Haplophragmoididae** Maync, 1952
Genus **Cribrostomoides** Cushman, 1910
Type species: *Cribrostomoides bradyi* Cushman, 1910

The original types of *Cribrostomoides* and *Labrospira* Hoglund were restudied by Loeblich & Tappan (1964, p. 225) and are regarded as synonymous. *Cribrostomoides* is similar to *Haplophragmoides* Cushman from which it differs in having an areal (a single slit or multiple openings) and not an interiomarginal aperture.

*Cribrostomoides latidorsata* (Bornemann)

(Pl. 1, Figs 16-17)

*Nonionina latidorsata* Bornemann, 1855, p. 339, pl. 16, fig. 4a-b (fide Hart 1970).

*Haplophragmium latidorsatum* (Bornemann). Chapman, 1892, p. 5, pl. 5, fig. 12a-b.


*Cribrostomoides latidorsata* (Bornemann). Hart, 1990, pl. 5, figs i-j.

**Description:** Specimens of *C. latidorsata* have a tight, planispiral coiling; involute spiral and umbilical sides; 5 to 5½ inflated chambers, increasing gradually in size with the final chamber overlapping and covering the umbilicus; axial periphery broadly rounded; equatorial periphery circular; moderately coarsely agglutinated; aperture a single areal slit.

**Range:** Upper Albian to Middle Cenomanian and Middle Turonian.

**Occurrence:** Very rare to rare.

*Cribrostomoides* sp. 1

(Pl. 1, Fig. 18)

**Description:** Planispiral test, involute spiral and umbilical sides; 6 to 7 chambers, triangular, inflated and increasing gradually in size; lateral periphery broadly rounded, equatorial periphery gently lobate; sutures flush to deep, radial; aperture areal and slit.
Remarks: Cribrostomoides sp. 1 is differentiated from Trochammina Parker & Jones in having a planispiral and not a trochospiral coiling.

Range: Upper Albian.

Occurrence: Very rare.

Genus HAPLOPHRAGMOIDES Cushman, 1910
Type species: Nonionina canariensis d’Orbigny, 1839

Haplophragmoides chapmani Morozova
(Pl. 2, Fig. 1)


Description: A very tight, involute, planispirally coiled test; 4 chambers increasing gradually; sutures deep and radial; moderately coarsely agglutinated; aperture interiomarginal slit; equatorial periphery circular.

Remarks: H. chapmani is differentiated from H. kirkii Wickenden in having a very tightly coiled test; a more coarsely agglutinated test and a nearly rounded equatorial periphery.

Range: Upper Albian to Middle Turonian.

Occurrence: Very rare to rare.

Haplophragmoides concavus (Chapman)
(Pl. 2, Figs 2-3)

Trochammina concava Chapman, 1892, p. 327, pl. 6, fig 14a-b (fide Bhalla 1969).
Haplophragmoides concava (Chapman). Tappan, 1940, p. 95, pl. 14, fig. 7a-c.
**Haplophragmoides concavus** (Chapman). Frizzell, 1954, p. 59, pl. 1, fig. 27a-c.
**Haplophragmoides concavus** (Chapman). Bhalla, 1969, p. 65, pl. 1, fig. 4.

**Diagnosis:** Specimens with thin, laterally compressed, involute tests, planispirally coiled; 4 to 5 chambers increasing gradually with the final chamber very large and overlapping; sutures radial and depressed; axial periphery rounded to sub-acute.

**Range:** Upper Albian to Middle Turonian.

**Occurrence:** Very rare to very abundant.

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**Haplophragmoides hagni** (Chapman)

(Pl. 2, Fig. 4)

**Haplophragmoides hagni** Bhalla, 1965, p. 40, text-fig. 1, no. 2a-b.

**Trochammina hagni** (Bhalla). Baksi, 1966, p. 8, pl. 1, figs 11a-b, 12a-b; pl. 2, figs 2a-b, 3.

**Haplophragmoides hagni** Bhalla. Bhalla 1969, pp. 66-67, pl. 1, fig. 6-7, text-fig. 3.

**Diagnosis:** The specimens are planispirally coiled, slightly evolute; final whorl with 10-11 chambers increasing gradually in size; periphery broadly rounded, equatorial periphery ovate; surface smooth; sutures flush and straight.

**Range:** Upper Albian to Lower Turonian.

**Occurrence:** Very rare to rare.

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**Haplophragmoides horridus** (Grzybowski)

(Pl. 2, Figs 5-6)

**Haplophragmium horridum** Grzybowski, 1901 (fide Charnock & Jones 1990).

**Haplophragmoides horridus** (Grzybowski). Kaminski et al., 1988, p. 189, pl. 5, fig. 11.

**Haplophragmoides horridus** (Grzybowski). Charnock & Jones, 1990, p. 170, pl. 5, figs 15-16; pl. 16, fig. 9.
**Diagnosis:** Test large, planispiral, involute, slightly compressed laterally. Six triangular, irregularly overlapping chambers; sutures depressed, wall medium to coarsely agglutinated; aperture multiple sutural and areal openings.

**Range:** Upper Albian to Middle Turonian.

**Occurrence:** Very rare to common.

**Haplophragmoides kirki** Wickenden

(Pl. 2, Figs 7-8)

Haplophragmoides kirki Wickenden, 1932, p. 85, pl. 1, fig. 1a-c (fide Cushman 1946).
Haplophragmoides kirki Wickenden. Cushman, 1946, pp. 21-22, pl. 2, fig. 23a-c.

**Description:** Planispiral, involute coiling; 4 (very rarely 5) inflated chambers with the final chamber very large and sometimes occupying nearly half of the test; equatorial periphery lobate and axial periphery broadly rounded; sutures radial and depressed; an interiomarginal, arched aperture; moderately arenaceous with a rough surface.

**Range:** Upper Albian to Middle Turonian.

**Occurrence:** Very rare to very abundant.

**Haplophragmoides sp. aff. H. multiformis** (Krasheninnikov)

(Pl. 2, Figs 9-10)

Haplophragmoides multiformis Krasheninnikov, 1974b, p. 636, pl. 2, figs 1a-b, 2a-b.

**Description:** Test laterally compressed, planispiral, involute, with umbilical side more strongly involute. Aperture interiomarginal slit; wall finely agglutinated; sutures radial to slightly curved and deep; 4 chambers, increasing slowly as added. Lateral periphery broadly rounded, equatorial periphery lobate.

**Range:** Upper Albian to Middle Turonian.
**Occurrence**: Very rare to frequent.

**Haplophragmoides sp. aff. H. multiformis** (Krasheninnikov) var. A

(Pl. 2, Fig. 11)

**Remarks**: The morphotypes included in *Haplophragmoides* sp. aff. *H. multiformis* var. A are differentiated from *Haplophragmoides* sp. aff. *H. multiformis* by a strongly laterally compressed, entirely involute, planispirally coiled test. The forms are highly compressed resulting in a laterally flattened test.

**Range**: Upper Albian to Middle Turonian.

**Occurrence**: Very rare to frequent.

**Haplophragmoides nonioninoides** (Reuss) var. angulosa Magniez-Jannin

(Pl. 2, Fig. 12)

*Haplophragmoides nonioninoides* Reuss, 1863, p. 30, pl. 1, fig. 8a-b.


*Haplophragmoides nonioninoides* (Reuss) var. angulosa Magniez-Jannin, 1975, pp. 36-37, pl. 2, figs 13-18, text-fig. 12.

**Remarks**: Similar to *H. nonioninoides* var. rotunda Magniez-Jannin from which it differs in having a completely involute and a laterally compressed test giving it a less rounded axial periphery.

**Range**: Upper Albian to Upper Cenomanian.

**Occurrence**: Very rare to rare.

**Haplophragmoides nonioninoides** (Reuss) var. rotunda Magniez-Jannin

(Pl. 2, Figs 13-14)

*Haplophragmoides nonioninoides* Reuss, 1863, p. 30, pl. 1, fig. 8a-b.

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**Haplophragmoides nonioninoides** (Reuss) var. *rotunda* Magniez-Jannin, 1975, pp. 35-36, pl. 2, figs 9-12, text-fig. 11.

**Diagnosis:** Planispiral test with a less evolute spiral side and an involute umbilical side; 9-10 inflated chambers, increasing slowly; equatorial periphery circular and lateral periphery broadly rounded.

**Range:** Upper Albian to Upper Cenomanian.

**Occurrence:** Very rare to common.

**Haplophragmoides walteri** (Grzybowski)

(Pl. 2, Fig. 15)

**Trocharminia walteri** Grzybowski, 1898, p. 290, pl. 11, fig. 31 (*fide* Charnock & Jones 1990).

**Haplophragmoides walteri** (Grzybowski). Gradstein & Berggren, 1981, p. 250, pl. 6, figs 5-6 (not fig. 7).

**Haplophragmoides walteri** (Grzybowski). Geroch & Nowak, 1983, pl. 2, fig. 22.

**Haplophragmoides walteri** (Grzybowski). Charnock & Jones, 1990, p. 170, pl. 6, figs 3-4; pl. 17, fig. 2.

**Diagnosis:** A planispirally coiled, flat, laterally compressed, involute test; 7-8 triangular, flat, chambers, increasing slowly; sutures broad, deep and radial; a narrowly rounded lateral periphery.

**Remarks:** A laterally compressed, flat test differentiates *H. walteri* from *H. nonioninoides*.

**Range:** Cenomanian to Middle Turonian.

**Occurrence:** Very rare.
**Haplophragmoides sp. 1**

(Pl. 2, Fig. 16)

**Description:** Tight, planispirally coiled, involute, slightly compressed test; equatorial periphery lobate giving an oval shape with the length being twice the width of the test; 5 triangular, weakly inflated chambers on the spiral side, increasing slowly except for the last one which is sub-globular and nearly double in size. On the umbilical side 6 triangular inflated to sub-globular chambers, final three chambers tend to overlap each other. Radial and deep sutures, interiomarginal slit-like to arched aperture, surface rough and coarsely agglutinated.

**Remarks:** *Haplophragmoides* sp. 1 differs from *H. horridus* in having an interiomarginal slit-like to arched aperture.

**Range:** Upper Albian to Lower Cenomanian.

**Occurrence:** Very rare.

**Haplophragmoides sp. 2**

(Pl. 3, Fig. 1)

**Description:** A small, planispirally coiled, involute test; 5 inflated chambers increasing slowly; sutures deep and radial; surface smooth.

**Range:** Upper Albian to Middle Turonian.

**Occurrence:** Very rare.

**Haplophragmoides sp. 3**

(Pl. 3, Fig. 2)

**Diagnosis:** A very tight, laterally compressed, planispirally coiled, involute test; 4-5 flat to weakly inflated chambers increasing slowly except for the final one which is inflated and tends to overlap. Lateral periphery broadly rounded; sutures distinct and radial; interiomarginal aperture.
Remarks: A strongly laterally compressed, tightly coiled test with flat chambers distinguishes this species from the other Haplophragmoides species.

Range: Lower to Middle Cenomanian.

Occurrence: Very rare.

Family LITUOLIDAE de Blainville, 1827
Subfamily AMMOMARGINULININAE Podobina, 1978
Genus AMMOBACULITES Cushman, 1910
Type species: Spirolina agglutinans d’Orbigny, 1846

Ammobaculites hofkeri Bhalla
(Pl. 3, Figs 3-4)

Ammobaculites hofkeri Bhalla, 1965, pp. 41-42, text-fig. 1.
Ammobaculites hofkeri Bhalla. Bhalla, 1969, pp. 72-73, pl. 1, figs 15-18, text-fig. 6.

Description: An evolute to less evolute planispiral to streptospiral early stage followed by an uncoiled, uniserial; straight to gently curved stage, slightly compressed but not a flat test. Three to five chambers in the early stage and 2-3 to 7 chambers in the uniserial stage, chambers increasing gradually, with the penultimate chamber having maximum width and the final chamber having maximum height; sutures distinctly deep; aperture terminal and round.

Remarks: The species shows dimorphism. Microspheric forms with a small initial coil followed by a large, flaring, uniserial stage and the megalospheric forms with a large initial coil followed by a short, stout uniserial stage.

Range: Upper Albian to Lower Turonian.

Occurrence: Very rare to rare.
**Ammobaculites sp. cf. A. minimus** Crespin

(Pl. 3, Fig. 5)

*Ammobaculites minimus* Crespin, 1953, p. 30, pl. 5, fig. 8.

*Ammobaculites minimus* Crespin. Scheibnerova, 1976, p. 44, pl. 6, fig. 6; pl. 7, figs 2-3.

**Remarks:** Poorly preserved specimens with a slightly compressed test, an indistinct, planispiral coil followed by a uniserial stage. Chambers increase slowly, aperture terminal and round.

**Range:** Upper Albian to Lower Cenomanian.

**Occurrence:** Very rare.

**Ammobaculites parvispira** ten Dam

(Pl. 3, Fig. 6)

*Ammobaculites parvispira* ten Dam, 1950, p. 10, pl. 1, fig. 8 (*fide* Neagu 1965).

*Ammobaculites parvispira* ten Dam. Neagu, 1965, pp. 4-5, pl. 1, figs 1-3.


**Diagnosis:** A tight, involute, planispiral early stage followed by a uniserial, rectilinear stage; sutures horizontal and deep; surface rough; aperture terminal and slit, on a produced neck.

**Range:** Upper Albian to Cenomanian.

**Occurrence:** Very rare to rare.
**Ammobaculites sp. aff. A. parvispira** ten Dam

(Pl. 3, Fig. 7)

**Description:** An involute, planispiral initial stage followed by an uncoiled, uniserial, rectilinear stage. Chambers inflated becoming globular in the final parts, increasing slowly; sutures deep, horizontal and straight. A terminal and slightly displaced aperture, which is elongate, slit-like and bordered by a lip.

**Range:** Upper Albian to Middle Cenomanian.

**Occurrence:** Very rare.

**Ammobaculites reophacoides** Bartenstein

(Pl. 3, Fig. 8)

*Ammobaculites reophacoides* Bartenstein, 1952, p. 307, fig. 1.

**Diagnosis:** A very tight, initial planispiral coil followed by a uniserial, rectilinear stage; about 3 chambers in the coiled stage with 5 in the uncoiled part. The test is compressed such that the chambers in the uniserial stage are longer than broader. Sutures horizontal and straight; surface rough, aperture terminal.

**Range:** Upper Albian to Lower Turonian.

**Occurrence:** Very rare.

**Ammobaculites subcretacea** Cushman & Alexander

(Pl. 3, Figs 9-10)

*Haplophragmium agglutinanus* Chapman (not d’Orbigny), 1892, p. 324, pl. 5, fig. 14 (fide Hart 1970).
Ammobaculites subcretacea Cushman & Alexander, 1930, p. 6, pl. 2, figs 9-10.

**Description:** An elongate test with an early involute, planispiral and later uniserial, rectilinear to slightly curved stage. Aperture terminal and round on a short neck, surface rough, sutures deep and horizontal. The species shows dimorphism. Microspheric forms are elongate and cylindrical with a small planispiral stage. The megalospheric forms are short and stout with a larger coiled stage. From 3 to 5/6 chambers in the planispiral and from 1/2 to 5/6 chambers in the uniserial stage; chambers inflated, increasing gradually with the final chamber globular and dome shaped.

**Range:** Upper Albian to Cenomanian.

**Occurrence:** Very rare to rare.

Superfamily **HAPLOPHRAGMIACEA** Eimer & Fickert, 1899
Family **AMMOSPHAEROIDINIDAE** Cushman, 1927
Subfamily **RECURVOIDINAE** Aleskseychik-Mitskevich, 1973
Genus **RECURVOIDES** Earland, 1934
Type species: **Recurvoides contortus** Earland, 1934

**Recurvoides gerochi** Pflaumann

(Pl. 3, Fig. 14)

Recurvoides gerochi Pflaumann, 1964, p. 102, pl. 14, fig. 1a-d.
Recurvoides gerochi Pflaumann. Krasheninnikov & Pflaumann, 1977, p. 570, pl. 5, fig. 2a-c.

**Diagnosis:** A tight, streptospiral coiling; 4 to 5 inflated chambers on the spiral side, umbilical side slightly involute with only 3 1/2 to 4 chambers visible. Moderately coarsely agglutinated; aperture interiomarginal and arched.
Range: Upper Albian.

Occurrence: Very rare.

**Recurvoides sp. 1**

(Pl. 3, Fig. 15)

**Diagnosis:** A streptospirally coiled early stage followed by a planispiral coiling; chambers inflated and increase slowly; sutures deep.

**Range:** Upper Albian and Upper Cenomanian to Lower Turonian.

**Occurrence:** Very rare to rare.

Family **LABYRINTHIDOMATIDAE** Loeblich & Tappan, 1988

Genus **BULBOPHRAGMIUM** Maync, 1952

Type species: **Haplophragmium aequale**

**Bulbophragmium aequale** Maync

(Pl. 3, Fig. 16)

*Bulbophragmium aequale* Maync, 1952, pl. 10, fig. 10.

*Bulbophragmium aequale* (Maync). Hart, 1970, p. 85, pl. 1, fig. 11.

*Bulbophragmium aequale* Maync. Hart et al., 1990, p. 952, pl. 1, fig. 1.

**Diagnosis:** A short test with early 3 chambers inflated to sub-globular and streptospirally coiled followed by 2 to 4, laterally compressed, uncoiled, rectilinear, uniserial stage; aperture terminal slit.

**Range:** Upper Albian to Lower Turonian.

**Occurrence:** Very rare to rare.
**Bulbophragmium cylindraceum** (Chapman)

(Pl. 3, Fig. 22)

**Reophax cylindracea** Chapman, 1892, p. 3, pl. 5, fig. 7a-b.

*Bulbophragmium (?) cylindraceum* (Chapman). Hart *et al.*, 1990, p. 952, pl. 1, fig. e.

**Diagnosis:** A planispiral coil followed by an uncoiled, uniserial stage, only one chamber in the uniserial stage, 3/4 chambers in the planispiral stage; aperture terminal and multiple openings; moderately coarsely agglutinated.

**Range:** Upper Albian.

**Occurrence:** Very rare.

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**Bulbophragmium sp. 1**

(Pl. 3, Fig. 17)

**Diagnosis:** A short, flaring test with four, moderately compressed chambers arranged in a streptospiral coil followed by an uncoiled, uniserial stage; aperture terminal slit.

**Range:** Upper Albian.

**Occurrence:** Very rare to rare.

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Superfamily **SPIROLECTAMMINACEA** Cushman, 1927

Family **SPIROLECTAMMINIDAE** Cushman, 1927

Subfamily **SPIROLECTAMMININAE** Cushman, 1927

Genus **AMMOBACULOIDES** Plummer, 1932

Type species: *Ammobaculoides navarroensis* Plummer, 1932

**Ammobaculoides mosbyensis** Eicher

(Pl. 3, Figs 19-21)


**Description:** A large, planispirally coiled early stage followed by an uncoiled stage with biserial chamber arrangement, becoming uniserial finally; test laterally compressed; surface coarsely agglutinated. Sutures depressed, radial to gently curved in the planispiral stage, straight and oblique in the biserial stage and horizontal in the uniserial stage of the test.

**Remarks:** Differs from *Ammobaculites* Cushman and *Lituola* Lamarck in having planispiral-biserial-uniserial stages of chamber arrangement.

**Range:** Upper Albian and Upper Cenomanian to Lower Turonian.

**Occurrence:** Very rare.

Genus **SPIROPLECTAMMINA** Cushman, 1927

Type species: *Textularia agglutinans* d'Orbigny

**Spiroplectammina lalickeri** Albritton & Phleger

(Pl. 3, Fig. 11)

**Spiroplectammina lalickeri** Albritton & Phleger, 1937, p. 353, text-figs 2-3 (fide Cushman 1946).

**Spiroplectammina lalickeri** Albritton & Phleger. Cushman, 1946, p. 29, pl. 6, figs 28-29.

**Diagnosis:** A tapering, slightly curved test; early tightly-coiled planispiral stage, later biserial. Chambers low and broad, increasing moderately, rapidly in the final stage; sutures oblique and straight.

**Range:** Upper Albian to Lower Cenomanian.

**Occurrence:** Very rare to rare.
Spiroplectammina sp. aff. S. semicomplanata (Carsey) var. juncea Cushman
(Pl. 3, Fig. 12)

 Spiroplectammina semicomplanata Carsey (fide Cushman 1946).
 Spiroplectammina semicomplanata (Carsey) var. juncea Cushman. Cushman, 1946, p. 29, pl. 6, fig. 15.

 **Diagnosis:** A very tight and tiny planispiral coil followed by a biserial, uncoiled stage, elongate test with nearly parallel sides. Finely agglutinated, aperture terminal slit.
 **Range:** Lower Turonian.
 **Occurrence:** Very rare.

**Spiroplectammina sp. 1**
(Pl. 3, Fig. 13)

 **Diagnosis:** A slender, slightly compressed test with nearly parallel sides; initial planispiral coil followed by an uncoiled, biserial stage; aperture terminal slit.
 **Range:** Lower Cenomanian.
 **Occurrence:** Very rare.

**Spiroplectammina sp. 2**
(Pl. 3, Fig. 18)

 **Diagnosis:** A laterally compressed, triangular test with gradually flaring sides. A tight planispiral coil followed by an uncoiled, biserial stage.
 **Remarks:** Poor preservation of specimens obscures almost all the morphological details.
 **Range:** Lower Cenomanian.
 **Occurrence:** Very rare.
Family **PSEUDOBOLIVINIDAE** Wiesner, 1931

Genus **PSEUDOBOLIVINA** Wiesner, 1931

Type species: *Pseudobolivina antarctica* Wieser, 1931

**Pseudobolivina variana** (Eicher)

(Pl. 3, Fig. 23)


**Diagnosis:** Specimens with either stout tests and biserial, cuneate chamber arrangement throughout or elongate tests with biserially arranged chambers in the first half of the test becoming uniserial in final half; laterally compressed; aperture terminal slit.

**Remarks:** Differs from *Textularia Defrance* in having a biserial to uniserial chamber arrangement and a narrow slit like aperture.

**Range:** Cenomanian to Lower Turonian.

**Occurrence:** Very rare.

**Pseudobolivina sp. aff. P. variana** (Eicher)

(Pl. 4, Fig. 1)

**Diagnosis:** An elongate, laterally compressed and twisted test; a biserial, cuneate arrangement of chambers, final 1 to 2 chambers becoming uniserial; chambers increasing moderately in size, final 2 to 3 sets add fairly rapidly; aperture terminal and a narrow slit.

**Range:** Upper Cenomanian to Lower Turonian.
Occurrence: Very rare.

**Pseudobolivina sp. cf. P. variana** (Eicher)

Remarks: A laterally compressed, slightly twisted test with biserial chamber arrangement, (?) becoming uniserial; aperture terminal and a narrow slit. Poor preservation of the specimens make definite identification of the species difficult.

Range: Upper Cenomanian to Lower Turonian.

Occurrence: Very rare.

Superfamily **TROCHAMMINACEA** Schwager, 1877
Family **TROCHAMMINIDAE** Schwager, 1877
Subfamily **TROCHAMMININAE** Schwager, 1877
Genus **TROCHAMMINA** Parker & Jones, 1859
Type species: *Nautilus inflatus* Montagu, 1859

**Trochammina wetteri** Stelck & Wall
(Pl. 4, Fig. 2)

*Trochammina wetteri* Stelck & Wall, 1955, p. 59, pl. 2, figs 1-3, 6 (fide Magniez-Jannin 1975).

*Trochammina umiatensis* Tappan, 1957, p. 214, pl. 67, figs 27a-c, 28-29 (fide Sliter 1980).

not *Trochammina wetteri* Stelck & Wall. Eicher, 1967, p. 184, pl. 18, figs 7, 9.

*Trochammina aff. wetteri* Stelck & Wall. Magniez-Jannin, 1975, pp. 57-60, pl. 4, figs 3-4, 8-12, 17-18; not figs 1-2, 5-7, 13-16, 19-20.

*Trochammina umiatensis* Tappan. Sliter, 1980, pl. 4, figs 1-2, 6-7.
**Diagnosis:** A low to moderate trochospiral test; 4 to 5 globular chambers increasing moderately. Equatorial periphery lobate, axial periphery broadly round; moderately coarsely agglutinated; aperture interiomarginal slit.

**Range:** Upper Albian to Lower Turonian.

**Occurrence:** Very rare to rare.

Superfamily **VERNEUILINACEA** Cushman, 1911

Family **VERNEUILINIDAE** Cushman, 1911

Subfamily **VERNEUILINOIDINAE** Suleymanov, 1973

Genus **UVIGERINAMMINA** Majzon, 1943

Type species: **Uvigerinammina jankoi** Majzon, 1943

**Uvigerinammina** sp. 1

(Pl. 4, Fig. 6)

**Diagnosis:** A laterally compressed (slightly) test with sac-like chambers; surface moderately coarsely agglutinated; aperture terminal, produced on a short neck.

**Range:** Upper Albian to Lower Cenomanian.

**Occurrence:** Very rare.

Subfamily **VERNEUILININAE** Cushman, 1911

Genus **GAUDRYINA** d'Orbigny, 1839

Type species: **Gaudryina rugosa** d'Orbigny

**Gaudryina pyramidata** Cushman

(Pl. 4, Figs 3-5)

**Gaudryina laeavigata** Franke var. **pyramidata** Cushman. 1926a, p. 587, pl. 16, fig. 8a-b.

**Gaudryina pyramidata** Cushman. Sliter, 1968, p. 48, pl. 3, fig. 9.

**Gaudryina pyramidata** Cushman. Kuhnt & Kaminski, 1990, p. 467, pl. 5, figs c-e, j.
**Diagnosis:** A conical trochoid to pyramidal test with initial one third to one half of the test triserial followed by a biserial stage. In the triserial stage test sides are gently to moderately concave with moderately acute edges. Chambers increasing slowly in the triserial stage, moderately fast in the biserial part. Aperture a low interiomarginal arch; transverse-section triangular.

**Range:** Upper Cenomanian to Lower Turonian.

**Occurrence:** Very rare.

Genus **VERNEUILINA** d'Orbigny, 1839  
Type species: **Verneuilina tricarinata** d'Orbigny, 1840

**Verneuilina muensteri** Reuss  
(Pl. 4, Fig. 7)

*Verneuilina muensteri* Reuss. Hart et al., 1989, p. 320, pl. 7.3, figs 7-8.

**Diagnosis:** A triserial, conical-pyramidal test, increasing rapidly in size with flat sides and sharp edges. Suture flush, aperture loop-shaped towards the centre of the test.  
**Range:** Lower to Middle Turonian.  
**Occurrence:** Very rare.

Family **TRITAXIIDAE** Plotnikova, 1979  
Genus **TRITAXIA** Reuss, 1860  
Type species: **Textularia tricarinata** Reuss, 1844

**Tritaxia** sp. **aff. T. ellisorae** Cushman  
(Pl. 4, Figs 11-12)

*Tritaxia ellisorae* Cushman, 1936, p. 5, pl. 1, fig. 9a-b.
**Tritaxia ellisorae.** Cushman. Cushman, 1946, p. 32, pl. 7, figs 10-11.


**Diagnosis:** This morphotype is characterised by having an elongate test with concave sides; triserial for most of the part with final few uniserial chambers; triangular cross-section; moderately coarsely agglutinated with terminal, round aperture.

**Range:** Upper Albian and Upper Cenomanian to Lower Turonian.

**Occurrence:** Very rare.

**Tritaxia pyramidata** Reuss

(Pl. 4, Figs 8-10)

**Tritaxia pyramidata** Reuss, 1862, pp. 32, 88, pl. I, fig. 9.

**Tritaxia pyramidata** Reuss. Barnard & Banner, 1953, p. 195, pl. VII, fig. 1a-b, text-fig. 5j-n.

**Tritaxia pyramidata** Reuss. Hart et al., 1989, p. 320, pl. 7.3, figs 2-3.

**Diagnosis:** Pyramidal test, triserial for most part with individuals becoming uniserial in final two or three chambers. Chambers flat in the triserial stage becoming inflated in the uniserial part. Sides concave with acute to sub-acute and sub-rounded edges. Aperture terminal and round; moderately to coarsely agglutinated.

**Remarks:** In the Late Cenomanian specimens tend to become uniserial in final stages.

**T. pyramidata** is differentiated from **T. singularis** Magniez-Jannin in having less excavated (concave) sides and a less coarsely agglutinated test.

**Range:** Upper Albian to Cenomanian.

**Occurrence:** Very rare to rare.
**Tritaxia tricarinata** Reuss

(Pl. 4, Figs 20-21)

*Tritaxia tricarinata* Reuss, 1844, p. 215 *(fide Hart 1970).*

**Diagnosis:** Morphotypes are triserial throughout with one terminally placed chamber; aperture terminal and round; moderately coarsely agglutinated.

**Range:** Lower to Middle Turonian.

**Occurrence:** Very rare.

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**Tritaxia sp. 1**

(Pl. 4, Fig. 13)

**Remarks:** Poor preservation of the specimens does not allow full morphological description. The specimens are characterised by having a short, stout, pyramidal test, triserial for most part becoming (?) uniserial in final stage; surface rough; coarsely agglutinated.

**Range:** Upper Campanian.

**Occurrence:** Very Rare.

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Family **GLOBOTEXTULARIIDAE** Cushman, 1927

Subfamily **LIEBUSELLINAE** Saidova, 1981

**REMESELLA** Vasicek, 1947

Type species: **Remesella mariae** Vasicek, 1947
**Remesella** sp. 1
(Pl. 4, Fig. 19)

**Diagnosis:** A stout test with a short early trochospiral and later biserial stage; chambers indistinct in the trochospiral stage, in the biserial stage chambers are inflated, final chambers becoming sub-globular to globular; aperture terminal and slightly arched.

**Range:** Upper Albian.

**Occurrence:** Very rare.

Superfamily **TEXTULARIACEA** Ehrenberg, 1838
Family **EGGERELLIDAE** Cushman, 1937
Subfamily **DOROTHIINAE** Balakhmatova, 1972
Genus **DOROTHIA** Plummer, 1931, emended Desai & Banner, 1987, p. 16.
Type species: **Gaudryina bulleta** Carsey, 1926

**Dorothia filiformis** (Berthelin)
(Pl. 4, Figs 14-16)

**Gaudryina filiformis** Berthelin, 1880, p. 25, pl. 1, fig. 8a-d (fide Magniez-Jannin).
**Dorothia filiformis** (Berthelin). Magniez-Jannin, 1975, pp. 83-86, pl. 8, figs 1-2, text-fig. 34.

**Diagnosis:** Specimens are characterised by having a narrowly elongate, slender test; triserial early portion of few chambers is followed by a long biserial stage of inflated chambers, increasing gradually in size. Moderately to coarsely agglutinated, cross-section rounded to ovoid.

**Range:** Upper Albian to Lower Turonian.

**Occurrence:** Very rare to frequent.
**Dorothia sp. 2**  
(Pl. 4, Figs 17-18)

**Description:** The specimens are characterised by having an elongate test, a trochospiral early stage is followed by a biserial stage. Chambers are sub-globular to inflated, increasing gradually, sutures deep and horizontal to oblique. Aperture interiomarginal slit with a thin lip; surface moderately coarsely agglutinated.  
**Range:** Upper Campanian to Lower Maastrichtian.  
**Occurrence:** Rare.

**Genus MARSSONELLA Cushman, 1933**  
Type species: *Gaudryina oxycona* Reuss, 1860

**Description:** In this study marssonellids are differentiated from dorothiid forms by their characteristic conical to sub-conical rapidly flaring tests.

**Marssonella oxycona** (Reuss)  
(Pl. 5, Fig. 1)

*Gaudryina oxycona* Reuss, 1860, p. 229, pl. 12, fig. 3 (fide Bandy 1951).  
*Marssonella oxycona* (Reuss). Bandy, 1951, p. 492, pl. 72, fig. 8.  

**Diagnosis:** A conical, broadly flaring test with trochospiral early stage followed by a biserial chamber arrangement. Aperture interiomarginal and slightly arched; cross-section oval; fine to moderately agglutinated.  
**Range:** Upper Albian to Middle Turonian.  
**Occurrence:** Very rare to rare.
Marssonella sp. cf. M. trochus (d’Orbigny)
(Pl. 5, Fig. 2)

Textularia trochus d’Orbigny, 1840, p. 45, pl. 4, figs 25-26 (fide Koutsoukos 1989).
Marssonella trochus (d’Orbigny) sensu Koutsoukos, 1989, pp. 88-89, pl. 6, figs 13-15.

Description: The morphotypes included under M. cf. trochus have a narrow and tapering-subconical test, flaring rapidly in the final part of the test. Sutures deep and horizontal; aperture interiomarginal slit or slightly arched; cross-section oval; fine to moderately agglutinated. The biserial stage has elongate chambers increasingly slowly, final chambers increase rapidly and tend to overlap.

Remarks: All the specimens in the study have broken tests so the early trochospiral stage is not seen. M. cf. trochus is differentiated from M. oxycona in having a rapidly flaring test.

Range: Upper Campanian to Lower Maastrichtian.

Occurrence: Rare.

Marssonella turris (d’Orbigny)
(Pl. 5, Fig. 3)

Textularia turris d’Orbigny, 1840, p. 46, pl. 4, figs 27-28 (fide Koutsoukos 1989).
Marssonella trochus (d’Orbigny) var. turris (d’Orbigny). Koutsoukos, 1989, p. 90, pl. 6, figs 19-20.

Diagnosis: A long, narrow-conical, slowly tapering test. Chambers are elongate, longer than broad, increasing slowly in the first half of the test, moderately fast in the final half. Sutures deep and horizontal; moderately agglutinated; cross-section circular; interiomarginal aperture.
**Range:** Upper Campanian to Lower Maastrichtian.

**Occurrence:** Rare.

Family **TEXTULARIIDAE** Ehrenberg, 1838
Subfamily **TEXTULARIINAE** Ehrenberg, 1838
Genus **TEXTULARIA** Defrance, 1834
Type species: **Textularia sagittula** Defrance in de Blainville, 1824

**Textularia sp. aff. chapmani** Lalicker

(Pl. 5, Fig. 4)

**Textularia chapmani** Lalicker, 1935, p. 13, pl. 2, figs 8a-c, 9 (fide Neagu 1965).
**Textularia chapmani** Lalicker. Neagu, 1965, p. 5, pl. 1, fig. 20.
**Textularia chapmani** Lalicker. Hart et al., 1989, p. 318, pl. 7.3, fig. 1.

**Diagnosis:** A biserial test, flaring gradually in the first half and rapidly in the final stages. Chambers moderately inflated, increasingly slowly except for the final two sets which add very rapidly. Sutures deep, straight to oblique; moderately coarsely agglutinated; aperture an interiomarginal arch.

**Remarks:** A rapidly widening test is distinctive to the specimens.

**Range:** Upper Albian to Lower Cenomanian.

**Occurrence:** Very rare.

**Textularia sp. aff. T. wilgunyaensis** Crespin

(Pl. 5, Fig. 5)

**Textularia wilgunyaensis** Crespin, 1963, p. 53-54, pl. 14, figs 5-11.
**Textularia wilgunyaensis** Crespin. Scheibnerova, 1974, p. 709, pl. 1, fig. 17.
**Description:** A biserial, elongate, slowly tapering test maintaining parallel sides. Inflated chambers, increasing slowly as added, sutures deep, horizontal to oblique; aperture interiomarginal slit; surface rough; coarsely agglutinated.

**Remarks:** The species is differentiated from *T. chapmani* in having an elongate test with nearly parallel sides and gradually increasing chambers.

**Range:** Upper Albian.

**Occurrence:** Rare.

**Textularia sp. 1**

(Pl. 5, Fig. 6)

**Description:** Slightly compressed, biserial, broad test with gradually flaring sides. Chambers increase gradually, surface rough, moderately-coarsely agglutinated; aperture interiomarginal slit.

**Remarks:** The species are differentiated from *T. chapmani* in having a broad, gently flaring test, a fewer number of chambers and a more coarsely agglutinated wall.

**Range:** Upper Albian.

**Occurrence:** Very rare.

**Textularia sp. 4**

(Pl. 5, Fig. 7)

**Diagnosis:** A biserial, laterally compressed test with rapidly flaring sides and sub-acute to acute edges. Cross-section lens shaped; aperture interiomarginal arch; surface smooth and finely agglutinated.

**Range:** Upper Campanian to Lower Maastrichtian.

**Occurrence:** Very rare.

Subfamily **SIPHOTEXTULARIINAE** Loeblich & Tappan, 1985

Genus **SIPHOTEXTULARIA** Finlay, 1939

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Type species: *Siphotextularia wairoana* Finlay, 1939

**Siphotextularia** sp. 1  
(Pl. 5, Fig. 13)

**Diagnosis:** A rhomboidal test with biserial chamber arrangement; aperture terminal and slit, on a produced neck.  
**Range:** Upper Cenomanian to Lower Turonian.  
**Occurrence:** Very rare.

**Subfamily PLANCTOSTOMATINAE** Loeblich & Tappan, 1984  
**Genus** CRIBROBIGENERINA Andersen, 1961  
Type species: *Cribrobigenerina parkerae* Andersen, 1961

**Cribrobigenerina** sp. 1  
(Pl. 5, Fig. 9)

**Diagnosis:** An elongate, slightly compressed test; early biserial-cuneate chamber arrangement followed by a uniserial stage; sutures deep and oblique; surface moderately agglutinated; aperture terminal and cribate.  
**Range:** Middle to Upper Cenomanian.  
**Occurrence:** Very rare.

**Genus OLSSONINA** Bermudez, 1949  
Type species: *Olssonina cribrosa* Bermudez, 1949

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**Olssonina sp. 1**
(Pl. 5, Fig. 10)

**Remarks:** Specimens are very poorly preserved, obscuring almost all the morphological characters. From the limited features available the nearest taxon referable is *Olssonina*. The specimens have a (?) biserial test; aperture terminal and cribrate.

**Range:** Upper Albian.

**Occurrence:** Very rare.

**Olssonina sp. 2**
(Pl. 5, Fig. 11)

**Diagnosis:** A biserial, laterally compressed, flat test; chambers broad and flat, increasing slowly; aperture terminal and cribrate together with a series of openings along the median line in the final part of the test.

**Remarks:** All the specimens have broken tests. *Olssonina sp. 2* is differentiated from *Textularia nexa* (Magniez-Jannin) in having a terminal and cribrate aperture (together with a series of openings along the median line).

**Range:** Upper Albian.

**Occurrence:** Very rare.

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**Genus PLANCTOSTOMA** Loeblich & Tappan, 1955

**Type species:** *Textularia luculenta* Brady, 1884

**Planctostoma sp. 1**
(Pl. 5, Fig. 12)

**Diagnosis:** A slender test with nearly parallel sides; biserial arrangement of chambers with final 2 to 3 chambers added uniserially; aperture multiple.
Remarks: Poorly preserved material.

Range: Upper Cenomanian to lower Turonian.

Occurrence: Very rare.

Family CHRYSALIDINIDAE Neagu, 1968
Genus PSEUDOCHRYSA Lidina Cole, 1941
Type species: Pseudochrysalidina floridana Cole, 1941

Pseudochrysalidina sp. 1
(Pl. 5, Fig. 8)

Diagnosis: A trochospiral early stage followed by a biserial chamber arrangement; chambers increasing very rapidly in the biserial stage; (?) aperture terminal and cribrate.

Remarks: Poor preservation.

Range: Upper Albian.

Occurrence: Very rare.

Suborder LAGENINA Delage & Herouard, 1896

Remarks: The forms belonging to the Suborder Lagenina are long ranging and are of very little, if any, stratigraphic value. The study is therefore kept brief.

Superfamily NODOSARIACEA Ehrenberg, 1838
Family NODOSARIIDAE Ehrenberg, 1838
Subfamily NODOSARIINAE Ehrenberg, 1838
Genus DENTALINA Risso, 1826
Type species: Nodosaria cuvieri d’Orbigny, 1826
**Dentalina catenula** Reuss

*(Pl. 6, Fig. 2)*

*Dentalina catenula* Reuss, 1860, p. 185, pl. 3, fig. 6 *(fide* Cushman 1946).


**Diagnosis:** Uniserial, slightly arcuate test; 3 to 6 chambers, forms with a tiny spine at the end of the initial chamber also present; sutures deep, horizontal to oblique; aperture terminal and on a produced neck; surface smooth.

**Range:** Upper Albian to Lower Turonian.

**Occurrence:** Very rare.

**Dentalina communis** (d’Orbigny)

*(Pl. 6, Fig. 1)*

*Nodosaria communis* d’Orbigny, 1826, p. 254, fig. 35 *(fide* Ramanathan & Rao 1982).

*Dentalina communis* (d’Orbigny). Plummer, 1931, p. 149, pl. 11, fig. 4.

*Dentalina communis* (d’Orbigny). Ramanathan & Rao, 1982, p. 55, pl. 1, fig. 11.

**Diagnosis:** Test uniserial, slightly arcuate; surface smooth; chambers inflated, increasing slowly as added; sutures flush and horizontal; aperture terminal and radiating.

**Remarks:** *D. communis* is distinguished from *D. trujilloi* Loeblich & Tappan by having flush, horizontal sutures and a rounded base.

**Range:** Upper Albian to Lower Turonian.

**Occurrence:** Very rare.
**Dentalina cylindroides** Reuss
(Pl. 6, Figs 3-4)

*Dentalina cylindroides* Reuss 1863, p. 41, pl. II, fig. 16.
*Dentalina cylindroides* Reuss. Sliter, 1980, pl. 6, figs 21-22.

**Diagnosis:** An oblong to tear-drop shaped test with two chambers; aperture terminal and radiate.
**Range:** Upper Albian to Middle Turonian.
**Occurrence:** Very rare.

**Dentalina distincta** (Reuss)
(Pl. 6, Figs 5-6)

*Dentalina distincta* Reuss, 1860, p. 184, pl. II, fig. 5 (*fide* Reuss 1863).
*Dentalina distincta* Reuss. Magniez-Jannin, 1975, pp. 147-148, pl. 11, figs 37-39, text-fig. 75a-h.

**Diagnosis:** Uniserial, rectilinear to gently arcuate test with a spine or a pinched initial chamber; aperture terminal and radiating.
**Range:** Upper Albian to Lower Turonian.
**Occurrence:** Very rare.

**Dentalina gracilis** d'Orbigny
(Pl. 6, Fig. 7)

*Dentalina gracilis* d'Orbigny, 1840, p. 14, pl. 1, fig. 5 (*fide* Cushman 1946).
*Dentalina gracilis* d'Orbigny. Sliter, 1980, pl. 7, fig. 1.
**Diagnosis:** A slender, uniserial, rectilinear to slightly arcuate test; initial chamber with a pointed end; chambers smooth, increasing slowly as added; aperture terminal and round.

**Range:** Upper Albian to Middle Turonian.

**Occurrence:** Very rare to rare.

**Dentalina sp. aff. D. hammensis** (Franke)
(Pl. 6, Fig. 8)

**Marginulina hammensis** Franke, 1928, p. 77, pl. 7, fig. 9 (fide Hart 1970).

**Dentalina hammensis** (Franke). Tappan, 1940, p. 102, pl. 16, fig. 3.

**Dentalina hammensis** (Franke). Hart, 1970, p. 132, pl. 9, fig. 3.

**Diagnosis:** A globular initial chamber followed by one rectangular, inflated chamber and then by sub-globular chambers. Test uniserial and rectilinear; aperture terminal, raised and rounded; surface smooth; cross-section round.

**Range:** Upper Albian to Middle Turonian.

**Occurrence:** Very rare.

**Dentalina lorneiana** d’Orbigny
(Pl. 6, Fig. 9)

**Dentalina lorneiana** d’Orbigny, 1840, p. 14, pl. 1, figs 8-9 (fide Cushman 1946).

**Dentalina lorneiana** d’Orbigny. Cushman, 1946, p. 66, pl. 23, figs 7-11.

**Diagnosis:** Uniserial test, arcuate in the early stage becoming rectilinear later; suture flush and thick, gently curved at the start becoming horizontal later; chambers inflated, subglobular to rectangular, increasing slowly; aperture terminal and oval.

**Range:** Upper Cenomanian to Lower Turonian.

**Occurrence:** Very rare.

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**Dentalina nana** Reuss

(Pl. 6, Fig. 10)


**Diagnosis:** Test uniserial, slightly curved and gently tapering at the base; chambers increasing very slowly as added except for the final chamber which is nearly half the test size.

**Range:** Upper Albian to Middle Cenomanian.

**Occurrence:** Very rare.

**Dentalina strangulata** Reuss

(Pl. 6, Figs 11-12)

*Dentalina strangulata* Reuss, 1860, p. 185, pl. 2, fig. 6 (fide Hart 1970).

**Diagnosis:** Rectilinear test with two to three/four globular to sub-globular or elongate and inflated, chambers; aperture terminal, on a neck; cross-section round; surface smooth.

**Range:** Upper Albian to Middle Cenomanian.

**Occurrence:** Very rare.

**Dentalina trujilloi** Loeblich & Tappan

(Pl. 6, Fig. 13)

*Dentalina trujilloi* Loeblich & Tappan, 1964, p. C516, fig. 403 (4).
**Diagnosis:** A uniserial, slightly curved, tapering test; surface smooth; aperture terminal and radial; sutures oblique and depressed.

**Range:** Upper Albian to Lower Turonian.

**Occurrence:** Very rare.

**Dentalina sp. 1**
(Pl. 6, Fig. 14)

**Diagnosis:** A uniserial elongate, nearly rectilinear test; 9 to 10 chambers, increasing slowly in the first half of the test, rapidly in the final part; aperture terminal and radiate; sutures deep and oblique, becoming horizontal in the final part; surface smooth.

**Range:** Upper Albian to Middle Turonian.

**Occurrence:** Very rare to rare.

**Dentalina sp. 2**
(Pl. 6, Fig. 15)

**Diagnosis:** A short, uniserial test; 4 inflated chambers; sutures deep and oblique; cross-section circular.

**Range:** Upper Albian to Lower Turonian.

**Occurrence:** Very rare to rare.

**Dentalina sp. 3**
(Pl. 6, Fig. 16)

**Diagnosis:** A spindle shaped test; chambers increasing slowly as added except for the last one, final chamber inflated and nearly half the test size, terminal and radiate aperture; horizontal and deep sutures; cross-section circular. **Dentalina sp. 3** is distinguished from **D. nana** in having a spindle shaped test.

**Range:** Upper Albian.
Occurrence: Very rare to rare.

**Dentalina sp. 5**
(Pl. 6, Fig. 17)

**Diagnosis:** A slender, uniserial, slightly arcuate test; aperture terminal and radiate; surface smooth. Sutures deep and strongly oblique in the early part of the test, less oblique in the final part. Six to eight chambers, increasing slowly except for the final two chambers which increase moderately fast.

**Range:** Upper Albian to Lower Turonian.

**Occurrence:** Very rare to common.

**Dentalina sp. 6**
(Pl. 6, Fig. 18)

**Diagnosis:** Uniserial, slightly arcuate test with an initial spine; 6 chambers increasing slowly as added; sutures deep and oblique; aperture terminal and radiate.

**Remarks:** A prominent initial spine distinguishes this species from other species.

**Range:** Upper Albian to Lower Turonian.

**Occurrence:** Very rare.

**Dentalina sp. 8**
(Pl. 6, Fig. 19)

**Description:** This species is characterised by a flat, club-shaped initial chamber with a vertical groove or a depression; followed by flat, rectangular chambers which gradually become inflated. Sutures flush and oblique, in some forms the sutures become horizontal in final part of the test; surface smooth. The species shows variation in the test shape. Small, club-shaped tests with a small, club-shaped initial chamber with a groove, followed by rectangular chambers. In the other case, elongate tests with a
spindle-shaped lower half and the groove covering one half to one third of the test, followed by rectangular chambers.

**Range:** Upper Cenomanian to Middle Turonian.

**Occurrence:** Rare to common.

Genus **ENANTIODENTALINA** Marie, 1941
Type species: **Enantiodentalina communis** Marie, 1941

**Enantiodentalina sp. 1**
(Pl. 6, Fig. 20)

**Diagnosis:** A slender, gently arcuate test; (?) a biserial-cuneate arrangement of inflated chambers in first half, becoming uniserial in later half of the test; aperture terminal and radiate; surface smooth.

**Range:** Upper Albian and Upper Cenomanian to Lower Turonian.

**Occurrence:** Very rare.

Genus **NODOSARIA** Lamarck, 1812
Type species: **Nautilus radicula** Linne, 1758

**Nodosaria affinis** Reuss
(Pl. 6, Fig. 21)

**Nodosaria affinis** Reuss, 1845, p. 26, pl. 13, fig. 16 (fide Cushman 1946).

**Nodosaria affinis** Reuss. Cushman, 1946, pp. 70-71, pl. 25, figs 8-23.

**Nodosaria ex gr. affinis** Reuss. Koutsoukos, 1989, p. 107, pl. 8, fig. 1.

**Diagnosis:** A uniserial, rectilinear test with two inflated chambers; surface covered with striations; aperture terminal and radiate; cross-section circular.

**Range:** Upper Albian to Turonian.
**Occurrence:** Very rare.

**Nodosaria lamellosocostata** Reuss

*(Pl. 6, Fig. 22)*

**Nodosaria lamellosocostata** Reuss, 1863, p. 38, pl. 2, fig. 6.


**Diagnosis:** A slender, rectilinear, tapering, uniserial test; chambers increase moderately with the final two chambers adding rapidly; final 2 to 3 chambers are more globular; surface covered with thick costae; sutures flush and horizontal; aperture terminal and round.

**Range:** Upper Albian to Lower Turonian.

**Occurrence:** Very rare.

**Nodosaria monile** Hagenow

*(Pl. 6, Fig. 23)*

**Nodosaria monile** Hagenow, 1842, p. 568 (*fide* Cushman 1946).

**Nodosaria monile** Hagenow. Cushman, 1946, p. 75, pl. 27, fig. 9.

**Diagnosis:** Uniserial, rectilinear test; surface smooth; sutures deep and horizontal; aperture terminal and round; cross-section circular.

**Range:** Upper Albian and Upper Cenomanian to Lower Turonian.

**Occurrence:** Very rare.

**Nodosaria orthopleura** Reuss

*(Pl. 6, Fig. 24)*

**Nodosaria orthopleura** Reuss, 1862, p. 89, pl. 12, fig. 5a-b (*fide* Neagu 1965).

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**Nodosaria orthopleura** Reuss. Hart, 1970, p. 124, pl. 7, fig. 9.

**Diagnosis:** An elongate, rectilinear, uniserial test; rectangular chambers; surface covered with 5 to 6 thick Costa; aperture terminal and round; sutures horizontal; cross-section hexagonal.

**Range:** Upper Albian to Lower Turonian.

**Occurrence:** Very rare.

**Nodosaria paupercula** Reuss

(Pl. 6, Fig. 25)

**Nodosaria paupercula** Reuss, 1845, p. 26, pl. 12, fig. 12 (*fide* Neagu 1965).

cf. **Nodosaria paupercula** Reuss. Neagu, 1965, p. 21, pl. 5, fig. 18.


**Diagnosis:** Uniserial, rectilinear test; 4 globular to sub-globular chambers; surface covered with thick costae; terminal and round aperture; sutures horizontal and deep.

**Range:** Middle Cenomanian to Middle Turonian.

**Occurrence:** Very rare.

**Nodosaria prismatica** Reuss

(Pl. 6, Fig. 30)

**Nodosaria prismatica** Reuss, 1863, pl. 2, fig. 7.

**Diagnosis:** Uniserial, rectilinear, tapering test; 5 to 6 rectangular, inflated chambers, increasing slowly as added; sutures horizontal and deep; surface with 5 costae; aperture terminal and round.

**Range:** Upper Albian.
Occurrence: Very rare.

**Nodosaria rugosa** ten Dam

(Pl. 6, Fig. 29)

*Nodosaria rugosa* ten Dam, 1946, p. 575, pl. 88, fig. 7 (fide Neagu 1965).
*Nodosaria rugosa* ten Dam. Neagu, 1965, p. 22, pl. 5, fig. 27.

**Diagnosis:** Test with two chambers, initial chamber very globular; surface rugose; aperture terminal, on an extended neck.

**Range:** Upper Albian to Upper Cenomanian.

**Occurrence:** Very rare.

**Nodosaria sceptrum** Reuss

(Pl. 6, Fig. 26)

*Nodosaria sceptrum* Reuss, 1862, p. 37, pl. 2, fig. 3 (fide Neagu 1965).

**Diagnosis:** Spindle shaped, uniserial test, surface costate; aperture terminal; suture horizontal.

**Range:** Upper Albian and Upper Cenomanian to Middle Turonian.

**Occurrence:** Very rare.

**Nodosaria zippei** Reuss

(Pl. 6, Fig. 27)

*Nodosaria zippei* Reuss, 1845, p. 25, pl. 8, figs 1-3 (fide Hart 1970).
*Nodosaria zippei* Reuss. Hart, p. 126, pl. 7, fig. 16.
**Diagnosis:** A very elongate-cylindrical test with nearly parallel sides, uniserial, rectilinear; surface covered with costae; aperture terminal and round; chambers increasing gradually; sutures flush and horizontal.

**Range:** Upper Albian.

**Occurrence:** Very rare.

**Nodosaria sp. 1**

(Pl. 6, Figs 31-32)

**Diagnosis:** Test with 1 to 2 inflated and oblong chambers; surface smooth; cross-section circular; aperture terminal and round, slightly raised.

**Range:** Upper Albian to Upper Cenomanian.

**Occurrence:** Very rare.

**Nodosaria sp. 4**

(Pl. 6, Fig. 33)

**Diagnosis:** Elongate, uniserial, rectilinear test; 7 to 8 inflated chambers, increasing slowly, the final two chambers increasing rapidly; aperture terminal and round; sutures horizontal and deep.

**Range:** Upper Albian.

**Occurrence:** Very rare.

**Nodosaria sp. 5**

(Pl. 6, Fig. 34)

**Diagnosis:** Uniserial, rectilinear to slightly arcuate test; aperture terminal and round; 5 chambers, initial chamber globular with a spine, followed by slowly increasing rectangular chambers; sutures horizontal and depressed.

**Range:** Upper Albian to Middle Cenomanian.
**Occurrence:** Very rare.

*Nodosaria* sp. 6

(Pl. 6, Fig. 28)

**Diagnosis:** A uniserial, rapidly tapering test; three chambers, with the initial chamber pointed; surface covered with striations; sutures horizontal; aperture terminal and round.

**Range:** Upper Cenomanian to Lower Turonian.

**Occurrence:** Very rare.

Genus *PSEUDONODOSARIA* Boomgaardt, 1949

Type species: *Glandulina discreta* Reuss, 1850

*Pseudonodosaria cylindracea* (Reuss)

(Pl. 7, Fig. 1)

*Pseudonodosaria (Glandulina) cylindracea* Reuss, 1845, p. 25, pl. 13 (fide Cushman 1946).

*Pseudonodosaria cylindracea* Reuss. Cushman, 1946, p. 76, pl. 27, figs 33-34.


**Diagnosis:** A uniserial, rectilinear test; chambers increasing slowly with the final one rapidly; sutures deep and horizontal; aperture terminal and round.

**Range:** Upper Albian and Upper Cenomanian to Lower Turonian.

**Occurrence:** Very rare.
Pseudonodosaria humilis (Roemer)
(Pl. 7, Fig. 2)

Pseudonodosaria humilis Roemer, 1841, p. 95, pl. 15, fig. 6 (fide Cushman 1946).
Pseudonodosaria manifesta (Reuss). Sliter, 1968, p. 72, pl. 8, fig. 18.
Pseudonodosaria ex gr. humilis (Reuss). Koutsoukos, 1989, p. 109, pl. 8, fig. 5.

Diagnosis: A cylindrical, uniserial test; some forms with overlapping chambers in the early part of the test, final chamber inflated and dome shaped; aperture terminal and round; sutures horizontal and deep.
Range: Upper Albian to Lower Cenomanian.
Occurrence: Very rare.

Pseudonodosaria mutabilis (Reuss)
(Pl. 7, Fig. 3)

Glandulina mutabilis Reuss, 1863, p. 58, p. 91, pl. 5, figs 7-11.
Pseudonodosaria mutabilis (Reuss). Hart, 1970, p. 149, pl. 11, fig. 16.

Diagnosis: A spindle shaped test with three chambers, final chamber occupying more than one half of the test; sutures flush and horizontal.
Range: Upper Albian to Lower Turonian.
Occurrence: Very rare.

Pseudonodosaria sp. 1
(Pl. 7, Fig. 4)

Diagnosis: A small, spindle shaped test with an apiculate base; strongly overlapping chambers; aperture terminal, radiating, on an extended neck.
Range: Upper Albian to Middle Turonian.
Occurrence: Very rare.

Pseudonodosaria sp. 2
(Pl. 7, Fig. 6)

Diagnosis: A subglobular to oval shaped test with overlapping chambers; aperture terminal and radiating.
Range: Upper Cenomanian to Lower Turonian.
Occurrence: Very rare.

Pseudonodosaria sp. 3
(Pl. 7, Fig. 7)

Diagnosis: An elongate, rectilinear test with overlapping chambers in the early part of the test; sutures deep and horizontal; aperture terminal.
Range: Upper Albian and Upper Cenomanian to Lower Turonian.
Occurrence: Very rare.

Pseudonodosaria sp. 4
(Pl. 7, Fig. 5)

Diagnosis: An inflated, ellipsoidal, uniserial test with 4 chambers; sutures horizontal and flush; aperture terminal and round.
Range: Lower to Middle Cenomanian.
Occurrence: Very rare.

Subfamily LINGULININAE Loeblich & Tappan, 1961
Genus LINGULINA d’Orbigny, 1826
Type species: Lingulina carinata d’Orbigny

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Lingulina sp. aff. *L. serrata* (Tappan)

(Pl. 7, Fig. 8)

*Lingulina serrata* Tappan, 1940, p. 107, pl. 16, fig. 22a-b.

**Diagnosis:** The specimens are broken and characterised by a uniserial, rectilinear test; elongate to rectangular chambers with chamber edges overlapping and slightly produced giving a sharp edge; aperture terminal and round to oval.

**Range:** Upper Cenomanian to Lower Turonian

**Occurrence:** Very rare.

**Subfamily FRONDICULARIINAE** Reuss, 1860

**Genus FRONDICULARIA** Defrance, 1826

Type species: *Renulina complanata* Defrance

*Frondicularia angulosa* d'Orbigny

(Pl. 7, Fig. 9)

*Frondicularia angulosa* d'Orbigny, 1840, p. 22, pl. 1, fig. 39 (fide Rasheed & Govindan 1968).

**Diagnosis:** A large globular proloculus with 1 to 2 thick costae followed by one chamber; test laterally compressed; periphery broadly truncate; aperture terminal.

**Range:** Upper Albian to Middle Turonian.

**Occurrence:** Very rare.
**Frondicularia archiaciana** d'Orbigny  
(Pl. 7, Fig. 15)

*Frondicularia archiaciana* d'Orbigny, 1840, p. 20, pl. 1, figs 34-36 (*fide* Cushman 1946).  
*Frondicularia archiaciana* d'Orbigny. Cushman, 1946, p. 91, pl. 37, figs 6, 8-20.  
*Frondicularia archiaciana* d'Orbigny. Hart, 1970, pp. 135-136, pl. 9, fig. 11.

**Description:** The specimens are characterised by a prominent proloculus with a tiny spine, followed by a uniserial test with gently flaring sides. The proloculus has 1-2 costae and the test surface is finely striated; sutures flush.  
**Range:** Cenomanian to Middle Turonian.  
**Occurrence:** Very rare to rare.

*Frondicularia filocincta* Reuss var. *filocincta* Magniez-Jannin  
(Pl. 7, Figs 10-11)

*Frondicularia filocincta* Reuss, 1863, p. 54, pl. 4, fig. 12a-b.  

**Diagnosis:** A flat, palmate, triangular to flame-shaped, uniserial test; a small, globular proloculus with striations followed by 5/6 broad chambers; surface smooth to finely striated; sutures curved and deep; aperture terminal.  
**Remarks:** *F. filocincta* var. *filocincta* is differentiated from *F. gaultina* in having a globular proloculus, each preceding chamber wider and slightly thicker from the earlier one, test palmate and triangular to flame-shaped.  
**Range:** Upper Albian and Upper Cenomanian to Middle Turonian.  
**Occurrence:** Very rare to rare.
Frondicularia gaultina Reuss
(Pl. 7, Figs 13-14)

Frondicularia gaultina Reuss, 1860, p. 194, pl. 5, fig. 5 (fide Magniez-Jannin 1975).
Frondicularia gaultina Reuss. Magniez-Jannin, 1975, p. 201, pl. 14, fig. 16.

**Diagnosis:** A flat, palmate, diamond shaped, uniserial test; an elongate, prominent proloculus with 2-3 striations followed by inverted V-shaped chambers. Sutures curved and flush; aperture terminal; periphery acute to sub-acute.

**Remarks:** *F. gaultina* is differentiated from *F. filocincta* in having a palmate, diamond shaped test; a more prominent, elongate proloculus and more closely spaced chambers, the chambers tend to maintain the width as added.

**Range:** Upper Albian to Middle Turonian.

**Occurrence:** Very rare.

Frondicularia sp. 1
(Pl. 7, Fig. 16)

**Diagnosis:** A globular proloculus with one to two striations followed by broad, slowly increasing chambers; surface smooth; test flat and palmate.

**Range:** Upper Albian.

**Occurrence:** Very rare.

Frondicularia sp. 4
(Pl. 7, Fig. 12)

**Diagnosis:** A uniserial, rectilinear test with nearly parallel sides. The specimens are characterised by a prominent-globular proloculus with 2-3 striations followed by two chambers; surface smooth; sutures flush and arched; aperture terminal.

**Range:** Cenomanian to Middle Turonian.

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Occurrence: Very rare.

**Frondicularia sp. 6**
(Pl. 7, Fig. 21)

Remarks: All specimens in the study are broken. A prominent proloculus with a basal spine and thick striations covering the test makes this species different from other Frondicularia species.

Range: Upper Cenomanian to Lower Turonian.

Occurrence: Very rare.

**Frondicularia sp. 7**
(Pl. 7, Figs 19-20)

Diagnosis: A palmate, uniserial test; a prominent proloculus with 1-2 striations and a tiny spine followed by two chambers. Surface smooth, aperture terminal; sutures flush and arched.

Range: Lower to Middle Turonian.

Occurrence: Very rare to rare.

Genus **TRISTIX** Macfadyen, 1941
Type species: *Rhabdogonium liasinum* Berthelin, 1879

**Tristix excavata** (Reuss)
(Pl. 7, Fig. 17)

*Rhabdogonium excavatum* Reuss, 1863, p. 91, pl. 12, fig. 8a-c.


*Tribrachia australiana* Ludbrook. Scheibnerova, 1978a, pl. 1, fig. 16.

Diagnosis: An elongate, uniserial, rectilinear test which is triangular in cross-section throughout with deeply concave sides; chambers low, broad and increasing gradually, strongly arched up; sutures distinct, deep and arched; surface smooth; aperture terminal and round.

Remarks: A variation in test size observed. Elongate tests with broad chambers and rounded edges or short tests with sharply acute sides and fewer chambers.

Range: Upper Albian to Cenomanian.

Occurrence: Very rare to common.

Family VAGINULINIDAE Reuss, 1860
Subfamily LENTICULININAE Chapman, Parr & Collins, 1934
Genus LENTICULINA Lamarck, 1804
Type species: Lenticulina rotulata Lamarck, 1804

Lenticulina cephalotes (Reuss)
(Pl. 7, Figs 22-23)

Cristellaria cephalotes Reuss, 1863, p. 67, pl. 7, figs 4-5, 6a-b.
Lenticulina/Lenticulina-Marginulina cephalotes (Reuss). Magniez-Jannin, 1975, pp. 110-111, pl. 11, figs 32-33 (not fig. 34), text-fig. 49.

Diagnosis: A prominent, globular to sub-globular proloculus with an initial coil followed by an uncoiled, gently curved test. Aperture terminal and radiate; 4-5 chambers in the final whorl; surface smooth; sutures flush and curved.

Remarks: Magniez-Jannin (1975, pp. 110-111) has included L. oligostegia (Reuss, 1860) under L. cephalotes. In this study cephalotes and oligostegia are recognised as separate species, with the former including forms with a slightly curved test and 4-5 inflated chambers.

Range: Upper Albian and Upper Cenomanian to Middle Turonian.

Occurrence: Very rare to rare.
**Lenticulina cephalotes** (Reuss) var. A

(Pl. 7, Figs 18, 24)

**Diagnosis:** The specimens are characterised by a slightly coiled initial stage followed by an uncoiled, rectilinear test; chambers inflated, increasing slowly as added; sutures deep to flush, curved in the early stage and becoming oblique to horizontal in final stages; surface smooth.

**Remarks:** *Lenticulina cephalotes* var. A is differentiated from *L. cephalotes* by the absence of a prominent, globular, proloculus followed by an arcuate to slightly curved test.

**Range:** Upper Albian to Cenomanian.

**Occurrence:** Very rare to rare.

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**Lenticulina circumcidanea** (Berthelin)

(Pl. 8, Fig. 1)

*Cristellaria circumcidanea* Berthelin, 1880, p. 52, pl. 3, fig. 1 (*fide* Ramanathan & Rao 1982).


**Description:** A lenticular-biconvex test, coiled in early part and uncoiled in final stages. Periphery sharply keeled; aperture terminal and radial; 5-7 chambers increasing slowly; surface smooth; sutures curved becoming less curved in final stages. Specimens show a variation in test shape and number of chambers. Short and stout tests have fewer number of chambers. By contrast, slender and elongate tests have a greater number of chambers.

**Range:** Upper Albian to Middle Turonian.

**Occurrence:** Common to frequent.
**Lenticulina sp. aff. L. frankei** (ten Dam)

(Pl. 8, Fig. 2)

*Saracenaria frankei* ten Dam, 1946, p. 573, pl. 88, fig. 1 (fide Neagu 1965).
*Lenticulina (Saracenaria) frankei* (ten Dam). Neagu, 1965, p. 16, pl. 4, figs 24-25.

**Diagnosis:** A slender and elongate to curved, biconvex test with a gently curved, involute initial stage followed by an uncoiled, evolute final stage. Aperture terminal and radiate; a sub-acute to sub-rounded periphery; 9-10, moderately inflated chambers; surface smooth.

**Remarks:** A slender test with a gently curved initial stage differentiates *L. aff. frankei* from *L. circumcidanea.*

**Range:** Upper Albian to Middle Turonian.

**Occurrence:** Very rare to frequent.

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**Lenticulina gaultina** (Berthelin)

(Pl. 8, Fig. 3)

*Cristellaria gaultina* Berthelin, 1880, p. 49, pl. 3, figs 15-19 (fide Neagu 1965).

**Diagnosis:** A planispiral, lenticular, biconvex test; periphery sub-acute; 8-10 chambers; sutures straight to curved.

**Range:** Upper Albian to Middle Turonian.

**Occurrence:** Very rare to frequent.
**Lenticulina ingenua** (Berthelin)
(Pl. 8, Fig. 4)

*Cristellaria ingenua* Berthelin, 1880, p. 54, pl. 3, figs 20-21a-b (fide Magniez-Jannin 1975).

**Diagnosis:** A lenticular test with a very tight initial coil followed by an uncoiled stage; sutures distinctly deep and oblique; periphery sharp.

**Range:** Upper Albian to Middle Cenomanian.

**Occurrence:** Very rare to rare.

**Lenticulina lanceolata** Magniez-Jannin
(Pl. 8, Fig. 5)


**Diagnosis:** The specimens are characterised by a diamond shaped test with a tight initial coil followed by an uncoiled stage. Periphery acute; surface smooth; chambers increase slowly, the final chamber slightly larger; sutures deep and strongly curved in early stage, becoming less curved to nearly horizontal in final stage.

**Range:** Upper Albian to Middle Turonian.

**Occurrence:** Very rare to rare.

**Lenticulina macrodisca** (Reuss)
(Pl. 8, Fig. 6)

*Cristellaria macrodisca* Reuss, 1863, p. 78, pl. 9, fig. 5.
*Lenticulina macrodisca* (Reuss). White, 1928, p. 12, pl. 28, fig. 7 (fide Neagu 1965).
Lenticulina (Robulus) macrodisca (Reuss). Neagu, 1965, p. 12, pl. 4, figs 7-8.

**Diagnosis:** A biconvex, lenticular test with a prominent umbilical callus; 8-12 chambers increasing slowly; sutures, distinct, curved and non-limbate; aperture terminal and radiate; keeled periphery.

**Remarks:** A well developed umbilical calcareous callus, sometimes occupying a quarter of the test, is very characteristic of the species.

**Range:** Upper Albion to Middle Turonian.

**Occurrence:** Very rare to very abundant.

**Lenticulina nodosa** (Reuss)

(Pl. 8, Fig. 7)

Lenticulina nodosa Reuss, 1863, p. 78, pl. 9, fig. 6.
Lenticulina nodosa (Reuss). Sliter, 1980, pl. 9, figs 5-8.

**Diagnosis:** A biconvex, bi-umbonate, lenticular test; 10-12 chambers, increasing slowly; sutures curved and raised; strongly wavy periphery.

**Remarks:** Distinct knot-like thickenings of the edges forming a wavy periphery and raised sutures are very characteristic of the species.

**Range:** Upper Albion to Middle Turonian.

**Occurrence:** Very rare to abundant.

**Lenticulina ex gr. oligostegia** (Reuss)

(Pl. 8, Figs 11-13)

Cristellaria oligostegia Reuss, 1860, p. 213, pl. 8, fig. 8 (fide Neagu 1965).
Lenticulina oligostegia (Reuss). Neagu, 1965, p. 11, pl. 4, figs 1-2.
**Lenticulina oligostegia** (Reuss). Ramanathan & Rao, 1982, p. 59, pl. 1, fig. 16a-b; pl. 3, fig. 9a-b.

**Diagnosis:** The specimens included under this morphogroup show a variation in test shape and size. Short and stout forms are characterised by a large proloculus followed by 1-2 chambers with a tear-drop shaped test. Forms with a less prominent proloculus have 6-7 chambers and a lenticular test shape. Intermediate forms with 3-5 chambers also occur. Surface smooth; sutures curved; aperture terminal and radiate.

**Range:** Upper Albian to Middle Turonian.

**Occurrence:** Rare to abundant.

**Lenticulina planiuscula** (Reuss)  
(Pl. 8, Fig. 8)

*Cristellaria planiuscula* Reuss, 1863, p. 71, pl. 7, fig. 15a-b.


**Diagnosis:** The specimens are characterised by a tiny proloculus followed by 5-7 chambers. Forms with slender, gently curved tests and short-lenticular tests are both included under *L. planiuscula*. Sutures oblique, aperture terminal and radiate.

**Range:** Upper Albian and Lower Turonian.

**Occurrence:** Very rare to rare.

**Lenticulina pseudolinearis** (Magniez-Jannin)  
(Pl. 8, Fig. 9)

*Marginulina linearis* Reuss, 1863, p. 60, pl. 5, fig. 15a-b.

*Lenticulina/Marginulina pseudolinearis* Magniez-Jannin, 1975, p. 127-129, pl. 11, figs 1-5, text-fig. 59.

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**Diagnosis:** A slender test with a globular proloculus, gently curved to an ordinary coiled initial stage followed by an uncoiled, uniserial stage; sutures curved early and becoming horizontal in the final stages; chambers increase slowly.

**Range:** Upper Albian to Upper Cenomanian to Lower Turonian.

**Occurrence:** Very rare.

**Lenticulina ex gr. rotulata** (Lamarck)
(Pl. 8, Fig. 14)

*Lenticulina rotulata* Lamarck, 1804, p. 188 (fide Cushman 1946).

**Diagnosis:** Morphotypes referred to *Lenticulina ex gr. rotulata* are characterised by lenticular, biconvex and bi-umbonate tests. Periphery sub-acute to acute to sharply acute; 8-10 chambers increasing gradually in size; sutures curved, elevated to flush.

**Range:** Upper Albian to Middle Turonian.

**Occurrence:** Very rare to frequent.

**Lenticulina saxocretacea** Bartenstein
(Pl. 8, Fig. 15)


**Remarks:** Raised to keeled, arched sutures, keeled periphery and lack of a well defined calcareous umbilical callus are characteristic of *L. saxocretacea*.

**Range:** Upper Albian to Middle Turonian.

**Occurrence:** Very rare to frequent.
**Lenticulina sternalis** (Berthelin)

(Pl. 8, Fig. 16)

*Cristellaria sternalis* Berthelin, 1880, p. 51, pl. III, fig. 2a-b (fide Magniez-Jannin 1975).


**Remarks:** The morphotypes included under *L. sternalis* are similar to *L. saxocretacea* from which they differ in having flush to deep sutures.

**Range:** Upper Albian.

**Occurrence:** Very rare.

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**Lenticulina sp. aff. *L. tripleura*** (Berthelin)

(Pl. 8, Fig. 10)

*Cristellaria tripleura* Reuss, 1860, p. 211, pl. 9, fig. 5a-b (fide Tappan 1940).

*Vaginulina tripleura* (Reuss). Tappan, 1940, p. 111, pl. 17, figs 11-12a-b.


**Diagnosis:** Arcuate, flame shaped test with a large, protruding proloculus followed by 4-5 chambers; chambers increasing slowly with the final chamber fairly big and triangular; sutures flush and curved; aperture terminal and radiate; periphery sub-acute to sub-rounded.

**Remarks:** *L. tripleura* resembles *L.* ex gr. *oligostegia* from which it is differentiated in having an arcuate, flame-shaped test. A large, globular proloculus differentiates *tripleura* from *L.* aff. *L. frankei*.

**Range:** Upper Albian and Upper Cenomanian.

**Occurrence:** Very rare.
Lenticulina variata (Magniez-Jannin)  
(Pl. 8, Fig. 17)

Lenticulina/Marginulina-Dentalina variata (Magniez-Jannin), 1975, pp. 136-139, pl. 11, figs 17-30, text-fig. 65.

**Diagnosis:** The specimens are characterised by a gentle initial coil followed by an arcuate, uniserial test. Sutures flush and curved; chambers increasing slowly; aperture terminal and radiate.

**Range:** Upper Albian and Upper Cenomanian.

**Occurrence:** Very rare.

Lenticulina warregoensis Crespin  
(Pl. 8, Fig. 18)

Lenticulina warregoensis Crespin, 1944, p. 21, pl. 1, fig. 8.  
Lenticulina warregoensis Crespin. Ramanathan & Rao, 1982, p. 60, pl. 12, fig. 5a-b.

**Diagnosis:** A lenticular test with a tightly coiled and compressed early stage followed by an uncoiled, inflated final part. Final whorl with 6-9 chambers, increasing slowly with the final chamber very wide and inflated, in some cases forming half of the test size. Sutures curved; surface smooth; periphery distinctly acute.

**Range:** Upper Albian to Middle Turonian.

**Occurrence:** Very rare to frequent.
**Lenticulina sp. 1**

(Pl. 8, Fig. 20)

**Diagnosis:** An arcuate test with a globular proloculus followed by 2-5 chambers; chambers increasing slowly as added; sutures deep and oblique.

**Range:** Upper Albian to Middle Turonian.

**Occurrence:** Very rare.

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**Lenticulina sp. 2**

(Pl. 8, Fig. 19)

**Diagnosis:** A lenticular test; 6-8 chambers, increasing gradually; sutures flush to gently depressed and curved; periphery gently acute.

**Range:** Upper Albian to Middle Turonian.

**Occurrence:** Very rare to rare.

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**Lenticulina sp. 4**

(Pl. 9, Fig. 1)

**Remarks:** A small umbilical callus and sickle shaped sutures are characteristic of the species.

**Range:** Upper Albian.

**Occurrence:** Common.

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**Lenticulina sp. 5**

(Pl. 9, Fig. 2)

**Diagnosis:** A stout, lenticular test; about 5 chambers in the final whorl with the final chamber very wide; sutures curved and flush, may be raised in the early part of the test; periphery broadly acute.
Remarks: The very wide final chamber and a broadly acute periphery is very distinctive in the lateral view.

Range: Upper Albian to Middle Turonian.

Occurrence: Very rare to rare.

_Lenticulina sp. 6_
(Pl. 9, Figs 3-4)

Diagnosis: Slender and elongate, slightly arcuate test with flush to a tiny, globular, protruding proloculus followed by 8-9 gradually increasing chambers; sutures deep and oblique.

Range: Upper Albian to Middle Turonian.

Occurrence: Very rare to rare.

_Lenticulina sp. 8_
(Pl. 9, Fig. 6)

Diagnosis: An arcuate, uniserial test, with a beak shaped initial end followed by 4-6 chambers. The chambers increase slowly, the final chamber slightly larger and inflated; sutures deep and oblique to straight.

Range: Upper Albian to Upper Cenomanian.

Occurrence: Very rare to rare.

Subfamily PALMULINAE Saidova, 1981
Genus NEOFLABELLINA Bartenstein, 1948
Type species: _Flabellina rugosa_ d’Orbigny
Neoflabellina sp. 1  
(Pl. 9, Fig. 5)

**Diagnosis:** A broad, flat, palmate test; a very prominent, globular proloculus followed by 3 flat chambers; sutures appear to be raised and curved.  
**Range:** Upper Albian.  
**Occurrence:** Very rare.

Subfamily MARGINULININAE Wedekind, 1937  
Genus ASTACOLUS Montfort, 1808  
Type species: Astacolus crepidulatus Montfort, 1808

Astacolus sp. 1  
(Pl. 9, Fig. 7)

**Description:** The specimens are characterised by a laterally compressed, arcuate, uniserial test; aperture terminal and radial; sutures deep, straight to curved in the early part of the test, becoming gently curved to oblique in the final part; surface smooth.  
**Range:** Upper Albian and Upper Cenomanian to Lower Turonian.  
**Occurrence:** Rare.

Genus MARGINULINA d'Orbigny, 1826  
Type species: Marginulina raphanus d'Orbigny, 1826

Marginulina acuticostata (Reuss) var. acuticostata (Magniez-Jannin)  
(Pl. 9, Fig. 8)

**Marginulina acuticostata** Reuss, 1863, p. 62, pl. VI, fig. 3a-b.  
**Marginulina acuticostata** (Reuss) var. acuticostata Magniez-Jannin, 1975, p. 113, pl. 10, figs 15-16.
**Description:** The specimens are distinguished by an elongate, uniserial test, straight to slightly arcuate; 4-5 inflated chambers, increasing slowly to moderately fast and becoming globular; aperture terminal, round and produced; sutures flush and nearly horizontal; surface covered with costae.

**Remarks:** A slender test and greater number of chambers in *Marginulina acuticostata* var. *acuticostata* differentiates it from *Marginulina acuticostata* var. *robusta* (Magniez-Jannin).

**Range:** Upper Albian to Lower Turonian.

**Occurrence:** Very rare.

*Marginulina acuticostata* (Reuss) var. *robusta* (Magniez-Jannin)

(Pl. 9, Fig. 9)

*Marginulina robusta* Reuss, 1863, p. 63, pl. 6, figs 5-6.


**Remarks:** Similar to *Marginulina acuticostata* var. *acuticostata* from which it differs in having a short and robust test and fewer number of chambers, 2-3 globular chambers.

**Range:** Upper Albian to Middle Cenomanian.

**Occurrence:** Very rare.

*Marginulina bullata* Reuss

(Pl. 9, Fig. 10)

*Marginulina bullata* Reuss, 1845, p. 29, pl. 13, figs 34-38 (*fide* Cushman 1946).


**Diagnosis:** Specimens have a slightly arcuate, uniserial test with a tight initial coil; 3-4 chambers; surface smooth; sutures flush and oblique.

**Range:** Upper Albian to Lower Turonian.
**Occurrence:** Very rare to rare.

**Marginulina costulata** (Chapman)

(Pl. 9, Fig. 11)

Cristellaria costulata Chapman, 1894, p. 649, pl. 9, fig. 10 (fide Magniez-Jannin 1975).
Lenticulina/Marginulina aff. costulata (Chapman). Magniez-Jannin, 1975, pp. 124-125, pl. 10, figs 36-41, text-fig. 56.

**Diagnosis:** An initial gentle coil followed by an arcuate, uniserial test; sutures depressed and slightly curved; surface with costae.

**Remarks:** Differs from *M. acuticostata* var. *acuticostata* in having weakly inflated chambers which do not become globular and the initial stage gently coiled and not curved.

**Range:** Upper Albian and Middle Cenomanian.

**Occurrence:** Very rare.

**Marginulina curvatura** Cushman

(Pl. 9, Fig. 12)

**Description:** The specimens are characterised by an evolute-planispiral early stage followed by a uniserial, slightly arcuate test. Periphery sharply angled following early chambers on the dorsal side. Chambers in the coiled stage flat to weakly inflated, in the uniserial stage inflated, final chamber globular and dome shaped. Sutures distinctly depressed, curved in early stage becoming horizontal.

**Range:** Upper Albian and Middle Cenomanian.

**Occurrence:** Very rare.
**Marginulina directa** Cushman
(Pl. 9, Fig. 13)

*Marginulina austinana* Cushman var. *directa* Cushman, 1937, p. 93, pl. 13, figs 5-8.
*Marginulina directa* Cushman. Bandy, 1951, p. 498, pl. 73, fig. 1a-b.

**Description:** Evolute to less evolute-planispiral coil followed by a uniserial, slightly arcuate test. Sutures depressed and curved in early part becoming straight and horizontal. Chambers increase slowly in the planispiral stage, increasing rapidly in the early uniserial stage more slowly in the final part.

**Remarks:** Absence of a keeled margin in *M. directa* differentiates it from *M. curvatura*.

**Range:** Upper Albian.

**Occurrence:** Rare.

**Marginulina inaequalis** Reuss
(Pl. 9, Fig. 14)

*Marginulina inaequalis* Reuss, 1860, p. 207, pl. 5, fig. 3 (fide Neagu 1965).

**Description:** A uniserial test with a gently curved initial stage; aperture terminal and radiate; sutures indistinct, flush, oblique with the final becoming horizontal; surface smooth, chambers increasing slowly.

**Range:** Middle Cenomanian to Lower Turonian.

**Occurrence:** Very rare.
*Marginulina jarvisi* Cushman

*(Pl. 9, Fig. 15)*

*Marginulina jarvisi* Cushman, 1938, p. 35, pl. 5, figs 17-18.

**Description:** A uniserial, arcuate test with a gentle curve at the initial stage; sutures flush, curved in the early part becoming straight later; 6-7 chambers; aperture terminal and radiate.

**Range:** Upper Albian to lower Turonian.

**Occurrence:** Very rare.

*Marginulina Jonesi* Reuss

*(Pl. 9, Fig. 16)*

*Marginulina Jonesi* Reuss, 1862, p. 61, pl. 5, fig. 15 (fide Neagu 1965).

**Description:** A small, uniserial, arcuate (gently curved in the initial stage) test. Surface with costae; chambers inflated; aperture terminal, round and produced.

**Range:** Upper Albian to Middle Turonian.

**Occurrence:** Very rare to rare.

*Marginulina sp. 1*

*(Pl. 9, Fig. 17)*

**Description:** The specimens are characterised by an overall globular test shape. A tiny globular to sub-globular proloculus followed by two tightly curved/coiled chambers and finally by the fourth chamber which is very large and globular, covering more than
two-thirds of the test. Forms with a less tight initial coil and slightly oval to elongate test shape are also present. Aperture terminal and radiate; sutures deep and oblique to curved becoming horizontal in final chamber.

**Range:** Upper Albian to Cenomanian.

**Occurrence:** Very rare to rare.

**Marginulina sp. 2**  
(Pl. 9, Fig. 18)

**Description:** A uniserial, gently arcuate test with a very globular proloculus followed by two inflated to sub-globular chambers, final chamber fairly big; aperture terminal, on a produced neck; sutures deep and slightly curved to horizontal; surface hispid.

**Range:** Upper Albian to Cenomanian.

**Occurrence:** Very rare.

Subfamily **VAGINULININAE** Reuss, 1860  
Genus **CITHARINA** d'Orbigny, 1839  
Type species: Vaginulina (Citharina) strigillata Reuss, 1846

**Citharina sp. 2**  
(Pl. 9, Fig. 19)

**Description:** A flat, palmate, uniserial test with a tiny spine at the base; chambers very narrow and increasing slowly; sutures depressed and arched; surface with faint striations, aperture terminal.

**Range:** Cenomanian.

**Occurrence:** Very rare.

Genus **PLANULARIA** Defrance, 1826  
Type species: Peneroplis auris Defrance, in de Blainville, 1824
**Planularia complanata** (Reuss)

(Pl. 9, Fig. 20)

*Cristellaria complanata* Reuss, 1845, p. 33, pl. 13, fig. 54a-b (*fide* Gawor-Biedowa 1972).

*Planularia bradyana* (Chapman). Gawor-Biedowa, 1972, p. 40-41, pl. 3, fig. 11.


**Description**: Planispiral coil followed by an uncoiled, flat, compressed test. Chambers broad and flaring, increasing slowly to moderately; sutures curved; margins sub-acute to sub-rounded; surface smooth.

**Range**: Upper Albian to Lower Turonian.

**Occurrence**: Very rare to rare.

**Genus VAGINULINA** d'Orbigny, 1826

Type species: *Nautilus legumen* Linne, 1758

**Vaginulina daini** (Schijfsma)

(Pl. 9, Figs 21-22)

*Vaginulina daini* Schijfsma (*fide* Ravindran 1980).

*Vaginulina daini* Schijfsma. Ravindran, 1980, pl. 5, fig. 1.

**Descriptions**: The species shows a variation in test shape, size and number of chambers. Elongate, slender, uniserial, slightly arcuate test with nearly parallel sides; a tiny knob shaped proloculus followed by 10-13 chambers. In the other type the test is short with flaring sides and a fewer number of chambers; a pointed or a beak-shaped end followed by 8-9 chambers. Sutures are curved to gently arched, thick and raised to flush; aperture terminal and radiate.

**Range**: Campanian.
Occurrence: Common.

**Vaginulina kochii** Roemer

(Pl. 9, Fig. 23)

Vaginulina kochii Roemer, 1841, p. 96, pl. 15, fig. 10 (fide Magniez-Jannin 1975).

Lenticulina/Vaginulina kochii subsp. kochii Magniez-Jannin, 1975, p. 166, pl. 14, figs 26-28, text-fig. 90k.

Lenticulina/Vaginulina kochii (Roemer) subsp. striolata Reuss. Magniez-Jannin, 1975, pp. 169-170, pl. 14, figs 31-32, text-fig. 90s.

Description: A uniserial, flat, laterally compressed test with truncate margins and flaring sides. A flush to protruding proloculus followed by 7-8 broad chambers; sutures raised, curved to straight; surface smooth or covered with fine striations.

Remarks: In the literature the subspecies kochii is differentiated from the subspecies striolata in the absence of striations in the former. Ornamentation alone is not a criteria for separating the two subspecies kochii and striolata. In the present study the concept of kochii and striolata is, therefore, not upheld and the two subspecies are included under the species *V. kochii*.

Range: Upper Albian to Middle Turonian.

Occurrence: Very rare to rare.

**Vaginulina marginulinoides** Reuss

(Pl. 9, Fig. 24)

Vaginulina marginulinoides Reuss, 1863, p. 44, pl. 3, fig. 5.


Description: A flat, compressed, arcuate, uniserial test with a large proloculus followed by 3-5 broad chambers, increasing slowly. Sutures flush, straight and oblique...
with a slight arch at the peripheral end; lateral periphery broadly acute. Specimens show a variation in test shape and size. Short and flaring tests have fewer number of chambers while slender and less flaring tests have greater number of chambers.

**Range:** Upper Albian to Middle Turonian.

**Occurrence:** Very rare to rare.

**Vaginulina sp. 1**

(Pl. 9, Fig. 25)

**Description:** A laterally compressed, uniserial test with sub-parallel sides gradually flaring to form a V-shaped test. A less prominent proloculus followed by 5-6 chambers; aperture terminal, produced; sutures straight and arched; surface with striations.

**Range:** Upper Albian to Middle Cenomanian.

**Occurrence:** Very rare.

**Vaginulina sp. 2**

(Pl. 10, Fig. 1)

**Diagnosis:** A flat, elongate, uniserial test; gently flaring, maintaining parallel to sub-parallel sides. Sutures raised, straight and arched; surface with 2-3 striations; proloculus with a thick costa which joins the striations.

**Range:** Upper Cenomanian to Lower Turonian.

**Occurrence:** Very rare.

**Vaginulina sp. 3**

(Pl. 10, Fig. 2)

**Diagnosis:** A prominent proloculus with a prominent costa and 4-5 striations. A flat, uniserial test with gradually flaring sides. Surface with faint striations; sutures curved and flame-like, raised and thick.
**Remarks:** A prominent proloculus, faint striations and curved, flame-like sutures distinguishes *Vaginulina* sp. 3 from *Vaginulina* sp. 1 and sp. 2.

**Range:** Upper Albian to Lower Turonian.

**Occurrence:** Very rare to rare.

*Vaginulina* sp. 3

(Pl. 10, Fig. 10)

**Diagnosis:** A prominent proloculus, faint striations and curved, flame-like sutures distinguishes *Vaginulina* sp. 3 from *Vaginulina* sp. 1 and sp. 2.

**Range:** Upper Albian to Lower Turonian.

**Occurrence:** Very rare to rare.

*Vaginulina* sp. 4

(Pl. 10, Fig. 10)

**Diagnosis:** A prominent and globular proloculus; slender test with nearly parallel sides; straight sutures and surface with thick striations are the distinguishing features of this species.

**Range:** Upper Cenomanian to Lower Turonian.

**Occurrence:** Very rare.

*Vaginulina* sp. 5

(Pl. 10, Figs 3-4)

**Diagnosis:** The specimens are characterised by a flame shaped, laterally compressed test. A large, globular proloculus followed by 1-2 chambers; sutures flush and oblique.

**Range:** Upper Albian and Lower to Middle Turonian.

**Occurrence:** Very rare.

*Vaginulina* sp. 6

(Pl. 10, Fig. 5)

**Diagnosis:** A slender, flat, uniserial test with gently flaring sides; sutures raised and arched; surface smooth.

**Range:** Upper Albian to Middle Turonian.

**Occurrence:** Very rare.
Vaginulina sp. 7
(Pl. 10, Fig. 6)

**Diagnosis:** A petal-shaped, compressed, uniserial test; chambers arched; sutures flush, straight and arched; surface smooth.

**Remarks:** A petal-shaped test and flush sutures differentiates Vaginulina sp. 7 from Vaginulina sp. 6.

**Range:** Upper Albian.

**Occurrence:** Very rare.

Family LAGENIDAE Reuss, 1862
Genus LAGENA Walker & Jacob, 1798
Type species: Serpula (Lagena) sulcata Walker & Jacob in Kanmacher, 1798

**Lagena acuticosta** Reuss
(Pl. 10, Fig. 7)

*Lagena acuticosta* Reuss, 1862, p. 305, pl. 1, fig. 4 (*fide* Cushman 1946).
*Lagena acuticosta* Reuss. Koutsoukos, 1989, p. 125, pl. 9, fig. 23.

**Diagnosis:** A unilocular, spindle-shaped, inflated test; surface covered with longitudinal costae.

**Range:** Middle Cenomanian to Middle Turonian.

**Occurrence:** Very rare.

**Lagena globosa** (Montagu)
(Pl. 10, Fig. 8)

Lagena globosa (Montagu). Sliter, 1980, pl. 7, fig. 21.

**Diagnosis:** A globular to elongate, unilocular test; surface smooth; aperture terminal and round, produced in some forms.

**Range:** Upper Albian to Middle Turonian.

**Occurrence:** Very rare to common.

**Lagena hispida** Reuss
(Pl. 10, Fig. 9)

Lagena hispida Reuss, 1858, p. 434 (fide Cushman 1946).
Lagena hispida Reuss. Cushman, 1946, p. 93, pl. 39, fig. 13.

**Diagnosis:** A globular to spindle-shaped, unilocular test with a spine; surface hispid; aperture terminal and round, produced on a neck.

**Range:** Upper Albian to Cenomanian.

**Occurrence:** Very rare to frequent.

**Lagena sp. aff. L. oxystoma** Reuss
(Pl. 10, Fig. 11)

Lagena oxystoma Reuss 1862, p. 334, pl. V, fig. 16.
Lagena oxystoma Reuss. Sliter, 1980, pl. 8, fig. 7.

**Diagnosis:** A globular, unilocular test; surface covered with blunt nodes; aperture terminal, on a produced neck.

**Range:** Upper Albian and Middle to Upper Cenomanian.

**Occurrence:** Very rare.
Lagena striatifera Tappan
(Pl. 10, Fig. 12)

Lagena striatifera Tappan, 1940, p. 112, pl. 17, fig. 18a-b.

**Diagnosis:** A globular, unilocular test; surface covered with 18-20 striations.

**Range:** Cenomanian to Middle Turonian.

**Occurrence:** Very rare to rare.

Family POLYMORPHINIDAE d'Orbigny, 1839
Subfamily FALSOGUTTULININAE Loeblich & Tappan, 1986
Genus TOBOLIA Dain, 1958
Type species: Tobolia veronikae Dain, 1958

Tobolia sp. 1
(Pl. 10, Fig. 14)

**Diagnosis:** A globular to sub-globular, tear-drop shaped test; strongly overlapping chambers; sutures flush and curved; aperture terminal and slit-like.

**Remarks:** Differs from Falsoguttulina Bartenstein in having strongly overlapping chambers.

**Range:** Upper Cenomanian.

**Occurrence:** Rare.

Subfamily POLYMORPHININAE d'Orbigny, 1839
Genus GLOBULINA d'Orbigny, 1839
Type species: Polymorphina gibba d'Orbigny, 1826
**Globulina lacrima** Reuss

(Pl. 10, Fig. 13)

Polymorphina (*Globulina*) lacrima Reuss, 1845, p. 40, pl. 12, fig. 6; pl. 13, fig. 83 (fide Cushman 1946).

Globulina lacrima Reuss. Cushman, 1946, p. 96, pl. 40, figs 11-12.


**Diagnosis:** A globular to sub-globular, somewhat elongate test; chambers strongly overlapping, extending at the base, becoming sigmoidal; sutures flush and oblique, visible only when moistened; surface smooth.

**Remarks:** *G. lacrima* differs from *G. prisca* Reuss in having a more globular test.

**Range:** Upper Albian to Middle Turonian.

**Occurrence:** Very rare to common.

**Globulina prisca** Reuss

(Pl. 10, Fig. 15)

Polymorphina (*Globulina*) prisca Reuss, 1863, p. 79, pl. 9, fig. 8 (fide Koutsoukos 1989).


**Remarks:** Similar to *G. lacrima* from which it differs in having a more elongate and compressed, spindle-shaped test.

**Range:** Upper Albian to Cenomanian.

**Occurrence:** Very rare to rare.
Globulina subsphaerica (Berthelin)
(Pl. 10, Fig. 16)

Polymorphina subsphaerica Berthelin, 1880, p. 58, pl. 4, fig. 18a-b (fide Magniez-Jannin 1975).
Globulina subsphaerica (Berthelin). Magniez-Jannin, 1975, pp. 227-228, pl. 15, figs 30-31, text-fig. 118.

**Diagnosis:** A globular to sub-globular test with strongly overlapping chambers (visible when moistened) followed by a fistulose overgrowth; surface hispid to spiny.

**Range:** Upper Albian.

**Occurrence:** Very rare.

Genus GUTTULINA d'Orbigny, 1839
Type species: Polymorphina communis d'Orbigny, 1826

Guttulina adhaerens (Olszewski)
(Pl. 10, Fig. 23)

Polymorphina adhaerens Olszewski, 1875, p. 119, pl. 1, fig. 11 (fide Cushman 1946).
Guttulina adhaerens (Olszewski). Cushman, 1946, p. 96, pl. 40, figs 8-10.

**Diagnosis:** An ovate, tear-drop like test; inflated clavate chambers, somewhat sigmoidal, arranged spirally in a quinqueloculine series; aperture terminal and radiate; surface smooth; sutures depressed.

**Remarks:** Differs from Globulina in having a quinqueloculine chamber arrangement.

**Range:** Upper Albian and Lower Turonian.

**Occurrence:** Very rare.
Subfamily RAMULININAE Brady, 1884
Genus RAMULINA Jones, 1875
Type species: Ramulina laevis Jones, 1875

**Remarks:** Representative specimens referred to this genus are in general found as single fragments with broken and irregular tubular projections, and very rarely as tubular projections of two or more chambers. This makes precise morphological description and differentiation difficult.

*Ramulina aculeata* Wright

(Pl. 10, Fig. 17)

*Dentalina aculeata* d'Orbigny. 1840, p. 13, pl. 1, figs 2-3.
*Ramulina aculeata* Wright, 1886, p. 331, pl. 27, fig. 11.
*Ramulina aculeata* (d'Orbigny). Cushman, 1946, p. 100, pl. 43, figs 11-16.
*Ramulina novaculeata* Bullard, 1953, p. 346, pl. 46, fig. 26.

**Diagnosis:** The specimens are characterised by single, globular to sub-globular and elongated fragments with stolon like necks at both ends; surface covered with short, stout and blunt spines.

**Remarks:** *R. aculeata* has a chequered taxonomic history. The species *Dentalina aculeata* d’Orbigny (1840, p. 13, pl. 1, figs 2-3) was initially described from the Tertiary while *R. aculeata* Wright (1886) was reported from the Upper Cretaceous of Northern Ireland. Subsequent workers (see Hart 1970, p. 164 for full synonymy) followed Wright’s determination until Loeblich & Tappan (1949), on the basis of outline, orientation and size, rendered *D. aculeata* d’Orbigny and *R. aculeata* Wright as synonymous. They (Loeblich & Tappan 1940) established that since *D. aculeata* looked like “*Dentalina*”, the name “*Ramulina*” was a misnomer. Since then both species have been ascribed either to d’Orbigny or Wright, with the initial description being
somewhat lost. Later Bullard (1953) renamed R. aculeata Wright as R. novaculeata. The figure of novaculeata Bullard (1953, pl. 46, fig. 26) does not, however, appear to be like the R. aculeata Wright described originally from the Cretaceous. Examination of the microfilm (see Hart 1970, p. 165) of d'Orbigny's type specimens show that D. aculeata is a Dentalina, quite unlike the type figure in the publication (d'Orbigny 1840, pl. 1, figs 2-3). This invalidates d'Orbigny's 1840 determination and upholds Wright's 1886 proposal of R. aculeata for the Cretaceous species.

**Range:** Upper Albian and Upper Cenomanian to Lower Turonian.

**Occurrence:** Very rare.

**Ramulina arkadelphiana** Cushman

(Pl. 10, Fig. 21)

Ramulina arkadelphiana Cushman. Neagu, 1965, p. 29, pl. 7, fig. 15 (not fig. 14).

**Diagnosis:** Test with irregularly tubular growth; surface smooth to gently hispid.

**Range:** Upper Albian to Lower Turonian.

**Occurrence:** Very rare.

**Ramulina fusiformis** Khan

(Pl. 10, Fig. 22)

Ramulina fusiformis Khan. Koutsoukos, 1989, p. 130, pl. 10, fig. 4.

**Diagnosis:** A single, fusiform, inflated chamber with broad openings at both ends; surface very hispid.

**Range:** Upper Albian to Lower Cenomanian.
**Occurrence:** Very rare to common.

**Ramulina globotubulosa** Cushman

(Pl. 10, Fig. 19)

Ramulina globotubulosa Cushman, 1938, p. 44, pl. 7, fig. 16 (fide Cushman 1946).
Ramulina globotubulosa Cushman. Cushman, 1946, p. 100, pl. 43, fig. 10.

**Description:** A single, globular chamber with short spines and thick tubular extensions.

**Range:** Upper Albian to Cenomanian.

**Occurrence:** Very rare to common.

**Ramulina sp. 1**

(Pl. 10, Fig. 18)

**Diagnosis:** The specimens are characterised by a single irregularly inflated chamber with thick, tubular extensions. Surface covered with thick, short and blunt spines giving a rough and robust appearance to the test.

**Range:** Upper Cenomanian to Lower Turonian.

**Occurrence:** Very rare.

Family **ELLIPSOLAGENIDAE** Silvestri, 1923
Subfamily **OOLININAE** Loeblich & Tappan, 1961
Genus **OOLINA** d’Orbigny, 1839
Type species: **Oolina laevigata** d’Orbigny, 1839
**Oolina sp. 1**
(Pl. 10, Fig. 20)

**Diagnosis:** A unilocular, ovate to spindle-shaped, inflated test with a tiny spine at the base; cross-section circular; aperture radiate, produced on a neck, sometimes round with radiate grooves.

**Remarks:** Differs from *Oolina* sp. 3 in having the aperture produced on a long neck with radiate grooves.

**Range:** Upper Albian to Middle Cenomanian.

**Occurrence:** Very rare.

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**Oolina sp. 2**
(Pl. 11, Fig. 1)

**Diagnosis:** A unilocular, sub-globular to tear-drop shaped test; aperture terminal and radiating; cross-section circular.

**Range:** Upper Cenomanian to Lower Turonian.

**Occurrence:** Very rare.

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**Oolina sp. 3**
(Pl. 11, Fig. 2)

**Diagnosis:** A unilocular, spindle-shaped test with an apiculate base; aperture terminal and radiate or with grooves.

**Range:** Upper Albian to Lower Turonian.

**Occurrence:** Very rare.

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Subfamily **ELLIPSOLAGENINAE** Silvestri, 1923

Genus **FISSURINA** Reuss, 1850

Type species: *Fissurina laevigata* Reuss, 1850
**Fissurina sp. 1**
(Pl. 11, Fig. 3)

**Diagnosis:** A unilocular, spindle-shaped test with an apiculate base; surface hispid; aperture terminal and slit, produced on a neck.

**Remarks:** Differs from Oolina d’Orbigny in having a slit-like aperture.

**Range:** Upper Cenomanian.

**Occurrence:** Very rare.

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**Fissurina sp. 2**
(Pl. 11, Figs 4, 6)

**Diagnosis:** A unilocular, spindle-shaped test, slightly compressed laterally; aperture terminal, slit; surface smooth.

**Range:** Upper Albian.

**Occurrence:** Rare.

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**Fissurina sp. 3**
(Pl. 11, Fig. 5)

**Diagnosis:** A globular, unilocular test; surface hispid; aperture terminal, slit.

**Range:** Upper Albian to Lower Turonian.

**Occurrence:** Very rare.

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**Fissurina sp. 4**
(Pl. 11, Fig. 7)

**Diagnosis:** A globular, unilocular test; aperture terminal, slit, produced on a neck; surface hispid.

**Range:** Upper Albian.
Occurrence: Very rare to common.

Genus PARAFISSURINA Parr, 1947
Type species: Lagena ventricosa Silvestri, 1904.

Parafissurina sp. 1
(Pl. 11, Fig. 10)

Diagnosis: A globular, unilocular test; aperture sub-terminal and crescentic, opening to one side of the test and with a tiny hooded appearance; peripheral margin keeled.

Range: Upper Albian.

Occurrence: Very rare.

Suborder ROBERTININA Loeblich & Tappan, 1984
Superfamily CERATOBULIMINACEA Cushman, 1927
Family CERATOBULIMINIDAE Cushman, 1927
Subfamily CERATOBULIMININAE Cushman, 1927
Genus CERATOLAMARCKINA Troelsen, 1954
Type species: Ceratobulimina tuberculata Brotzen, 1948

Ceratolamarckina sp. 1
(Pl. 11, Figs 8-9)

Description: A plano-convex (umbilical side plane), trochospire test with $2^{1/2}$ coils; surface smooth; spiral side with broad, rapidly increasing chambers; sutures curved and flush. Umbilical side with triangular chambers; sutures deep and radial.

Range: Middle Cenomanian to Middle Turonian.

Occurrence: Very rare to common.
Family **EPISTOMINIDAE** Wedekind, 1937
Subfamily **EPISTOMININAE** Wedekind, 1937
Genus **HOEGLUNDINA** Brotzen, 1948
Type species: *Rotalia elegans* d’Orbigny, 1826

**Hoeglundina sp. 1**
(Pl. 11, Figs 11-12)

**Description:** An asymmetrical, biconvex trochospire with spiral side convex and umbilical side conical-convex. Spiral side with $2^{1/2}$ coils; about 8 to 10/12 chambers in the final whorl, increasing slowly; sutures thick, distinct, slightly to distinctly curved. Umbilical side with 6 to 8, triangular chambers; lateral periphery sharply acute; outline round.

**Remarks:** The material is very poorly preserved. *Hoeglundina* has an aragonitic test which is not well preserved in anything other than clay sediments.

**Range:** Cenomanian to Middle Turonian.

**Occurrence:** Frequent to very abundant.

Superfamily **CONORBOIDACEA** Thalmann, 1952
Family **CONORBOIDIDAE** Thalmann, 1952
Genus **CONORBOIDES** Hofker, 1952
Type species: *Conorbis mitra* Hofker, 1951

**Remarks:** *Conorboides* differs from *Conorbina* Brotzen in having an open umbilicus and secondary areal openings.
Conorboides sp. 1
(Pl. 11, Figs 14-15)

**Description:** The specimens are characterised by a moderate to moderately high trochospire, plano-convex to extremely asymmetrical biconvex test with a strongly convex spiral side and a flat to gently convex umbilical side; narrowly acute periphery. Spiral side evolute with $2^{1/2}$ whorls, 5-6 petaloid to rectangular chambers in the final whorl, increasing slowly; sutures thick and strongly oblique to curved. Umbilical side involute with 5 triangular chambers which have a somewhat bulbous end at the umbilicus; sutures radial and deep. Umbilicus open; primary aperture a low interiomarginal umbilical arch following the umbilicus; secondary apertures areal.

**Range:** Middle Cenomanian to Middle Turonian.

**Occurrences:** Very rare to common.

Conorboides sp. 2
(Pl. 11, Figs 16-17)

**Description:** A triangular, low trochospire, asymmetrically biconvex test; spiral side with 2 to $2^{1/2}$ whorls, the inner whorls raised like a mound (with a tiny knob) on the nearly flat final whorl; umbilical side with inflated chamber giving a very convex appearance. Spiral side with 5 chambers in the final whorl, increasing slowly, chambers petaloid to elongate, final chamber semi-circular; sutures oblique, thick and raised, final suture deep. Umbilical side with 4 triangular chambers, final chamber petaloid to semi-circular; sutures deep and radial. Aperture interiomarginal umbilical slit; periphery narrowly round.

**Range:** Upper Cenomanian to Middle Turonian.

**Occurrences:** Very rare to rare.
**Conorboides** sp. 3  
(Pl. 11, Fig. 13)

**Description:** An oval, very low to flat trochospiral test with $1^{1/2}$ coils; a tiny proloculus followed by moderately rapidly increasing chambers; 5 to $5^{1/2}$ flat to gently inflated chambers in the final whorl; sutures deep and radial.  
**Range:** Upper Albian.  
**Occurrences:** Rare.

Suborder **GLOBIGERININA** Delage & Herouard, 1896  
Superfamily **HETEROHELICACEA** Cushman, 1927  
Family **GUEMBELITRIIDAE** Gallitelli, 1957  
Genus **GUEMBELITRIA** Cushman, 1933  
Type species: **Guembelitria cretacea** Cushman, 1933.

**Guembelitria cenomana** (Keller)  
(Pl. 12, Fig. 1)

**Guembelitria harrisi** Tappan, 1940, p. 115, pl. 19, figs 2a-b.  
**Guembelitria cenomana** (Keller). Caron, 1985, p. 57, pl. 24, figs 3-4.

**Diagnosis:** A very minute, triserial test with rapidly flaring sides; chambers increasing slowly with final set of chambers, very large and globular and added very rapidly; aperture interiomarginal arch.  
**Range:** Middle Cenomanian to Lower Turonian.  
**Occurrence:** Very rare to frequent.

Family **HETEROHELICIDAE** Cushman, 1927  
Subfamily **HETEROHELICINAE** Cushman, 1927
Genus **Heterohelix** Ehrenberg, 1843
Type species: **Textularia americana** Ehrenberg, 1843

**Heterohelix globulosa** (Ehrenberg)
(Pl. 12, Fig. 2)

*Textularia globulosa* Ehrenberg, 1840, p. 135, pl. 4, figs 2, 4-5, 7-8 (fide Koutsoukos 1989).

**Diagnosis:** A biserial test; chambers sub-globular increasing slowly in early part, fairly rapidly in final part; final chambers very globular; aperture interiomarginal arch; surface smooth.

**Range:** Upper Albian and Upper Cenomanian to Middle Turonian.

**Occurrence:** Very rare to abundant.

**Heterohelix moremani** (Cushman)
(Pl. 12, Fig. 3)

*Guembelina moremani* Cushman, 1938, p. 10, pl. 2, figs 1-3.
*Heterohelix moremani* (Cushman). Nederbragt, 1991, 344, pl. 2, figs 6-7 and pl. 3, figs 1-2.
**Diagnosis:** A slender test with biserial chamber arrangement; sub-globular to reniform chambers, increasing slowly to moderately fast; aperture an interiomarginal arch.

**Range:** Upper Albian and Upper Cenomanian to Lower Turonian.

**Occurrence:** Very rare to frequent.

Genus **BIFARINA** Parker & Jones, 1872

Type species: **Dimorphina saxipara** Ehrenberg, 1854

**Bifarina** sp. 1

(Pl. 12, Figs 4-5)

**Diagnosis:** Test with an early biserial stage followed in some cases by a few cuneate chambers and finally uniserial chambers; chambers in the uniserial stage have a very characteristic and sharp shoulder; aperture terminal and on a short neck; surface smooth.

**Remarks:** Number of chambers in the uniserial stage varies from 1 to 3, this gives the test a short-stout shape or elongate-slender appearance, depending on the number of chambers in the uniserial stage.

**Range:** Upper Albian to Lower Turonian.

**Occurrence:** Very rare to frequent.

**Bifarina** sp. 2

(Pl. 12, Figs 6-7)

**Diagnosis:** An elongate, slender and tapering test with early biserial stage of flat and compressed chambers and finally uniserial stage of inflated chambers with prominent and sharp shoulders, chambers increasing gradually; aperture terminal.

**Range:** Lower to Middle Turonian.

**Occurrence:** Very rare.
Superfamily **PLANOMALINACEA** Bolli, Loeblich & Tappan, 1957
Family **GLOBIGERINELLOIDIDAE** Longoria, 1974
Subfamily **GLOHIGERINELLOIDINAE** Longoria, 1974
Genus **GLOBIGERINELLOIDES** Longoria, 1974
Type species: Globigerinelloides algeriana Cushman & ten Dam, 1948

**Globigerinelloides bentonensis** (Morrow)

(Pl. 12, Fig. 8)

non Anomalina eaglefordensis Moreman, 1927, p. 99, pl. 16, fig. 9 (fide Carter & Hart 1977).

Anomalina bentonensis Morrow, 1934, p. 201, pl. 30, fig. 4 (fide Carter & Hart 1977).
non Planomalina caseyi Bolli, Loeblich & Tappan, 1957, p. 24, pl. 1, figs 4-5.
Globigerinelloides bentonensis (Morrow). Eicher & Worstell, 1970, pp. 297, pl. 8, figs 17-19; pl. 9, fig. 3.

**Diagnosis:** A small, evolute, planispiral test; final whorl with 6 to 7 globular chambers, increasing slowly; sutures deep, radial to slightly curved; surface smooth.

**Remarks:** There is a great deal of taxonomic confusion between G. bentonensis, G. caseyi and G. eaglefordensis. Carter & Hart (1977, pp. 27-28) have addressed this problem in great detail. Briefly, *G. eaglefordensis* was differentiated from
G. bentonensis in having a smaller, less inflated and a more evolute test and G. caseyi was regarded as a junior synonym of G. eaglefordensis. Study of topotype specimens (under scanning electron microscope) of caseyi and bentonensis show the two species to be identical (Carter & Hart 1977). Comparing the views of different authors (regarding the taxonomic confusion between these three species) Carter & Hart (1977) concluded that the concept of caseyi, as a viable species, is doubtful and that size alone is not a criteria in separating eaglefordensis from bentonensis. Carter & Hart (1977) therefore upheld G. bentonensis as a valid name (see Carter & Hart 1977, pp. 27-28 for details).

G. bentonensis is often confused for Hedbergella planispira (Tappan) from which it is distinguished in having a planispiral test.

**Range**: Middle Cenomanian to Middle Turonian.

**Occurrence**: Very rare to frequent.

**Globigerinelloides sp. aff. G. maridalensis** (Bolli)

(Pl. 12, Fig. 9)

Planomalina maridalensis Bolli, 1959, p. 261, pl. 20, figs 4-6 (fide Koutsoukos 1989).


Globigerinelloides maridalensis (Bolli). Longoria, 1974, p. 86-88, pl. 9, figs 4-7, 10-13; pl. 27, fig. 18.


**Diagnosis**: A tight, involute, laterally compressed, planispiral test; 4 to 4½/5 inflated, triangular chambers; final chamber fairly large, about one-third of the test; sutures deep and radial.

**Range**: Upper Albian to Middle Cenomanian.

**Occurrence**: Very rare.
**Globigerinelloides ultramicra** (Subbotina)

*(Pl. 12, Fig. 11)*

**Globigerinelloides ultramicra** Subbotina, 1949, p. 33, pl. 1, figs 17-18 *(fide Koutsoukos 1989).*


**Diagnosis:** A bi-umbonate, planispiral, involute to less evolute test, 7 to (?) 8 chambers; outline lobate; periphery round; aperture interiomarginal, with a lip.

**Range:** Upper Albian to Lower Cenomanian.

**Occurrence:** Very rare.

Family **PLANOMALINIDAE** Bolli, Loeblich & Tappan, 1957

Genus **PLANOMALINA** Loeblich & Tappan, 1946

Type species: **Planomalina apsidostroba** Loeblich & Tappan

**Planomalina buxtorfi** (Gandolfi)

*(Pl. 12, Fig. 16)*

**Planulina buxtorfi** Gandolfi, 1942, p. 103, pl. 3, fig. 7a-c *(fide Caron 1985, p. 65).*

**Planomalina buxtorfi** (Gandolfi). Wonders, 1975, pl. 1, fig. 4, text-fig. 4.

**Planomalina buxtorfi** (Gandolfi). Robaszynski & Caron, 1979, pp. 45-46, pl. 1, figs 2-4.

**Planomalina buxtorfi** (Gandolfi). Caron, 1985, p. 65, figs 29(1-2).

**Description:** A bi-umbonate, symmetrical biconvex, laterally compressed, planispiral test. Primary aperture equatorial, extending to the umbilicus on either side, bordered by a lip; outline lobate; surface smooth; 7 to 8 chambers in the final whorl; single keeled which splits and follows the sutures; sutures on both sides curved and raised.
Remarks: Pl. buxtorfi differs from Pl. praebuxtorfi Wonders in having a greater number of chambers, raised sutures throughout and a keel on all chambers.

Range: Upper Albian.

Occurrence: Very rare to very abundant.

Superfamily ROTALIPORACEA Sigal, 1958

Family HEDBERGELLIDAE Loeblich & Tappan, 1961

Subfamily HEDBERGELLINAE Loeblich & Tappan, 1961

Genus HEDBERGELLA Bronnimann & Brown, 1958

Type species: Anomalina lomeiana d’Orbigny var. trochoidea Gandolfi, 1942

Hedbergella delrioensis (Carsey)
(Pl. 12, Fig. 12)

Globigerina cretacea d’Orbigny var. delrioensis Carsey, 1926, p. 43 (fide Koutsoukos 1989, p. 221).


Hedbergella delrioensis (Carsey). Robaszynski & Caron, 1979, pp. 123, 128, pl. 22, figs 1-2; pl. 23, figs 1-3.

Hedbergella (Hedbergella) ex gr. delrioensis (Carsey). Koutsoukos, 1989, pp. 221-223, pl. 25, figs 1-7.

Description: An asymmetrical biconvex (spiral side slightly more convex), moderate to moderately high trochospire, 2 to 2½ coils, periphery round, outline lobate. Five to (?) six, inflated, sub-globular to globular chambers in the final whorl, increasing slowly to rapidly; surface papillate, hispid to smooth; sutures deep and radial; primary aperture interiomarginal, extra-umbilical to umbilical arch.

Range: Upper Albian to Lower Turonian.

Occurrence: Very rare to abundant.


**Hedbergella sp. aff. H. globigerinelloides** (Subbotina)  
(Pl. 12, Fig. 13)

Globigerina globigerinelloides Subbotina, 1949, p. 32, pl. 2, figs 11-16 (fide Krasheninnikov 1974b).

**Hedbergella globigerinelloides** (Subbotina). Krasheninnikov, 1974b, p. 665, pl. 1, fig. 13-15.

**Description:** A small and tightly coiled, flat trochospiral test; about 1 1/2 to 2 coils; periphery round, outline semi-lobate. Aperture interiomarginal, extra-umbilical to umbilical arch; 5 1/2 to 6 inflated to sub-globular chambers in the final whorl; sutures deep, radial to oblique.

**Remarks:** Differs from *H. planispira* (Tappan) in having a smaller and tightly coiled test.

**Range:** Upper Albian to Lower Cenomanian.

**Occurrence:** Common to very abundant.

**Hedbergella infracretacea** (Glaessner)  
(Pl. 12, Fig. 14)

**Hedbergella infracretacea** Glaessner, 1937, p. 28, fig. 1 (fide Koutsoukos 1989).

**Hedbergella infracretacea** (Glaessner). Krasheninnikov 1974b, p. 664, pl. 1, figs. 1-3.

**Hedbergella infracretacea** (Glaessner). Koutsoukos, 1989, p. 224, pl. 25, figs 16-19.

**Description:** A tight trochospire, few specimens with the early coils slightly raised above the last whorl; one and a half whorls; final whorl with 4 1/2 to 5 1/2 globular chambers, increasing rapidly; periphery round; outline lobate.

**Remarks:** Differs from *H. delrioensis* in a tightly coiled test with fewer number of coils.
**Range:** Upper Albian to Lower Cenomanian.

**Occurrence:** Frequent.

**Hedbergella planispira** (Tappan)

(Pl. 12, Fig. 10)

Globigerina planispira Tappan, 1940, p. 122, pl. 19, fig. 12.

Hedbergella planispira (Tappan). Loeblich & Tappan, 1961, p. 276-277, pl. 5, figs 4-11.

Hedbergella planispira (Tappan). Robaszynski & Caron, 1979, pp. 139, 144, pl. 27, figs 1-3; pl. 28, figs 1-4.


**Description:** A small, very low trochospire, nearly flat test; 2½ coils; periphery round; outline lobate. Final whorl with 6 to 8/9 inflated to globular chambers, increasing gradually, sutures deep, radial to slightly oblique; aperture extra-umbilical to umbilical with a lip.

**Range:** Upper Albian to Middle Turonian.

**Occurrence:** Very abundant.

**Hedbergella simplex** (Morrow)

(Pl. 12, Fig. 15)

Hastigerinella simplex Morrow, 1934, pp. 198-199, pl. 30, fig. 6 (fide Carter & Hart 1977).

Hedbergella amabilis Loeblich & Tappan, 1961, p. 274, pl. 3, figs 1-10.

**Hedbergella simplex** (Morrow). Robaszynski & Caron, 1979, pp. 145, 150, pl. 29, figs 1-3; pl. 30, figs 1-2.

**Description:** The specimens are characterised by a small, low trochospire test with 1½ to (?) 2 coils; strongly lobate equatorial periphery. Four to five globular to sub-clavate chambers in the final whorl; sutures deep and radial.

**Range:** Upper Albian to Middle Turonian.

**Occurrence:** Very rare to rare.

**Genus WHITEINELLA** Pessagno, 1967

**Type species:** *Whiteinella archaeocretacea* Pessagno, 1967

**Whiteinella aprica** (Loeblich & Tappan)

(Pl. 12, Figs 17-19)

**Ticinella aprica** Loeblich & Tappan, 1961, p. 292, pl. 4, figs 14-16.

**Whiteinella aprica** (Loeblich & Tappan). Eicher & Worstell, 1970, p. 314, pl. 11, fig. 7a-c; pl. 12, fig. 1a-c.

**Whiteinella aprica** (Loeblich & Tappan). Robaszynski & Caron, 1979, pp. 157, 160, pl. 32, figs 1-2.

**Hedbergella (Whiteinella) aprica** (Loeblich & Tappan). Koutsoukos, 1989, p. 233, pl. 27, figs 1-6.

**Description:** A very slightly asymmetrical (spiral side is plane to slightly convex), low trochospire test; periphery rounded. Final whorl with 5 to (?) 5½ inflated chambers, increasing slowly, surface pustulose; sutures deep and radial; outline lobate. Umbilicus shallow and wide, about one-fourth of the maximum diameter; primary aperture extra-umbilical to umbilical, portici present.

**Remarks:** Differs from *W. archaeocretacea* in having radial sutures and a rounded periphery without an imperforate band.
**Range:** Upper Cenomanian to Middle Turonian.

**Occurrence:** Rare to very abundant.

**Whiteinella archaeocretacea** Pessagno, 1967

*(Pl. 13, Figs 1-2, 5)*

Whiteinella archaeocretacea Pessagno, 1967, pp. 288-289, pl. 51, figs 2-4; pl. 54, figs 19-25; pl. 100, fig. 8.

Whiteinella archaeocretacea Pessagno. Robaszynski & Caron, 1979, pp. 161, 167-168, pl. 33, figs 1-3; pl. 34, figs 1-2.

**Hedbergella (Whiteinella) archaeocretacea** (Pessagno). Koutsoukos, 1989, pp. 234, pl. 27, figs 7-12.

**Description:** A low trochospire, flat biconvex test; peripheral border imperforate. Final whorl with 5 chambers increasing fairly rapidly, initial chambers globose, becoming elongate in the direction of coiling; outline lobate; sutures deep, radial and straight in early chambers, becoming curved and oblique in final parts. Umbilicus wide, about one-fourth of the maximum diameter; aperture more umbilical, portici present.

**Remarks:** Differs from other Whiteinella species in having an imperforate periphery, final chambers elongated and later sutures deep and curved.

**Range:** Upper Cenomanian to Middle Turonian.

**Occurrence:** Rare to frequent.

**Whiteinella baltica** (Douglas & Rankin)

*(Pl. 13, Figs 3-4, 6-7)*

Whiteinella baltica Douglas & Rankin, 1969, p. 198, text-fig. 9a-c.

**Hedbergella bornholmensis** Douglas & Rankin, 1969, p. 193, text-fig. 6a-i.

**Rugoglobigerina alpina** Porthault, 1969, pl. 2, fig. 2a-c.

Whiteinella baltica Douglas & Rankin. Caron, 1978, pl. 4, figs 4-5.
Whiteinella baltica Douglas & Rankin. Robaszynski & Caron, 1979, pp. 169, 174, pl. 35, figs 1-5; pl. 36, figs 1-2.

Whiteinella baltica Douglas & Rankin. Caron, 1985, p. 79, figs 37(1-3).

**Description:** A low trochospire, almost bilaterally symmetrical test, periphery rounded. Final whorl with $3^{1/2}$ to 5 globose chambers, increasing very rapidly in size; equatorial periphery lobate, forms with $3^{1/2}$ chambers have the final chamber fairly large giving a tri-lobate outline; sutures deep and radial; surface spinose. Umbilicus narrow, less than one-fourth of maximum diameter; aperture extra-umbilical to umbilical, bordered by portici.

**Remarks:** Douglas & Rankin (1969) established two new species- *H. bornholmensis* (with $3^{1/2}$ chambers in the final whorl and a trilobate periphery) and *W. baltica* (4 chambers in the final whorl). Porthault (1969) erected a new species- *W. alpina* with 5 chambers in the final whorl. The geographical/latitudinal distribution of *bornholmensis, baltica* and *alpina* may reflect a shallow to deeper-water habitat respectively (Hart pers. comm.). The 3 chambered *bornholmensis* were reported from Denmark, the four chambered *baltica* from UK and the 5 chambered *alpina* from Southern France (Hart pers. comm.). Robaszynski & Caron (1979) observed that the difference between these three species is minor and the species *baltica* appeared to be the representative of the population of the three forms. Regarding the use of *baltica* over *alpina*, the species *baltica* was published in September 1969 and *alpina* in 1969, without indication of the month of publication. Hence, after the International Commission of Zoological Nomenclature (ICZN) (article 21, b, ii), the name *baltica* is given priority over *alpina*. The *W. baltica* population from the Cauvery Basin includes representatives of all these three morphotypes. The population as a whole is represented, however, by the four chambered *W. baltica* form.

**Range:** Upper Cenomanian to Middle Turonian.

**Occurrence:** Very rare to frequent.
Whiteinella brittonensis (Loeblich & Tappan) (Pl. 13, Figs 8-10)

Hedbergella brittonensis Loeblich & Tappan, 1961, p. 274-275, pl. 4, fig. 1a-c.
Whiteinella brittonensis (Loeblich & Tappan). Robaszynski & Caron, 1979, pp. 175, 180, pl. 37, figs 1-2; pl. 38, figs 1-2.

**Description:** A moderately high trochospire test, periphery round, outline lobate; final whorl with 5 globular chambers, increasing slowly; sutures radial and deep. Aperture extra-umbilical to umbilical not extending to the periphery, portici developed; umbilicus narrow, about one-fifth of the maximum diameter.

**Remarks:** Differs from *W. paradubia* (Sigal) in having a less high trochospire.

**Range:** Upper Cenomanian to Middle Turonian.

**Occurrence:** Very rare to rare.

Subfamily ROTUNDININAE Bellier & Salaj, 1977
Genus PRAEGLOBOTRUNCANA Bermudez, 1952
Type species: Globorotalia delrioensis Plummer, 1931

Praeglobotruncana aumalensis (Sigal) (Pl. 13, Figs 11-13)

Praeglobotruncana aumalensis (Sigal). Robaszynski & Caron, 1979, pp. 25, 28, pl. 42, fig. 1.

**Description:** An asymmetrical biconvex (spiral side more convex), moderately high trochospire test; chambers are gently compressed to subangular, frequently marked by concentration of pustules, at least in the first chambers of last whorl. Umbilicus about
one-fourth of the maximum diameter; aperture extraumbilical-umbilical with a lip. Final whorl with 5 to 6, inflated chambers, becoming petaloid, increasing slowly; sutures deep, radial in early part and then curved; outline lobate; surface covered with pustules.

Remarks: Differs from *W. archaeocretacea* in a moderately high trochospire and chambers not elongated in the direction of coiling. Differs from *P. stephani* (Gandolfi) in not having raised spiral sutures.

Range: Cenomanian to Middle Turonian.

Occurrence: Rare to frequent.

**Praeglobotruncana delrioensis** (Plummer)

(Pl. 13, Fig. 14)

Globorotalia delrioensis Plummer, 1931, p. 199, pl. 13, fig. 2a-c (fide Caron 1985).

Praeglobotruncana delrioensis (Plummer). Robaszynski & Caron, 1979, pp. 29, 32, pl. 43, figs 1-2.

Praeglobotruncana delrioensis (Plummer). Caron, 1985, p. 65, figs 30(1-2).

Description: A flat to low trochospire test with 2 to 2½ whorls; an imperforate peripheral band lined by faint rows of pustules. Final whorl with 5 to 6 chambers ranging from compressed petaloid to sub-globular to globular, initial chambers increasing slowly, final chambers more rapidly. Sutures deep and radial; surface pustulose; outline lobate; aperture an extra-umbilical to umbilical arch.

Remarks: A variation in test compression, development of peripheral imperforate band and shape of chambers (flat, compressed to globular) is observed. Differs from *P. stephani* (Gandolfi) in having a lower trochospire.

Range: Upper Albian to Lower Cenomanian.

Occurrence: Rare to frequent.
**Praeglobotruncana gibba** Klaus

(Pl. 13, Figs 15-18)


Praeglobotruncana stephani Gandolfi var. gibba Klaus, 1960, pp. 304-305; holotype designated in Reichel 1950, pi. 16, fig. 6; pl. 17, fig. 6 (fide Klaus 1960).

Praeglobotruncana gibba Klaus. Robaszynski & Caron, 1979, pp. 33, 38, pl. 41, fig. 3; pl. 44, figs 1-2; pl. 45, figs 1-2.

Praeglobotruncana gibba Klaus. Caron, 1985, p. 65, fig. 30(3-4).

**Description:** A high trochospire test with 2 1/2 to 3 well-developed whorls; periphery with 2 to (?)3 rows of pustules, becoming smoother towards final chamber. Aperture extraumbilical-umbilical, bordered by a lip; lips of the preceding apertures imbricate and partially visible; umbilicus about one-fourth of the maximum diameter. Final whorl with 5 to 5 1/2/6 petaloid to triangular, flat to gently inflated chambers, increasing moderately with a slightly pustulose surface. Spiral sutures curved and beaded (few specimens with final 1 to 2 chambers with non-beaded and curved sutures), umbilical sutures radial and deep.

**Remarks:** In the Praeglobotruncana phylogeny (Klaus 1960, Robaszynski & Caron 1979), with the increase in the height of the spire *P. stephani* (Gandolfi) evolves into *P. gibba*. The *gibba* reported from the Cauvery Basin follow the same pattern of *stephani* to *gibba* transformation, with one exception. The forms reported from Europe (Robaszynski & Caron 1979) show a gradual increase in the height of the spire, resulting in mound-shaped, high trochosporic *gibba*. The *gibba* reported from the Cauvery Basin show a more robust transformation. A rapid increase in the spire height with the inner whorls sitting like a lobe on the final whorl, resulting in a block-shaped high trochosporic *gibba*. These high trochosporic forms have a highly developed beaded ornamentation on their spiral sides and very well developed rows of pustules. In some
cases these rows of pustules are highly developed and can be referred to two closely spaced keels in the final chambers of the last whorl.

P. gibba differs from P. stephani in having a higher trochospire, well developed and distinct $2^{1/2}$ to 3 whors.

**Range:** Upper Albian to Middle Turonian.

**Occurrence:** Rare to common.

**Praeglobotruncana helvetica** (Bolli)

(Pl. 14, Figs 1-5)

Globotruncana helvetica Bolli, 1945, p. 226, pl. 9, figs 6-8, text-fig. 1.


Praeglobotruncana helvetica (Bolli). Robaszynski & Caron, 1979, pp. 39, 42, pl. 46, figs 1-2.

**Diagnosis:** The specimens are characterised by a strongly asymmetrical, plano-convex test (spiral side plane); single keeled. Spiral side with 4 to $4^{1/2}$ (rarely 5) petaloid chambers in the final whorl and a flat surface, chambers increasing moderately; sutures raised; outline lobate.

**Remarks:** The typical Tethyan form of helvetica (with 7 chambers in the final whorl, Robaszynski & Caron 1979) do not occur in the Cauvey Basin (see Chapters 5 & 6 for further details).

**Range:** Lower to Middle Turonian.

**Occurrence:** Rare to Common.

**Praeglobotruncana praehelvetica** (Trujillo)

(Pl. 14, Figs 6-8)

**Praeglobotruncana praehelvetica** (Trujillo). Robaszynski & Caron, 1979, pp. 43, 46, pl. 47, figs 1-2.

**Remarks:** Similar to *P. helvetica* from which differs in having depressed and not raised sutures on the spiral side and no true keel, only a sharp line of pustules. Differs from *Whiteinella* in having a flat spiral side.

**Range:** Lower to Middle Turonian.

**Occurrence:** Rare to frequent.

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**Praeglobotruncana stephani** (Gandolfi)

(Pl. 14, Fig. 9-12)

Globotruncana stephani Gandolfi, 1942, p. 130, pl. 3, fig. 4a-c (fide Caron 1985, p. 65).

**Praeglobotruncana stephani** (Gandolfi). Robaszynski & Caron, 1979, pp. 47, 50, pl. 41, figs 1-2; pl. 48, figs 1-3.

**Praeglobotruncana stephani** (Gandolfi). Caron, 1985, p. 65, figs 30(3-4).

**Description:** A low to moderately high trochospire; chamber outline marked by 2 to 3 rows of pustules, becoming fainter in last chambers. Spiral side with petaloid chambers, flat to gently inflated, increasing moderately; sutures curved and beaded, at least in the first chambers of the inner whorl. Aperture extrumbilical to umbilical, just reaching the periphery, bordered by a lip; umbilicus one-fourth of the maximum diameter; outline lobate.

**Remarks:** The *stephani* population reported from the Cauvery Basin develop into highly calcified and ornamented forms. Strongly beaded spires, moderately high trochospire and very well developed rows of pustules (which may be confused for two closely spaced keels in final chambers of final whorl) are characteristic of these *stephani.*
Differs from *P. aumalensis* in having raised to beaded spiral sutures and well developed rows of pustules. Differs from *P. gibba* in having a low to moderate trochospture.

**Range:** Upper Albian to Middle Turonian.

**Occurrence:** Common to abundant.

**Family** ROTALIPORIDAE Sigal, 1958

**Subfamily** ROTALIPORINAE Sigal, 1958

**Genus** ROTALIPORA Brotzen, 1942

**Type species:** *Rotalipora turonica* Brotzen, 1942

*Rotalipora appenninica* (Renz)

(Pl. 14, Figs 13-15)

Globotuncana appenninica Renz, 1936, p. 14, fig. 2 (fide Caron 1985, p. 67).

*Rotalipora appenninica appenninica* (Renz). Luterbacher & Premoli Silva, 1962, pp. 266-268, pl. 19, figs 1-2; pl. 20, figs 1-4; pl. 21, figs 1-4.

*Rotalipora appenninica* (Renz). Robaszynski & Caron, 1979, pp. 59, 64; pl. 4, figs 1-3; pl. 5, figs 1-3.


**Description:** A symmetrical biconvex, low trochospture test with 2 to 2½ whorls; periphery marked by a single keel which follows the sutures on the dorsal side; outline lobate. Spiral side with 6 petal-shaped chambers in the final whorl, chamber increasing rapidly; sutures raised and those of the last whorl joining the preceding whorl at right angles. Umbilical side with 5½ to 6 chambers in the final whorl, final chamber relatively large; sutures deep and radial; surface smooth to pustulose. Primary aperture an extra-umbilical to umbilical arch, secondary aperture umbilical in early chambers, sometimes becoming sutural; umbilicus 1/4 to 1/5 of the maximum diameter.

**Remarks:** Differs from *R. gandolfii* Luterbacher & Premoli-Silva in lacking a true
peri-umbilical flange and in having spiral sutures joining the preceding whorl at right angles.

**Range:** Upper Albian to Upper Cenomanian.

**Occurrence:** Very rare to frequent.

**Rotalipora brotzeni** (Sigal)

(Pl. 14, Fig. 16; Pl. 15, Figs 1-3)

**Thalmanninella brotzeni** Sigal, 1948, p. 102, pl. 1, fig. 5; pl. 2, figs 6-7 (fide Caron 1985, p. 67).

**Rotalipora brotzeni** (Sigal). Robaszynski & Caron, 1979, pp. 65, 68, pl. 6, figs 1-2.

**Rotalipora brotzeni** (Sigal). Caron, 1985, p. 67, figs 31(5-7).

**Description:** A slightly asymmetrical, biconvex test (umbilical side slightly more convex); single-keeled; outline lobate. Petaloid chambers, increasing moderately; spiral sutures raised and oblique; umbilical sutures curved-oblique and raised (at least in the early part of chambers of the last whorl). Primary aperture extra-umbilical to umbilical, secondary apertures umbilical.

**Remarks:** Differs from **R. gandolfii** in having raised umbilical sutures and spiral sutures oblique. Spiral sutures always oblique in relation to the preceding sutures distinguishes it from **R. gandolfii**, where the sutures are at right angles.

**Range:** Upper Albian to Middle Cenomanian.

**Occurrence:** Rare.

**Rotalipora cushmani** (Morrow)

(Pl. 15, Figs 4-6)

**Globorotalia cushmani** Morrow, 1934, p. 199, pl. 31, fig. 4a-b (fide Caron 1985, p. 69).

**Rotalipora cushmani** (Morrow). Robaszynski & Caron, 1979, pp. 69, 74, pl. 7, fig. 1;
**Rotalipora cushmani** (Morrow). Caron, 1985, p. 69, figs 31(8-11).

**Description:** An equally biconvex, high trochospire test; a single, beaded keel; outline lobate. Spiral side with $4^{1/2}$ to 5 semi-circular chambers, increasing rapidly, ornamented with pustules; sutures raised and curved. Umbilical side with $4^{1/2}$ triangular, strongly inflated chambers, pustulose (at least the early chambers). A wide umbilicus; primary aperture extraumbilical-umbilical; secondary apertures sutural, bordered by a lip.

**Remarks:** Differs from *R. montsalvensis* Mornod in having a high trochospire, raised spiral sutures and a more pronounced ornamentation.

**Range:** Middle to Upper Cenomanian.

**Occurrence:** Rare.

**Rotalipora sp. aff. R. deeceki** (Franke) (Pl. 15, Figs 7-8)

*Rotalipora deeceki* Franke, 1925 (*fide* Robaszynski & Caron 1979). *Rotalipora deeceki* (Franke). Robaszynski & Caron, 1979, pp. 75, 80, pl. 9, figs 1-2; pl. 10, figs 1-2.

**Description:** An asymmetrical, biconvex test with a highly vaulted umbilical side; single-keeled; outline gently lobate. Spiral side with 6 crescent to petal-shaped chambers, increasing gradually; sutures raised and strongly oblique. Umbilical side with 6 to $6^{1/2}$ inflated chambers, increasing gradually; sutures radial to slightly curved; appear to be raised in the early part of the test, but deep later. Primary aperture extraumbilical-umbilical; secondary apertures umbilical; umbilicus wide with a peripheral umbilical ridge.

**Range:** Upper Cenomanian.

**Occurrence:** Rare.
Rotalipora gandolfii Luterbacher & Premoli-Silva

(Pl. 15, Figs 9-10)

Rotalipora gandolfii Luterbacher & Premoli-Silva. Robaszynski & Caron, 1979, pp. 81, 84, pl. 11, figs 1-2.
Rotalipora gandolfii Luterbacher & Premoli-Silva. Caron, 1985, p. 69, figs 33(5-7).

Description: An equally biconvex test; single-keeled; outline lobate. Spiral side with $5^{1/2}$ petaloid chambers in the final whorl, increasing moderately rapidly; sutures raised and oblique, (?) suture in the last chamber slightly at right angle. Umbilicus is 1/3 of the maximum diameter, peripheral flanges; primary aperture extraumbilical-umbilical; secondary aperture umbilical.

Remarks: Differs from R. appenninica in having peripheral flanges on all chambers and oblique spiral sutures. R. gandolfii is considered to be a transitional form between R. appenninica and R. brotzeni (Robaszynski & Caron 1979).

Range: Upper Albian to Upper Cenomanian.

Occurrence: Rare.

Rotalipora greenhornensis (Morrow)

(Pl. 15, Fig. 14-15)

Globorotalia greenhornensis Morrow, 1934, p. 199, pl. 31, fig. 1 (fide Caron 1985).
Rotalipora greenhornensis (Morrow). Robaszynski & Caron, 1979, pp. 85, 90, pl. 12, figs 1-2; pl. 13, figs 1-2.
Rotalipora greenhornensis (Morrow). Caron, 1985, p. 69, figs 32(1-2).

Description: An asymmetrical, biconvex test, umbilical side more convex; single-keeled; outline lobate. Spiral side with 7 to 9 crescent-shaped to semi-circular
chambers, increasing slowly; sutures raised and curved. Umbilical side with 7 to 8 trapezoidal, slowly increasing chambers; sutures curved and raised.

Remarks: Differs from R. brotzeni in having a greater number of chambers and a more asymmetrical test.

Range: Middle to Upper Cenomanian.

Occurrence: Rare.

**Rotalipora micheli** (Sacal & Debourle)

(Pl. 11-13)


*Rotalipora micheli* (Sacal & Debourle). Robaszynski & Caron, 1979, pp. 91, 94, pl. 14, figs 1-3.

**Description:** Asymmetrical test with umbilical side inflated and more convex; single-keeled; outline lobate. Spiral side with 5 to 7 petaloid chambers in the final whorl, increasing rapidly; sutures raised and oblique. Umbilical side with 5 to 6 triangular and inflated chambers, sutures radial and deep. Primary aperture extraumbilical-umbilical; secondary apertures umbilical, sometimes becoming sutural; well-developed ad-umbilical thickening but no true periumbilical ridges.

Remarks: Differs from *R. appenninica* in having an asymmetrical test, oblique spiral sutures and an ad-umbilical thickening. *R. micheli* is considered a transitional form between *R. appenninica* and *R. reicheli*.

Range: (?) Upper Albian to Lower Cenomanian.

Occurrence: Rare to common.
**Rotalipora montsalvensis** Mornod

(Pl. 15, Fig. 16; Pl. 16, Fig. 1)

**Rotalipora montsalvensis** Mornod. Robaszynski & Caron, 1979, pp. 95, 98, pl. 15, figs 1-2.

**Rotalipora montsalvensis** Mornod. Caron, 1985, pp. 69, figs 32(3-4).

**Diagnosis:** An equally, biconvex test, single-keeled, outline strongly lobate; primary aperture extraumbilical-umbilical, secondary apertures sutural. Spiral side with 4 to 5 radially elongate chambers in the final whorl, increasing rapidly; sutures depressed.

**Remarks:** Radially elongate and rapidly increasing chambers and strongly depressed sutures are characteristic of **montsalvensis**.

**Range:** Cenomanian.

**Occurrence:** Rare.

**Rotalipora reicheli** Mornod

(Pl. 16, Figs 2-7)

**Globotruncana (Rotalipora) reicheli** Mornod, 1949-50, pp. 583-584, text-fig. 5 (IV a-c) (fide Caron 1985, p. 69).

**Rotalipora reicheli** Mornod. Robaszynski & Caron, 1979, pp. 99, 106, pl. 16, fig. 1; pl. 17, fig. 1; pl. 18, figs 1-2.

**Rotalipora reicheli** Mornod. Caron, 1985, p. 69, figs 32(5-6).

**Description:** A strongly asymmetrical test, spiral side flat to concave (to the last chamber) with the early whorls raised at the centre, umbilical strongly vaulted; single-keeled. Primary aperture extra-umbilical to umbilical, secondary apertures umbilical; umbilicus very wide, 1/2 to 1/3 of the maximum diameter; peri-umbilical
ridges well developed on all chambers forming a kind of rampart around the umbilicus. Spiral side with petaloid chambers, final two chambers becoming semi-circular; sutures raised and oblique in early part, final two tending to be more perpendicular. Umbilical side with $5^{1/2}$ to 6 triangular and inflated chambers; sutures radial to slightly sinuous and deep.

**Remarks:** In Europe (Robaszynski & Caron 1979) the established stratigraphic range of *R. reicheli* is Middle Cenomanian. By contrast in the Cauvery Basin *reicheli* is observed to have a much longer time range (from the latest-early Cenomanian to the late Cenomanian). In the present study *R. reicheli* is reported from the early Cenomanian, when it makes its first appearance to the late Cenomanian, extinction level of *Rotalipora* species (see Chapter 5 for further details).

A strongly plano-convex profile and a prominent periumbilical ridge are characteristic of *reicheli*. Differs from *R. deeckeii* in having a wide umbilicus, umbilical sutures deep and not raised, last chamber higher than it is wide and often concave. Distinguished from *R. micheli* in having greater number of slowly increasing, crescent shaped chambers; strongly asymmetrical plano-convex test; wide umbilicus and spiral sutures in the last two chambers becoming perpendicular.

**Range:** Cenomanian.

**Occurrence:** Rare to common.

*Rotalipora subticinensis* (Gandolfi)
(Pl. 16, Figs 8-11)

*Globotruncana (Thalmanninella) ticinensis* subsp. *subticinensis* Gandolfi, 1957, p. 59, pl. 8, figs 1a-c (fide Caron 1985, p. 72).

*Rotalipora subticinensis* (Gandolfi). Robaszynski & Caron, 1979, pp. 107, 110, pl. 19, figs 1-2.

*Rotalipora subticinensis* (Gandolfi). Caron, 1985, p. 72, figs 33(1-2).
Remarks: The specimens reported as *R. subticinensis* are similar to *R. ticinensis* (Gandolfi) from which they differ in having a lower trochospiral test and secondary apertures present between the last 3/4 chambers of the final whorl. Robaszynski & Caron (1979) differentiate *R. subticinensis* from *R. ticinensis* in having a lower trochospire, supplementary apertures only in the last 3 to 4 chambers and lacking keel on the last three or four chambers. The *R. subticinensis* reported from the Cauvery Basin have a keel present throughout the periphery, becoming weak (in some cases) on the final 3/4 chambers.

Range: Upper Albian.

Occurrence: Rare.

**Rotalipora ticinensis** (Gandolfi)

(Pl. 16, Figs 12-14; Pl. 17, Figs 1-2)

Globotruncana ticinensis Gandolfi, 1942, pl. 2, fig. 3a-c (fide Caron 1985, p. 72).


**Rotalipora ticinensis** (Gandolfi). Caron, 1985, p. 72, figs 33(3-4).

Description: A high trochospire, biconvex test; a keel on all chambers; outline subcircular. Spiral side with 7 petaloid chambers in the final whorl, increasing gradually; sutures raised, oblique to gently curved and bordered by a rim (in the inner whorls and few early chambers of the final whorl). Umbilical side with 7 triangular chambers, increasing gradually, early chambers faintly pustulose; sutures deep, radial to very gently curved. Primary aperture extraumbilical-umbilical, secondary apertures within the aperture along the sutures; umbilicus about 1/5 of the maximum diameter.

Remarks: Differs from *R. subticinensis* in having a higher trochospiral test and supplementary apertures present between all the chambers (see also Remarks under *R. subticinensis*).

Range: Upper Albian.
Occurrence: Rare.

**Rotalipora sp. 1**

(Pl. 17, Fig. 6)

**Description:** An equally biconvex test, single-keeled, outline lobate; primary aperture extraumbilical-umbilical, nearly peripheral. Spiral side with 5½ chambers in the final whorl; sutures depressed and oblique in early part, final two raised and perpendicular. Umbilical side with 4½ to 5½ triangular and inflated chambers; sutures radial and deep.

**Range:** Upper Albian to Lower Cenomanian.

**Occurrence:** Very rare to rare.

**Rotalipora sp. 2**

(Pl. 17, Figs 3-5)

**Description:** A slightly asymmetrical, biconvex test, spiral side slightly less convex; single-keeled; outline lobate. Primary aperture extra-umbilical to umbilical, secondary aperture umbilical (seen only in the last chamber); umbilicus small, about 1/5 of the maximum diameter. Final whorl with 5 triangular, inflated, moderately increasing chambers; sutures deep, radial to very gently curved.

**Range:** Lower Cenomanian.

**Occurrence:** Very rare.

Superfamily **GLOBOTRUNCANACEA** Brotzen, 194

Family **GLOBOTRUNCANIDAE** Brotzen, 1942

Subfamily **GLOBOTRUNCANINAe** Brotzen, 1942

Genus **DICARINELLA** Porthault, 1970

(sensu Robaszynski & Caron, 1979, pp. 51-55)

Type species: **Globotruncana indica** Jacob & Sastry, 1950
Remarks: *Dicarinella* is characterised by the presence of two distinct keels separated by an imperforate band; umbilical sutures radial and deep and an extraumbilical-umbilical primary aperture. It differs from *Praeglobotruncana* Bermudez in having portici and two well developed keels separated by an imperforate band, and from *Marginotruncana* Hofker in having depressed and radial sutures on the umbilical side.

**Dicarinella algeriana** (Caron)

(Pl. 17, Figs 7-9)

*Praeglobotruncana algeriana* Caron, 1966, pp. 74-75, holotype, figured by Reichel, 1950, pp. 612-613, pl. 16, fig. 8, pl. 17, fig. 8, as *Globotruncana* (Globotruncana) aff. renzi Thalmann & Gandolfi (fide Caron 1985, p. 43).

*Dicarinella algeriana* (Caron). Robaszynski & Caron, 1979, pp. 57, 60, pl. 49, fig. 2; pl. 50, figs 1-2.

*Dicarinella algeriana* (Caron). Caron, 1985, p. 43, figs 17(1-2).

**Description:** A low to moderately high trochospire; periphery with two keels separated by a narrow imperforate band, becoming less distinct and in the final chambers often reduced to one or absent completely; outline lobate. Spiral side with 5 to $5^{1/2}/6$ petaloid chambers with a flat surface, gradually increasing in size; sutures curved and depressed. Umbilical side with $5^{1/2}$ to 6 triangular, inflated chambers; sutures deep and radial; primary aperture extraumbilical-umbilical, bordered by a lip; lips of the preceding apertures appear to be developing an imbricate pattern around the umbilicus.

**Remarks:** *D. algeriana* is a transitional form between *P. stephani* and *D. imbricata* (Mornod). It differs from *stephani* in having spiral sutures depressed and two closely spaced keels. The *stephani* reported from the Cauvery Basin have a more ornamented test with forms having pustules which could be confused for two closely spaced keels (see Remarks under *P. stephani* for details). The raised and beaded spiral sutures of the *stephani* reported from the Basin differentiates them from *algeriana*. The lack of a wide
imperforate peripheral band and an imbricated pattern of the keels differentiates *algeriana* from *imbricata* (Mornod).

**Range:** Middle Cenomanian to Middle Turonian.

**Occurrence:** Rare to frequent.

**Dicarinella canaliculata** (Reuss)

(Pl. 17, Figs 10-12)

*Rosalina canaliculata* Reuss, 1854, p. 70, pl. 26, fig. 4a-b (fide Caron 1985, p. 43).

*Marginotruncana canaliculata* (Reuss) Pessagno, 1967, p. 303, pl. 74, figs 5-8.

*Dicarinella canaliculata* (Reuss). Robaszynski & Caron, 1979, pp. 67, 70, pl. 53, figs 1-3.

*Dicarinella canaliculata* (Reuss). Caron, 1985, p. 43, figs 17(5-6).

**Description:** A flat trochospire test with a sub-rectangular profile marked by two, widely spaced, parallel keels, keels continuing to the last chamber and separated by an imperforate band. Spiral side flat to gently convex; 5 to 6 petaloid chambers, increasing slowly; sutures raised and curved; outline lobate. Umbilical side with $5^{1/2}$ to 6 trapezoidal, inflated chambers; sutures deep and radial in early chambers, becoming curved later. Umbilicus 1/5 to 1/4 of the maximum diameter; primary aperture extraumbilical-umbilical with a portici.

**Remarks:** A flat trochospire with two, widely spaced, parallel keels, continuing to the last chamber is characteristic of *D. canaliculata*.

**Range:** Upper Cenomanian to Middle Turonian.

**Occurrence:** Rare to frequent.
**Dicarinella hagni** (Scheibnerova)

(Pl. 17, Figs 13-18; Pl. 18, Figs 1-13)

_Praeglobotruncana hagni_ Scheibnerova, 1962, p. 219, fig. 6a-c (fide Caron 1985, p. 45).


_Dicarinella hagni_ (Scheibnerova). Robaszynski & Caron, 1979, pp. 79, 84-86, pl. 56, figs 1-2; pl. 57, figs 1-2.

_Dicarinella hagni_ (Scheibnerova). Caron, 1985, p. 45, figs 18(1-3).

_Dicarinella hagni_ (Scheibnerova). Kuhnt, et al. 1986, pl. 6, fig. 6.

**Description:** The morphotypes reported as _D. hagni_ from the Cauvery Basin show a wide variation in the spire height, convexity of the test and in the development of keels and periumbilical ridge. Specimens reported vary from having a moderate to moderately high trochospiral tests with a slightly asymmetrical, biconvex profile (umbilical side more convex) to strongly plano-convex to concavo-convex profiles, with spiral side flat to gently concave and umbilical side strongly vaulted. Rarely low trochospiral, equally biconvex tests are also present. Periphery marked by either two, closely spaced, parallel keels or two, less closely spaced keels with the spiral keel diverging obliquely per chamber giving a slightly imbricated pattern on the dorsal side. The keels often become fainter, or disappearing completely, on the last or penultimate chamber. These morphotypes often show the development of a periumbilical ridge at least in the final one or two chambers. Spiral side with 5 to 6, petaloid to semi-circular chambers with their surfaces flat to gently convex, the last two chambers becoming concave; sutures raised and oblique, sometimes beaded. Umbilical side with 4½ to 5, triangular and inflated chambers, increasing slowly; sutures radial and deep. Umbilicus about 1/4 to 1/3 of the maximum diameter; aperture extraumbilical-umbilical, portici present; outline lobulate to slightly lobulate.

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Remarks: The hagni population from the Cauvery Basin differs significantly from that reported as *D. hagni* from Europe (Robaszynski & Caron 1979). The European Working Group on Planktonic Foraminifera (Robaszynski & Caron 1979) report only low trochospiral, asymmetrical biconvex forms of *D. hagni* from Europe, differentiating them from the plano-convex “conca vata” group. In this study low to moderately high trochospire tests with biconvex to plano-convex profiles are grouped under hagni. From the Tarfaya Basin, Morocco, Kuhnt *et al.* (1986, pl. 6, fig. 6) reporting plano-convex forms of *D. hagni* comment that the morphotype (plano-convex) seems to characterise the boreal realm and is quite common in the early Turonian. Kuhnt *et al.* (1986) do not describe the morphological character of these plano-convex *D. hagni* forms occurring in the Tarfaya Basin, Morocco. This restricts the comparison of the *D. hagni* from the Tarfaya Basin with those occurring in the Cauvery Basin to a minimum.

Jacob & Sastry (1950) reported *Globotruncana indica*, a new species from the Cauvery Basin, having a plano-convex test and two keels. The Working Group (Robaszynski & Caron 1979) consider that *G. indica* shows a morphological similarity with *D. hagni*. In the absence of topotypes or any duplicate material available for the study during the preparation of the Atlas of Mid-Cretaceous Planktonic Foraminifera (Robaszynski & Caron 1979), the Working Group could not clarify the taxonomic status of *G. indica*. *D. hagni* was therefore retained as a more adequate taxon to identify the European forms.

Lamolda (1977) describes a new plano-convex species, *D. elata*, from Northern Spain, ranging from the late Cenomanian to early Coniacian. Lamolda (1977) differentiates *D. elata* from *G. indica* by the presence of a single keel instead of a double keel (as present in *indica*) on the outer whorl of *elata*. Topotype specimens of *D. elata* were made available (Lamolda pers. comm.) for comparative study. The specimens were, however, limited in number (only two specimens made available) and the material was not well preserved. This did not allow a thorough comparison of the morphological
characters of *D. elata* and *D. hagni* (reported in this study). From the published description of *D. elata* (Lamolda 1977) and the limited observation possible on the topotype specimens provided, the plano-convex *D. hagni* reported from Cauvery Basin appear to be different from *D. elata*. The *hagni* reported from the Cauvery Basin differ from *elata* in having a periumbilical ridge in final one or two chambers and two well developed keels. It is worth mentioning here that in the *D. elata* topotype specimens made available, there appears to be a very faint double keel in the final one or two chambers. This could, however, be an error in observation (or simply a second row of pustules (as reported by Lamolda 1977) being confused for a second keel by the author), especially considering that the material provided is not well preserved and is limited to only two specimens.

In the absence of a clear taxonomic status for *G. indica* and *D. elata*, *D. hagni* is used, at this stage of work, as the valid name for the plano-convex morphotypes occurring in the Cauvery Basin.

**Range:** Upper Cenomanian to Middle Turonian.

**Occurrence:** Abundant.

**Dicarinella imbricata** (Mornod)

(Pl. 18, Figs 14-18)

**Globotruncana (Globotruncana) imbricata** Mornod, 1949-50, pp. 589-590, fig. 5 (III a-d) (fide Caron 1985, p. 45).

**Dicarinella imbricata** (Mornod). Robaszynski & Caron, 1979, pp. 87, 92, pl. 58, figs 1-2; pl. 59, figs 1-2.

**Dicarinella imbricata** (Mornod). Caron, 1985, p. 45, figs 18.4-5.

**Description:** A low to moderate trochospire with a convexo-concave test (spiral side convex), an imbricated keel pattern accentuates the convexo-concave impression. Periphery with two keels separated by a wide, imperforate band (except in the last two
The spiral keel diverges obliquely per chamber from the umbilical keel, following the spiral sutures; the keel-band thus appears to be discontinuous resulting in an imbricated sequence. Umbilicus small, about 1/5 of the maximum diameter; primary aperture extraumbilical-umbilical, no portici; outline lobate. Spiral sutures curved and raised (marked by the continuation of the spiral keel); petaloid chambers, increasing slowly.

**Remarks:** A diverging spiral keel forming an imbricated pattern and absence of portici are characteristic of *D. imbricata*.

**Range:** Upper Cenomanian to Middle Turonian.

**Occurrence:** Rare to abundant.

**Genus GLOBOTRUNCANA** Cushman, 1927

Type species: *Pulvinulina arca* Cushman, 1926

**Remarks:** The genus *Globototruncana* is characterised by the presence of primary aperture umbilical and an umbilical system composed of tegilla (covering a large part of the umbilicus) bordering the successive apertures and having both proximal and distal apertures. A moderately high trochospiral test, nearly symmetrical lateral profile with two parallel keels on all chambers, equally developed and separated by a wide imperforate band.

**Globototruncana arca** (Cushman)

(Pl. 19, Figs 1, 5)

*Pulvinulina arca* Cushman, 1926, p. 23, pl. 3, fig. 1a–c (*fide* Caron 1985, p. 50).

*Globototruncana churchi* Martin, 1964, p. 79, pl. 9, fig. 5 (*fide* Caron 1985, p. 50).

*Globototruncana arca* (Cushman). Robaszynski *et al.* 1984, pp. 182, 184, pl. 1, figs 2-3; pl. 4, figs 1-3.

*Globototruncana arca* (Cushman). Caron, 1985, p. 50, figs 19 (4-8).
**Description:** Two specimens (one is broken) of *G. arca* have been recovered in this study. A symmetrical biconvex, moderate to moderately low trochospire test; periphery with two well developed keels on all chambers, separated by a wide imperforate band. Spiral side with 6 crescent to petaloid shaped chambers in the final whorl, increasing slowly; sutures curved, raised and beaded, meeting at acute angles (straight in the last chamber); outline lobate. Umbilical side with 5½ to 6 chambers last two chambers somewhat elongated and rectangular; sutures raised and curved in last chambers. Umbilicus is about 1/2 to 1/3 of the maximum diameter; tegillum not well preserved; adumbilical ridges developed on all chambers.

**Remarks:** In Europe *G. arca* is characterised by a moderately high trochospire (Robaszynski et al. 1984, pp. 184). The specimens reported as *G. arca* from the Cauvery Basin have a moderate to moderately low trochospire (similar to Robaszynski et al. 1984, pl. 4. fig. 1 but not figs 2-3). The specimens, except for a low spire height, have the other morphological features of *G. arca* as described by Robaszynski et al. 1984.

**Range:** Campanian.

**Occurrence:** Very rare.

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**Genus MARGINOTRUNCANA** Hofker, 1956

*(sensu* Robaszynski & Caron, 1979, pp. 97-101)*

Type species: *Rosalina marginata* Reuss, 1846

**Remarks:** A biconvex to plano-convex test; primary aperture extraumbilical-umbilical; two keels and more or less sigmoidal, elevated sutures on the umbilical side are characteristic of *Marginotruncana*. It differs from *Dicarinella* in possessing elevated umbilical sutures and from *Globotruncana* in a clearly extraumbilical primary aperture.
**Marginotruncana marginata** Reuss  
*(Pl. 19, Figs 2-4, 6-14)*

**Rosalina marginata** Reuss, 1845, p. 36, pl. 13, figs 18a-b *(fide Caron 1985, p. 61).*

**Globotruncana linneiana marginata** (Reuss). Jirova, 1956, pp. 241-242, pl. 1, fig. 1a-c *(fide Caron 1985, p. 61).*

**Marginotruncana marginata** (Reuss). Robaszynski & Caron, 1979, pp. 107, 112-114, pl. 63, figs 1-2; pl. 64, figs 1-2.

**Marginotruncana marginata** (Reuss). Caron, 1985, p. 61, figs 26.3-4.

**Description:** The *M. marginata* population reported from the Cauvery Basin shows a significant variation in the spire height; convexity of the test; development of keels and ornamentation of the spiral sutures. Specimens with low (equally biconvex) to very moderate (spiral side very slightly more convex) trochospire with two well developed keels separated by a wide imperforate band and the spiral keel slightly diverging obliquely per chamber. These forms have deep and oblique spiral sutures (few early chambers of the final whorl occasionally have raised sutures). In the other type the specimens have a moderately high (spiral side clearly more convex) trochospire with two well developed keels (separated by a very narrow imperforate band), keels reduced to one in the penultimate chamber and finally disappearing in the last chamber or totally absent to very faint in last 3 to 4 chambers. These forms have the first few (usually first two) chambers with depressed and oblique spiral sutures, becoming less oblique to perpendicular (in last two chambers), raised and beaded. Both types have a wide umbilicus, more than 1/3 of the maximum diameter; umbilical sutures appear radial and deep, marked by U-shaped, sigmoidal rim which gives a raised appearance to the sutures; aperture extraumbilical to umbilical, with well developed portici; outline lobate; 5½ petaloid to globular chambers.

**Remarks:** In Europe *M. marginata* is characterised by a biconvex, low trochospire; two slightly developed keels separated by a narrow peripheral band and spiral sutures oblique (depressed to slightly raised) (Robaszynski & Caron 1979). The *marginata*
population occurring in the Cauvery Basin differs significantly from that reported from Europe (Robaszynski & Caron 1979). The specimens are characterised by a more robust development of morphological characters (as discussed above).

**Range:** Lower to Middle Turonian.

**Occurrence:** Rare.

**Marginotruncana schneegansi** (Sigal)

(Pl. 20, Figs 1-15)

*Globotruncana schneegansi* Sigal, 1952, p. 33, pl. 34 (fide Caron 1985, p. 61).

*Marginotruncana schneegansi* (Sigal). Robaszynski & Caron, 1979, pp. 135, 140, pl. 70, figs 1-2; pl. 72, figs 1-2.

*Marginotruncana schneegansi* (Sigal). Caron, 1985, p. 61, figs 27(3-6).

**Description:** The *M. schneegansi* population reported from the Cauvery Basin shows a variation in the spire height and in the development of keels. Forms, similar to that reported from Europe (Robaszynski & Caron 1979, p. 140), with a low trochospiral and equally biconvex test have two parallel rows of closely spaced pustules forming the keels. These forms are rare. In the other, more frequent type, contrary to their European counterparts, the specimens are characterised by a moderately high trochospiral. These forms have two well developed, closely spaced keels, with the spiral keel diverging obliquely per chamber to the dorsal side. These specimens of *schneegansi* closely resemble *D. hagni* (reported from Cauvery Basin) from which they differ in having a higher trochospiral test and spiral sutures joining the preceding sutures at right angles. This differentiation, however, does not always hold. Intermediate forms between *M. schneegansi* and *D. hagni* are also present. Both these types are characterised by 5 to 6 chambers in the final whorl; spiral sutures raised and at about right angles to the preceding sutures, sometimes final sutures weakly beaded; umbilical sutures depressed and radial, becoming sigmoidal in final parts. Aperture
extraumbilical-umbilical, portici present; umbilicus about 1/4 to 1/3 of the maximum diameter; outline gently lobate.

**Remarks:** Differs from *M. marginata* in the absence of a U-shaped sigmoidal ring around the umbilicus.

**Range:** Upper Cenomanian to Middle Turonian.

**Occurrence:** Rare to frequent.

Suborder **ROTALEINA** Delage & Herouard, 1896

Superfamily **BOLIVINACEA** Glaessner, 1937

Family **BOLIVINIDAE** Glaessner, 1937

Genus **BOLIVINA** d'Orbigny, 1839

Type species: Bolivina plicata d'Orbigny, 1839

**Bolivina sp. aff. B. incrassata** Reuss

(Pl. 21, Fig. 1)

*Bolivina incrassata* Reuss, 1851, p. 29, pl. 5, fig. 13 (*fide* Cushman 1946, p. 127).


**Description:** An elongate, slender, biserial test with nearly parallel to gently flaring sides; chambers numerous and elongate, increasing slowly; sutures deep, straight and oblique.

**Remarks:** The specimens tentatively referred to *Bolivina aff. incrassata* are recorded from the mid-Turonian *P. helvetica* Zone. In the literature *B. incrassata* is reported from a much younger, Campanian to Maastrichtian, stratigraphic age. Koutsoukos (1989, p. 136), however, reports *B. incrassata* from as old as Late Coniacian-Santonian age from the Sergipe Basin, Brazil.

**Range:** Lower to Middle Turonian.
**Occurrence**: Common to abundant.

**Bolivina textilaroides** Reuss

(Pl. 21, Fig. 2)

*Bolivina textilaroides* Reuss, 1862, p. 81, pl. 10, fig. 1 (fide Tappan 1940, p. 118).
*Bolivina textilaroides* Reuss. Tappan, 1940, p. 118, pl. 18, fig. 8a-c.

**Diagnosis**: An elongate, tapering, biserial test; chambers increasing gradually, sutures deep; aperture terminal and loop shaped.

**Range**: Upper Albian.

**Occurrence**: Very rare.

**Bolivina sp. 1**

(Pl. 21, Fig. 3)

**Description**: A rhomboidal, compressed, biserial test with flaring sides; chambers broad, increasing slowly in early stage moderately rapidly in final part; sutures deep and straight; surface smooth; aperture loop-shaped.

**Remarks**: The specimens referred to *Bolivina sp. 1* differ from *Bolivinoides* Cushman in having a smooth surface and not ornamented with thick, longitudinal lobes; although a rhomboidal test with flaring sides is more characteristic of *Bolivinoides*.

**Range**: Cenomanian to Lower Turonian.

**Occurrence**: Very rare to rare.

Genus **TAPPANINA** Gallitelli, 1955

Type species: *Bolivinita selmensis* Cushman, 1933

**Tappanina sp. 1**

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Diagnosis: Test small, rhomboidal with gently flaring sides; chambers broad and carinate, biserially arranged.

Range: Cenomanian to Middle Turonian.

Occurrence: Rare to very abundant.

Superfamily TURRILINACEA Cushman, 1927
Family TURRILINIDAE Cushman, 1927
Genus PRAEBULIMINA Hofker, 1953
Type species: Bulimina ovulum Reuss, 1844

Praebulimina elata Magniez-Jannin (Pl. 21, Fig. 6)

Praebulimina elata Magniez-Jannin. Peryt & Lamolda, 1996, fig. 7.3.

Diagnosis: A small, spindle-shaped test with a tapering base and a very inflated to bulbous end; triserial chamber arrangement; aperture interiomarginal, loop-shaped; surface smooth.

Range: Upper Albian to Middle Turonian.

Occurrence: Rare to frequent.

Praebulimina nannina (Tappan) (Pl. 21, Fig. 5)

Bulimina nannina Tappan, 1940, p. 116, pl. 19, fig. 4a-b.
Praebulimina ex gr. nannina (Tappan). Koutsoukos, 1989, p. 145, pl. 12, fig. 4.
**Diagnosis:** A minute, tapering, triserial test with a very bulbous apertural end; last whorl with chambers very inflated-sub-globular, occupying half of the test; aperture loop-shaped.

**Range:** Upper Albian to Cenomanian.

**Occurrence:** Very rare to rare.

Superfamily **FURSENKOINACEA** Loeblich & Tappan, 1961
Family **FURSENKOINIDAE** Loeblich & Tappan, 1961
Genus **CORYPHOSTOMA** Loeblich & Tappan
Type species: *Bolivina plaitum* Carsey, 1926

**Coryphostoma sp. 1**
(Pl. 21, Fig. 7)

**Description:** A slender, laterally compressed and narrow test with a biserial-cuneate arrangement of chambers gradually becoming uniserial in final part. Sutures oblique and deep; surface smooth; aperture interiomarginal and loop-shaped.

**Range:** Upper Albian to Lower Turonian.

**Occurrence:** Very rare to rare.

**Coryphostoma sp. 2**
(Pl. 21, Fig. 8)

**Description:** The specimens are characterised by an early biserial chamber arrangement, becoming biserial-cuneate in the middle and finally tending to become uniserial. Sutures straight, oblique and deep; aperture interiomarginal and loop-shaped.

**Remarks:** The specimens differ from *Pleurostomella* Reuss in having a loop-shaped aperture and no bifid tooth.

**Range:** Upper Cenomanian to Lower Turonian.

**Occurrence:** Very rare.
**Coryphostoma sp. 3**
(Pl. 21, Fig. 9)

**Description:** A conical, tapering test with a biserial-cuneate arrangement of chambers, final chamber becoming uniserial; sutures flush and oblique; aperture terminal and loop-shaped to slit-like.

**Range:** Upper Cenomanian to Middle Turonian.

**Occurrence:** Rare to common.

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Superfamily **PLEUROSTOMELLACEA** Reuss, 1860

Family **PLEUROSTOMELLIDAE** Reuss, 1860

Subfamily **PLEUROSTOMELLINAE** Reuss, 1860

Genus **ELLIPSOGLANDULINA** Silvestri, 1900

Type species: **Ellipsoglandulina laevigata** Silvestri 1900

**Ellipsoglandulina concinna** (Olbertz)
(Pl. 21, Fig. 10)

**Ellipsoglandulina concinna** Olbertz (fide Sliter 1977).

**Ellipsoglandulina concinna** Olbertz. Sliter, 1977, pi. 6, fig. 11.

**Description:** A spindle-shaped, uniserial test with overlapping chambers; final chamber inflated, large, and occupying more than one half of the test. Sutures nearly horizontal and flush; aperture terminal and semi-lunate.

**Range:** Upper Albian.

**Occurrence:** Very rare.
**Ellipsoglandulina sp. 1**

(Pl. 21, Fig. 11)

**Description:** The specimens are characterised by an inflated, fusiform test; strongly overlapping chambers with the final chamber very large, occupying nearly the whole of the test; aperture terminal and semi-lunate; surface smooth.

**Remarks:** *Ellipsoglandulina* sp. 1 differs from *E. concinna* in having strongly overlapping chambers and a very large final chamber.

**Range:** Upper Albian.

**Occurrence:** Very rare.

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**Ellipsoglandulina sp. 2**

(Pl. 21, Fig. 12)

**Description:** A slightly compressed, tapering, uniserial test; sutures horizontal and deep; 6 to 7 chambers, increasing slowly, moderately rapidly in final stages; aperture terminal and semi-lunate.

**Range:** Upper Albian.

**Occurrence:** Very rare.

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Genus *PLEUROSTOMELLA* Reuss, 1860

Type species: *Dentalina subnodosa* Reuss, 1851

**Pleurostomella nitida** Morrow

(Pl. 21, Fig. 13)

*Pleurostomella nitida* Morrow, 1934, p. 94, pl. 30, fig. 22 (fide Cushman 1946, p. 132).

*Pleurostomella nitida* Morrow. Cushman, 1946, p. 132, pl. 54, fig. 24.
**Description:** A sub-globular initial chamber followed by biserial-cuneate and then uniserial-cuneate chamber arrangement; test slightly compressed laterally; surface smooth; sutures deep and oblique; aperture terminal with a hood.

**Range:** Upper Albian and Upper Cenomanian to Lower Turonian.

**Occurrence:** Rare to common.

**Pleurostomella obtusa** Berthelin

(Pl. 21, Fig. 14)

**Pleurostomella obtusa** Berthelin, 1880, p. 29, pl. 1, fig. 9 (fide Neagu 1965, p. 29).


**Description:** A prominent globular to sub-globular initial chamber followed by cuneate arrangement of chambers; aperture terminal with a projecting hood and two triangular teeth. The specimens show a variation in test shape and size. Short, stout forms with 2 to 3 inflated to sub-globular chambers and slender, elongate tests with 6 to 7 inflated chambers. Intermediate forms with 4 to 6 chambers also present.

**Range:** Upper Albian to Lower Turonian.

**Occurrence:** Rare to common.

**Pleurostomella reussi** Berthelin

(Pl. 21, Fig. 15)

**Pleurostomella reussi** Berthelin, 1880, p. 28, pl. 1, figs 10-12 (fide Neagu 1965, p. 30).


**Description:** A slender, tapering test; early biserial-cuneate and later uniserial-cuneate chamber arrangement, chambers inflated, last chamber becoming globular; aperture terminal with hood.
Remarks: Differs from *P. obtusa* in having a tapering test, less inflated chambers and the initial chamber not globular.

**Range:** Upper Albian to Lower Turonian.

**Occurrence:** Rare to common.

*Pleurostomella reussi* Berthelin var. A

(Pl. 21, Fig. 16)

Remarks: Similar to *P. reussi* from which it differs in having very rapidly increasing chambers, final 1 to 2 chambers very large and globular to inflated.

**Range:** Upper Cenomanian to Lower Turonian.

**Occurrence:** Rare.

Superfamily **STILOSTOMELLACEA** Finlay, 1947

Family **STILOSTOMELLIDAE** Finlay, 1947

Genus **STILOSTOMELLA** Guppy, 1894

Type species: *Stilostomella rugosa* Guppy, 1894.

*Stilostomella* sp. 1

(Pl. 21, Fig. 17)

**Diagnosis:** Test small, uniserial and rectilinear; chambers increase gradually with a prominent and sharp shoulder; aperture terminal, on a neck; surface smooth.

**Range:** Upper Albian to Middle Turonian.

**Occurrence:** Rare to frequent.
Stilostomella sp. 2
(Pl. 21, Fig. 18)

**Diagnosis:** A slender, uniserial, rectilinear to slightly arcuate test; 10 to 11 rectangular to bell-shaped chambers, with moderate to prominent shoulders, increasing gradually; sutures horizontal and deep; aperture terminal.

**Range:** Middle Cenomanian to Middle Turonian.

**Occurrence:** Very rare to rare.

Superfamily DISCORBACEA Ehrenberg, 1838
Family CONORBINIDAE Reiss, 1963
Genus CONORBINA Brotzen, 1936
Type species: Conorbina marginata Brotzen, 1936

Conorbina sp. 1
(Pl. 21, Figs 21-22)

**Description:** An asymmetrical biconvex, trochospiral test with spiral side conical-convex and umbilical side gently convex; periphery narrowly acute. Spiral side with 5 to 6 broad, sub-rectangular to petaloid chambers in the final whorl, increasing slowly; sutures thick, strongly oblique to curved. Umbilical side with 4, triangular chambers with a swollen end (more prominent in the final chamber) at the umbilicus; sutures radial, deep and less distinct; aperture interiormarginal slit, secondary areal openings.

**Remarks:** Differs from Conorboides Hofker in having a closed umbilicus and aperture not extending to the umbilicus.

**Range:** Upper Albian and Upper Cenomanian to Middle Turonian.

**Occurrence:** Very rare to common.
Conorbina sp. 2
(Pl. 21, Figs 23-24)

**Description:** Test similar to Conorbina sp. 1 from which it differs in having a less asymmetrical to symmetrical biconvex test; a very prominent umbilical boss; no areal openings and umbilical sutures radial and deep to oblique and slightly raised.

**Range:** Upper Cenomanian to Middle Turonian.

**Occurrence:** Very rare to frequent.

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Superfamily ASTERIGERINACEA d’Orbigny, 1839

Family ALFREDINIDAE Singh & Kalia, 1972

Genus EPISTOMAROIDES Uchio, 1952

Type species: Discorbina polystomelloides Parker & Jones, 1865

**Remarks:** Loeblich & Tappan (1988, pp. 604-605) uphold Hansen & Rogl’s view that the type species of Anomalina d’Orbigny, *A. punctulata* d’Orbigny, is identical with *Epistomaria punctulata* Said and congeneric with species now known as *Epistomaroides*. As a very broad concept for Anomalina previously had resulted from the somewhat generalised original figures, and as the type specimen was lost, a petition was submitted to ICZN (International Commission of Zoological Nomenclature) for suppression of Anomalina and retention of Epistomaroides as a valid genus (Loeblich & Tappan 1988, pp. 604-605).

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**Epistomaroides indica** (Sastry & Sastri)
(Pl. 21, Figs 19-20; Pl. 22, Fig. 1)

**Anomalina indica** Sastry & Sastri, 1966, pp. 293-294, pl. 19, fig. 10.

**Description:** A plano-convex to asymmetrical-biconvex, trochosire; spiral side flat to weakly convex, umbilical side conical-convex; periphery subrounded to subacute, rarely
rounded. Spiral side evolute with 10 to 11, gently inflated chambers in the final whorl, increasing slowly, final 2-3 chambers very inflated; sutures deep and oblique. Umbilical side involute, 7 to 10, inflated chambers; sutures deep and radial; aperture a low, interiomarginal arch, becoming peripheral.

**Range:** Upper Albian to Middle Turonian.

**Occurrence:** Very rare to very abundant.

**Epistomaroides sp. 1**
(Pl. 22, Figs 2-4)

**Description:** A globular, plano-convex to concavo-convex, trochospire; spiral side plane to gently concave, umbilical side conical-convex; periphery broadly rounded. Spiral side with 1½ to (?) 2 coils; 7 inflated to sub-globular chambers in the final whorl, increasing slowly; sutures deep, radial to gently curved. Umbilical side with 5½ to 6, triangular, inflated chambers, increasing gradually, final chamber is added rapidly; sutures radial and deep; aperture an interiomarginal slit, bordered by a thin lip.

**Range:** Upper Albian to Middle Turonian.

**Occurrence:** Very rare to frequent.
**Description:** A moderately low trochospire; 2½ to 3 whorls with the initial whorls minute and slightly raised above the final one. Final whorl with 4 inflated, sub-globular to globular chambers; sutures deep and oblique; surface smooth; umbilicus one-third of the maximum diameter; aperture umbilical to extra-umbilical, nearly peripheral with an umbilical flap (which is broken in most cases); outline lobate.

**Range:** Upper Albian to Middle Turonian.

**Occurrence:** Rare to frequent.

Family **GLOBOROTALITIDAE** Loeblich & Tappan, 1984

Genus **GLOBOROTALITES** Brotzen, 1942

Type species: **Globorotalia multisepta** Brotzen, 1942

**Globorotalites** sp. 1

(Pl. 22, Figs 10-11)

**Description:** A plano- to concavo-convex, low trochospire with 2½ to 3 whorls; inner whors sit like a tiny knob in the plano-concave final whorl. Spiral side evolute, elongate, sausage to kidney shaped chambers increasing slowly; sutures deep, oblique to curved. Umbilical side involute, 5 to 6 inflated and triangular chambers; sutures radial and deep. Aperture interiomarginal slit, extending to the umbilicus; umbilicus deep and with a narrow pit; periphery sub-rounded to sub-acute; outline gently lobate to wavy.

**Range:** Upper Albian to Middle Turonian.

**Occurrence:** Very rare to frequent.

**Globorotalites** sp. 2

(Pl. 22, Figs 7-9)

**Description:** A low trochospire, plano-convex test with a flat spiral side and a conical umbilical side. Final whorl with 5 to 6 chambers, spiral sutures oblique, limbate to
raised; umbilical sutures deep and radial. Periphery acute and carinate; aperture an interiomarginal slit, midway between the umbilicus and periphery; surface smooth. **Range**: Upper Albian and Lower Turonian. **Occurrence**: Very rare to common.

Family **OSANGULARIIDAE** Loeblich & Tappan, 1964

Genus **GOUPILLAUDINA** Marie, 1958

Type species: **Goupillaudina daguini** Marie, 1958

**Goupillaudina daguini** Marie

(Pl. 22, Fig. 12)

Goupillaudina daguini Marie, 1957, pp. 863-864, pl. 63, fig. 2, text-fig. 1a-f.


**Diagnosis**: A lenticular, laterally compressed to discoidal, involute test; prominent and elevated central boss on both sides; lunate and strongly arched chambers; sutures strongly curved; periphery broad and acute. **Range**: Upper Campanian. **Occurrence**: Rare.

Genus **OSANGULARIA** Brotzen, 1940

Type species: **Osangularia lens** Brotzen, 1940

**Osangularia** sp. 1

(Pl. 22, Fig. 13)

**Diagnosis**: A lenticular, biumbonate, biconvex, trochospire; 10-12 chambers, increasing slowly; sutures not distinct, flush to (?) raised, oblique to curved; sharply
acute periphery; aperture a narrow V-shaped slit separated into interiomarginal and aeral openings.

**Range:** Upper Albian and Upper Cenomanian to Middle Turonian.

**Occurrence:** Very rare to frequent.

Family **HETEROLEPIDAE** Gonzales-Donoso, 1969
Genus **HETEROLEPA** Franzenau, 1884
Type species: **Heterolepa simplex** Franzenau, 1884

*Heterolepa* sp. 1
(Pl. 22, Figs 14-15)

**Diagnosis:** An asymmetrical, low trochospire test with $2^{1/2}$ coils; spiral side evolute, sutures oblique to curved; umbilical side involute and conical-convex, sutures radial; periphery acute.

**Range:** Cenomanian to Middle Turonian.

**Occurrence:** Very rare to frequent.

*Heterolepa* sp. 2
(Pl. 22, Fig. 16)

**Remarks:** Similar to cf. *Heterolepa* sp. 1 from which it differs in having greater number of coils (about 3 coils) and a lenticular, equally biconvex test.

**Range:** Middle Cenomanian to Lower Turonian.

**Occurrence:** Very rare.

Family **GAVELINELLIDAE** Hofker, 1956
Subfamily **GYROIDINOIDINAE** Saidova, 1981
Genus **GYROIDINOIDES** Brotzen, 1942
Type species: **Rotalina nitida** Reuss, 1844

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Remarks: The morphotypes included within the genus *Gyroidinoides* are characterised by strongly asymmetrical, biconvex to rare plano-convex-conical, trochospiral test. Spiral side gently convex with a mound or knob shaped early spire on the final whorl and strongly conical umbilical side. Forms with plano-convex, flat or concave spiral side are also present, but are rare. Aperture interiomarginal-peripheral slit, extending on to the dorsal side; spiral sutures flush, oblique to curved, becoming radial; umbilical sutures radial and flush to deep. A combination of these characters with subtle variations has produced different morphotypes along with intermediate forms. This has created a considerable problem in speciation. At this stage of work they are recognised only as different species without giving a specific species name.

Magniez-Jannin (1975, pp. 239-246) has published a lengthy account of the genus *Valvulineria/Gyroidinoides*. The work is in French, a language in which the author is disadvantaged.

*Gyroidinoides* sp.1

(Pl. 22, Fig. 17; Pl. 23, Figs 1-2)

Description: The specimens are characterised by a spiral side very gently convex and umbilical side strongly conical. Spiral side with $2^{1/2}$ whorls, about 8 to 11 chambers in the final whorl increasing slowly, sutures flush, oblique to slightly curved (in few cases final sutures becoming radial). Umbilical side with 7-8 to 9-10, triangular, inflated chambers; sutures radial and flush; umbilicus a tiny pit.

Range: Upper Albian to Middle Turonian.

Occurrence: Very rare to frequent.
**Gyroidinoides** sp. 2  
(Pl. 23, Figs 3-5)

**Diagnosis:** A distinct boss on the spiral side, concealing the early part of the test followed by 6 chambers in the final whorl, is characteristic of this species.  
**Range:** Upper Albian to Cenomanian.  
**Occurrence:** Very rare to frequent.

**Gyroidinoides** sp. 3  
(Pl. 23, Figs 6-7)

**Remarks:** Very similar to *Gyroidinoides* sp. 2 from which it differs in having a smaller knob shaped spiral boss, 1.5 whorls visible and a greater number of chambers, from 6-8 to 10-12, in the final whorl. Forms with as many as 13 to 14 chambers and a much larger spiral boss are also reported.  
**Range:** Upper Albian to Cenomanian.  
**Occurrence:** Rare to very abundant.

**Gyroidinoides** sp. 4  
(Pl. 23, Figs 10-12)

**Description:** A plano-convex test with a flat spiral side; periphery narrowly round to bluntly acute, $2^{1/2}$ whorls with about 11 to 13 chambers in the final whorl. The species closely resembles *Gyroidinoides* sp. 1 from which it differs in a plano-convex profile and a bluntly acute periphery.  
**Range:** Upper Albian to Middle Turonian.  
**Occurrence:** Very rare to very abundant.
**Gyroidinoides sp. 5**  
(Pl. 23, Figs 8-9)

**Remarks:** Very similar to *Gyroidinoides* sp. 5 from which it differs in having a fewer number of chambers; a more inflated test and a rounded periphery.  
**Range:** Upper Albian to Middle Turonian.  
**Occurrence:** Very rare to frequent.

**Gyroidinoides sp. 6**  
(Pl. 23, Figs 13-14)

**Remarks:** A plano-convex test with narrowly round to bluntly acute periphery differentiates *Gyroidinoides* sp. 6 from *Gyroidinoides* sp. 2 and *Gyroidinoides* sp. 3. A very indistinct spiral side with about (?) 8 chambers in the final whorl makes it different from *Gyroidinoides* sp. 4 and *Gyroidinoides* sp. 5.  
**Range:** Cenomanian to Lower Turonian.  
**Occurrence:** Very rare to common.

**Gyroidinoides sp. 7**  
(Pl. 23, Figs 15-16)

**Diagnosis:** A very prominent mound to slightly raised inner spire sitting on a concave final whorl and a lobate to wavy periphery is characteristic of this species.  
**Range:** Upper Albian to Cenomanian.  
**Occurrence:** Very rare to frequent.
**Gyroidinoides** sp. 8  
(Pl. 23, Figs 17-18; Pl. 24, Fig. 1)

**Diagnosis:** The specimens are characterised by an oval shape; 3 to $3^{1/2}$ coils with chambers increasing slowly in the first two whorls and moderately fast in the remaining part of the test.

**Remarks:** Some specimens with a very prominent and protruding mound which can be confused for *Gyroidinoides* sp. 2 and *Gyroidinoides* sp. 3, but on wetting the specimens the evolute nature of the species shows clearly.

**Range:** Upper Albian to Middle Turonian.

**Occurrence:** Very rare to common.

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**Gyroidinoides** sp. 9  
(Pl. 24, Figs 2-4)

**Diagnosis:** A very globular, asymmetrical biconvex test; the spire sitting like a tiny knob in the concave final whorl; $1^{1/2}$ to (?) 2 whorls; 6 to 7-8 chambers in the final whorl and suture perpendicular to gently curved.

**Remarks:** It appears to be a transitional form between *Gyroidinoides* sp. 1 and *Gyroidinoides* sp. 2.

**Range:** Upper Albian to Lower Turonian.

**Occurrence:** Rare to common.

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Subfamily **GAVELINELLINAE** Hofker, 1956

Genus **GAVELINELLA** Broten, 1942

Type species: *Discorbina pertusa* Marsson, 1878
**Gavelinella baltica** Brotzen

*(Pl. 24, Figs 6-8)*

Gavelinella baltica Brotzen, 1942, p. 52, pl. 1, fig. 7 *(fide* Hart 1970).


**Description:** An asymmetrical biconvex to weakly plano-convex, low trochospire test with a convex spiral side and a flat to gently convex umbilical sides; 2 to 2½ whorls; outline round and becoming lobate in final part of the test. Spiral side with 10 to 12 chambers, increasing slowly with final 3-4 chambers expanding more rapidly giving a lobate periphery; sutures deep and curved. Periphery subacute to narrowly round; aperture an interiomarginal slit, extending from the periphery to the umbilicus.

**Remarks:** *G. baltica* differs from a closely resembling *G. intermedia* (Berthelin) in having a rapidly expanding final 3-4 chambers which gives it a lobate periphery.

**Range:** Upper Albian to lower Turonian.

**Occurrence:** Very rare to very abundant.

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**Gavelinella berthelini** (Keller)

*(Pl. 24, Figs 11-13)*


Gavelinella berthelini (Keller). Gawor-Biedowa, 1972, pp. 118-120, pl. 16, fig. 1a-c, text-fig. 11.

Gavelinella berthelini (Keller). Hart & Swiecicki, 1988, fig. 2.

**Description:** The specimens are characterised by an asymmetrical biconvex to plano-convex trochospire with 1½ to 2 whorls; a narrowly round to bluntly acute periphery; outline round to slightly wavy because of the inflation of chambers in final
part of the test. Spiral side convex with a prominent umbilical boss concealing much of the test, umbilical side flat to less convex. Aperture and interiomarginal arch, extending to the ventral side; 9 to 11 chambers increasing slowly with the final 2-3 moderately fast.

**Remarks:** An umbilical boss on the spiral side is very distinctive to *G. berthelini*. A variation in size of the test and umbilical boss is observed.

**Range:** Upper Albian to Middle Turonian.

**Occurrence:** Very rare to abundant.

**Gavelinella cenomanica** (Brotzen)

(Pl. 24, Figs 5, 9)

*Cibicidoides (Cibicides) cenomanica* Brotzen, 1942, p. 54, pl. 2 (*fide* Hart 1970).

**Diagnosis:** Umbilicus marked by a beaded calcite rim with a central depression is diagnostic of this species. A low trochospire; 9-11 chambers, increasing slowly; outline round; periphery narrowly round; sutures deep and curved.

**Range:** Upper Albian.

**Occurrence:** Rare.

**Gavelinella intermedia** (Berthelin)

(Pl. 24, Figs 15-17)

*Anomalina intermedia* Berthelin, 1880, p. 67, pl. 4, fig. 14a-b (*fide* Hart 1970).
Remarks: Similar to *G. baltica* from which it differs in a slowly increasing chambers (in the final whorl) throughout and a round outline. Presence of an umbilical boss (on the spiral side) in *G. intermedia* is a debated issue (Hart pers. comm.)

Range: Upper Albian to Middle Turonian.

Occurrence: Very rare to very abundant.

**Gavelinella reussi** (Khan)

(Pl. 24, Figs 10, 14, 18)

Rosalina complanata Reuss var. Reuss, 1863, p. 86, pl. 11, fig. 3a-c.

Anomalina complanata (Reuss), Berthelin, 1880, p. 66, pl. 4, figs 12-13.

Anomalina complanata (Reuss), Chapman, 1898, pp. 3-4, pl. 1, fig. 4a-c.

Anomalina ammonoides (Reuss), Chapman, 1898, pp. 4-5, pl. 1, fig. 5a-c.

**not** Anomalina berthelini Keller, 1935, p. 552, pl. 2, figs 25, 27.

Anomalina berthelini ten Dam (nom. nov. for *A. complanata* Berthelin, non Reuss), 1944, p. 105.


Gavelinella berthelini (Keller)-*G. plummerae* (Tappan)-*G. reussi* (Khan)

plexus Koutsoukos. Koutsoukos 1989, pp. 188-190, pl. 18, figs 29-32 (not figs 27-28), not pl. 19, figs 1-4.

Description: A symmetrical to gently asymmetrical biconvex, low trochospire with spiral side being slightly more convex in few cases; a narrowly round periphery. Spiral side with a tiny umbilical boss in a central depression, followed by rapidly increasing 7 to 8 inflated, trapezoidal chambers; sutures depressed, gently curved to oblique sometimes becoming radial. A lobate outline; aperture interiomarginal slit.

Remarks: *G. reussi* has a very chequered nomenclatural history. Hart (1970,
pp. 213-214) has given a comprehensive account of the various attempts, made in past, to address the problem. Here the previous work of Hart (1970), including the more recent discussions (Hart pers. comm.) and author’s own observations are presented.

The species, *G. reussi* (as accepted in the present study), was first described by Reuss (1863) as "*R. complanata var.*". Berthelin (1880) reported the specimens in the Gault Clay of France (Albian) as *A. complanata* Reuss 1851. *A. complanata* is, however, a Senonian species; quite distinct from "*R. complanata var.*" of Reuss (1863). Chapman (1898) while upholding Berthelin’s description for *A. complanata* figured yet another form. Later, Keller (1935) observed that Berthelin’s (1880) specimens (described as *A. complanata* Reuss) were not the same as those originally described as *A. complanata* by Reuss (1851). Keller (1935) therefore proposed a new name, *A. berthelini*, for Berthelin’s specimens (described from the Gault Clay of France (Albian), Berthelin 1880). The holotype selected for *A. berthelini*, however, came from the Cenomanian (and not Albian), and while it is superficially similar, is in fact a later development of the same lineage. *A. berthelini* Keller cannot therefore be applied to the Albian forms with certainty. Parallel to this, ten Dam (1944) recognising the initial nomenclatural mistakes proposed a new name, *A. berthelini*, unaware of Keller’s (1935) work. This failed to resolve the confusion as *A. berthelini* (proposed by ten Dam 1944) was an objective homonym of Keller’s species.

Unaware of both Keller’s (1935) and ten Dam’s (1944) works, Khan (1950) attempted to address the same problem (i.e. Chapman’s figures for *A. complanata* did not resemble those of Reuss in 1851 and a new name was needed). Khan (1950) proposed a new variety- *A. complanata* var. *reussi*, selecting a holotype from his material from the Gault Clay of Folkestone (SE England). Later these were found to be the juvenile specimens of the form wrongly identified by Chapman and Khan as *R. ammonoides* Reuss (*A. ammonoides* (Reuss)) and identical with Berthelin’s *A. complanata* Reuss (= ten Dam’s invalid *A. berthelini*). Hart (1970, p. 214) argued that immaturity (juvenility) of specimens is not a rationale for invalidating the nomenclature (Khan’s
new variety- \textit{A. complanata} var. \textit{reussi}), and since it is a distinct species Khan’s work should be upheld.

Later, Malapris (1965) proposed that in the middle Albian \textit{A. complanata} Reuss (described by Berthelin) and \textit{A. intermedia} Berthelin are variants of a single species. Since \textit{A. complanata} was not a valid name, Malapris (1956) placed all these forms in \textit{A. intermedia} and erected a new subgenus, \textit{Berthelina}, under the genus \textit{Gavelinella}. Koutsoukos (1989, pp. 188-190) giving a comprehensive account of \textit{G. berthelini-G. plummerae} (Tappan)-\textit{G. reussi} and stating that the three species are morphological variants has put them under \textit{G. plexus} Koutsoukos (Koutsoukos 1989). In this study \textit{G. reussi} is recognised as a separate species. It must be noted, however, that if Malapris (1956) is correct (as commented by Hart 1970, p. 215) then \textit{G. reussi} (Khan) should be downgraded to a variety of \textit{G. intermedia}.

A very modest umbilical boss (just a tiny knob) which does not stand out in its lateral view, fewer number of chambers and a lobate outline are characteristic of the specimens reported as \textit{G. reussi} in the present study. The profile of \textit{G. reussi-G. rudis} (Reuss)-\textit{G. berthelini-G. tourainensis} Butt group is, however, a contentious issue (Hart \textit{pers. comm.} 1996). Forms ranging from having a tiny calcite rim to a very modest umbilical boss (as observed in the present study) to a more prominent boss developing into a total boss and finally forming a robust boss reflect the \textit{reussi-rudis-berthelini-tourainensis} gavelinellid lineage.

\textbf{Range}: Upper Albian to Middle Turonian.

\textbf{Occurrence}: Very rare to rare.

\textit{Gavelinella rudis} (Reuss)

(Pl. 25, Figs 1-5)

\textit{Anomalina rudis} Reuss, 1863, p. 87, pl. 11, fig. 7.
\textit{Gavelinella rudis} Reuss, Neagu, 1965, p. 32, pl. 8, fig. 8.

**Description:** A very globular but a flat biconvex (umbilical side is slightly convex in some of the specimens), (?) planispiral to low trochospiral test with 2 to 2\(\frac{1}{2}\) whorls and a broadly round periphery. Spiral side evolute to partially involute, some specimens with a calcite boss concealing the spire; umbilical side involute; 8 to 10 inflated chambers in the final whorl, increasing slowly, final 3 to 4 chambers expand rapidly. Sutures deep, oblique, slightly curved to radial; aperture interiomarginal arch; outline lobate to semi-lobate, rarely round; umbilicus deep. An inflated-sub-globular test and rapidly expanding final chambers are characteristic of *G. rudis*.

**Remarks:** *G. rudis* although showing close similarity to *G. baltica* and to a lesser extent to *G. intermedia* is morphologically different. It appears to be an intermediate form between *G. intermedia* and *G. baltica*.

**Range:** Upper Albian to Middle Turonian.

**Occurrence:** Very rare to very abundant.

**Gavelinella schloenbachi** (Reuss)

(Pl. 25, Figs 6-10)

*Rotalina schloenbachi* Reuss, 1862, p. 84, pl. 10, fig. 5a-c.

**Gavelinella schloenbachi** (Reuss). Gawor-Biedowa, 1972, pp. 129-131, pl. 16, fig. 2a-c.

**Description:** A low-moderately low to moderate-moderately high trochospire, 2\(\frac{1}{2}\) to (?) 3 whorls, concavo-convex to asymmetrical biconvex test, acute periphery. A variation in test shape and chambers observed. Spiral side is always more convex; umbilical side concave to gently convex, inflation of chambers tend to reduce the concave effect of the test. Spiral side evolute; specimens with inner whorls sitting like a tiny mound on the very flat final whorl; in the other case there is a gradual but steady rise in the spire height; both types result in a final mound shaped test. Spiral side with 9
to 10, crescentic to semi-circular, flat to concave chambers, increasing slowly; chambers do not stack to form an imbricated pattern but spread out like a Japanese fan; sutures deep and strongly arched to curved. Umbilical side involute, 8 to 9 crescentic-shaped chambers, final chambers becoming triangular and inflated; sutures deep and fairly strongly curved. Aperture interio-marginal slit extending from the umbilicus to the periphery, bordered by a thin lip; umbilicus deep; outline lobate to wavy.

Remarks: It appears that the generic and specific status of *G. schloenbachi* has been greatly confused with *Osangularia schloenbachi*. Crittenden (1988, pp. 366-385) has made a remarkable effort to solve this problem. He pointed out that the same species has been reported as *Osangularia/Planularia/Discorbis/Eponoides* and that there has been misconceptions regarding its stratigraphic range and geographical distribution. He compared these different species and concluded that the same species has been described under different names and that *O. schloenbachi* (Reuss), ranging latest Aptian-early Albian to earliest Cenomanian, should be the accepted name. This includes *Eponoides utaturensis* (Sastri & Sastry 1966) reported from the upper Albian of Uttatur Formation, Trichinopoly District, SE India. In this process, Crittenden came across Gawor-Biedowa's material, reported as *G. schloenbachi* (Reuss) (Gawor-Biedowa 1972) from the late Albian to lowermost Turonian of Poland. Crittenden observed that although Gawor-Biedowa's material showed remarkable similarities in morphological appearance to *O. schloenbachi* it is actually morphologically and stratigraphically different from all the other synonymous species. Crittenden (1988) finally came to the conclusion that if *Rotalia schloenbachi* sensu Reuss 1862 is actually a *Gavelinella* then Gawor-Biedowa is correct, and in that case a new name needs to been given to the species he describes as *O. schloenbachi*. Edwards (1981) argues that the species originally described by Reuss (1862) from the Albian is a *Gavelinella* and that in the Senonian several stratigraphically significant lineages arose from a *Gavelinella schloenbachi* (Reuss) ancestor.

The specimens reported under *G. schloenbachi* in this study match with
Gawor-Biedowa's (1972) material and not *O. schloenbachi* as reported by Crittenden (1988). The specimens do not have a biumbonate test, raised spiral and umbilical sutures and an *Osangularia* aperture, characteristic of *O. schloenbachi* as described by Crittenden (1988).

**Range:** Upper Albian to Middle Cenomanian.

**Occurrence:** Very rare to abundant.

**Gavelinella tourainensis** Butt

(Pl. 25, Figs 11-13)

_Gavelinopsis tourainensis_ Butt, 1966, p. 176, pl. 4, figs 1-3.

**Description:** A trochospiral, strongly plano-convex test with spiral side convex and umbilical side flat. Spiral side evolute, 3 whorls (visible in few specimens and only on wetting the specimen), a very prominent, raised, central boss sitting like a mound on the nearly flat final whorl; final whorl with about (?) 10-11 chambers (in majority of the specimens only final 4 to 5 chambers visible on wetting the specimen); sutures depressed and gently curved to oblique. Umbilical side with about 10 chambers, increasing moderately; sutures limbate in early part, deep and curved in later part; a tiny calcite knob with tiny calcite lobes at sutural ends in early part. Aperture interiomarginal slit; axial periphery bluntly acute; equatorial periphery round becoming wavy in final 4 to 5 chambers.

**Range:** Middle Cenomanian to Middle Turonian.

**Occurrence:** Very rare to abundant.
Gavelinella sp. 1  
(Pl. 25, Fig. 14)

**Description:** A symmetrical biconvex, low to moderate trochospire test, with a sub-acute periphery; 12 to 14 chambers in the final whorl, increasing slowly, final 3 to 4 chambers inflated and expand rapidly giving a lobate outline. A modest calcite boss in a depression in the spiral side and a calcite hook in the umbilical side; sutures very gently curved and flush in early part, becoming radial and deep later; outline round becoming lobate in the final 3 to 4 chambers; aperture an interiomarginal slit with a thin lip.

**Remarks:** The specimens resemble *G. baltica* in having a rapidly expanding final 3 to 4 chambers and *G. berthelini* in having a calcite boss (although less prominent). It differs in having a much younger stratigraphic range.

**Range:** Campanian.

**Occurrence:** Very rare.

Gavelinella sp. 2  
(Pl. 25, Figs 15-16)

**Description:** An asymmetrical, plano-convex to concavo-convex (umbilical side plane to concave), low trochospire test. Spiral side involute, umbilical side less evolute to involute; a tiny calcite boss on the spiral side; about 10 to 13 chambers in the final whorl, increasing slowly; sutures flush to raised, gently curved to straight. Aperture (?) appears to be a tiny interiomarginal arch; outline round; lateral periphery narrowly round to sub-acute.

**Range:** Campanian.

**Occurrence:** Very rare.
**Gavelinella sp. 3**  
(Pl. 25, Figs 17-18)

**Description:** Variation in the convexity of test is observed. Strongly asymmetrical tests with acute periphery, spiral side strongly convex (the calcite boss enhances the convexity) and a flat to weakly concave umbilical side. Less common are weakly asymmetrical biconvex tests with the spiral side more convex than the umbilical side and a narrowly round periphery. A prominent calcite boss (spiral side), concealing the spire is characteristic of this species. Outline round; (?) a tiny calcite knob or node in the umbilicus.

**Remarks:** The species closely resembles *G. berthelini* from which it differs in stratigraphic range.

**Range:** Campanian.

**Occurrence:** Rare.

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**Gavelinella sp. 4**  
(Pl. 26, Fig. 1)

**Remarks:** The specimens are poorly preserved. An asymmetrical plano-convex test, spiral side strongly convex; sharply acute periphery; outline circular. Only final 3 to 4 chambers visible (on wetting the specimens); sutures flush, oblique to gently curved.

**Range:** Campanian.

**Occurrence:** Rare.

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**Gavelinella sp. 5**  
(Pl. 26, Figs 2-3)

**Description:** A flat trochospiral to nearly planispiral test with $2^{1/2}$ to (?) 3 coils; periphery narrowly round; outline oval to nearly pentagonal shaped. Final whorl with
4 1/2 to 5 inflated chambers, increasing slowly; final chamber more or less elongate and tubular, adding rapidly; sutures deep, straight and oblique to very gently curved.

Range: Upper Albian.

Occurrence: Very rare to rare.

\textbf{Gavelinella sp. 6}

(Pl. 26, Fig. 4)

\textbf{Description}: An ovate, flat, laterally compressed, trochospiral test with a prominent calcite boss on the spiral side and a broad, bluntly acute periphery; 8 to 9 flat, strongly arched chambers; sutures depressed and strongly curved; aperture interiomarginal slit and (?) extends on the spiral side.

Range: Upper Albian and Upper Cenomanian to Lower Turonian.

Occurrence: Very rare.

Genus \textit{LINGULOGAVELINELLA} Malapris, 1965

Type species: \textit{Lingulogavelinella albiensis} Malapris, 1965

\textbf{Remarks}: \textit{Lingulogavelinella} morphotypes are characterised by a low trochospire test; ventral side concave, flat or gently convex, with a closed umbilicus and tongue like extensions of the chamber walls forming a stellate umbilical pattern. Aperture an interiomarginal equatorial arch, extending from the periphery to the umbilicus.

(Loeblich & Tappan, 1988, p. 641).

\textit{Lingulogavelinella albiensis} Malapris

(Pl. 26, Figs 5-6)

\textit{Lingulogavelinella albiensis} Malapris, 1965, p. 140, pl. 4, figs 5-8.

**Descriptions:** An involute, asymmetrical plano-convex, low trochospire with dorsal side gently concave to flat and ventral side conical convex; narrowly round periphery. Aperture interiomarginal arch; 6 to 7 gently inflated chambers, increasing slowly, final 2 to 3 chambers expand rapidly; a star shaped umbilical pattern on the dorsal side; outline round becoming lobate in final chambers.

**Range:** Upper Albian and Upper Cenomanian.

**Occurrence:** Very rare to rare.

**Lingulogavelinella globosa** (Brotzen)

(Pl. 26, Figs 7-9)

Anomalinoides globosa Brotzen, 1945, p. 49, pl. 2, fig. 6a-c (fide Carter & Hart 1977).

Orostella turonica Butt, 1966, p. 180, pl. 3, fig. 6 and pl. 4, fig. 4.


Lingulogavelinella asterigerinoides (Plummer) sub sp. turonica Butt. Narayanan & Scheibnerova, 1975, pp. 28-29, pl. 1, figs 1-5; pl. 2, figs 1-7.


Lingulogavelinella globosa (Brotzen). Hart et al., 1989, p. 350, pl. 7.18, figs 8-10.

**Description:** A low trochospire to a (?) nearly planispiral, globular to sub-globular test; periphery broadly round; outline round to semi-lobate; aperture a small interiomarginal arch, extending to the periphery on the dorsal side. Spiral side involute; 6 to 7 inflated to sub-globular chambers, increasing slowly, final 2 to 3 chambers increase more rapidly; relict aperture on the spiral side forms a star shape pattern; sutures deep and curved, becoming radial. Umbilical side less involute to slightly evolute; 6 to 7 inflated chambers; sutures deep, radial to gently curved; umbilicus deep.

**Range:** Upper Cenomanian to lower Turonian.
**Occurrence:** Rare to abundant.

**Lingulogavelinella jarzevae** (Vasilenko)

(Pl. 26, Figs 10-12)


*Cibicides* (*Cibicides*) *jarzevae* Vasilenko, 1954, p. 121, pl. 17, fig. 3 (fide Carter & Hart 1977).


**Diagnosis:** A plano-convex test with dorsal side flat and with a stellate pattern made from fusion of relict apertures; ventral side conical convex; periphery bluntly acute. Umbilical side with $5\frac{1}{2}$ triangular, elevated and moderately increasing chambers; sutures deep and radial.

**Range:** Upper Albian.

**Occurrence:** Very rare.

**Genus ORITHOSTELLA** Eicher & Worstell, 1970

Type species: *Orithostella viriola* Eicher & Worstell, 1970

**Remarks:** The genus *Orithostella* is very similar to *Lingulogavelinella* from which it differs in having imperforate flaps forming a stellate pattern on the dorsal side.
Orithostella indica Scheibnerova

(Pl. 26, Figs 14-16)

Orithostella indica Scheibnerova, 1974, p. 715, pl. 7, figs 4, 8-13, pl. 8, figs 1-9, pl. 11, fig. 9.

Orithostella indica Scheibnerova. Narayanan & Scheibnerova, 1975, pl. 1, fig. 5.

Orithostella indica Scheibnerova sub sp. marksi Narayanan & Scheibnerova, 1975, pl. 1, figs 6-8; pl. 2, figs 8-13.

Description: An involute; low trochospire; asymmetrical biconvex to plano-convex test, spiral side flat to less convex. Sutures deep, curved to strongly curved; 9 to (?)10 inflated chambers, increasing rapidly; the dorsal side with tongue like extensions forming a stellate pattern with a central calcite loop or hook; outline wavy; periphery bluntly acute to narrowly round; aperture interiomarginal arch, extending to the dorsal side.

Remarks: Narayanan & Scheibnerova (1975) identify a late Cenomanian O. indica sub sp. marksi from the Uttatur Group, Trichinopoly District, SE India. They differentiate the sub sp. marksi from the late Albian species O. indica in having a more inflated and a much larger, approximately twice, test. This difference is not observed and the O. indica population, in this study, includes both large and small sized tests and less to more inflated tests from the Albian to Cenomanian.

Range: Upper Albian to Lower Turonian.

Occurrence: Common to very abundant.

Orithostella viriola Eicher & Worstell

(Pl. 26, Figs 13, 17)

Orithostella viriola Eicher & Worstell, 1970, p. 294, pl. 6, figs 6-8, 10.
**Diagnosis:** A low trochospire; $1^{1/2}$ to (?)2 whorls; asymmetrical plano-convex test with dorsal side flat and ventral side conical convex; periphery bluntly acute to narrowly round. Aperture interiomarginal, peripheral arch; relict apertures forming a stellate pattern on the dorsal side; 9 to (?)10 flat chambers, increasing slowly; sutures depressed and curved.

**Range:** Upper Albian.

**Occurrence:** Very rare.

Superfamily **ORBITOIDACEA** Schwager, 1876  
Family **LEPIDORBITOIDIDAE** Vaughan, 1933  
Subfamily **LEPIDORBITOIDINAE** Vaughan, 1933  
Genus **LEPIDORBITOIDES** Silvestri, 1907  
Type species: **Orbitoides socialis** Leymerie, 1851

**Lepidorbitoides** sp. cf. **L. socialis** Leymerie  
(Pl. 27, Figs 1-4)

**Orbitolites socialis** Leymerie, 1851, p. 191 (fide Vredenburg 1908, p. 202).  
**Orbitoides socialis** Schlumberger, 1902, p. 258, pl. VI, figs 3, 6-7; pl. VIII, figs 15-16 (fide Vredenburg 1908, p. 202).  
**Orbitoides (Lepidocylinia) ? socialis** Leymerie. Vredenburg 1908, pp. 203-204, pl. XXVII, figs 1-2.  
**Lepidorbitoides socialis** (Leymerie). Ellis & Messina, 1967, figs 1-43.  
**Lepidorbitoides socialis** Leymerie. Loeblich & Tappan, 1988, p. 651, pl. 742, figs 1-6.

**Remarks:** The study of larger foraminifera, occurring in the Campanian-Maastrichtian successions in India, has been neglected. Until now, no systematic approach to study these foraminifera has been taken. It is not the scope of the present research to study these larger foraminifera in detail, but it is acknowledged that the problem needs to be
addressed. As mentioned earlier (see Section 1.3.2.(ii) in Chapter 1), the identification of foraminifera in thin section is a specialised and an independent branch of micropalaeontology. In the present study, as a non-specialist in thin section foraminiferal study, only limited observations were possible.

In the larger foraminifera the character of equatorial layers is considered most diagnostic in classification. This is because it records more or less clearly the progressive range from primary planispiral (or trochospiral) growth to annular or concentric growth. The study requires a detailed analysis of several equatorial and transverse sections of the foraminifera, a procedure not adopted in this project. In the present study the identifications are based, primarily, on the comparison of thin section material with the published literature (Vredenburg 1908, Ellis & Messina 1967, Ravindran 1980, Haynes 1981, Loeblich & Tappan 1988, Sartorio & Venturini 1988, Caus et al. 1996, Hart pers. comm.).

The unique feature of the Campanian-Maastrichtian succession in the Cauvery Basin is the absence of Omphalocylus Bronn, a Maastrichtian larger foraminifera. In European and Middle Eastern Maastrichtian rocks, the Lepidorbitoides and Orbitoides d’Orbigny are usually associated with Omphalocylus (M.B. Hart pers. comm.). Vredenburg (1908), however, reports the occurrence of Omphalocylus in association with Orbitoides from the uppermost Cretaceous succession of North India.

**Diagnosis:** A large, flattened spheroid- “flying saucer” shaped to flattened lenticular test, surface covered with solid pustules or knobs. In thin section the embryonic group consists of two chambers. A circular protoconch enclosing a semi-lunar to reniform deuteroconch. In the paucity of good equatorial and axial sections it is difficult to determine the relative sizes of the protoconch and deuteroconch. This bilocular embryonic architecture is characteristic of L. socialis (see Ellis & Messina 1967, figs 9, 26-28, 31, 37, 41, 44-45; Loeblich & Tappan 1988, pl. 742, figs 1, 6).

**Range:** Upper Campanian to lower Maastrichtian.

**Occurrence:** Abundant.
Superfamily ROTALIACEA Ehrenberg, 1839
Family CALCARINIDAE Schwager, 1876
Genus SIDEROLITES Lamarck, 1801
Type species: Siderolites calcitrapoides Lamarck, 1801

Siderolites calcitrapoides Lamarck
(Pl. 27, Figs 5-9)

Siderolites calcitrapoides Lamarck, 1801, p. 376 (fide Loeblich & Tappan, 1988, p. 672).
Siderolites spp. Lamarck. Ravindran, 1980, pi. 17, fig. 3.
Siderolites calcitrapoides Lamarck. Loeblich & Tappan, 1988, p. 672, pl. 783, figs 1-8.

Remarks: As discussed above.

Diagnosis: A large, calcareous, lenticular test with solid pustules or knobs; 4 to 6 large, coarse spines arising near the proloculus in the plane of coiling; canal system consists of spiral canals in the umbilical region connecting to lateral intraseptal canals and a marginal canal from which arise bundles of ramifying spine canals.

Range: Upper Campanian to lower Maastrichtian.

Occurrence: Common to frequent.
Chapter 5

The mid-Cretaceous microbiostatigraphy
in the Cauvery Basin
Biostratigraphy is the use of fossil content and its distribution in a rock unit, to organise and correlate the strata into biostratigraphical units. The fundamental unit in a biostratigraphic classification is a “biozone”. The established practice of referring to the biostratigraphic unit as “zone” should be replaced for the more precise term “biozone” (Holland et al. 1978). Biozones are of different types, many of which are based on the stratigraphic range of the index taxon (usually species) (Hedberg 1976, Holland et al. 1978, Robaszynski & Caron 1979, Whittaker et al. 1992). In practice, disappearances are difficult to establish and extinction levels should be used only when well defined. A good stratigraphical practice is, therefore, to define the base of a biozone on the first appearance of a new taxon, allowing the top of the biozone to be fixed by the base of the succeeding biozone (Whittaker et al. 1992, p. 816); except where the biozone is defined by the total range of the diagnostic species. By contrast, in oil industry the extinction level of a species is used to define the upper limit of a biozone. This is because of caving and sample mixing, which commonly occurs in well-cutting samples, that only the last appearances (extinction levels) of species have biostratigraphic significance. In well-section studies the biozones are therefore defined by the last appearance (highest occurrence) of the diagnostic species.

India was joined with Australia and Antarctica until the late Jurassic-early Cretaceous. Rifting between East Gondwanaland continents (Australia, Antarctica and India) in the late Jurassic-early Cretaceous initiated the opening of the Indian Ocean (see Chapter 2). After the initial lacustrine to marginal marine conditions, during the (?) Aptian-earliest Albian, full marine conditions were established by the Albian, during which the Karai Clay Formation was deposited in the Cauvery Basin (see Chapter 3). Karai Formation is a dominantly argillaceous unit comprising of dirty brown to rust yellow clays, silty clays, sandy clays, dark to light grey and black shales; glauconitic- and organic-rich in places. This interval marks the first appearance of foraminifera in the Basin. Throughout the succession the fauna is influenced by
sea-level changes. The so-called mid-Cretaceous oceanic anoxic events (Schlanger & Jenkyns 1976) had a significant affect on the foraminiferal population (see Chapter 6). In addition, palaeogeographic changes, e.g., break-up of East Gondwanaland, northward shift of India, opening of the Indian Ocean and closure of the Tethys, etc., influenced the faunal assemblage. Movement of India from its position in the Austral biogeoprovince (in the early Cretaceous) to its more northerly position (close to the Tethyan biogeoprovince) during the late Cretaceous influenced the appearance, diversification and speciation of the foraminiferal population.

The proposed microfossil zonation schemes are based on composite study of the microfauna from three wells-Karai-3, Karai-4, Karai-6 (between Karai and Kulakkalnattam villages) and from the Karai-Kulakkalnattam traverse (Fig. 5.1). The proposed schemes (Table 5.1) are based on outcrop study and are primarily defined for regional application. The Tables (Tables 5.1 to 5.4) used in this Chapter are enclosed at the end of the Chapter. A correlation between the proposed planktonic foraminiferal zonal scheme with other well-established schemes (Table 5.2) shows close analogies. The range charts (Tables 5.3 & 5.4) present the stratigraphic distribution and relative abundance of foraminifera as observed in these sections.

5.2 Proposed planktonic foraminiferal biozonal scheme

The early mid-Cretaceous succession in the Cauvery Basin (on-shore) is characterised by an extremely low diversity planktonic foraminiferal assemblage. The only planktonic foraminifera present is the long-ranging Hedbergella planispira (Tappan), which represents 99% of the planktonic fauna, and is, therefore, of little or no value. This does not allow a planktonic foraminiferal biostratigraphic zonation, correlatable on a regional and an international scale, until the late Albian. From the post early-late Albian, when Rotalipora subticinensis (Gandolfi) first appears, a planktonic biozonal scheme is possible. Previous workers, e.g., Banerji & Mohan 1970, Banerji 1973, Narayanan 1973, Venkatachalapathy & Ragothaman 1995, Govindan et al. 1996 etc.,
Figure 5.1: Geological map of the Karai-Kulakkalnattam area showing the positions of the Karai-3, Karai-4 and Karai-6 wells (after Ramanathan & Rao 1982).
recognise a *H. planispira* biozone during the early to earliest late Albian. It must be noted, however, that these workers have used the absence of any other planktonic foraminifera during the early to earliest late Albian interval, as to the presence of *H. planispira* as a diagnostic species, to define the *H. planispira* biozone in the Basin. The top of the succession is cut by a sudden regression (see Chapters 3 & 7), bringing an abrupt, but forced disappearance of the planktonic foraminifera. In a more recent publication Govindan et al. (1996), using borehole data (surface and subsurface), establish a complete planktonic foraminiferal biozonation for the Cretaceous succession (from Albian to Maastrichtian) in the Cauvery Basin.

In this study the mid-Cretaceous planktonic foraminiferal biozonation schemes established by Robaszynski & Caron (1979), Wonders (1980) and Caron (1985) are followed, but with due caution. Not all biozones defined by these workers are represented in the area. The biostratigraphic units defined in the proposed scheme are for the most part Interval Range Biozones (IRBs). Four IRBs (with two sub-biozones), one Concurrent Range Biozone (CRB) and one Partial Range Biozone (PRB) are established for the mid-Cretaceous Karai Formation in the Cauvery Basin. The lower limit of an IRB (this study) is defined by the first appearance of the characteristic species, after which the biozone is named. Its upper limit is marked by the first appearance of the next succeeding species, characteristic of the following IRB. A Concurrent Range Biozone (CRB) is established by the concurrent occurrence (overlapping ranges) of several taxa. A Partial Range Biozone (PRB) is defined within the stratigraphic range of a particular taxon, above the last appearance of the preceding taxon and below the first appearance of the next succeeding taxon.

5.2.1 Definition of the biozones

**Rotalipora subticinensis** Biozone

*Category:* Interval Range Biozone.
**Lower limit:** First appearance of *R. subticinensis*.

**Upper limit:** First appearance of *R. appenninica* (Renz).

**Diagnostic feature/s:** Absence of any other *Rotalipora* species is characteristic of the Biozone.

**Age:** Earliest late Albian.

**Reference section/s:** Karai-Kulakkalnattam traverse.

**Associated microfauna:** *Globigerinelloides* sp. 1, *Hedbergella delrioensis* (Carsey), *H. planispira* and *H. simplex* (Morrow).

*R. subticinensis* is very rare. The Biozone contains a well preserved but a very low-diversity planktonic assemblage, dominated by tiny *H. planispira* constituting 99% of the planktonic fauna. Throughout this Biozone the planktonic fauna comprises about 25 to 30% of the foraminiferal population.

**Remarks:** Robaszynski & Caron (1979) established a *R. subticinensis-ticinensis* (Gandolfi) IZ in the late Albian. Later, Wonders (1980) and Caron (1985) established a *R. subticinensis* and a *R. ticinensis* IZs, identified by the first appearances of *subticinensis* and *ticinensis* respectively. The *R. subticinensis* IZ of Wonders (1980) and Caron (1985) represents the *R. subticinensis-ticinensis* IZ of Robaszynski & Caron (1979).

In this study *R. subticinensis* and *R. ticinensis* do not occur together in any of the studied samples. *R. subticinensis* disappears after which *R. appenninica* makes its first appearance followed shortly by *R. ticinensis* in the *R. appenninica-Planomalina buxtorfi* (Gandolfi)-*R. ticinensis* CRB (this study). This allows the recognition of a *R. subticinensis* IRB in the Cauvery Basin. *R. subticinensis* IRB (this study) represents the *R. subticinensis-ticinensis* IZ of Robaszynski & Caron (1979) and *R. subticinensis* IZ of Wonders (1980) and Caron (1985).

**R. appenninica-Pl. buxtorfi-R. ticinensis** Biozone

**Category:** Concurrent Range Biozone.
Lower limit: First appearance of *R. appenninica*.

Upper limit: First appearance of *R. brotzeni* (Sigal).

Diagnostic feature/s: The first appearance of *Pl. buxtorfi* coincides or is shortly after the first appearance of *appenninica* and is therefore significant in identifying the lower boundary of the Biozone. *R. ticinensis* makes its first appearance in this Biozone. Concurrent occurrence of *R. appenninica*, *Pl. buxtorfi* and *R. ticinensis* is characteristic of the Biozone.

Age: Late Albian.

Reference section/s: Karai-4 and Karai-Kulakkalnattam traverse.


Beautifully preserved and well developed *Pl. buxtorfi* and *R. appenninica* constitute the bulk (approximately 93 percent) in the *appenninica-buxtorfi-ticinensis* count. Overall the Biozone is characterised by a well preserved, low-diversity planktonic fauna (comprising 35-40% of the foraminiferal population) dominated by *H. planispira* (85%) and *H. aff. globigerinelloides* (10%).

Remarks: Various workers, through time, have used different combinations of *appenninica*, *buxtorfi* and *ticinensis* to establish biostratigraphic zones in the late Albian (Table 5.2). These schemes differ slightly from one another, e.g., the late Albian *Pl. praebuxtorfi* Wonders, *ticinensis-buxtorfi* and *appenninica-buxtorfi* Interval Zones of Wonders (1980) are identified as *appenninica* Interval Zone by Caron (1985) and Sliter (1989). *Pl. buxtorfi* has been described from the Gault Clay of Folkestone, immediately below the base of the Glaucocitic Marl, the lithostratigraphical base of the Cenomanian in SE England. This occurrence of *Pl. buxtorfi* is coincident with a flood of *Globigerinelloides bentonensis* (Morrow), which is used as the Albian-Cenomanian boundary marker in the North Sea Basin (Birkelund et al. 1984, Hart et al. 1989).

Magniez-Jannin (1981) reporting rare occurrence of *buxtorfi* with *appenninica* in the latest Albian from the uppermost Gault Clay succession from Abbotscliff, SE England established a *Pl. buxtorfi* Zone. Hart et al. (1989) observed that the occurrence of
Pelagia buxtorfi in the chalk succession (at Folkestone, SE England) is very restricted and does not fulfil the criterion to establish a *Pl. buxtorfi* Zone as described by Magniez-Jannin (1981). The first appearance of *appenninica* marks the beginning of post-Albian biostratigraphic zonation in England (Hart et al. 1989). Narayanan in 1977 (followed by Venkatachalapathy & Ragothaman 1995) identified a *Pl. buxtorfi* Total Range Zone (TRZ), of late Albian age, in the Uttatur Group (Karai Clay Formation this study) of the Cauvery Basin, India.

In this study *appenninica* and *buxtorfi* occur in the Karai-4 well and in the Karai-Kulakkalnattam traverse while in the Karai-Kulakkalnattam traverse *appenninica* is associated with *ticinensis*. The *buxtorfi* and *ticinensis*, however, do not occur together. Since *buxtorfi* and *ticinensis* have a restricted occurrence (in terms of association), but share the common *appenninica* species, the best proposal, at this stage of work, is an *appenninica-buxtorfi-ticinensis* CRB.

**Rotalipora brotzeni Biozone**

**Category:** Interval Range Biozone.

**Lower limit:** First appearance of *R. brotzeni*.

**Upper limit:** First appearance of *R. reicheli* Momod.

**Diagnostic feature/s:** *R. gandolfii* (Luterbacher & Premoli-Silva), *R. micheli* (Sacal & Debourle) and *R. cf. montsalvensis* (Momod) make their first appearance, shortly after or with *R. brotzeni*, in the Biozone. *Pl. buxtorfi* and *R. ticinensis* are absent, having become extinct before *brotzeni* first appeared.

**Age:** Latest Albian to early Cenomanian.

**Reference section/s:** Karai-4, Karai-Kulakkalnattam traverse.

Remarks: The late Albian Breistroffer oceanic anoxic event (OAE-1c) is observed in this Biozone (see Chapter 6 for details). The anoxic event brought major morphological changes in the planktonic foraminiferal population. An impoverished, low diversity foraminiferal assemblage, comprising of juvenile and weakly ornamented planktonic foraminifera, characterise the early part of the Biozone. Towards the top of the Biozone a very slight increase in the diversity and a considerable improvement in the morphology (e.g., test size, ornamentation, etc.) and in the abundance of the planktonic foraminiferal assemblage is observed. Well developed, robust and highly ornamented species of Rotalipora and Praeglobotruncana dominate the upper part of the Biozone (see Chapter 6 for details).

A flood of G. bentonensis, which appears to occur at the same level all over south-east England (Hart et al. 1989) and coincides with the influx of G. bentonensis in the North Sea Basin, is used as an Albian-Cenomanian boundary marker over much of the North Sea Basin.

Rotalipora reicheli Biozone

Category: Interval Range Biozone.
Lower limit: First appearance of R. reicheli.
Upper limit: Last occurrence of Rotalipora species.
Age: Early to late Cenomanian (see remarks).
Reference section/s: Karai-4, Karai-6, Karai-Kulakkalattam traverse.
Remarks: In the Cauvery Basin *R. reicheli* is observed (Narayanan 1977, Govindan 1996, this study) to have a much longer time range (from the latest-early Cenomanian to the late Cenomanian). In Europe the stratigraphic ranges of *reicheli* and *cushmani* are used to define *R. reicheli* TRZ (middle Cenomanian) and *R. cushmani* TRZ (late Cenomanian) respectively (Robaszynski & Caron 1979, Caron 1985). Narayanan (1977), for the first time, observed that in the Uttatur Formation (Karai Formation this study) of the Cauvery Basin (SE, India) *R. reicheli* continued from the early Cenomanian, when it makes its first appearance to the late Cenomanian (extinction level of the *Rotalipora* species). Narayanan (1977) established a *R. reicheli* IRZ with two subzones, *R. reicheli-appenninica* subzone and *R. reicheli-cushmani* subzone in the Cauvery Basin. More recently Govindan et al. (1996) have established a *R. reicheli* TRZ in the Basin. They (Govindan et al. 1996) argue that since *R. reicheli* has an extended range in the Basin and that the *R. cushmani* is extremely rare; a *R. reicheli* TRZ is the best compromise. In the present scheme of biozonation, however, Narayanan’s work (Narayanan 1977) is upheld. The *R. reicheli-appenninica* Sub-biozone (this study) is defined by the concurrent occurrence of *reicheli* and *appenninica* and an absence of *cushmani*. The first appearance of *cushmani* defines the lower limit of *reicheli-cushmani* Sub-biozone. The *R. reicheli* IRB (this study) represents *R. reicheli* TRZ and *R. cushmani* TRZ of Robaszynski & Caron (1979).

Planktonic foraminiferal studies in the Northwest Shelf, Australia (Wonders 1992, Wright & Apthorpe 1995, Apthorpe pers. comm.) also reflect an extended time range for some of the “index” species in the eastern Indian Ocean. Wonders (1992), observing the longer time range reflected by some “index” species in the Indian Ocean, has raised the question of validity of applying classical Tethyan zonal markers in the Austral province.

*Rotalipora reicheli-appenninica* Sub-biozone

**Category:** Interval Range Sub-biozone.
**Lower limit:** First appearance of *R. reicheli*.

**Upper limit:** First appearance of *R. cushmani* (Morrow).

**Diagnostic feature/s:** The association of *R. reicheli* and *R. appenninica* together with the absence of *R. cushmani*, *R. gandolfi* and *R. greenhornensis* Morrow is characteristic of the Biozone.

**Age:** Early to middle Cenomanian.

**Reference section/s:** Karai-4, Karai-Kulakkalnattam traverse.

**Associated microfauna:** *Globigerinelloides* sp. 1, *H. delrioensis*, *H. planispira*, *P. aumalensis*, *P. stephani*, *R. appenninica*, *R. brotzi*, *R. micheli*, *R. montsalvensis*.

**Remarks:** *R. reicheli-appenninica* Sub-biozone (this study) corresponds to the *R. reicheli* TRZ of Robaszynski & Caron (1979) and Caron (1985).

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**Rotalipora reicheli-cushmani** Sub-biozone

**Category:** Interval Range Sub-biozone.

**Lower limit:** First appearance *R. cushmani*.

**Upper limit:** Last occurrence of *Rotalipora* species.

**Age:** Middle to late Cenomanian.

**Diagnostic feature/s:** *R. cushmani*, *R. deeckei*, *R. greenhornensis* and *R. reicheli* assemblage is diagnostic of the sub-biozone.

**Reference section/s:** Karai-6, Karai-Kulakkalnattam traverse.

**Associated microfauna:** *Dicarinella algeriana* (Caron), *D. imbricata* (Monrod), *P. aumalensis*, *P. stephani*, *R. appenninica*, *R. deeckei* (Franke), *R. greenhornensis*, *R. micheli* (Sacal & Debourle), *R. montsalvensis*, *R. reicheli*, *W. aprica*, *W. archaeocretacea*, *W. baltica*, *W. brittonensis*.

**Remarks:** *R. reicheli-cushmani* Sub-biozone (this study) corresponds to the *R. cushmani* TRZ of Robaszynski & Caron (1979), Wonders (1980) and Caron (1985).
Whiteinella archaeocretacea Biozone

Category: Partial Range Biozone.

Lower limit: Last occurrence of Rotalipora species.

Upper limit: First appearance of Praeglobotruncana helvetica (Bolli).

Diagnostic feature/s: Absence of Rotalipora species and P. helvetica with a high diversity planktonic foraminiferal assemblage comprising of Dicarinella, Praeglobotruncana and Whiteinella species is characteristic of the Biozone.

Age: Latest Cenomanian to earliest Turonian.

Reference section/s: Karai-3, Karai-4, Karai-6, Karai-Kulakkalnattam traverse.

Associated microfauna: D. algeriana, D. canaliculata (Reuss), D. hagni (Scheibnerova), D. imbricata, M. schneegansi (Sigal), P. aumalensis, P. gibba Klaus, P. stephani, W. aprica, W. archaeocretacea, W. baltica, W. brittonensis.

Remarks: The Biozone is characterised by major morphological changes in the planktonic foraminiferal community. Rotalipora disappears and Hedbergella are largely replaced by Whiteinella species. Amongst the keeled fauna, Dicarinella and Marginotruncana species appear. A high diversity planktonic assemblage characterised by robust and well preserved fauna is diagnostic of the Biozone. A flood of robust, highly ornamented planktonic fauna is very characteristic. The major changes in the planktonic foraminifera occurring in this Biozone is associated with the late Cenomanian-early Turonian oceanic anoxic event (see Chapter 6).

Praeglobotruncana helvetica (Bolli) Biozone

Category: Interval Range Biozone.

Lower limit: First appearance of P. helvetica.

Upper limit: The upper limit cannot be defined as the succession is cut by a sudden and sharp regression (see Chapters 3 & 7).

Age: Early to middle Turonian.

Reference section/s: Karai-3, Karai-Kulakkalnattam traverse.

The planktonic foraminiferal assemblage, comprising 60-65% of the total foraminiferal population, is dominated by large, robust and highly ornamented population. Plano-convex *helvetica* and *praehelvetica* and high trochospire *hagni*, *stephani* and *schneegansi* appear in high percentages.

**Remarks:** The typical Tethyan form of *helvetica* (with 7 chambers in the final whorl, Robaszynski & Caron 1979) do not occur in the Cauvery Basin. The *helvetica* reported from the Cauvery Basin are moderately large forms, with 4 to 4½ chambers in the final whorl. It is worth mentioning here that foraminiferal studies in SE England (Hart et al. 1989) record *helvetica* with 4 to 4½ chambers in the final whorl. The large, 6 to 7 chambered, single keeled Tethyan forms of *helvetica* are not reported in the Cretaceous succession from UK (Hart et al. 1989).

Robaszynski & Caron (1979), Wonders (1980) and Caron (1985) have used the stratigraphic range of *helvetica* to establish *P. helvetica* TRZ. The mid-Cretaceous Karai Clay Formation is cut by a sudden regression (this study, see Chapters 3 & 7), bringing a forced disappearance of planktonic foraminifera, including *helvetica*. The upper limit of the *helvetica* Biozone cannot, therefore, be defined in the Cauvery Basin (on-shore study) and *helvetica* IRB is favoured to *helvetica* TRB.

In the outcrop section (this study) the Karai Clay Formation is followed by the Garudamangalam Sandstone Formation (see Chapter 3 for details on the lithostratigraphy of the Basin). The Garudamangalam Sandstones are devoid of foraminifera (this study) and this does not allow further biozonation of the mid-Cretaceous succession in the Basin (on-shore part). Equivalent sediments (equivalent to the Garudamangalam Sandstones) in a shallow well (on-shore well, Kunnam-2) record (Govindan et al. 1996, p. 168, fig. 7) an early-mid Turonian
P. helvetica TRZ (sensu Govindan et al. 1996) followed, in the late Turonian, by an approximately 39 m (between 15-54 m interval in the Kunnam well-2) thick unit devoid of foraminifera. This late Turonian unfossiliferous (no foraminifera) unit is followed, in the Coniacian, by Marginotruncana renzi (Gandolfi) PRZ (sensu Govindan et al. 1996). Equivalent sediments (late Turonian unfossiliferous unit in the on-shore part) from the deeper part of the Basin are reported (Govindan et al. 1996) to be fossiliferous, being dominated by whitenellid group. Govindan et al. (1996) have used the occurrence of whitenellids to establish a late Turonian Whitenellid Zone (sensu Govindan et al. 1996, fig. 7) for the deeper part of the Basin.

5.3 Proposed Benthonic Foraminiferal Biozone Scheme

The mid-Cretaceous succession (Karai Formation) in the Cauvery Basin is rich in benthonic foraminifera. No previous attempt, however, has been made to establish a benthonic zonation scheme, with one exception. Narayanan & Scheibnerova (1975) proposed four benthonic zones for the late Albian-early Turonian succession in the Basin. The zonation scheme (Narayanan & Scheibnerova 1975) does not meet the standard practice of defining a biostratigraphic zone as outlined by Hedberg 1976, Holland et al. 1978, Bulletin A.A.P.G. 1983 and Whittaker et al. 1992. A need, therefore, exists for a formal benthonic foraminiferal zonal scheme for the mid-Cretaceous succession in the Cauvery Basin, to be established.

Unlike the planktonic foraminifera, which allow a biozonation only after the first appearance of R. subticinensis in the late Albian, benthonic foraminifera can be used for biozonation from the early mid-Cretaceous. The succession is characterised by a rich assemblage of both agglutinated and calcareous benthonic foraminifera. The use of agglutinated foraminifera in the proposed biozonation scheme, however, is very restricted. This is because the agglutinated foraminifera are very inconsistent in terms of their abundance. Where they are consistent the species are long-ranging (present throughout the succession) and do not show any significant change in their abundance.
Seven biozones, comprising one Interval Range Biozone (IRB), one Concurrent Range Biozone (CRB), two Partial Range Biozones (PRBs) and three Acme Biozones, are proposed in the benthonic biozonation scheme for the mid-Cretaceous succession of the Cauvery Basin (Table 5.1). The scheme is primarily for regional application. An Acme Biozone represents the period of time when, for some reason, a particular taxon has an extraordinary abundance. The Acme Biozones are subjective and of local application as their objective definition remains a problem. There exists always a possibility that local factors influenced an acme, which may be unrelated to the acme of the same species or fossil group elsewhere (Whittaker et al. 1992, p. 816).

5.3.1 Definition of the biozones

**Gavelinella schloenbachi** (Reuss)-**G. baltica** Brotzen Biozone

**Category:** Partial Range Biozone.

**Lower limit:** not defined (as discussed under remarks).

**Upper limit:** First appearance of *Bulbophragium aequale* Maync, *B. cylindraceum* (Chapman) and *Cribrostomoides latidorsata* (Bornemann).

**Diagnostic feature/s:** The Biozone is characterised by a very high abundance of Gavelinella Brotzen species, accounting for about 35-40% of the benthonic population.

**Age:** Early-late Albian.

**Reference section/s:** Karai-Kulakkalnattam traverse.


The Biozone has a high diversity and well preserved benthonic microfauna. Benthonic foraminifera account for about 60% of the population. Gavelinella amongst the calcareous and Haplophragmoides Cushman in the agglutinated forms dominate the population.
Remarks: In the Karai-Kulakkalnattam traverse (and in the Karai wells) the base of the Karai Clay Formation is not recorded. *G. schloenbachi* and *G. baltica* occur in the first sample collected from the Karai-Kulakkalnattam traverse (reference section for the Biozone), but this may not necessarily be the first appearance of the species. This explains why the Biozone is a PRB and not an IRB and that the base of the Biozone cannot, therefore, be defined.

**Bulbophragium aequale-B. cylindraceum-Cribrostomoides latidorsata Biozone**

**Category:** Concurrent Range Biozone.

**Lower limit:** First appearance of *B. aequale, B. cylindraceum* and *C. latidorsata*.

**Upper limit:** First appearance of *Orithostella indica* (Scheibnerova).

**Diagnostic feature/s:** Concurrent occurrence of *aequale, cylindraceum* and *latidorsata* is characteristic of the Biozone. *Tritaxia pyramidata* Reuss, *Globorotalites* sp. 2 and *G. cenomanica* (Brotzen) disappear at or just before the upper limit of the Biozone. *G. schloenbachi* population reduces significantly at the start of the Biozone and subsequently disappearing completely or few sporadic occurrences making to the top.

**Age:** Late Albian.

**Reference section/s:** Karai-Kulakkalnattam traverse.

**Corresponding planktonic biozone (this study):** Includes *subticinensis* IRB to *appenninica-buxtorfii-ticinensis* CRB (in part).


The lower part of the Biozone is characterised by a moderate to moderately high benthonic diversity and abundance. Towards the top of the Biozone a fall in diversity and abundance is observed with a significant drop at the top. The mid-Cretaceous
anoxic event (see Chapter 6) accounts for this significant drop in the benthonic population.

**Remarks:** Although the first appearance of *B. aequale, B. cylindraceum* and *C. latidorsata* defines the base of the Biozone, it is not being identified as an IRB. Considering the low abundance of these three species, it is preferred here to use the concurrent occurrence of them to establish a Concurrent Biozone as to use their first occurrences to define an Interval Range Biozone.

In the Cretaceous succession of SE England Hart *et al.* (1989) establish a *Plectina mariae* (Franke)-*Bulbophragmium aequale folkestoniensis* (Chapman) Concurrent Range Zone (Zone 7 of Carter & Hart 1977) of earliest Cenomanian age. The zone coincides with the “Glauconitic Marl” and a flood of very large, coarsely agglutinated *Lituolacea*, e.g., *B. aequale folkestoniensis* together with purely Cenomanian benthonic foraminifera, e.g., *Arenobulimina advena* (Cushman), *Flourensina intermedia* ten Dam, *Marssonella ozawai* Cushman, *Plectina mariae, G. baltica, Lingulogavelinella jarzevae* (Vasilenko).

**Orithostella indica** Biozone

**Category:** Interval Range Biozone.

**Lower limit:** First appearance of *O. indica*.

**Upper limit:** First appearance (with an extraordinary abundance) of *Lingulogavelinella globosa* (Broten) and reappearance (with an acme) of *O. indica*.

**Diagnostic feature/s:** A very high abundance of well developed and beautifully preserved *O. indica*.

**Age:** Latest Albian to late Cenomanian.

**Reference section/s:** Karai-Kulakkalnattam traverse, Karai-6.

**Corresponding planktonic biozone (this study):** From *appenninica-buxtortitricinensis* CRB (in part) to *archaeocretacea* PRZ (in part).

Remarks: During the latest Albian-middle Cenomanian the O. indica population is characterised by large and well preserved specimens. From a very modest appearance (3% of the total bentonic population) in the latest Albian, the O. indica population increased rapidly. During the early to middle Cenomanian O. indica constituted 14% of the total bentonic population. An improvement in the size and preservation of the specimens is also observed. During the early-late Cenomanian O. indica percentage dropped significantly (2% of the bentonic population), finally disappearing (only temporarily) in the late Cenomanian.

Overall the Biozone is characterised by a fluctuating bentonic fauna. The fall in the bentonic diversity and abundance observed in the aequale-cylindrical-latidorsata Biozone continues in this Biozone (only lower part) before beginning to improve in the early Cenomanian. In the late Cenomanian (towards the top of the Biozone) for a second time a fall in the diversity of bentonic fauna is observed. This fall in the bentonic diversity is at the expense of calcareous forms. The agglutinated foraminifera, at this time, show an improvement in diversity and abundance. The fluctuating bentonic diversity and abundance associated with this Biozone is related to the mid-Cretaceous anoxic events (see Chapter 6).

Narayanan & Scheibnerova (1975) established an O. indica-Osangularia utaturensis (Scheibnerova) Zone (late Albian) and an O. indica marksi (Narayanan & Scheibnerova) Zone (early Cenomanian) in the Uttatur Group (Karai Formation this study) of the Cauvery Basin. Narayanan & Scheibnerova (1975) differentiated O. indica marksi from O. indica in the size and inflation of the test. They observed that, in the Cenomanian, from the late Albian O. indica population evolved large forms with tests up to twice the size (of the late Albian forms) and with inflated tests. This Cenomanian
form was identified by Narayanan & Scheibnerova (1975) as a new subspecies marksi. This observation of Narayanan & Scheibnerova (1975) is not upheld here. In the present study large sized and inflated tests are present from the late Albian to the Cenomanian.

The O. indica IRB (this study) includes the O. indica-O. utaturensis and O. indica marksi Zones of Narayanan & Scheibnerova (1975).

**Lingulogavelinella globosa-Orithostella indica Biozone**

**Category:** Acme Biozone.

**Lower limit:** First appearance with an extraordinary abundance of L. globosa associated with reappearance and an acme of O. indica.

**Upper limit:** Last occurrence of the extraordinary abundance of L. globosa and O. indica.

**Diagnostic feature/s:** This is a very thin biozone characterised by an acme of well preserved L. globosa and O. indica. G. baltica makes its last occurrence in this Biozone.

**Age:** Latest Cenomanian to (?) earliest Turonian.

**Reference section/s:** Karai-Kulakkalnattam traverse, Karai-3, Karai-4 and Karai-6.

**Corresponding planktonic biozone (this study):** W. archaeocretacea PRZ (in part).

**Associated microfauna:** A. cretaceus, H. concavus, H. kirki, G. baltica, G. berthelini, G. intermedia.

The benthonic diversity, which had dropped towards the top of the O. indica IRB, improves. This improvement in the benthonic diversity is observed dominantly in the agglutinated population.

**Remarks:** Narayanan & Scheibnerova (1975) established a late Cenomanian L. asterigerinoides asterigerinoides (Plummer) Zone and an early Turonian L. asterigerinoides turonica (Butt) Zone in the Uttatur Group (Karai Formation this study) of the Cauvery Basin. Narayanan & Scheibnerova (1975) recognise L. turonica
(Butt) as a sub-species *turonica* of *L. asterigerinoides* (Plummer) in the Turonian, differentiating it from the Late Cenomanian *L. asterigerinoides* in having a fewer number of chambers in the final whorl. This difference is not upheld in the present study and *L. asterigerinoides* and *L. turonica* are identified as *L. globosa* (see Chapter 4 for taxonomic details).

*L. globosa*-*O. indica* Acme Biozone (this study) represents the *L. asterigerinoides asterigerinoides* and *L. asterigerinoides turonica* Zones of Narayanan & Scheibnerova (1975).

**Gavelinella berthelini-G. intermedia Biozone**

**Category:** Partial Range Biozone.

**Lower limit:** Last occurrence of *L. globosa* and *O. indica*.

**Upper limit:** An extraordinary abundance (acme) of *G. tourainensis* Butt.

**Diagnostic feature/s:** A thin biozone characterised by a low diversity benthonic population.

**Age:** Earliest Turonian.

**Reference section/s:** Karai-Kulakkalnattam traverse, Karai-3 and Karai 6.

**Corresponding planktonic Biozone (this study):** From *W. archaeocretacea* PRZ (in part) to *P. helvetica* IRZ (in part).

**Associated microfauna:** Most of the benthonic species disappear. *Haplophragmoides* species, *G. berthelini* and *G. intermedia* from the previous biozone continue and are in good abundance.

**Remarks:** The Biozone is characterised by a sharp drop in the benthonic population, falling to as low as 20% (of the total foraminiferal population) in some cases. The assemblage is dominated by planktonic fauna and the benthonic foraminifera are represented by long-ranging taxa. The low benthonic diversity associated with the Biozone is due to the late Cenomanian-early Turonian anoxic event (see Chapter 6).
Gavelinella tourainensis Biozone

**Category:** Acme Biozone.

**Lower limit:** An acme of *G. tourainensis*.

**Upper limit:** Sudden disappearance of *G. tourainensis* replaced by an acme of *H. kirki* Wickenden and *H. aff. multiformis* (Krasheninnikov).

**Diagnostic feature/s:** An acme of beautifully preserved and large forms of *G. tourainensis* characterise the Biozone.

**Age:** Early to early-middle Turonian.

**Reference section/s:** Karai-Kulakkalnattam traverse and Karai-3.

**Corresponding planktonic biozone (this study):** *P. helvetica* IRB (in part).

**Associated microfauna:** *Gavelinella* species continue from the previous Biozone. An impoverished agglutinated foraminiferal assemblage comprising mainly of *Haplophragmoides* species and to a lesser extent *A. cretaceus* is present. The mid-Turonian microfaunal population is dominated by a well preserved, robust, high diversity planktonic assemblage and a low diversity benthonic fauna, comprises of long-ranging taxa. The mid-Cretaceous anoxic event (see Chapter 6) accounts for a low diversity benthonic fauna in the Biozone.

**Remarks:** *G. tourainensis* makes a very modest (virtually insignificant) first appearance in the Cenomanian (in the *Q. indica* IRB, this study). The Cenomanian succession is characterised by sporadic occurrences of one or two specimens. This is followed by a flood of *G. tourainensis*, comprising 34% of the benthonic population, in the early Turonian. The disappearance of *G. tourainensis*, unlike its appearance, was very sudden. Benthonic fauna is facies controlled and this sudden disappearance of *G. tourainensis*, along with other calcareous benthonic fauna, could be due to the sudden regression at the top of the succession (see Chapters 3 & 7). This acme of *G. tourainensis* in the Turonian is used to identify the *G. tourainensis* Acme Biozone in the Cauvery Basin.
**Haplophragmoides kirki-H. aff. multiformis Biozone**

**Category:** Acme Biozone.

**Lower limit:** A sudden abundance (acme) of *H. kirki* and *H. aff. multiformis*.

**Upper limit:** not defined (as discussed under remarks).

**Diagnostic feature/s:** An acme of *H. kirki* and *H. aff. multiformis* and a complete absence of planktonic foraminifera is diagnostic. The Biozone is characterised by an extremely low diversity and a very high abundance of benthonic fauna, comprising exclusively of moderately coarsely agglutinated taxa. The agglutinated foraminifera constitute 99% of the microfaunal population in the Biozone.

**Age:** Middle Turonian.

**Reference section/s:** Karai-Kulakkalnattam traverse.

**Associated microfauna:** *H. kirki* and *H. aff. multiformis* constitute about 80% of the microfauna. Other agglutinated foraminifera present are *H. concavus* and few rare occurrences of *Cribrostomoides* Cushman, *Glomospira* Rzehak and *Trochammina* Parker & Jones species.

The microfossil assemblage is characterised by a very high abundance (99% of the total foraminiferal population) but a low diversity, agglutinated taxa. The planktonic foraminifera are absent and the calcareous benthonic fauna reduced to 1%.

**Remarks:** In the Middle Turonian the Karai Formation is abruptly terminated by a sudden and sharp regression (see Chapters 3 & 7). The top of the Karai Formation ends up against a coarse-grained, carbonate-rich concretionary sandstone bed. The upper limit of the Biozone cannot, therefore, be defined. The sharp drop in the sea-level brought an abrupt but forced disappearance of planktonic fauna. This sudden regression brought major changes in the benthonic community, which are facies controlled. Agglutinated taxa expanded (in terms of abundance) at the expense of the calcareous forms. This is reflected in a low diversity but a very high abundance of agglutinated taxa with only two species constituting for about 80% of the microfaunal population.
5.4 Summary

The mid-Cretaceous succession (on-shore) in the Cauvery Basin, SE India has a rich foraminiferal suite. Biozonation schemes, based on planktonic and benthonic foraminifera, are proposed for the mid-Cretaceous Karai Formation. The proposed biostratigraphic classification is in accordance with the guidelines outlined by Hedberg 1976, Holland et al. 1978, Bulletin A.A.P.G. 1983 and Whittaker et al. 1992. These schemes are primarily defined for regional application. A planktonic foraminiferal biozonation scheme, comprising of four IRBs (with two sub-biozones), one CRB and one PRB, is established. In the absence of a formal benthonic foraminiferal biozonation scheme, for the first time, a benthonic scheme is proposed. Seven biozones, comprising of one IRB, one CRB, two PRBs and three Acme biozones, are proposed in the benthonic zonal scheme.
Table 5.1: Proposed Foraminiferal Biozonation Schemes for the mid-Cretaceous succession in the Cauvery Basin, S.E. India.

<table>
<thead>
<tr>
<th>Stages</th>
<th>Planktonic Foraminifera Scheme</th>
<th>Benthonic Foraminifera Scheme</th>
</tr>
</thead>
<tbody>
<tr>
<td>Turonian</td>
<td>cut by a sudden regression</td>
<td>cut by a sudden regression</td>
</tr>
<tr>
<td></td>
<td><em>P. helvetica</em> Interval Range Biozone</td>
<td><em>H. kirki-H. aff. multiformis</em> Acme Biozone</td>
</tr>
<tr>
<td></td>
<td><em>W. archaeocretacea</em> Partial Range Biozone</td>
<td><em>G. tourainensis</em> Acme Biozone</td>
</tr>
<tr>
<td></td>
<td><em>R. reicheli</em> IRB</td>
<td><em>G. berthelini-G. intermedia</em> PRB</td>
</tr>
<tr>
<td></td>
<td><em>reicheli-cushmani</em> Sub-biozone</td>
<td><em>L. globosa-O. indica</em> Acme Biozone</td>
</tr>
<tr>
<td>Cenomanian</td>
<td><em>reicheli-appenninica</em> Sub-biozone</td>
<td><em>Orithostella indica</em> Interval Range Biozone</td>
</tr>
<tr>
<td></td>
<td><em>R. brotzeni</em> Interval Range Biozone</td>
<td></td>
</tr>
<tr>
<td>Upper Albian</td>
<td><em>R. appenninica-Pl. buxtorfi-R. ticinensis</em> Concurrent Range Biozone</td>
<td><em>B. aequale-B. cylindraceum-C. latidorsata</em> Concurrent Range Biozone</td>
</tr>
<tr>
<td></td>
<td><em>R. subticinensis</em> Interval Range Biozone</td>
<td><em>G. schloenbachi-G. baltica</em> PRB</td>
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</tbody>
</table>
Table 5.2: Correlation of Planktonic Foraminiferal Zonal Scheme with the other established schemes for the mid-Cretaceous interval.

<table>
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<tr>
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<td>Turonian</td>
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<td></td>
<td></td>
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</tr>
<tr>
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<td>helvetica</td>
<td>helvetica</td>
<td>helvetica-sigali</td>
<td>helvetica-sigali</td>
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<tr>
<td>archaeoarectacea</td>
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<td></td>
</tr>
<tr>
<td>reicheli-cushmani</td>
<td></td>
<td>cushman</td>
<td>algeriana</td>
<td>cushman</td>
<td>cushman</td>
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<td></td>
<td>reicheli</td>
<td>greenhornensis</td>
<td>cushman</td>
<td>cushman</td>
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</tr>
<tr>
<td>brotzeni IRB</td>
<td></td>
<td>brotzeni</td>
<td>globotruncanoides</td>
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<td>brotzeni</td>
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<td>subticinensis</td>
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</tr>
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<td></td>
<td>planispira</td>
<td>breggiensis</td>
<td>breggiensis</td>
<td>breggiensis</td>
<td></td>
<td></td>
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</tbody>
</table>

*Venkatachalapathy & Ragothaman 1995
Tables 5.3 and 5.4

Range Charts for the mid-Cretaceous foraminifera

Key

<table>
<thead>
<tr>
<th>Count Range</th>
<th>Description</th>
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</thead>
<tbody>
<tr>
<td>1-3</td>
<td>(V. rare)</td>
</tr>
<tr>
<td>4-10</td>
<td>(rare)</td>
</tr>
<tr>
<td>11-25</td>
<td>(common)</td>
</tr>
<tr>
<td>26-75</td>
<td>(frequent)</td>
</tr>
<tr>
<td>76-100</td>
<td>(abundant)</td>
</tr>
<tr>
<td>&gt; 101</td>
<td>(V. abundant)</td>
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</tbody>
</table>

(Based on 301 specimen counts in 250, 125 and 63 fraction sizes)
Table 5.3: Biostratigraphic distribution and relative abundance of the mid-Cretaceous planktonic foraminifera in the Cauvery Basin.
Table 5.3 (cont.): Biostratigraphic distribution and relative abundance of the mid-Cretaceous planktonic foraminifera in the Cauvery Basin.
Table 5.4: Biostratigraphic distribution and relative abundance of the mid-Cretaceous benthonic foraminifera in the Cauvery Basin.
Table 5.4 (cont.): Biostratigraphic distribution and relative abundance of the mid-Cretaceous benthonic foraminifera in the Cauvery Basin.
Table 5.4 (cont.): Biostratigraphic distribution and relative abundance of the mid-Cretaceous benthonic foraminifera in the Cauvery Basin.

<table>
<thead>
<tr>
<th>Stages</th>
<th>Biostratigraphic Zones</th>
<th>Benthonic Foraminifera</th>
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<td>Intra-Albian Zone</td>
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</tr>
<tr>
<td></td>
<td></td>
<td>G. aff. gordialis</td>
</tr>
<tr>
<td></td>
<td></td>
<td>G. lacrima, G. prisca, G. subsphaerica, Glomospira charoides, Glomospirella gaultina</td>
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<td></td>
<td>Globoquadra sp. 2, Globoquadra sp. 1, Gyroidinoides sp. 1, Gyroidinoides sp. 2, Gyroidinoides sp. 3, Gyroidinoides sp. 4, Gyroidinoides sp. 5, Gyroidinoides sp. 6, Gyroidinoides sp. 7, Gyroidinoides sp. 8</td>
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<tr>
<td></td>
<td></td>
<td>G. intermedia, G. cenomanica</td>
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<td></td>
<td>G. rudis, G. schloenbachi, G. tourainensis</td>
</tr>
<tr>
<td></td>
<td></td>
<td>G. aff. gordialis, G. lacrima, G. prisca, G. subsphaerica, Glomospira charoides, Glomospirella gaultina</td>
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<td></td>
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<tr>
<td></td>
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<td>G. intermedia, G. cenomanica</td>
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<td></td>
<td>G. rudis, G. schloenbachi, G. tourainensis</td>
</tr>
<tr>
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<td></td>
<td>G. aff. gordialis, G. lacrima, G. prisca, G. subsphaerica, Glomospira charoides, Glomospirella gaultina</td>
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<tr>
<td></td>
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<td>G. intermedia, G. cenomanica</td>
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<td>G. rudis, G. schloenbachi, G. tourainensis</td>
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<tr>
<td></td>
<td></td>
<td>G. intermedia, G. cenomanica</td>
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<td>G. rudis, G. schloenbachi, G. tourainensis</td>
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<td>Globoquadra sp. 2, Globoquadra sp. 1, Gyroidinoides sp. 1, Gyroidinoides sp. 2, Gyroidinoides sp. 3, Gyroidinoides sp. 4, Gyroidinoides sp. 5, Gyroidinoides sp. 6, Gyroidinoides sp. 7, Gyroidinoides sp. 8</td>
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<tr>
<td></td>
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<td>G. intermedia, G. cenomanica</td>
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<td>G. rudis, G. schloenbachi, G. tourainensis</td>
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Table 5.4 (cont.): Biostratigraphic distribution and relative abundance of the mid-Cretaceous benthonic foraminifera in the Cauvery Basin.
Table 5.4 (cont.): Biostratigraphic distribution and relative abundance of the mid-Cretaceous benthonic foraminifera in the Cauvery Basin.
Table 5.4 (cont.): Biostratigraphic distribution and relative abundance of the mid-Cretaceous benthonic foraminifera in the Cauvery Basin.
<table>
<thead>
<tr>
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<tr>
<td></td>
<td>lower</td>
<td>middle</td>
<td>upper</td>
</tr>
<tr>
<td>schoenbachi-landona indica CRB</td>
<td>Indica IRB</td>
<td>globosia-intermedia PRB</td>
<td>tourmalina Acme B.</td>
</tr>
</tbody>
</table>

| P. humilis |
| P. mutabilis |
| Pseudonodosaria sp. 1 |
| Pseudonodosaria sp. 2 |
| Pseudonodosaria sp. 3 |
| Pseudonodosaria sp. 4 |
| Quadrimorphina camerata |
| Ramulina aculeata |
| R. arkadelphiana |
| R. fusiformis |
| R. globotubulosa |
| Ramulina sp. 1 |
| Reophax scorpiurus |
| Recurvoides gerochi |
| Recurvoides sp. 1 |
| Remesella sp. 1 |
| Reophax cf. ampullacea |
| Reophax sp. 1 |
| Rhabdammina sp. 1 |
| Rhizammina ex gr. indivisa |
| Saccammina alexanderi |
| Silicosigmoilina sp. 1 |
| Siphotextularia sp. 1 |
| Spiroplectammina lalickeri |
| S. semicomplanata var. juncea |
| Spiroplectammina sp. 1 |
| Spiroplectammina sp. 2 |
| Stilostomella sp. 1 |
| Stilostomella sp. 2 |
| Tappana sp. 1 |
| Textularia aff. chapmani |
| T. aff. wilgynyaensis |

Table 5.4 (cont.): Biostratigraphic distribution and relative abundance of the mid-Cretaceous benthonic foraminifera in the Cauvery Basin.
Table 5.4 (cont.): Biostratigraphic distribution and relative abundance of the mid-Cretaceous benthonic foraminifera in the Cauvery Basin.

<table>
<thead>
<tr>
<th>Textularia sp. 1</th>
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<tbody>
<tr>
<td>Tristix excavata</td>
<td>T. pyramidata</td>
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<td>Tritaxia aff. ellisorae</td>
<td>T. tricornata</td>
</tr>
<tr>
<td>Verneuilina muensteri</td>
<td>V. marginulinoides</td>
</tr>
<tr>
<td>Vaginulina sp. 1</td>
<td>Vaginulina sp. 2</td>
</tr>
<tr>
<td>Vaginulina sp. 3</td>
<td>Vaginulina sp. 4</td>
</tr>
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<td>Vaginulina sp. 5</td>
<td>Vaginulina sp. 6</td>
</tr>
<tr>
<td>Vaginulina sp. 7</td>
<td>V. kochii</td>
</tr>
</tbody>
</table>

Table 5.4 (cont.): Biostratigraphic distribution and relative abundance of the mid-Cretaceous benthonic foraminifera in the Cauvery Basin.
Chapter 6

The mid-Cretaceous oceanic anoxic events (OAEs) and sea-level changes in the Cauvery Basin
6.1 Introduction

In the Cretaceous three intervals are reported as "Oceanic Anoxic Events" (OAEs) (Arthur & Schlanger 1979, Jenkyns 1980). These are during (1) late Barremian through Albian OAE-1, (2) late Cenomanian-early Turonian (Bonarelli event) OAE-2 and (3) Coniacian-Santonian OAE-3. Within the Lower Cretaceous strata in southern France a number of anoxic events are recognised (Breheret et al. 1986, Breheret 1988, Larson et al. 1992, Kauffman & Hart 1996). They are, the early Aptian Goguel event (=Selli event (OAE-1a) in central Italy, Coccioni et al. 1989), the late Aptian Jacob event, the early Albian Paquier event (OAE-1b) and the late Albian Breistroffer event (OAE-1c). The mid-Cretaceous anoxic events (OAE-1 and OAE-2) are more widespread than the upper Cretaceous event (OAE-3). The Coniacian-Santonian OAE-3 event mainly affected the southern North Atlantic, Caribbean and South Atlantic regions only. Two models have been developed to account for the high accumulation of organic carbon-rich sediments on diverse basinal settings. They are, (1) the anaerobic, restricted basin model, e.g., Black Sea and (2) the expanded oxygen-minimum model, accounting for anoxic events in the Indian and the Pacific Oceans and parts of the young South Atlantic and North Atlantic Oceans (Arthur & Schlanger 1979, Arthur et al. 1987).

pelagic and shelf limestones, which may lack the dark shales, show high $^{13}$C values, characteristic of the anoxic events. Positive $^{13}$C values, phosphate and manganese enrichment and high silica (due to abundant radiolarian tests) are the geochemical signatures associated with these events. The mid-Cretaceous eustatic changes in sea-level, which caused the expansion of the oxygen-minimum zone, had a major affect on the microfaunal community. The intensity and the extent of the oxygen-depletion zones, had an effect on the diversity, abundance and morphologic characters (e.g., size, ornamentation, etc.) of the microfauna inhabiting the water column and the sea-floor at that time. The events record a low diversity, high abundance planktonic assemblages with a complete absence to an impoverished benthonic population; depending on the intensity of dysoxia/anoxia.

From the Cauvery Basin, SE India, early Cretaceous organic-rich, black shales were first described from the Ariyalur-Pondicherry sub-basin by Subbaraman (1968). Later Bhatia & Jain (1969) reported similar Aptian-Albian black shales from the offshore parts of the Cauvery Basin. Govindan (1982, 1993) and Govindan & Ramesh (1995) have correlated the occurrence of these organic rich black shales in the Cauvery Basin with the global “Cretaceous Anoxic Events”. Subsurface studies (Govindan 1993, Govindan & Ramesh 1995) record moderate to high TOC (total organic carbon) values (2 to 4 %) at the late Albian Breistroffer and the Cenomanian-Turonian Bonarelli events. The academic and commercial significance of these “organic-rich shales” has yet not been fully appreciated.

The present study of the mid-Cretaceous foraminifera from the Cauvery Basin records two levels, (1) the latest Albian/Albian-Cenomanian and (2) the late Cenomanian-Turonian, when sharp increases in the planktonic:benthonic ratios (P:B ratio) are reported. The high P:B ratio levels are associated with a reduction in the benthonic diversity. These events coincide with the globally reported mid-Cretaceous Breistroffer OAE-1c and the Bonarelli OAE-2 oceanic anoxic events. The study shows that the OAE-1c in the Cauvery Basin appears to be much closer to the
Albian-Cenomanian boundary and that the OAE-2 extends to the early mid-Turonian. The late Albian anoxic event in the Basin is not as strong as the late Cenomanian-Turonian event. These anoxic events had a major affect on the foraminiferal population. This Chapter aims to study, (1) the affect of mid-Cretaceous OAEs on the planktonic foraminiferal population and (2) to infer the mid-Cretaceous sea-level changes in the Cauvery Basin, using planktonic foraminifera (see also Tewari et al. 1996a in Appendix 1).

6.2 Method

The work is based on the composite study of foraminifera populations from the on-shore well data and field samples (see Chapter 1 for details on sample preparation). Core samples were obtained from three, 120 m deep wells- Karai-3, Karai-4 and Karai-6, drilled between Karai and Kulakkalnattam villages, in the Ariyalur area (Fig. 6.1). The wells encounter grey-black shales, glauconitic- and organic-rich in places; with brown gypseous shales in the top 30 m from the surface. Field samples collected from the Karai-Kulakkalnattam traverse (Fig. 6.1) are rust yellow to dirty brown, silt- and sand-rich claystones, glauconitic- and organic-rich in places. The gypsum is a post-depositional weathering phenomenon. Tropical weathering (high heat and humidity) has resulted in superficial gypsum concentrations (see Section 3.4.2. (ii.a) for details). Figures 6.2 and 6.3 (enclosed at the end of this Chapter) show the planktonic:benthonic ratio, benthonic diversity, agglutinated:calcareous ratio and planktonic foraminifera percentage graphs for the Karai-Kulakkalnattam traverse and the Karai wells respectively.

A pilot palynological study (P. Dodsworth pers. comm.) was done on 20 surface samples collected (R. Venkatachalapathy pers. comm., see Section 1.3.1 for details on sample collection) at the Cenomanian-Turonian boundary from the Karai-Kulakkalnattam traverse (Fig. 6.1). The study shows that the clays are now barren of palynomorphs. A rational explanation to this could be a high susceptibility of
Figure 6.1: Geological map of the Karai-Kulakkalnattam area showing the positions of the Karai-3, Karai-4 and Karai-6 wells (after Ramanathan & Rao 1982).
organic-walled palynomorphs to the tropical weathering associated with these latitudes (K. Dornig & P. Dodsworth pers. comm.).

6.3 The affect of the mid-Cretaceous OAEs on the planktonic foraminiferal population in the Cauvery Basin

The mid-Cretaceous oceanic anoxic events had a major affect on the foraminiferal population (e.g., Hart & Bailey 1979, Jarvis et al. 1980, Kuhnt et al. 1986, Peryt & Wyrwicka 1991, 1993, Hart 1993, Peryt et al. 1994, Kauffman & Hart 1996). The intensity and extent of the oxygen minimum zone influenced the diversity, speciation, abundance and morphological characters (e.g., test size, ornamentation etc.) of the foraminiferal assemblages. High planktonic:benthonic ratios associated with low benthonic diversity characterise these anoxic events. Major readjustments in the planktonic foraminifera occurred at or during these anoxic levels.

These anoxic events coincide with the sea-level maxima and eustatic rises in sea-levels (e.g., Schlanger & Jenkyns 1976, Jenkyns 1980, Thurow et al. 1992, Kauffman & Hart 1996, etc.). In addition to the eustatic sea-level rises there are, however, other factors which, directly or indirectly, influence the faunal and floral community in a basin (e.g., Be’ 1959, 1960, Boltovskoy 1959, Stehli 1965, Bandy 1967, Scheibnerova 1971a, 1971b, Hallock 1987, Ottens & Nederbragt 1992). The changes in palaeo-temperature, palaeo-latitudes, existence of migration routes, capability of the fauna to disperse and speciate, etc., all play an important role. These palaeo-geographic and palaeo-oceanographic factors together with local factors (e.g., basin architecture, tectonics, sediment influx) have a direct or an indirect affect in the existing community. The recognition of these factors, while assessing the affect these anoxic events had on the microfaunal community is, therefore, of primary importance.

In the Cauvery Basin the break-up of East Gondwanaland, northward shift of India from its position in the Austral realm (in the early Cretaceous) to the Tethyan realm (in
the late Cretaceous), opening of the Indian Ocean and the closure of Tethys influenced the microfaunal community. It is not the scope of the present study to evaluate the combined effect of these multiple factors on the foraminiferal community. This Chapter considers the effect of the anoxic events on the foraminiferal assemblages. Nevertheless, it is recognised that the faunal and floral assemblages of any basin are a reflection of a synthesis of global and local factors which existed at that particular time in the geological history.

6.3.1 The late Albian/Albian-Cenomanian event

The Upper Albian succession (\textit{R. subticinensis} to \textit{R. brotzeni} (in part) Biozones) is present in the lower sections of the Karai-4 well (Fig. 6.3A) and in the Karai-Kulakkalnattam traverse (Fig. 6.2). At a depth of about 100-110 m in the Karai-4 well (Fig. 6.3A), an abrupt increase occurs in the planktonic:benthonic ratio (P:B ratio) and a reduction in the benthonic diversity (B. diversity), within the \textit{R. brotzeni} Interval Biozone (see also Tewari et al. 1996a in Appendix 1). In the Karai-Kulakkalnattam traverse (Fig. 6.2) the P:B ratio fluctuates throughout the late Albian with a sharp rise in the P:B ratio, associated with a fall in benthonic diversity in the late \textit{subticinensis} early \textit{appenninica-buxtorfi-ticinensis} Biozones. The event in the Cauvery Basin appears to be much closer to the Albian-Cenomanian boundary than in the Vocontian Trough. A low-diversity, impoverished, benthonic population is reported which suggests that dysaerobic to poorly oxic bottom-water conditions existed in the Basin.

Until the early late Albian the Basin had well oxygenated conditions. A high diversity and a rich benthonic population, characteristic of well oxygenated water, is reported from the Basin. Amongst the calcareous foraminifera well-developed, large and beautifully preserved \textit{Gavelinella baltica} Brotzen, \textit{G. intermedia} (Berthelin), \textit{G. rudis} (Reuss), \textit{G. schloenbachii} (Reuss), \textit{Gyroidinoides} Brotzen and \textit{Lenticulina} Lamarck species are reported. The agglutinated foraminifera account for 10-20\% of the foraminiferal population. The morphotypes present are mainly the planispiral...
Haplophragmoides Reuss species and Ammodiscus cretaceus (Reuss). A small percentage of streptospiral and trochospiral-biserial forms e.g., Bulbophragmium Maync, Ammobaculites Cushman and Dorothia filiformis (Berthelin) are present. During the latest Albian-earliest Cenomanian dysaerobic to anoxic conditions developed in the Basin. The event records a low diversity, impoverished benthonic microfauna. During the anoxia a sharp reduction, of approximately 35-40%, in the benthonic foraminifera occurred. The Gavelinella species record a reduction of about 80%, of the total Gavelinella population. Amongst the agglutinated foraminifera a reduction from 20% (of the total foraminiferal population) to as low as <1%, and a fall in diversity from 26 to 6 (a fall of about 80% in the number of agglutinated species) is observed. The recovery from the anoxic event saw an improvement in the preservation, morphological characters, diversity and abundance of the benthonic population.

The oceanic anoxic event had a significant affect on the planktonic foraminiferal population of the Cauvery Basin. A low diversity, poorly preserved planktonic assemblage was present during the anoxic event. The planktonic fauna expanded considerably after the anoxia. The full recovery from the anoxic event is dominated by well-developed, diverse and highly ornamented species of Rotalipora Brotzen and Praeglobotruncana Bermudez. The lower Upper Albian succession in the Cauvery Basin is characterised by a rich, but low diversity planktonic assemblage. Tiny, globular, Hedbergella planispira (Tappan) dominate (90% of the planktonic population). The remaining 10% of planktonic foraminifera, comprising mainly of early forms of Rotalipora and Praeglobotruncana species, show major morphological changes during the anoxic event. During the event, the Rotalipora comprised small forms, each with a weakly developed keel. Soon after, the Rotalipora established themselves and expanded considerably, before disappearing completely in the late Cenomanian, when Dicarinelia Porthault and Whiteinella Pessagno made their first appearance (Figs. 6.2 & 6.3A). Following the appearance of juvenile specimens of R. appenninica (Renz) and R. brotzeni (Sigal) during the anoxic event, well developed forms belonging to R. appenninica, R. brotzeni, R. micheli (Sacal & Debourle) and
R. reicheli (Momod) appeared with the start of the recovery. The recovery of the Rotalipora saw a development in their morphological characters and an improvement in the quality of their preservation. Forms appear that possess well preserved primary and secondary apertures and a chamber profile marked by a well developed single keel continuing along the spiral side. Species of R. reicheli and R. micheli show well developed and very prominent adumbilical thickening. In fully grown adults of R. reicheli this periumbilical ridge is so well developed on all chambers that it forms a rampart along the umbilicus. The population was dominated by strongly asymmetrical R. reicheli, with a flat to gently concave spiral side and a strongly vaulted umbilical side. By the late Cenomanian, the Rotalipora started to reduce in number before disappearing at the end of the Cenomanian, when early forms of Dicarinella and Whiteinella made their first appearance.

Praeglobotruncana appears to be the most tolerant genus during the event. Forms of P. stephani (Gandolfi) and P. gibba Klaus appeared from before the crisis, survived the event and continued up in the Cenomanian. A major change of the ornamentation and spire height occurs, however, as the Praeglobotruncana population recovered from the event. P. stephani and P. gibba began with forms that have a low to moderate spire height and weakly calcified tests changing to a gentle beaded nature. These stephani and gibba have poorly preserved umbilical structures with chamber outlines marked by two very faint rows of pustules which becomes fainter and finally disappear completely. From a stock of such weakly developed morphological characters there evolved robust, highly calcified and beaded stephani and gibba with moderately high to very high trochospiral forms. The European Working Group on Planktonic Foraminifera (Robaszynski & Caron, 1979) established that, with an increase in height of the spire, stephani evolves into gibba. The stephani and gibba in the Cauvery Basin follow the same stephani to gibba transformation rule, as seen in their European counterparts. There is, however, one exception. The forms reported from Europe (Robaszynski & Caron, 1979) show a gradual increase in the height of the low to moderately high stephani, resulting in a mound-shaped high trochospiral gibba. In the Cauvery Basin
examples, the increase in the height of the spire sees a more robust approach with inner whorls sitting like a lobe on the final whorl, thus giving a block shaped high trochospiral gibba. These highly developed gibba and stephani also show very highly developed beaded ornamentation on their spiral sides, and very well developed rows of pustules. In some cases these rows of pustules could be referred to as two closely spaced keels in the final chambers of the last whorl.

The appearance of keeled taxa (single keeled Rotalipora) during the OAE was significant. After this latest Albian-earliest Cenomanian anoxic event, no major taxonomic change occurred in the planktonic fauna until the next anoxic event in the late Cenomanian-early Turonian. There was, however, progressive speciation (in the planktonic foraminifera) between the two anoxic events.

6.3.2 The late Cenomanian to mid-Turonian event

In the late Cenomanian-Turonian interval, for the second time, oxygen depletion conditions are observed in the Cauvery Basin (see also Tewari et al. 1996a in Appendix 1). At two levels, one in the late Cenomanian-early Turonian (in the uppermost reicheli-cushmani Sub-biozone and, more prominent within the archaeocretacea Biozone) and second in the middle Turonian (within the helvetica Biozone), an increase in the planktonic:benthonic ratio and a reduction in the benthonic diversity occurs (Figs. 6.2, 6.3B & 6.3C). These two levels are part of the one anoxic event, coinciding with the world-wide Cenomanian-Turonian oceanic anoxic event. Unlike the globally reported OAE-2, which spanned the latest Cenomanian-earliest Turonian time interval; anoxic conditions in the Cauvery Basin were present until the early mid-Turonian. Local (e.g., regional tectonics, basin architecture and subsidence, rate of sediment supply, etc.) and global (e.g., oscillating Cretaceous sea-level, palaeo-latitude, palaeo-geography) factors control the development, relative position, expansion and intensity of the oxygen depletion zone in a basin. These factors appear to have allowed the persistence of anoxic conditions in the Cauvery Basin during the early
mid-Turonian. The intensity and extent of the oxygen minimum layer, in the Basin, fluctuated during the late Cenomanian-middle Turonian period. This is reflected in the multiple peaks and falls observed in the P:B ratio and benthonic diversity graphs (Figs. 6.2 & 6.3B). The late Cenomanian-early Turonian succession is present in the Karai-6 well and in the Karai-Kulakkalnattam traverse; while the mid-Turonian succession is reported from the Karai-3 well and in the Karai-Kulakkalnattam traverse (Figs. 6.2 & 6.3C). The Cenomanian-Turonian succession is characterised by dark-grey to black, glauconite-rich shales with sporadic fragments of xylic material, coal and pyrite. In general a low diversity, moderately poor to poorly preserved, low-oxygen tolerant benthonic foraminiferal assemblage is reported throughout the event. Low oxygen levels in bottom waters (during anoxia) had a differential affect on the calcareous benthonic foraminifers. A progressive impoverishment (in terms of diversity and abundance) and test size diminution of calcareous assemblage is observed. Presence of an impoverished benthonic population suggests that dysaerobic-oxic conditions existed in the Basin during the late Cenomanian-Turonian anoxic event. During this event a net reduction of about 40-50% in the benthonic population is reported. The reduction occurs in two steps. The first is in the latest Cenomanian-earliest Turonian (uppermost reicheli-cushmani Sub-biozone and within the archaeocretacea Biozone) when a reduction of about 30-40% is recorded. This is followed by a second reduction of about 10-12% (of the remaining benthonic population) in the middle Turonian (helvetica Biozone). The reductions in the benthonic population are observed to be more significant in the calcareous forms as compared to the agglutinated ones. In between these two reductions, the period of latest early Turonian to the earliest mid-Turonian, a temporary recovery in the calcareous benthonic population is observed. The recovery is not so much in terms of diversity and abundance of the fauna but more towards an improvement in morphological characters and the quality of preservation. The recovery is observed at a depth of 70-90 m and 28-43 m in the Karai-3 well. During this interval large sized and beautifully preserved G. berthelini, Orithostella indica Scheibnerova, Lingulogavelinella globosa (Brotzen) and Lenticulina species dominated. A possible explanation of this
temporary recovery (in terms of morphological characters and quality of preservation in calcareous foraminifera) could be when, due to local factors, some oxic-conditions developed in the Basin. Amongst the agglutinated foraminifera, during the anoxic event, an improvement, both in diversity and abundance is observed (e.g., Hart & Bailey 1979, Peryt & Wyrwicka 1993, Peryt 1994, this study, etc.). The low oxygen tolerance of agglutinated taxa allowed them to expand during these dysaerobic to anoxic conditions. In the agglutinated:calcareous ratio graphs (Figs. 6.2, 6.3B & 6.3C) two to three, small spikes (more prominent in Fig. 6.2) reflect intervals, when an improvement in the agglutinated fauna is observed. The benthonic (calcareous) microfauna is composed dominantly of Gavelinella berthelini, G. intermedia, G. tourainensis Butt, Gyroidinoides, Bolivina d'Orbigny, Hoeglundina Brotzen, Lenticulina and O. indica. Amongst the agglutinated forms planispiral Haplophragmoideas species dominate with rare occurrences of Ammodiscus cretaceous and trochospiral to biserial Ammobaculites species and Dorothisa filiformis are present.

A major reshuffling occurred within the planktonic community in the latest Cenomanian-earliest Turonian (e.g., Jarvis et al. 1988, Caron & Homewood 1983, Hart & Ball 1986, Kauffinan & Hart 1996, this study). The dominant deep-water fauna disappeared completely (e.g., extinction of Rotalipora species) or were greatly reduced in numbers (e.g., reductions in P. gibba and P. stephani). The anoxic event was followed by a rapid re-colonisation by the deeper-water fauna. Important structural changes occurred during the anoxic event. Rotalipora disappeared completely and Dicarinella, Whiteinella and Marginotruncana Hofker came into existence. Hedbergella Bronnimann & Brown which was dominant before the event, was largely replaced by Whiteinella. Well preserved W. aprica (Loeblich & Tappan), W. archaeocretacea, W. baltica Douglas & Rankin and W. brittonensis (Loeblich & Tappan) are rare before the event, but expanded considerably. Amongst the Praeglobotruncana population, stephani and gibba morphotypes follow the same pattern of recovery as they did after the late Albian anoxic event, with a further enhancement in the spire height and beaded ornamentation. In the mid-Turonian (helvetica Biozone) small, plano-convex
praehelvetica (Trujillo) and helvetica (Bolli) with weakly developed single keel, reduced to concentration of pustules in most cases, appeared. The full recovery of helvetica saw well developed forms with 4 to 4½, rarely 5 chambers in the final whorl and a flat spiral side with a single keel. The typical Tethyan helvetica (large forms with 7 chambers in the final whorl, Robaszynski & Caron 1979) are not reported from the Cauvery Basin. Hart & Bailey (1979) and Hart et al. (1989) have made similar observations (i.e. the absence of 7 chambered Tethyan helvetica forms) from the mid-Cretaceous foraminiferal assemblages in the SE England and NW Europe (40° N palaeo-latitude).

The first Dicarinella to appear were juvenile D. imbricata (Momod) with low trochospiral forms and chamber outlines marked by a weak concentration of pustules. Soon Dicarinella, especially D. hagni (Scheibnerova), dominated the population, along with Praeglobotruncana, Marginotruncana and Whiteinella. D. hagni reported from the Cauvery Basin appear to be different to those that have been reported as D. hagni from Europe. The European Working Group on Planktonic Foraminifera (Robaszynski & Caron 1979) report low trochospiral asymmetrical biconvex forms of D. hagni in Europe, differentiating them from the plano-convex “concavata” group. Under the “concavata” group (Robaszynski & Caron 1979) are included forms with clearly asymmetrical plano-convex to concavo-convex low trochospiral tests, a periumbilical ridge and early globigerina-like chambers elevated above the outer whorl as a little prominence in the centre of the test. The three forms belonging to the “concavata” group (D. primitiva (Dalbiez), D. concavata (Brotzen) and D. asymetrica (Sigal)) occur one after the other in the Coniacian-Santonian interval. The first hagni which appear in the Cauvery Basin have all the characters of a true D. hagni as described from Europe (Robaszynski & Caron 1979). They have a low trochospiral-asymmetrical biconvex test with two closely spaced keels, often disappearing on the last or penultimate chamber. Soon after the OAE, D. hagni shows major morphological changes with a tendency for the development of forms very similar to the “concavata” group. From the typical...
D. hagni develop morphotypes having a moderate-asymmetrical trochospiral test with a more convex spiral side in comparison to the typical hagni, although the umbilical side still is more convex. The morphotypes have less closely spaced double keels with the keel diverging to give a slight imbricated pattern on the dorsal side. At the same time, within the hagni population, appeared plano-convex to concavo-convex morphotypes with the inner whorls sitting like a knob in the final whorl. Both these morphotypes show the development of a periumbilical ridge, at least in the final one or two chambers. The full recovery of D. hagni saw well developed plano-convex to concavo-convex hagni with spiral side flat to gently concave and a periumbilical ridge in the last one or two chambers (see Chapter 4 for taxonomic details). The only ways in which these plano-convex hagni are different from the “concavata” group are that they occur with a foraminiferal assemblage belonging to the W. archaeocretacea and P. helvetica Biozones, of late Cenomanian-mid Turonian age and they do not have early globigerina-shaped chambers. From the Cenomanian-Turonian shelf-deposits of the Tarfaya Basin (N. Morocco) Khunt et al. (1986) report a plano- to concavo-convex D. hagni (Khunt et al. 1986, pl. 6, fig. 6). They (Khunt et al. 1986) observe that the plano- to concavo-convex morphotypes are quite common in the lower Turonian succession of the Tarfaya Basin and that the species appears to mainly characterise the boreal realm. The publication (Khunt et al. 1986) does not discuss the taxonomy of the D. hagni occurring in the Tarfaya Basin, hence not allowing any comparison of the material with the Cauvery Basin morphotypes.

In the genus Marginotruncana, juveniles of M. marginata (Reuss) were the first to appear. The full expansion of the Marginotruncana population was dominated by M. schneegansi (Sigal) and to a lesser extent by M. marginata. The schneegansi and marginata population in the Cauvery Basin is different from that reported from Europe (Robaszynski & Caron 1979) in having a more robust development in their morphological characters (see Chapter 4 for taxonomic details). In Europe M. marginata is characterised by a biconvex, low trochospire test with two slightly developed keels separated by a narrow peripheral band and oblique, depressed to
slightly raised spiral sutures (Robaszynski & Caron 1979). The *marginata* population reported from the Cauvery Basin shows a significant variation in the spire height, convexity of the test, development of keels and ornamentation of the spiral sutures (see Chapter 4 for taxonomic details). Specimens with low to moderate trochosire with two well developed keels separated by a wide imperforate band and spiral keel slightly diverging obliquely per chamber are present. These forms have deep and oblique spiral sutures with few early chambers in the final whorl occasionally having raised sutures. Along with these types occur *marginata* specimens with moderately high trochosire, two well developed keels separated by a very narrow peripheral band, keels reduced to one in the penultimate chamber and finally disappearing in the last chamber or totally absent to very faint in the final three or four chambers. These forms have early oblique spiral sutures, becoming less oblique to perpendicular (in last two chambers), raised and gently beaded.

Similar to *marginata*, the *schneegansi* population reported from the Basin shows a significant variation in the spire height and in the development of keels (see Chapter 4 for taxonomic details). Forms, similar to those reported from Europe (Robaszynski & Caron 1979), with low trochosire and equally biconvex test have two parallel rows of closely spaced pustules forming the keels. In the other type, contrary to their European counterparts, the specimens are characterised by a moderately high trochosire. These forms have two well developed, closely spaced keels, with the spiral keel diverging from the umbilical keel per chamber to the dorsal side. The final development of these *M. schneegansi* closely resemble the *D. hagni* (high trochospiral forms of *hagni* reported from the Cauvery Basin) from which they differ in having a higher trochospiral test and spiral sutures joining the preceding sutures at right angles. This differentiation, however, does not always hold. Full expansion of the population has forms intermediate between *M. schneegansi* and *D. hagni*.

A comparison of the planktonic fauna from the Cauvery Basin with other basins in the world gives an impression that the fauna from SE India is composed of a more robust
individuals. After the Cenomanian-Turonian anoxic event, a more ornamented and more prominently keeled fauna dominated the Cauvery Basin. Cretaceous planktonic foraminiferal study from the Northwest shelf of Australia (Wright & Apthorpe 1976, 1995, Wonders 1992) reflect some interesting differences from the standard Tethyan assemblages. Comparative studies report a longer time range for some “index” species (Wonders 1992) and a more ornamented fauna (Apthorpe pers. comm., author’s own observations on the material from sites 761, 762, 763) from the eastern Indian Ocean.

6.4 Mid-Cretaceous sea-level changes

Cretaceous was a time of oscillating sea-levels. After the decline in the early Valanginian, the sea-level began to rise rapidly reaching its Mesozoic-Cenozoic peak in the early Turonian (Haq et al. 1987, 1988). Widespread mid-Cretaceous transgressions are recognised in the early Late Albian and in the Early Turonian followed by a marked regression in the Late Turonian. Eustatic sea-level changes controlled these transgressions and regressions, except in regions of rapid contemporaneous tectonics (Hancock & Kauffinan 1979, Hancock 1989). The sea-level changes and global eustatic curves (Vail et al. 1977, Haq et al. 1987, 1988) are based, for most part, on commercial seismic data. This approach is beset with two problems. First, the sea-level curves (based on seismic data) do not take into account factors of basin subsidence, rate of sediment flux, etc., which greatly influence the relative sea-level change. Second, access to seismic data is not always made available. Mechanisms must, therefore, exist which allow an average geologist to interpret sea-level changes within the limits of an individual’s field/s of specialisation. Micropalaeontology provides one such mechanism. Planktonic foraminifera have been used successfully, with caution, to infer mid-Cretaceous sea-level changes (Hart & Carter 1975, Hart & Bailey 1979, Hart 1980a,b, Hart & Ball 1986).
6.4.1 Planktonic foraminifera as a means of recognition of sea-level changes

Be' (1977) recognised that there exists a preference in the modern planktonic foraminifera for specific water depths in the modern oceans. A broad stratification of water column into a “shallow-water” (upper 50 m), an “intermediate-water” (upper 50-100 m) and a “deep-water” (below 100 m); each inhabited by a characteristic faunal association is established (Be' 1977). The juveniles usually occur in surface waters, shallower than 50 m, and as they mature they migrate to their preferred water depth. The adults of all species, however, migrate diurnally within their preferred depth range. Sampling across the shelf will, therefore, encounter a change in foraminiferal assemblage; reflecting the changing water depth. A sample from the neritic zone will contain 99% of benthonic fauna. On the contrary, a sample from the oceanic realm (above the CaCO₃ compensation depth) will yield an assemblage with 99% of planktonic foraminifera. This planktonic:benthonic ratio has been used to attempt to measure the depth of deposition in marine sediments (Phleger & Parker 1951, Grimsdale & Morkhoven 1955, Flexer & Starinsky 1970).

It has been suggested that the Cretaceous fauna, similarly, showed a preference for water depth and probably have had similar, if not the same, depth stratification as observed in the modern oceans (Hart & Bailey 1979, Hart 1980a, Caron & Homewood 1983, Hart & Ball 1986). Water depth is a major controlling factor in the diversification and speciation of planktonic fauna. However, other factors, e.g., nutrient supply, salinity, water temperature, surface water current, pH values, etc., have a considerable influence. The pattern of evolution of planktonic foraminifera, maximum size (diameter) analysis, ornamentation of the test and planktonic:benthonic ratios have been used, with caution, to indicate major mid-Cretaceous sea-level changes (Carter & Hart 1975, Hart & Bailey 1979, Hart 1980a, 1980b, Hart & Ball 1986, Leary & Hart 1989). Hart & Bailey (1979) argue that the accurate evolutionary lineage of planktonic foraminifera can only be observed in the oceanic sediments, where the species are free
to exploit the desired depth at any time in their evolutionary history. The faunal assemblage from oceanic sediments cannot, therefore, reflect the depth preference of the then inhabiting fauna. On the contrary, faunal assemblages from the shelf will reflect the changing water depth. Hart & Bailey (1979) suggest that the appearance of deeper-water planktonic species in the shelf sediments is, therefore, probably in response to the changes in water depth (encroachment of the shelf during transgression) and not evolution.

It is well established that the mid-Cretaceous anoxic events were due to major marine transgressions resulting from eustatic sea-level rises (Arthur & Schlanger 1979, Jenkyns 1980). Bio-events, associated with the anoxia, are reflected at local, regional and global levels (Reymont 1977, Khunt 1986, Kauffman & Hart 1996). The events are characterised by an increase in planktonic foraminifera associated with a complete absence of an impoverished benthonic fauna (dominated by agglutinated taxa). The anoxic events had a major affect on the planktonic foraminifera. The movement of the oxygen minimum zone in the water column has affected the evolution of the planktonic foraminiferal population (Hart & Ball 1986, Jarvis et al. 1988). Hart & Ball (1986) establish the relationship between the evolution of planktonic foraminifera and presence of mid-Cretaceous anoxic events. Major morphological changes in the fauna are documented within the anoxic periods (Hart & Ball 1986), which resulted from eustatic sea-level rises. Hart & Bailey (1979) identify different depth zones, numbered 1 to 4, in the mid-Cretaceous shelf seas. Each of these depth zones was characterised by a selected assemblage of planktonic foraminifera. The non-keeled, spinose, “shallow-water” Hedbergellids and Whiteinellids of zone 1 were followed by “intermediate-water” single-keeled Rotalipora species and moderately spired to plano-convex Praeglobotruncana species in zones 2 and 3. The “deep-water” fauna (zone 4) had highly spired and highly calcified forms, e.g., P. gibba, D. hagni and plano-convex forms, e.g., P. helvetica. If Hart & Bailey (1979), Caron & Homewood (1983) and Hart & Ball (1986) are right in assessing that water depth has been the controlling factor in the expansion of mid-Cretaceous foraminifera in the shelf areas,
then the planktonic foraminiferal assemblages should reflect, in general, the sea-level positions (transgressions vs. regressions).

These sea-level changes and the associated anoxic events, should have also influenced the benthonic community. Agglutinated taxa are geographically the most wide-spread, occurring in abyssal plain (below CaCO₃ compensation depth), brackish water, marginal marine environments, etc. (Haynes 1981). The dysoxic to anoxic conditions during the OAEs had a differential affect on the benthonic fauna. The low oxygen tolerance of agglutinated taxa allows them to live in conditions unfavourable for calcareous benthonic fauna. These OAEs are characterised by an impoverished benthonic population. The low oxygen levels in the bottom waters, during the OAEs, favoured an expansion of the agglutinated taxa. An increase in the agglutinated forms (over the calcareous ones) may not necessarily indicate anoxic conditions (resulting from transgressions) or deep marine conditions. The sharp rise in number of agglutinated taxa in the late mid-Turonian, in the Cauvery Basin, is very dramatic (Fig. 6.2). This is a result of the sudden shallowing of the Basin (as discussed later). An increase in agglutinated forms, associated with an increase in planktonic forms will, however, undoubtedly reflect transgressive events.

It must be emphasised, however, that application of planktonic foraminifera to measure sea-level changes should be practised with great caution, if not scepticism. Water depth is equal to the accommodation space available minus the sediment accumulated. Changes in water depth is a function of various factors and sea-level rise is only one of them. So even during a relative sea-level rise, rapid sedimentation (basin infilling) can keep the water depth constant. An increase in water depth, therefore, may not necessarily result from a sea-level rise. Also “transgressions” and “regressions” should not be confused with sea-level “rises” and “falls” respectively. Eustatic sea-level changes, basin subsidence, rate of sedimentation and local factors (which are unique to every basin) should all be taken into account before reaching any conclusion.
6.4.2 Recognition of the mid-Cretaceous sea-level changes in the Cauvery Basin by means of planktonic foraminifera

The planktonic foraminiferal assemblage, from the mid-Cretaceous shelf succession of the Cauvery Basin, represents open marine conditions. The study shows four levels of distinct structural changes and/or speciation in the planktonic fauna. These four levels are, in the latest Albian-earliest Cenomanian, late mid-Cenomanian, latest Cenomanian-earliest Turonian and mid-Turonian. The changes observed in the planktonic fauna are in terms of structural readjustments, test size, ornamentation, diversity and abundance of the fauna.Appearances and expansions in keeled, highly calcified and high spired and/or plano-convex forms, at these levels, is significant. These levels of significant change in the planktonic foraminifera reflect major mid-Cretaceous sea-level changes in the Basin. The two levels of major taxonomic change in the planktonic fauna fall within the mid-Cretaceous anoxic events. At or during the latest Albian-earliest Cenomanian interval (OAE-1c), the appearance of keeled taxa was a significant development. After the recovery from the OAE-1c no structural changes in the planktonic community is observed until the latest Cenomanian-earliest Turonian (OAE-2). The latest Cenomanian-earliest Turonian event is the most dramatic. The event saw a major readjustment of the planktonic community (as discussed under Section 6.3.2). In between the two anoxic events (mid- to late Cenomanian), and after OAE-2 (late mid-Turonian) there was a considerable speciation in the morphological characters (e.g., size, ornamentation, calcification etc.) of the planktonic foraminifera. No major structural change in the planktonic fauna is observed during the post OAE-1c to pre OAE-2 and post OAE-2 time intervals. The peaks in the planktonic:benthonic and agglutinated:calcareous ratio graphs of the Cauvery Basin (Fig. 6.2) occur at or very near the same levels. Peaks in the P:B ratio coincide with the spikes in the agglutinated:calcareous graph. This simultaneous increase in the planktonic and agglutinated taxa (at the expense of calcareous benthonic) suggests an increase in water depth. The four intervals in the mid-Cretaceous when planktonic and agglutinated fauna expand reflect times of
increased water depth, when the shelf was transgressed by the sea (Hancock & Kauffman 1979, Haq et al. 1987, 1988, Raju et al. 1993).

The study shows that during the late Albian the shelf experienced a major flooding event. The upper Albian-lower Cenomanian succession records two prominent peaks, first in the latest Albian (Fig. 6.2) and a second in the earliest Cenomanian (Fig. 6.3A), in the planktonic:benthonic ratio (P:B ratio) and a fall in the benthonic diversity (B. diversity) graphs (Figs 6.2 & 6.3A). The event coincides with the Late Albian oceanic anoxic event (OAE-1c). The lower Upper Albian succession is dominated by shallow-water *Hedbergella*. By the late Albian, juveniles of *Rotalipora* and *Praeglobotruncana* species are found. The recovery from the late Albian oceanic anoxic event saw beautifully preserved and well developed *Rotalipora* and *Praeglobotruncana* species (as discussed under Section 6.3.1). The appearance of single keeled, moderately spired to plano-convex species of *R. appenninica*, *R. brotzeni* and *R. reicheli* together with moderate to high spired and well ornamented *P. stephani* and *P. gibba* is significant. In Hart & Bailey (1979) depth zonation scheme this assemblage falls within the range of zone 2 (lower part) and zone 3, an intermediate water depth, population. The species that inhabit deeper-waters will be reported (in substantial numbers) in the shelf sediments only when sufficient water depth is made available. This, together with an overall increase in the percentage of planktonic fauna over the benthonic fauna reflects an increase in the water depth over the shelf. The occurrence of intermediate to relatively deep-water *Rotalipora* and *Praeglobotruncana* species in the shelf sediments of the Basin indicate a flooding event. It suggests that during the latest Albian-earliest Cenomanian the shelf was transgressed by the sea. This increase in water depth is also reflected in the benthonic population. During the anoxia the agglutinated fauna shows a slight expansion in the late Albian and at the Albian-Cenomanian boundary (Fig. 6.2).

After the appearance of keeled taxa in the late Albian, the early Cenomanian-early mid-Cenomanian interval does not show any marked structural change in the planktonic fauna. The late Albian and the Albian-Cenomanian abrupt rise in the
planktonic:benthonic ratio, during the OAE-1c, dropped sharply (Figs 6.2 & 6.3A). After this initial drop in the P:B ratio, the graph remains more or less constant (Fig. 6.2) or shows a gradual decline (Fig. 6.3A) during the early to early mid-Cenomanian. A near constant to gradual decline in planktonic percentage suggests that the water depth remained more or less constant or reduced gradually. This implies that the interplay of sea-level positions, sediment infilling and Basin subsidence, during the early Cenomanian to early mid-Cenomanian, maintained a near constant water depth on the shelf. If the late Albian sea-level rise was followed by a stillstand (taking into account that the Basin subsidence and eustatic sea-level changes resulted in a relative stillstand position) then sediment infilling should have allowed shallowing of the Basin. In that case a significant drop in planktonic fauna should be observed. Although a gradual fall in the planktonic percentage is observed in the Karai-4 well (Fig. 6.3A), but this is probably due to the lack of close sampling and may not reflect Basin shallowing. In the Karai-Kulakkalnattam traverse, the P:B ratio graph (Fig. 6.2) remains more or less constant. This implies that with any of the perceived combinations possible, between the sea-level changes, sediment infilling and Basin subsidence; a relative rise in the sea-level should have existed during the early Cenomanian. This allowed a near constant water depth (hence a constant planktonic percentage) to be maintained on the shelf. The idea of a relatively rising sea-level, keeping ahead of any shallowing brought about by sediment infilling and Basin subsidence, is supported by the benthonic fauna. There is an expansion of agglutinated taxa (Fig. 6.2) with a relatively high planktonic percentage at this time.

The gradual rise in the sea during the early to early mid-Cenomanian was followed by a sudden pulse of deepening in the late mid-Cenomanian. The P:B ratio graphs (Figs 6.2 & 6.3A) do not reflect this very well, which could be due to the lack of close sampling for the mid-Cenomanian interval. The study of morphological characters of the planktonic foraminifera, however, strongly support a pulse of deepening. The planktonic fauna shows an increase in the test size, ornamentation and spire height.
Progressive speciation and expansion in the Rotalipora and Praeglobotruncana population is observed. The assemblage is dominated by large, well developed, plano-convex R. reicheli and moderately spired R. cushmani, R. deeckei, R. greenhornensis and R. montsalvensis. Amongst the Praeglobotruncana population moderately high to very high spired and highly calcified forms of stephani and gibba with highly beaded ornamentation colonised. The dominance of high spired and plano-convex species during the late mid-Cenomanian is a reflection of a further increase in water depth on the shelf.

The second major, but not the maximum (as discussed later), transgression was in the earliest Turonian. Important taxonomic changes (for the second time), in the planktonic foraminiferal community, occurred at the Cenomanian-Turonian boundary. The deep-water fauna either disappeared or were greatly reduced in numbers. This coincides with the globally reported Cenomanian-Turonian oceanic anoxic event (OAE-2). A sharp rise in the P:B ratio (Figs 6.2, 6.3B & 6.3C) associated with an expansion of the agglutinated taxa (at the expense of calcareous benthonic) is reported at this level. Major readjustments (related to convexity of the test, spire height, position of aperture, development of keel/s, calcification, etc.) in the planktonic foraminifera occurred (as discussed under section 6.3.2). The single-keeled Rotalipora disappeared and were replaced by new, keeled (including double keeled) taxa. Hedbergella was largely replaced by Whiteinella, Dicarinella and Marginotruncana appeared (see Tewari et al. 1996a in Appendix I). The recovery from the anoxic event was rapid and was followed by re-colonisation of deeper-water taxa. The appearance and expansion of strongly plano-convex D. hagni (reported from Cauvery Basin) and of high-spired, heavily calcified D. imbricata, P. stephani, P. gibba, W. brittonensis and Marginotruncana species (as discussed under Section 6.3.2) was very important. In Hart & Bailey (1979) depth stratification, the plano-convex and high-spired morphotypes characterise deeper-waters (zone 4). The appearance and diversification of strongly plano-convex and very high-spired morphotypes, in large numbers, suggests that the shelf (Cauvery Basin) experienced a major, perhaps not the maximum (as
discussed later), transgression at this time. This allowed, the otherwise deeper-water inhabiting species to invade the shelf.

The Mesozoic-Cenozoic eustatic sea-level curve records its peak in the early Turonian (Haq et al. 1987, 1988). Studies from the basins across the world (Hart & Bailey 1979, Hancock & Kauffman 1979, Hancock 1989) record maximum transgression (resulting from eustatic sea-level maxima) in the early Turonian. The present study in the Cauvery Basin, reports a major transgression in the early Turonian, but this does not appear to be the maximum flooding event. The planktonic foraminiferal study suggests that the maximum water depth attained by the shelf (Cauvery Basin) was in the mid-Turonian (as discussed later). What the study fails to show is whether this mid-Turonian maximum flooding event was a regional phenomenon (in terms of the Indian Ocean) or simply a local effect (resulting from subsidence along SE coast of India).

The absolute (eustatic) sea-level rise is not relevant in determining the water depth across the continental shelf. It is the flooding of the shelf, hence the relative sea-level rise (together with basin infilling), which governs the water depth and in turn the distribution of planktonic foraminifera. One thing which is clear from the study, in the Cauvery Basin, is that maximum water depth was attained in the mid-Turonian. This idea of maximum water depth (across the shelf) during the mid-Turonian is reflected in the constantly rising P:B ratio (Figs 6.2 & 6.3C). A mechanism should, therefore, have existed which allowed a relative rise in the sea-level (keeping ahead of Basin shallowing) even after the early Turonian flooding event. If it is accepted that the global sea-level curve (Haq et al. 1987, 1988) is applicable to every basin, then the early Turonian major flooding event in the Cauvery Basin is in response to the eustatic changes. This early Turonian flooding event in the Basin, should, in a strict sense, also be the maximum flooding event. The event should, therefore, be followed by a gradual fall in the sea-level with a major regression in the late Turonian (following Haq et al. 1987, 1988 sea-level curve). This, however, is not the case in the Cauvery Basin. After the major flooding event in the early Turonian, water depth across the shelf continues
to increase. The Basin reaches its maximum water depth in the mid-Turonian (as reflected by the planktonic foraminifera). Taking the argument further and incorporating the effect of contemporaneous tectonics in a basin, the picture becomes somewhat clear. While the major flooding event in the early Turonian could be taken to be as a result of eustatic sea-level rise; the mid-Turonian maximum flooding event recorded in the Basin, could be explained to be tectonically controlled (local tectonics) and, therefore, taken to be a local phenomenon. After the eustatic sea-level rise in the early Turonian local subsidence allowed a relative rise in the sea-level in the Cauvery Basin (even though the eustatic sea-level was dropping according to Haq et al. 1987, 1988), with the maximum flooding of the shelf occurring in the mid-Turonian.

A completely different approach to this problem is to question the accuracy of the Haq et al.'s (1987, 1988) sea-level curve. This raises doubts on the validity of its application to the Indian Ocean. Haq et al.'s (1987, 1988) curve is biased. Firstly (as discussed earlier), the sea-level curve is based on commercial seismic data and does not take into account basin subsidence, sediment flux etc. Secondly, their work (Haq et al. 1987, 1988) is based on the data from the Atlantic and Pacific Oceans. How well this sea-level curve fits in with the Indian Ocean is not clear. In that case the sea-level curve (Haq et al. 1987, 1988) may not necessarily reflect the true picture for the Indian Ocean. The possibility does exists that while the Mesozoic-Cenozoic peak was reached, in the Atlantic and Pacific Oceans, in the early Turonian; it was not until mid-Turonian that Indian Ocean had its peak. These inferences are, however, over simplistic. In actual practice eustatic sea-level changes are more complicated. Plate movements, sea-floor spreading, etc. play an important role in governing the overall eustatic response of sea.

The shelf experienced maximum flooding in the mid-Turonian when there was a final flux of deeper-water fauna. This is reflected in the P:B ratio graphs which maintain a constant high, reaching its peak (Figs 6.2 & 6.3C) in the mid-Turonian. The appearance of plano-convex *P. helvetica* and *P. praehelvetica* morphotypes in the mid-Turonian, is
significant. Strongly plano-convex *P. helvetica*, *P. praehelvetica* and *D. hagni* dominate. Amongst the high-spired forms are highly ornamented and heavily calcified *P. gibba*, *P. stephani*, *W. brittonensis*, *M. schneegansi* and *M. marginata*. The diversification of plano-convex morphotypes in the mid-Turonian reflects final pulse of deepening in the shelf. The mid-Turonian assemblage is dominated by a very diverse, very robust, deep-water inhabiting taxa. This suggests that, perhaps the maximum transgression in the Cauvery Basin occurred in the early mid-Turonian, a little later than the globally recorded Cenozoic-Mesozoic maxima in the early Turonian. This pulse of maximum water-depth in the Cauvery Basin, in the early mid-Turonian could, however, be simply due to local factors, e.g., Basin subsidence (as discussed earlier). Similar mid-Turonian sea-level phenomenon (pulse of deepening) has been reported from elsewhere (Pratt et al. 1993, Jenkynks et al. 1994). Several authors (e.g., Scholle & Arthur 1980, Arthur et al. 1987, Jenkyns et al. 1994, etc.) using carbon-isotope profile as a proxy for sea-level demonstrate a remarkable similarity between the $^{13}$C peaks and sea-level rises. The mid-Cretaceous carbon-isotope curve shows a rapid decay after its peak at the Cenomanian-Turonian boundary (e.g., Scholle & Arthur 1980, Pomerol 1983, Jarvis et al. 1988, Peryt & Wyrwicka 1993, Jenkyns et al. 1994, Peryt et al. 1994, Holser et al. 1996, etc.). Jenkyns et al. (1994) observe that in the Chalk sections in southern England and Scaglia sections from central Italy this rapid decay (after its peak in the Cenomanian-Turonian) in the mid-Cretaceous carbon-isotope curve is punctuated by a minor positive $^{13}$C excursion in the mid-Turonian. A mid-Turonian $^{13}$C spike is also reported in the isotope curve from the Western Interior Seaway of North America (Pratt et al. 1993). These mid-Turonian positive excursions, possibly indicating a sea-level rise, are interpreted (Jenkyns et al. 1994) to reflect a regional and not a global sea-level phenomenon. In that case the mid-Turonian pulse of deepening in the Cauvery Basin (as discussed earlier) is simply a local phenomenon.

In the latest mid-Turonian the succession is cut by a sudden regression (see Chapter 7 for details). From a very high P:B ratio a sharp and an abrupt fall in the planktonic percentage, associated with an equally sharp rise in the agglutinated taxa occurs (Fig.
6.2). This drop in the planktonic fauna (from 60-65% of the total foraminiferal population to zero) reflects the sudden withdrawal of sea from the shelf (see Chapter 7 for details). The succession is characterised by a very high abundance (99% of the total foraminiferal population) but a low diversity agglutinated taxa. On the Mesozoic-Cenozoic sea-level curve (Haq et al. 1987, 1988) the early Turonian peak is followed by a major regression in the late Turonian. The late Turonian major regressive event is reported globally (Hancock & Kauffman 1979, Hart & Bailey 1979, Haq 1987, 1988, Hancock 1989). This globally reported late Turonian regressive event in the Cauvery Basin occurs a little earlier, in the late mid-Turonian. This once again casts doubts on the accuracy and hence applicability of Haq et al.’s (1987, 1988) sea-level curve. At the same time it points out that the regional and local factors (e.g., tectonics, basin subsidence, etc.) play a significant role when translating the global signatures to regional and local level. In the Cauvery Basin the local factors, definitely played an important role in delaying (e.g., delaying early Turonian maximum transgression) and predating (e.g., late Turonian eustatic regression) global events.

6.5 Summary

The mid-Cretaceous succession of the Cauvery Basin records a rich foraminiferal assemblage. The study shows that the globally reported mid-Cretaceous anoxic events (OAE-1c and OAE-2), resulting from world-wide marine transgressions, are present in the Basin. The late Albian/Albian-Cenomanian event (OAE-1c) and the late Cenomanian-early Turonian event (OAE-2) record major taxonomic changes in the planktonic foraminifera. After these mid-Cretaceous OAEs, a more ornamented and more prominently keeled fauna dominated the Cauvery Basin. The study reflects, in general, the pattern of mid-Cretaceous sea-level changes in the Basin. The pattern of evolution and expansion of the planktonic foraminifera suggests a continuously rising sea-level (keeping ahead of Basin shallowing) in the mid-Cretaceous; with four periods of major transgressions. These levels are, at the late Albian, mid-Cenomanian, late Cenomanian-early Turonian and mid-Turonian intervals. The pattern of sea-level
changes in the Cauvery Basin followed, in general, the global sea-level curve, but has been influenced by local factors.
Table 6.2:  Planktonic:benthonic ratio, benthonic diversity, agglutinated: calcarceous ratio and planktonic foraminifera percentage graphs for the Karai-Kulakkamlam traverses.

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Figure 6.2: Planktonic:benthonic ratio, benthonic diversity, agglutinated; calcarceous ratio and planktonic foraminifera percentage graphs for the Karai-Kulakkamlam traverses.
Figure 6.3: Planktonic:benthonic ratio, benthonic diversity, agglutinated: calcareous ratio and planktonic foraminifera percentage graphs for the Karai-4, Karai-6 and Karai-3 wells.
Chapter 7

Application of ichnology to sequence stratigraphic concepts to the late Turonian-Coniacian Garudamangalam Sandstone Formation
7.1 Introduction

Ichnology has a unique position in stratigraphic studies. Trace fossils record the in-situ behaviour pattern of benthonic organisms, as dictated and/or modified by the then existing environmental constraints (Pemberton et al. 1990, 1994). The sensitivity of trace fossils to palaeoenvironmental changes is a function of sea-level fluctuations. Ichnology contains, therefore, a unique blend of information on sedimentology and palaeontology of depositional environments. When used with caution and in conjunction with sedimentary and palaeontology data, ichnofossil studies hold a great potential for their application in sequence stratigraphy. Table 7.1 and Figure 7.1 presents a glossary of sequence stratigraphy terms used in this Chapter.

7.2 Application of ichnology to sequence stratigraphy

"Sequence stratigraphy is the study of rock relationships within a chronostratigraphic framework of repetitive, genetically related strata bounded by surfaces of erosion or nondeposition, or their correlative conformities" Van Wagoner et al. (1988). Sequence stratigraphy involves the recognition of systems tracts defined by unconformities and bounding discontinuities, related to cycles of sea-level fluctuation. Different systems tracts occur at different positons of relative sea-level. The objective in sequence stratigraphic study is the identification of major breaks in deposition and corresponding bounding discontinuities. These discontinuities have a variety of expressions. They can be erosional discontinuities, non-depositional hiatuses or depositional discontinuities. The discontinuities can range from very sharp to subtle. It is in the latter case where ichnology, along with other available data, e.g., stratigraphic position, palaeontology, sedimentology, etc., can be applied effectively to recognise various types of discontinuities and their genetic interpretation (Pemberton et al. 1994). The surfaces that bound sequences and/or systems tracts have, in general, distinct ichnologic signatures. Trace fossil characteristics across two sequence boundaries are similar, despite significant lithologic differences.
• **Bounding discontinuity**: a laterally traceable discontinuity; can be an unconformity, ravinement surface, onlap or downlap surface, condensed horizon or hardground.

• **Condensed horizon**: distinctively thin, marine, stratigraphic unit of low or negligible sediment accumulation; characterised by sediment starvation (very low or negligible sedimentation rates, Loutit et al. 1988) or sediment by-passing (Kidwell 1989).

• **Forced regression**: a seaward translation of shoreline occurring in response to relative sea-level fall and is independent of sediment flux variation (Posamentier et al. 1992).

• **Highstand systems tract (hst)**: is the upper-most systems tract and overlies the surface of maximum flooding. A hst records later stages of eustatic sea-level rise, highstand and early sea-level fall. The top of the hst is bounded by a type 1 or type 2 sequence boundary (Van Wagoner et al. 1988).

• **Lowstand systems tract (lst)**: is the lowermost systems tract. If it lies directly on a type 1 sequence boundary it is called lowstand systems tract and if on a type 2 boundary it is called shelf-margin systems tract. The lst records sea-level lowstand and the earliest phases of subsequent transgression. The top of the lst is marked by a transgressive surface (Van Wagoner et al. 1988).

• **Marine flooding surface**: a surface separating younger from older strata, across which there is evidence of an abrupt increase in water depth (Van Wagoner et al. 1988).

• **Maximum flooding surface**: a transgressive surface separating a transgressive systems tract (below) from a highstand systems tract (above). It is commonly characterised by a condensed horizon (Van Wagoner et al. 1988).

• **Parasequence**: a relatively conformable succession of genetically related beds or bedsets bounded by marine flooding surfaces and their correlative surfaces. Parasequences are separated by marine flooding surfaces across which there is evidence of deepening and, therefore, may reflect shorter-term, lower magnitude fluctuations in sea-level (Van Wagoner et al. 1988).

• **Ravinement surface**: an erosion surface produced during marine transgression of a formerly subaerial environment.

• **Sequence**: is the fundamental unit in sequence stratigraphy. It is a relatively conformable succession of genetically related strata bounded at its top and base by unconformities and their correlative conformities. As the bounding unconformities are produced by relatively rapid, high magnitude sea-level falls, each sequence represents a major eustatic cycle. Depositional sequences are made up of a varying number of smaller scale parasequences. A sequence is divided into systems tracts (Van Wagoner et al. 1988).

• **Systems tracts**: a linkage of contemporaneous depositional systems corresponding to distinct phases of the associated eustatic cycle. There are three types of systems tracts—(1) lowstand systems tract, (2) transgressive systems tract, and (3) highstand systems tract. Systems tracts are facies-independent. They can be recognised on the basis of their position within a sequence, character of their bounding surfaces, general sedimentary, palaeontology and geochemical characters and parasequence stacking patterns (Posamentier & Vail 1988, Van Wagoner et al. 1988).

Table 7.1: Glossary of sequence stratigraphic terms used in this Chapter.
• **Transgressive systems tract (tst):** is the middle systems tract of both type 1 and type 2 sequences. The base of tst is a transgressive surface at the top of the lowstand or shelf margin systems tracts. The sediments reflect sediment input associated with rapid landward migration of the shoreline and consequent landward trapping of sediments. The upper part of the tst is bounded by maximum flooding surface (Posamentier & Vail 1988, Van Wagoner et al. 1988).

• **Type 1 sequence boundary (SB):** is bounded by a type 1 SB characterised by subaerial exposure and concurrent subaerial erosion associated with stream rejuvenation, a basinward shift in facies, a downward shift in coastal onlap and onlap of overlying strata. A type 1 SB forms when the rate of eustatic sea-level fall exceeds the rate of basin subsidence at the depositional shoreline break, producing a relative sea-level fall at that position (Posamentier & Vail 1988, Van Wagoner et al. 1988).

• **Type 2 sequence boundary (SB):** is bounded by a type 2 SB marked by subaerial exposure and a downward shift in coastal onlap; but no subaerial erosion and a basinward shift in facies. A type 2 SB is interpreted to form when the rate of eustatic fall is less than the rate of basin subsidence at the depositional shoreline break, so that no relative fall in sea-level occurs at this shoreline position (Posamentier & Vail 1988, Van Wagoner et al. 1988).

Table 7.1 (cont.): Glossary of sequence stratigraphic terms used in this Chapter.

Trace fossils, because they represent behaviour patterns, contain substantial information for palaeo-environmental studies. These behavioural patterns are genetically controlled but not phylogenetically restricted (Pemberton 1994). The recognition of these behavioural trends facilitate environmental interpretations. The ichnofossils have been grouped into nine ichnofacies (Pemberton 1994). These include, one non-marine Scoyenia facies; five marine, softground facies and three substrate-controlled ichnofacies. The marine, softground ichnofacies are further divided into the nearshore marine and coastal facies (Psilonichnus, Skolithos and Cruziana); open marine Zoophycos facies and deep marine Nereites facies. The substrate-controlled (based on substrate type and consistency) ichnofacies include the firmground Glossifungites, woodground Teredolites and hardground Trypanites ichnofacies. The ichnofacies reflect environmental factors, e.g., substrate consistency, oxygen levels, food supply, etc., to which the trace-making organisms adapted (Frey & Pemberton 1984, Frey et al. 1990). The distribution of these ichnofacies is not necessarily controlled by water-depth, a commonly held misconception (Frey et al. 1990). Many
Figure 7.1: Eustatic curve showing the position of different systems tracts.
environmental parameters, e.g., water turbidity, food supply, grain size, etc., however, do tend to change with water depth. These changing parameters (with water depth) affect the corresponding trace fossil assemblage. Trace fossil associations in this respect can reflect palaeobathymetric trends.

Various workers, e.g., Downing & Walker (1988), Reinson et al. (1988), Savrda (1991a,b), Savrda & King (1993), Savrda et al. (1993), Pemberton et al. (1994), etc., demonstrate how ichnology could be employed to resolve breaks in the deposition. The first is by recognition of substrate-controlled ichnofacies, which mark a time gap between the original deposition of a unit and later superposition of a post-depositional trace fossil suite. In clastic settings most of the substrate-controlled trace fossil assemblages are associated with an erosion, during which the substrate is exhumed and made available for the organisms. There are some exceptions to this rule. In contrast to firmgrounds and hardgrounds, the woodgrounds are resilient substrates and may not necessarily be erosionally exhumed. Depositional breaks, especially marine flooding surfaces and condensed sections, may be semilithified or lithified (Loutit et al. 1988) and subsequently colonised without any erosion. In carbonate settings, firmground and hardground surfaces may occur as a result of submarine cementation (Bromley 1975) at the sediment-water interface (nondepositional break). In general recognition of substrate-controlled ichnofacies is regarded as equivalent to the erosional discontinuity in stratigraphic record. The substrate-controlled ichnofossil suite corresponds to a hiatus, during which the substrate was exhumed by erosion and subsequently colonised, before the deposition of the overlying unit.

The second approach, to the application of ichnology in sequence stratigraphy concepts, is a careful analysis of vertical ichnologic successions which reflect fundamental changes in depositional settings. Detailed ichno-sedimentologic and ichno-palaeontologic studies (e.g., Downing & Walker 1988, Reinson et al. 1988, Savrda 1991a,b, Savrda & King 1993, Savrda et al. 1993, Pemberton et al. 1994, etc.) demonstrate that degree of bioturbation, general ichnofabric and ichnofossil
assemblages vary significantly between different systems tracts within each sequence. These variations reflect changes in substrate consistency, sediment rate, energy levels, etc., which are a function of both magnitude and phase of the associated sea-level cycle. This twin approach of ichno-sedimentology and ichno-palaeontology holds a great potential in the application of ichnology to sequence stratigraphic studies.

In a pilot study, ichnology is used to apply sequence stratigraphic concepts to the late Turonian-Coniacian Garudamangalam Sandstone Formation (see Chapter 3 for details on lithostratigraphy) in the Cauvery Basin. It must be noted, however, that the approach is very basic and is limited to the identification of broad sequence stratigraphic concepts. It is not the scope of present study to address high resolution sequence stratigraphy of the Basin.

7.3 Application of ichnology to sequence stratigraphy concepts to the late Turonian-Coniacian Garudamangalam Sandstone Formation

The early late Albian to latest mid-Turonian Karai Clay Formation consists of claystones, silty- and sandy-claystones. Sediments of the Karai Formation are interpreted as having been deposited under relatively deep, open-marine, outer shelf depths (based on planktonic foraminiferal studies). The contact (as discussed later) with the overlying Garudamangalam Sandstone Formation is erosional in places and conformable at others. The Garudamangalam Formation is a latest Turonian-Coniacian estuarine-nearshore shallow-marine, siliciclastic unit. It consists of fine to coarse calcareous sandstones (including distinct layers of carbonate-cemented sandstone concretions), shell-rich sandstones, pebble-conglomerate sandstones, hard calcareous sandstone, fine- to medium-grained silts and silty-sandstones. The Formation is divided into two members (Fig. 7.2), a lower Kulakkalnattam Sandstone Member and an upper Anaipadi Sandstone Member. The Garudamangalam Formation is followed unconformably by the (?) late Santonian-early Campanian Sillakudi Sandstone Formation (see Chapter 3 for details on the lithostratigraphy of the Cauvery Basin).
Hiatus

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<table>
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<th>FORMATIONS</th>
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<tr>
<td>Karai Clay Formation</td>
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- terebratulids
- small ammonites
- log ground (xylic) material
- rhynchonellids
- large ammonites
- calcareous sandstone nodules
Following the deposition of relatively deeper-water, open marine Karai Clay Formation there was a major regression in the latest-mid/earliest late Turonian. Regression, a basinward migration of the shoreline, is a function of rate of sediment flux and relative changes in sea-level. Posamentier et al. (1992) have recognised two types of regressions. A “normal regression”, which results when the rate of clastic input to the shoreline is greater than the space (accommodation) available in the shelf. There is, however, one exception to this rule. In shelves with high wave and current activity no regression will occur, despite high rates of clastic input. The sediment, in these cases, will be dispersed over a wide area not allowing the self to prograde. Normal regressions occur during a relative sea-level stillstand or rise. By contrast, “forced regression” is a function of relative sea-level fall and is independent of the sediment flux variations in the shelf. Forced regressions are commonly associated with a zone of sedimentary by-pass, subaerial exposure and possible fluvial erosion (between the new and the preceding shorelines). An abrupt occurrence of anomalously coarser and more proximal sediments in a distal marine setting is a major feature of forced regression (Posamentier et al. 1992). In such cases the shallow-water and shoreface facies occur detached from the shoreline. The basal contact of these deposits (during forced regression) have a sharp base, commonly erosional in the proximal part, forming an unconformity (i.e. sequence boundary). Seaward, these deposits grade into a conformable contact (Posamentier et al. 1992).

The latest-mid/earliest late Turonian regressive event (in the Cauvery Basin), towards the top of the Karai Clay Formation, marks a rapid, out-of-sequence shallowing. The planktonic foraminifera were significantly reduced (see Chapter 6) by a rapid shallowing of the seaway. In the Kulakkalnattam river section (Locality 1 in Fig. 7.3) the top of the clay succession (Karai Clay Formation) records a sharp reduction in the planktonic foraminifera, from 60-65% of the total foraminiferal population to zero (Fig. 7.4). A diverse and high abundance planktonic assemblage is replaced by a very low diversity, but a very high abundance (99.9% of the total population) agglutinated fauna (e.g., *Haplophragmoides kirki* Wickenden, *H. aff. multiformis* Krasheninnikov,
1. Kulakkalnattam stream section- concretions
2. near Kottur-small ammonites & brachiopods
3. Stream section between Mungalpari & Sattanur
4. 2 km west of Kulattur-large ammonites
5. North of Kulattur-pebble-conglomerate bed
6. 2 km north of Garudamangalam
7. 2.5 km west of Kunnam- shell sandstone
8. Mungalpari- shell sandstone
9. 1.5 km north of Alundalippur
10. Garudamangalam quarry- shell sandstone
11. Gully section near Saradamangalam
12. Stream section near Saturbhagam
13. Sattanur tree

Figure 7.3: Location map of the studied localities and those mentioned in this Chapter.
Figure 7.4: Geological succession in the river section 1 km SW of Kulakkalnattam village (Locality 1 in Figure 7.3).

### KARAI CLAY FORMATION  |  KULAKKALNATTAM SANDSTONE MEMBER
---|---
MIDDLE - UPPER TURONIAN

<table>
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<tr>
<th>Selected Foraminifera</th>
<th>Planotetric</th>
<th>Agglutinated</th>
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<tr>
<td>Dicarinella algeriana</td>
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<td>Dicarinella imbricata</td>
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<td>Marginotruncana schneegansi</td>
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<td>Praeglobotruncana praehelvetica</td>
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<td>Whiteinella brittonensis</td>
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<td>Haplophragmoides concavus</td>
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<td>Haplophragmoides kiri</td>
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<td>Haplophragmoides aff. multiformis</td>
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Diagram: Geological layers, samples, foraminifera distribution.
H. concavus Chapman and other quite rare Haplophragmoides spp. and Cribrostomoides sp.). The abrupt juxtaposition of eustarine-nearshore Kulakkanattam Sandstones (coarser and more proximal facies) against the relatively deeper marine Karai Clays (distal marine facies) represents a case of forced regression (sensu Posamentier et al. 1992) resulting from a major fall in the relative sea-level. The boundary between the two lithostratigraphic units (Karai Formation and Garudamangalam Formation) constitutes, therefore, a type-1 sequence boundary (sensu Posamentier et al. 1988), caused by forced regression. This late Turonian regression is known from a wide geographical area (e.g., Hancock 1976, 1989, Hancock & Kauffman 1979, Hart & Bailey 1979, Haq et al. 1987, 1988, Raju et al. 1993, etc.) and identifies a most important sequence boundary in which it is described.

Approximately 1.5 km north of Alundalippur (Locality 9 in Fig. 7.3) the contact between the underlying Karai Formation and the overlying Garudamangalam Formation is erosional. The relief of the contact is not very sharp and the trace fossil assemblage (at the contact) is used to identify the subtle erosional expression. Here (1.5 km north of Alundalippur, Locality 9 in Fig. 7.3) the base of the Garudamangalam Formation has a pebble-conglomerate horizon associated with a limited occurrence of substrate-controlled Teredolites (woodground) and Glossifungites (firmground, Photo 7.1) trace fossil suite. The pebbles are made of garnet (some approximately 30x15 cm in size), basement gneiss and quartz. The presence of a pebble-conglomerate horizon indicates that the Basin was under subaerial erosion during the lowstand of relative sea-level (following the forced regression). During the period of erosion firmground surfaces were produced. Subsequent transgression exposed the former lowstand erosional discontinuity to marine and marginal marine conditions and introduced (as discussed later) xylic (woodground substrate) material to the marine settings. Organisms then colonised the exhumed firmgrounds and the introduced xylic (woodground) substrates. The lowstand systems tract is absent here (1.5 km north of Alundalippur, Locality 9 in Fig. 7.3) and the transgressive systems tract (represented by the Garudamangalam Formation) is juxtaposed over the sequence boundary.
Photo 7.1: Glossifungites (firmground) trace fossil suite occurring in association with a pebble conglomerate horizon at the base of the Garudamangalam Sandstone Formation, approximately 1.5 km north of Alundalippur (Locality 9 in Fig. 7.3).

(unconformity). The erosional unconformity formed during the lowstand of relative sea-level is extensively modified during the ravinement process. The association of a pebble lag with substrate controlled ichnofacies suggests that the discontinuity is an amalgamated lowstand erosion (unconformity) and transgressive lag. The contact is interpreted as being an erosional surface representing a coplanar sequence boundary-transgressive ravinement surface. Near the Kulakkalnattam powerline (in the Kulakkalnattam river section, Locality 1 in Fig. 7.3) a less well developed ravinement surface (transgressive surface of erosion) is observed. Here (at the Kulakkalnattam powerline) the post-Karai Clay erosive surface lacks a substrate-controlled trace fossil suite, but is marked by a thin layer of basement pebbles representing a transgressive lag. A similar coplanar sequence boundary-transgressive surface, associated with
substrate-controlled ichnofacies, has been reported (Savrda 1991b) from Alabama. Savrda (1991b) observed that, at the Cretaceous-Tertiary contact in Alabama, a substrate-controlled ichnofacies occurred only where the lowstand unconformity (sequence boundary) amalgamated with the overlying transgressive surface of erosion. The lowstand systems tract is absent here (1.5 km north of Alundalippur and power line near Kulakkalnattam; Localities 9 and 1 in Fig. 7.3 respectively) and the transgressive systems tract is juxtaposed above the sequence boundary.

At other places the contact between the underlying Karai Clay Formation and the overlying Garudamangalam Sandstone Formation is conformable. In the Kulakkalnattam river section (Locality 1 in Fig. 7.3) and approximately 2 km north of Garudamangalam (Locality 6 in Fig. 7.3) the Karai Clay terminates abruptly beneath a distinct layer (double layer in some cases) of carbonate-cemented, sandstone concretions (Photo 7.2) and/or cannon-ball nodules (Photo 7.3). These nodular-concretionary layers are followed (to a lesser extent in Locality 6, Fig. 7.3) by medium- to coarse-grained calcareous sandstones. The sandstone unit (including the concretions) represents the lower part of the Kulakkalnattam Sandstone Member (lower member of the Garudamangalam Sandstone Formation). The distinct layer (double layer in some cases) of concretions (Photos 7.2 & 7.3) at the base of the Kulakkalnattam Sandstone Member (lower member of the Garudamangalam Formation) has been reported (e.g., Jain 1976, Nair & Vijayam 1981, Sundaram & Rao 1986, etc.) as a conglomerate bed, being used to identify a major unconformity between the underlying Karai Clay Formation and the overlying Garudamangalam Sandstone Formation. These are, however, carbonate-cemented, sandstone concretions which are interpreted here as having formed (as discussed below) during several marine flooding events. Taylor et al. (1994) observed that cementation, a common phenomenon within shallow-marine sandstones, frequently is in the form of laterally extensive, carbonate cemented horizons, often occurring as nodule layers within the lowstand deposits. Diagenetic studies (Taylor et al. 1994) show that this cementation is predominantly early and may be related to periods of low sediment accumulation.
Photo 7.2: Carbonate-cemented, sandstone concretions at the base of the Garudamangalam Sandstone Formation, Locality 6 in Fig. 7.3.

Photo 7.3: A cannon-ball, nodular layer of concretions at the base of the Garudamangalam Sandstone Formation, Locality 6 in Fig. 7.3).
Marine flooding surfaces represent periods of depositional hiatuses (low or negligible sediment accumulation) when the underlying sands remain within shallow early diageneric zones for relatively long periods. This allows early diageneric solutes, that cause carbonate cementation, to build up within the sediment pore spaces. Taylor et al. (1994) conclude that it is conceivable, therefore, for extensive early cementation to occur in association with major marine flooding surfaces within depositional sequences. Taylor et al. (op. cit.) explain the occurrence of carbonate concretions in the Blackhawk Formation, Utah by this mechanism (cementation below marine flooding surfaces). The highly condensed nature (as discussed later) of the Kulakalnattam Sandstone Member, during several transgressive phases (marine flooding events), provided the same conditions, highly conducive to early cementation, as proposed by Taylor et al. (1994). These flooding events led to the development of the nodular-concretionary layers within the lowstand deposits of the Kulakalnattam Sandstones. Consequently the top of the Karai Clay Formation (at Kulakalnattam river section and 2 km north of Garudamangalam; Localities 1 and 6 in Fig. 7.3 respectively) marks a conformable sequence boundary. Similar carbonate concretions, with fossil wood (bored by teredinids) preserved as nuclei, are reported from the Eocene London Clay (Huggett & Gale, 1995). The carbonate stable isotope studies suggest that most (if not all) of the London Clay concretions formed within the sulphate reduction zone (Huggett 1994, Huggett & Gale 1995).

Ichnologic studies support the association of the carbonate-cemented concretionary horizons (occurring at the base of the Kulakalnattam Member) with marine flooding events, as suggested by Taylor et al. (1994). Marine flooding events are short transgressive phases (in the overall transgression) resulting in the development of parasequences within a sequence. The flooding events reflect an abrupt deepening and are associated with marine hiatuses (Loutit et al. 1988), representing times of low or negligible sediment accumulation with little or no erosion. Lithification during these depositional hiatuses (low or negligible sediment accumulation) allows firmgrounds (omission surfaces) and hardgrounds to develop. In the Kulakalnattam Sandstone
Member the sandstone concretions are either highly bioturbated (e.g., *Thalassinoides, Ophiomorpha, Diplocraterion*, etc.) or preserve horizontal and cross laminations. The surface of the concretions are colonised by firmground *Glossifungites* ichnofacies represented by robust, monospecific *Thalassinoides* (Photo 7.4)- an omission suite trace marker. It should be noted that here (the surface of the concretions) the occurrence of *Glossifungites* (firmgrounds) ichnofacies is associated with a depositional and not an erosional discontinuity. The concretionary horizons reflect several flooding events (parasequences) with the *Thalassinoides* colonised concretion surfaces interpreted to be representing the omission surfaces (depositional discontinuities) developed during marine hiatuses associated with marine flooding surfaces. Along with the *Thalassinoides* the concretions have a low diversity, low abundance borings, e.g., *Diplocraterion, Ophiomorpha*, etc.. Included with the concretions are *Teredolites*-infested log grounds (clavate borings in xylic material, see Hart *et al.*, 1996, Tewari *et al.*, in review). Substrate-controlled *Teredolites* ichnofacies (Photo 7.5) occurs both in-situ, but more commonly as allochthonous fossil logs in dried-up river and stream beds (Fig. 7.3) where the Formation is exposed. The *Teredolites* borings are filled (see Tewari *et al.*, in review), in most cases, with coarse-grained, unconsolidated, siliciclastic sediments of the Garudamangalam Formation. The preservation of these allochthonous log grounds (*Teredolites*-infested xylic material) suggest their association with the Garudamangalam Sandstone Formation. When seen in-situ the *Teredolites*-infested log grounds occur on the top of these concretions. Savrda (1991a,b), Savrda & King (1993) and Savrda *et al.* (1993) observed that the occurrence of substrate-controlled *Teredolites* ichnofacies is not random but is closely linked to sea-level changes. They (Savrda 1991a,b, Savrda & King 1993 and Savrda *et al.* 1993) demonstrate that the concentration of *Teredolites* is most common during sea-level rises, when the sea transgresses the previously exposed coastal-plain settings. If these settings are forested, this flooding will result in an influx of wood material into marine and marginal-marine environments. The concentration of logs in the Kulakkanattam Sandstone Member implies that a transgressive event inundated a coastal woodland area (similar to that reported by Savrda & King (1993) from western
Photo 7.4: Robust, monospecific *Thalassinoides* (an omission suite trace marker) colonising the surface of carbonate cemented, sandstone concretions, at the Kulakkalnattam river section (Locality 1 in Fig. 7.3).

Photo 7.5: Allochthonous *Teredolites* (woodground) ichnofacies (surface riddled with borings) collected from the Kulakkalnattam river section (Locality 1 in Fig. 7.3).
Alabama) thereby causing a local influx of xylic material. The intensely burrowed concretion surfaces (colonised with Thassalinoides- an omission trace suite marker) and the association of Teredolites, both lines of evidence suggest a transgressive event (followed by successive marine flooding events) above the post Karai Clay sequence boundary.

The Kulakkalnattam Sandstone Member is fine to coarse calcareous sandstone (with distinct layers of concretions), silty sandstones, ferruginous sands, argillaceous siltstones, pebbly sandstones. Included within the Member are mono-specific, shell-rich (a restricted marine fauna of oysters and gastropods) sandstone beds (e.g., Kunnam and Garudamangalam, Photo 7.6) and conglomerate beds containing quite fresh, pink feldspars. The Member is quite thin (including shell-rich and conglomerate beds) and is highly condensed in nature. In sequence stratigraphy, condensed horizons are thin, marine stratigraphic units, characterised by very low sedimentation rates (Loutit et al. 1988). They correspond to marine flooding surfaces and may include the surface of maximum starvation (Loutit et al. 1988) which is the maximum flooding surface (the upper part of transgressive systems tract and basal part of highstand systems tract). The standard model of condensed transgressive lags (with reworked fossil assemblages because of its association with erosional ravinement), resulting from sediment starvation (Loutit et al. 1988) is challenged by Kidwell (1989). Kidwell (1989) has demonstrated that condensed horizons can also result from dynamic by-passing of sediments with the by-passed sediments accumulating in deeper-water environments. The condensed sections are, therefore, distinctively thin, transgressive records of low or negligible sediment accumulation and result from sediment starvation (Loutit et al. 1988) or sediment by-passing (Kidwell 1989). Until a basinal picture is available it is difficult to say whether condensation in the Kulakkalnattam Sandstone Formation is due to sediment starvation or dynamic by-passing of sediments. The poorly sorted shells (with respect to size and shape) in the sandstones suggest that no significant transport of the shell material took place. The Sandstones contain either horizontal planar laminations or are highly bioturbated (e.g., Thalassinoides, Diplocraterion,
Photo 7.6: Shell-rich sandstone bed in the Kulakkalnattam Sandstone Member (Garudamangalam Sandstone Formation) at the Garudamangalam quarry.

Photo 7.7: The 18 m long Sattanur fossil tree in the Anaipadi Sandstone Member (Garudamangalam Sandstone Formation) at Sattanur (Locality 13 in Fig. 7.3).
Ophiomorpha, etc.,) with abundant Teredolites-infested logs. The abundance of xylic material in the Kulakkalnattam Sandstone is interpreted to be the combined effect of two factors. The influx of xylic substrate during the successive flooding events (transgressions) and concentration of drifted wood during the sediment starvation (or sediment by-passing) in a shallow marine shelf setting (similar to that described from central Alabama by Savrda & King 1993). There is no evidence of significant wave or current reworking of the sands. It is possible that xylic material may have been carried down estuarine channels and trapped on shallow flanking sandflats where colonisation by Teredolites occurred. It is interpreted that the Kulakkalnattam Sandstones reflect a transgressive-stillstand, landward retrogradation process in the Cauvery Basin. The condensed shell-rich sandstone beds (including concretion horizons) developed during several marine flooding events. Ravinement during each renewed flooding stripped off the older facies while the periodic stillstands (in the overall transgression) allowed the deposition of pebble-conglomerate beds.

The inclusion of further log-grounds (including the 18 m long Sattanur tree, Photo 7.7, Locality 13 in Fig. 7.3) and ammonites (Photo 7.8) higher in the succession, coupled with the general abundance of fossils (Fig. 7.2) suggests that the Anaipadi Sandstone Member (upper member of the Garudamangalam Sandstone Formation) completes the transgressive systems tract, representing the initial regressive phase of the following highstand systems tract. The maximum flooding surface may equate with the floods of very large ammonites (some are about one meter in diameter, Photo 7.8) reported in the succession (approximately 2 km west of Kulattur, Locality 4 in Fig. 7.3). Condensed sections are aerially most extensive at the time of maximum transgression (Loutit et al. 1988). The lack of and/or accessibility to exposures in the outcrop (in the area studied) did not allow confirmation of the aerial extent of the Anaipadi Member. The flood of large ammonites (Photo 7.8) with a general abundance of fossils (Fig. 7.2) and woodgrounds (Photo 7.7) in the succession reflects, however, presence of the maximum flooding event. The top of the Anaipadi Sandstone Member completes the sequence (in the area studied) marking a major break in the deposition in the Basin.
Photo 7.8: Giant ammonite occurring in the Anaipadi Sandstone Member (Garudamangalam Sandstone Formation), approximately 2 km west of Kulattur (Locality 4 in Fig. 7.3).

Photo 7.9: Fluvial sandstones and silty-sandstones with reworked, mud, fresh feldspar pebbles and sandstone cobbles. In a stream section, near Saturbahagam (Locality 12 in Fig. 7.3).
The base of the overlying Sillakudi Sandstone Formation (especially in the stream section near Saturbhagam, Locality 12 in Fig. 7.3, Photo 7.9) shows clean, unconsolidated, fluvial sandstones and silty-siltstones which pass up into the normal marine sediments associated with the remainder of the succession. The fluvial sandstones contain reworked, fresh feldspars pebbles and cobbles (up to 30 cm diameter). The unit has very large scale trough cross-beds (sets up to 3 m wide) with pale grey mud drapes in some foresets. Mud drapes may indicate some marine tidal influence although this may also be the result of seasonal changes in discharge. The presence of fresh feldspar and sandstone clasts suggests incursion into older facies and presence of a post Garudamangalam Sandstone sequence boundary at the base of the Sillakudi Formation. The hiatus (? post-Coniacian to late Santonian) between the Garudamangalam Sandstone Formation and the overlying Sillakudi Sandstone Formation is stratigraphically very similar to a major hiatus in the successions on the Brazilian coastal margin (Koutsoukos & Hart 1990).

7.4 Summary

Ichnofossil information, used in conjunction with the data from sedimentology and palaeontology, is used to assess the sequence stratigraphy of the Basin. In the present study the Garudamangalam Sandstone Formation is interpreted to reflect one complete cycle of sea-level change in the Cauvery Basin. The latest mid/earliest late Turonian (post-Karai Clay) forced regression in the Basin resulted in a basinward shift of the shoreline bringing an abrupt juxtaposition of estuarine-nearshore Garudamangam Formation over the relatively deep, outer shelf Karai Formation. The contact is erosional in places and conformable at others. Several flooding events allowed concretionary horizons (at the base of the Garudamangalam Formation) and condensed shell-rich sandstone beds to develop. Associated ravinement process during the successive flooding events eroded the older facies and the intervening stillstands allowed the pebble-conglomerate beds to be deposited. This transgressive-stillstand process allowed the landward retrogradation till the maximum flooding surface was
reached, after which the shoreline started to retreat basinward. The top of the Garudamangalam Formation is bounded by another unconformity (sequence boundary) marking the completion of a sequence. The Formation is interpreted to represent one complete depositional sequence, bounded by sequence boundaries (unconformities).
Chapter 8

Conclusions
8.1 Introduction

The present research was directed towards a more comprehensive understanding of the microbio- and litho-stratigraphy of the Cauvery Basin, Southeast India. The study is complemented with a systematic palaeontological (foraminiferal) study, recognition of the mid-Cretaceous oceanic anoxic events (OAEs), the affect of these OAEs on the planktonic foraminiferal population and the mid-Cretaceous sea-level changes in the Cauvery Basin. The study, although only initial, has contributed to a better understanding of the Cretaceous micropalaeontology and stratigraphy of the Basin. The results of the study are discussed in detail within the preceding Chapters of the thesis. This Chapter briefly summarises the major objectives met during the course of this research.

8.2 Lithostratigraphy

The importance of an integrated litho- and bio-stratigraphic approach towards the understanding of a basin history has been emphasised in the previous Chapters. Despite previous attempts, the lithostratigraphy of the Cauvery Basin, as it stands (prior to this work), remains much the same as that established in the mid-nineteenth century. The lack of proper lithological groupings, appreciation of major facies changes, a proper understanding of the mid-Cretaceous faulting and insufficient sedimentological analysis has lead, in past, to major errors in interpretations. This study has attempted to present a revised lithostratigraphic classification for the Cretaceous succession of the Cauvery Basin, in accordance with the recommendations provided in the code of stratigraphical procedure. It is acknowledged that the stability in a classification is maintained by the use of the rule of priority and by the preservation of established names. Throughout the process of revision attempt has been made to address the problem without doing injustice to the original author or compromising the standard practice of stratigraphical procedure. The study presents a revised lithostratigraphy with lithofacies relationship in the Cauvery Basin (on-shore part).
8.3 Systematic palaeontology

A systematic record of the planktonic and benthonic foraminifera reported from the Aptian-Maastrichtian succession in the Cauvery Basin is presented. During the course of this study 300 species, belonging to 91 genera have been recognised. Systematic taxonomic descriptions (in line with Western standards), illustrations (by means of scanning electron microphotographs) and a record of biochronostratigraphic range with relative abundance of different species are presented. Significant variations (in morphology and stratigraphic range) in the planktonic foraminifera from the Cauvery Basin are described for the first time.

8.4 Microbiostratigraphy

The mid-Cretaceous succession (on-shore) in the Cauvery Basin has a rich foraminiferal suite. Two microfossil biozonation schemes, based on planktonic and benthonic foraminifera, are proposed. These schemes are primarily defined for regional application. A planktonic foraminiferal biozonation scheme, comprising of four Interval Range Biozones (IRBs) (with two sub-biozones), one Concurrent Range Biozone (CRB) and one Partial Range Biozone (PRB), is established. In the absence of a formal benthonic biozonation scheme, for the first time, a benthonic scheme is proposed. Seven biozones, comprising of one IRB, one CRB, two PRBs and three Acme biozones are proposed in the benthonic zonal scheme.

8.5 Mid-Cretaceous oceanic anoxic events and sea-level changes

The present study of the mid-Cretaceous foraminifera from the Cauvery Basin records two levels, (1) the latest Albian/Albian-Cenomanian and (2) the late Cenomanian to mid-Turonian, when anoxic conditions developed in the Basin. These events coincide with the globally reported mid-Cretaceous Breistroffer OAE-1c and the Bonarelli
OAE-2 oceanic anoxic events (OAEs). The study shows that the OAE-1c in the Cauvery Basin appears to be much closer to the Albian-Cenomanian boundary and that the OAE-2 extends to the early mid-Turonian. The late Albian anoxic event in the Basin is not as strong as the late Cenomanian-Turonian event. These anoxic events had a major affect on the microfaunal population. Major readjustments in the planktonic foraminiferal population is observed. After these mid-Cretaceous OAEs, a more ornamented and more prominently keeled fauna dominated the Cauvery Basin. The pattern of evolution and expansion of planktonic foraminifera are used to infer the mid-Cretaceous sea-level changes in the Basin. The study suggests a continuously rising sea-level (keeping ahead of Basin shallowing) in the mid-Cretaceous; with four periods of major transgressions. These levels are, at the late Albian, mid-Cenomanian, late Cenomanian-early Turonian and mid-Turonian intervals. The pattern of sea-level changes in the Cauvery Basin followed, in general, the global sea-level curve, but has been influenced by local factors.

8.6 Application of sequence stratigraphy concepts

In a pilot study, palaeontology (including ichnology) in conjunction with the data from sedimentology and palaeontology, is used to assess the sequence stratigraphy of the Basin. A comprehensive study on the *Teredolites*-infested fossil wood is done. This includes the study of morphological characters of the *Teredolites* and its palaeoenvironmental significance.

8.7 Suggestions for further research

As mentioned earlier (see Chapter 1), the Cretaceous sediments of the Cauvery Basin have been investigated since the mid-nineteenth century. Since then various workers have contributed to the understanding of the bio- and litho-stratigraphy of the Basin. Despite intensive research, opinions, in general, amongst the workers are divided and the stratigraphy of the Basin, as it stands at the present time, remains much the same as
that established in the mid-nineteenth century. A need, therefore, exists to take a fresh look into the existing stratigraphy of the Basin. The present research was directed towards a better understanding of the microbio- and litho-stratigraphy of the Basin. The research, far from being exhaustive, has attempted a revision to bring the existing stratigraphy in line with modern standards.

It is suggested that further research should be directed to an integrated micropalaeontological, sedimentological and sequence stratigraphic studies. The following study areas are suggested:

1. Extending the present study to complementary areas of the Cauvery Basin and offshore areas to get a full picture of the Basin. More extensive study of the outcrops and well-sections together with well-sections selected from off-shore areas. The primary objectives would be refining the proposed revised lithostratigraphy of the Basin and establishing the depositional history of the Basin.

2. The present study shows that the planktonic foraminifera from the Cauvery Basin reflects a longer time range for some “index” species and more ornamented individuals. Further work needs to be done in this line with a comparison of the fauna from the Cauvery Basin with that of the other basins in the Austral and Tethyan realm. A need exists to check the validity of applying classical Tethyan zonal markers in the Austral province.

3. The study of larger benthonic foraminifera, occurring in the Campanian-Maastrichtian succession in the Basin, has been neglected so far. Until now, no systematic approach to study these larger foraminifera has been taken and the problem needs to be addressed.

4. The study of the mid-Cretaceous oceanic anoxic events and their affect on the microfaunal community needs to be extended. A twin approach, integrating
micropalaeontological and geochemical studies, is needed to assess the full extent of these anoxic conditions in the Basin. For such an approach the outcrop study should be supplemented with data from complementary well-sections in the offshore areas. This will eventually help in assessing the full hydrocarbon potential of the Basin.

5. Sequence stratigraphy is still a new branch of study in India. It is proposed to extend the fundamental approach of the present study (the pilot study of applying sequence stratigraphy concepts to the late Turonian-Coniacian succession in the Basin). It is recommended that an interdisciplinary approach, integrating microbiostratigraphy, ichnology, sedimentology, seismic stratigraphy and sequence stratigraphy, should be taken. Such an approach has both academic and commercial significance.


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Appendix 1

Published papers
Foraminiferal recovery after the mid-Cretaceous oceanic anoxic events (OAEs) in the Cauvery Basin, southeast India

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Abstract: The Cauvery Basin, SE India, is one of the best exposed late Mesozoic to Tertiary basins in India. The study of foraminiferal assemblages from the core samples obtained from two 120 m deep wells in the basin records the occurrence of two mid-Cretaceous anoxic events in the basin. Abrupt increases in planktonic:benthonic ratios and reductions in benthonic diversity are recorded in the late Albian and in the late Cenomanian-early Turonian. These events coincide with worldwide oceanic anoxic events (OAEs).

The OAEs had an impact on the microfauna of the basin, with approximately 35-45% of the benthonic species not surviving and major morphological changes occurring in the planktonic community. The late Cenomanian–early Turonian event was more significant than the late Albian event, with considerable readjustments occurring in the planktonic foraminifera. The genus *Rotaliopora* disappeared and the genus *Hedbergella* was largely replaced by *Whitienella*. *Marginotruncana* appeared for the first time and the *Dicarinella* population expanded considerably. *Praeglobotruncana* was the most tolerant genus, undergoing least change. The planktonic foraminifera evolved from small, weakly ornamented forms with poorly developed keels into robust, well ornamented forms with well developed keels. The pattern of evolution of planktonic foraminifera suggests a recolonization of deeper water environments after the late Cenomanian–early Turonian anoxic event.

The break up of East Gondawanaland (India, Antarctica and Australia) in the late Mesozoic was responsible for the development of the Indian Ocean (Powell et al. 1988; Moores 1991). Major changes in the plate configuration took place which influenced the Cretaceous palaeogeography of the Indian sub-continent. New sedimentary basins were developed and two episodes of widespread flood-basalt extrusions occurred (Acharyya & Lahiri 1991). The Cretaceous basins of the east coast of India cut across the NW-trending Permian–Triassic Gondwana grabens (Sastri et al. 1981). They are often precursors of the Tertiary basins and present-day shelves. Others were intra-cratonic basins, occurring as narrow troughs which were later flooded by the Deccan basalts. Figure 1 shows the distribution of the Cretaceous rocks in the Indian sub-continent, together with the location of the Cauvery Basin.

The Cauvery Basin, SE India, is one of the best exposed late Mesozoic–Tertiary basins in India. It covers an area of about 25 000 km² on land, between latitude 12°15'N near Pondicherry and latitude 8°15'N to the south of Ramanathapuram (Fig. 1). The depth of the crystalline basement does not exceed more than 4.5 km in any part of the basin on land, but may reach nearly 6 km offshore. The basin is bounded to the west by the outcrops of the igneous and metamorphic rocks of the Indian Archaean shield. North of the latitude 10°N, the basin opens into the present offshore area of the Bay of Bengal. To the south, the basin is bounded to the east and southeast by the Archaean crystalline massifs of Sri Lanka. The basin is block-faulted, comprising horsts and grabens. It is a peri-cratonic shelf in the north and an intra-cratonic graben in the south (Sastri et al. 1973, 1981; Banerji 1983). Geophysical surveys and drilling by the Oil and Natural Gas Corporation of India have established that the basin comprises several depressions or sub-basins separated from each other by buried basement ridges (Ramanathan 1968, Sastri et al. 1977). The Ariyalur–Pondicherry depression is the largest and northern-most depression of the basin and contains three important outcrops, at Pondicherry, Vrindhanachalam and Ariyalur (Sastri et al. 1973, 1981; Banerji 1983).

In the Cretaceous system, three intervals are reported as Oceanic Anoxic Events (Arthur & Schlanger 1979; Jenkyns 1980). These are (i) Late Barremian through Albian, (ii) Late Cenomanian to early Turonian, and (iii) Coniacian to Santonian. These Cretaceous OAEs record worldwide marine transgressions, when large amounts of organic carbon were accumulated because of the development of poorly oxygenated oceanic water masses and expanded oxygen minimum zones (Arthur & Schlanger 1979; Jenkyns 1980). Hart (1980a), Hart & Ball (1986) and Jarvis et al. (1988) suggest that the anoxic events had a major effect on the planktonic foraminifera and that the movement of the oxygen minimum zone in the water column has affected the evolution of the planktonic foraminiferal population.

This paper concentrates on the core samples obtained from two 120 m deep wells, Karai-4 and Karai-6, drilled between Karai and Kulakkalnattam villages, in the Ariyalur area (Fig. 2). The wells encounter grey-black shales throughout, with brown gypseous shales in the top 30 m from the surface. The gypsum is a post-depositional weathering phenomenon. Each sample

Fig. 1. Distribution of Cretaceous rocks on the Indian sub-continent, Cauvery basin in the enclosed box (after Acharyya & Lahiri 1991).
Fig. 2. Geological map of the Karai-Kulakkalnattam area showing positions of the Karai-4 and Karai-6 wells (after Venkataraman & Rangaraju 1965 in Ramanathan & Rao 1982).

Fig. 3. Biostratigraphic correlation between Karai-4 and Karai-6 wells, based on planktonic foraminifera.
was divided into 500, 250, 125 and 63 micron grain size-fractions, and from each fraction size 301 complete foraminifera were picked. Where the 301 count was not met, the whole fraction was used. Foraminiferal assemblages of the R. appenninica (Renz) Interval Zone to W. archaeeocretacea Pessagno Partial Range Zone are described from the two wells (Fig. 3). This study shows that the late Albian and the late Cenomanian-early Turonian, OAEs are recorded in the basin.

The Late Albian event

At a depth of about 100-110m in the Karai-4 well, an abrupt increase occurs in the planktonic:benthonic ratio and a fall occurs in the benthonic diversity in the late Albian, within the R. brotzeni Interval Zone (Fig. 4). The Albian-Cenomanian boundary is placed at the first appearance of Tritaxia pyramidata Reuss 1862 in the Karai-4 well. A revised base of the Cenomanian is proposed just above the extinction of Planomalina buxtorfi (Gandolfi 1942) (Kennedy et al. 1995 pers. comm.). The event saw major morphological development amongst the Rotalipora Brotzen 1942 and Praeglobotruncana Bermudez 1952 (Fig. 5). During this period, the Rotalipora comprised small forms, each with a weakly developed keel. Soon after, the Rotalipora established themselves and expanded considerably, before disappearing in the late Cenomanian, when Dicharinella Porthault-1970 and Whiteinella Pessagno-1967 made their first appearance. Following the appearance of juvenile specimens of R. appenninica (Renz 1936) and R. brotzeni (Sigal 1948) during the anoxic event, well developed forms belonging to the species appenninica, brotzeni, micheli (Sacal & Debourle 1957), monsalvensis (Mormod 1950) and reicheli (Mormod 1950) appeared with the start of the recovery. The recovery of the Rotalipora saw a development in their morphological characters and an improvement in the quality of their preservation. Forms appear that possess well preserved primary and secondary apertures and a chamber profile marked by a well developed single keel continuing along the spiral side. Species of R. reicheli and R. micheli show well developed and very prominent adumbilical thickening. In fully grown adults of R. reicheli this perumbilical ridge is so well developed on all chambers that it forms a rampart along the umbilicus. The population was dominated by strongly asymmetrical R. reicheli, with a flat to gently concave spiral side and a strongly vaulted umbilical side. By the late Cenomanian, the Rotalipora started to reduce
in number before disappearing at the end of the Cenomanian, when juvenile forms of *Dicarinella* and *Whiteinella* made their first appearance. *Praeglobotruncana* appears to be the most tolerant genus during the event. Forms of *P. stephani* (Gandolfi 1942) and *P. gibba* (Klaus 1960) appeared from before the crisis, survived the event, and continued up. A major change of the ornamentation and spire height occurs, however, as the *Praeglobotruncana* population recovered from the event. *P. stephani* and *P. gibba* began with forms that have a low to moderate spire height and weakly calcified tests changing to a more robust nature. These *stephani* and *gibba* have poorly preserved umbilical structures with chamber outlines marked by two very faint rows of pustules which become fainter and finally disappear completely. From a stock of such weakly developed morphological characters there evolved robust, highly calcified and beaded *stephani* and *gibba* with moderately high to very high trochospiral forms. The European Working Group on Planktonic Foraminifera (Robaszynski & Caron 1979) established that, with an increase in height of the spire, *stephani* evolves into *gibba*. The *stephani* and *gibba* in the Cauvery Basin follow the same *stephani* to *gibba* transformation rule, as seen in their European counterparts. There is, however, one exception. The forms reported from Europe (Robaszynski & Caron 1979) show a gradual increase in the height of the low to moderately high *stephani*, resulting in a mound-shaped high trochospiral *gibba*. In the Cauvery Basin examples, the increase in the height of the spire sees a more robust approach with inner whorls sitting like a lobe on the final whorl, thus giving a block-shaped high trochospiral *gibba*. These highly developed *gibba* and *stephani* also show very highly developed beaded ornamentation on their spiral sides, and very well developed rows of pustules. In some cases these rows of pustules could be referred to as two closely spaced keels in the final chambers of the last whorl.

In Alpine Europe the Albian records two prominent peaks of TOC in the late Cenomanian-Early Turonian event. At a depth of 52–55 m in Karai-6 well, there is an increase in the planktonic benthic ratio and a fall in the benthonic diversity in the late Cenomanian–Early Turonian, within the *W. archaeocretacea* Partial Range Zone (Fig. 6). The Cenomanian–Turonian boundary is placed at the last occurrences of *Orithostella indica* Scheinbnerova 1972 subsp. *markisi* Narayanam 1975 and *Gavelinella baltica* Brozten 1942 of late Cenomanian age, and at the first occurrence of *Lingulogavelinella turonica* Butt 1966 of early Turonian age. This event coincides with the worldwide Cenomanian–Turonian anoxic event which caused a major readjustment within the planktonic community (Fig. 7). *Reaialipora* disappeared completely and *Dicarinella, Whiteinella* and *Marginotruncana* Hofker 1956 came into existence. *Hedbergella* Bronnimann & Brown 1958, which was dominant before the event, is largely replaced by *Whiteinella*. Well preserved *W. aprica* (Loeblich & Tappan 1961), *W. archaeocretacea* Pessagno 1967, *W. baltica*...
Fig. 6. Planktonic–benthonic ratio and benthonic diversity graphs showing the position of the late Cenomanian–early Turonian OAE in the Karai-6 well.

The first Dicarinella to appear were juvenile *D. imbricata* (Mornod 1950) with low trochospiral forms and chamber outlines marked by a weak concentration of pustules. Soon *Dicarinella*, especially *D. hagni* (Scheibnerova 1962), dominated the population, along with *Praeglobotruncanca* and *Whiteinella*. *D. hagni* reported from the Karai-6 well are different to those that have been reported as *D. hagni* from Europe. The European Working Group on Planktonic Foraminifera (Robaszynski & Caron 1979) report low trochospiral asymmetrical biconvex forms of *D. hagni* in Europe, differentiating them from the plano-convex 'concava' group. Under the 'concava' group (Robaszynski & Caron 1979) are included forms with clearly asymmetrical planoconvex to concavo-convex low trochospiral tests, a perumbilical ridge and early globigerina-like chambers elevated above the outer whorl as a little prominence in the centre of the test. The three forms belonging to the 'concava' group (*D. primitiva* (Dalbiez 1955), *D. concava* (Brotzen 1934), and *D. asymetrica* (Sigal 1952)) occur one after the other in the Coniacian–Santonian interval. The first *hagni* which appear in the Karai-6 well have all the characters of a true *D. hagni* as described from Europe (Robaszynski & Caron 1979). They have a low trochospiral–asymmetrical biconvex test with two closely spaced keels, often disappearing on the last or penultimate chamber. Soon after the OAE, *D. hagni* shows major morphological changes with a tendency for the development of forms very similar to the 'concava' group. From the typical *D. hagni* develop morphotypes having a moderate-asymmetrical trochospiral test with a more convex spiral side in comparison to the typical *hagni*, although the umbilical side still is more convex. These morphotypes have less closely spaced double keels with the spiral keel diverging from the umbilical keel to give a slight imbricated pattern on the dorsal side. At the same time, within the *hagni* population, appeared planoconvex to concavo-convex morphotypes with the inner whorls sitting like a knob in the final whorl. Both these morphotypes show a development of perumbilical ridge at least in the final one or two chambers. The full recovery of *D. hagni* saw well developed plano-convex to concavo-convex *hagni* with spiral
side flat to gently concave and a periumbilical ridge in the last one or two chambers. The only ways these plano-convex hagni are different from the 'concaustica' group are that they occur with a foraminiferal assemblage belonging to W. archaecretacea Zone, of late Cenomanian-early Turonian age and they do not have early globigerina-shaped chambers.

Jacob & Sastry (1950) report a new species, Globorurruncana indica, along with a Cenomanian fauna, from the Cauvery Basin, having a plano-convex test with two keels. The European Working Group on Planktonic Foraminifera (Robaszynski & Caron 1979) consider G. indica to show a morphological similarity with D. hagni. In the absence of topotypes or any duplicate material available for the study during the preparation of the Atlas of Mid-Cretaceous Planktonic Foraminifera (Robaszynski & Caron 1979), the working group could not fully clarify the taxonomic status of G. indica. D. hagni was therefore retained as a more adequate taxon to identify the European forms. Lamolda (1977) describes a new plano-convex species, D. elata, from northern Spain, ranging from the late Cenomanian(?)-early Turonian to the early Coniacian. Lamolda differentiates D. elata from G. indica by the presence of a single keel instead of a double keel on the outer whorl of elata. The plano-convex hagni in the Karai-6 well are different from D. elata because they have a periumbilical ridge in the final one or two chambers and two well developed keels. In the absence of clear taxonomic status for G. indica and D. elata, D. hagni is used here as the valid name, following the European Working Group (Robaszynski & Caron 1979).

In the genus Marginotruncana, juveniles of M. marginata (Reuss 1845) were the first to appear. The full expansion of the Marginotruncana population was dominated by M. schneegansi (Sigal 1952). The M. schneegansi in the Karai-6 well includes forms with a very high trochospiral test. These are different from the M. schneegansi reported from Europe (Robaszynski & Caron 1979), which have a low trochospiral test.

Conclusions

It has been suggested (Hart & Bailey 1979; Hart 1980b) that the planktonic: benthonic ratio and the evolution of the planktonic foraminifera can be used, with caution, to indicate major changes in water depth. The late Albian and the late Cenomanian-early Turonian events in the Cauvery Basin are represented by an increase in the planktonic: benthonic ratio, with a fall by approximately 35-45% of the benthonic population. This coincides with the sea-level maxima and eustatic rises in sea-levels, which caused the development of an expanded oxygen minimum zone. The planktonic foraminiferal growth pattern suggests a late Albian and a late Cenomanian-early Turonian sea-level maxima with intermittent periods of fluctuating sea-level in the basin. The recovery of the fauna from the late Albian OAE was dominated by shallow water Hedbergella and intermediate water Rota­lipora and Praeglobotruncana. By the mid­ Cenomanian, relatively deeper-water R. reicheli and R. micheli were established and expanded considerably, but disappeared completely at the end of the Cenomanian. At the Cenomanian–Turonian boundary, there was a second influx of deeper water fauna. The development of high-spired and highly calcified Praeglobotruncana and Marginotruncana and of plano-convex Discarinella was a significant development towards the return of deeper water fauna after the Cenomanian–Turonian event.

The study of foraminiferal assemblage in the Cauvery Basin suggests the following:

1. The mid-Cretaceous anoxic events OAE-1 and OAE-2, which may have resulted from world wide marine transgressions, are also present in the Cauvery Basin.
2. The Late Albian and Cenomanian–Turonian boundary intervals were the times of sea-level maxima, with intermittent periods of fluctuating sea-level.
3. These anoxic events are responsible for major changes in the planktonic foraminiferal population.
4. The planktonic foraminifera indicate that the late Cenomanian–early Turonian OAE was followed by recolonization of deeper water environments.
5. A comparison of the planktonic fauna from the Cauvery Basin with other basins in the world gives an impression that the fauna from SE India is composed of more robust individuals. After these mid-Cretaceous OAEs, a more ornamented and more prominently keeled fauna dominated the Cauvery Basin.

We thank D. J. van der Zwaan for kindly providing the Karai well samples. David Peacock is thanked for his help in the preparation of Figs 3-7 and for reading the manuscript. John Abraham is thanked for drafting Figs 1 and 2.

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A revised lithostratigraphic classification of the Cretaceous rocks of the Trichinopoly District, Cauvery Basin, Southeast India

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ABSTRACT: A revised lithostratigraphic classification for the Cretaceous in the Trichinopoly District is proposed. Seven units of formational status, arranged within three "groups" are established. Adhering to the guidelines set for lithostratigraphical classification, nine new members are proposed. With the revision of the existing members and proposal of nine new members, the total number of formal members is now seventeen.

INTRODUCTION
The late Jurassic-earliest Cretaceous rifting between India and Australia-Antarctica developed a number of NE-SW trending basins in the Indian Precambrian crystalline basement (Powell et al. 1988). The Cauvery Basin is the southern-most basin along the eastern margin of India (text-fig I). The basin comprises several depressions or sub-basins (Ramanathan 1968, Sastri et al. 1973, 1981). The Ariyalur-Poundicherry depression is the southern-most sub-basin, containing three important outcrops at Ariyalur, Poundicherry and Vridhanchalam (Ramanathan 1968, Sastri et al. 1973, 1981). This paper describes the work carried out in the Ariyalur outcrop of Trichinopoly District.

JUSTIFICATION FOR A REVISION
The Cretaceous succession of the Cauvery Basin has been the subject of intensive research since the early studies of Blandford (1862). During that time a number of stratigraphic "units" have become well-established, almost by historical precedent. Various workers have established major lithostratigraphic units in the Cretaceous rocks in the Cauvery Basin (e.g. Banerji 1973, Sastri et al. 1977, Rasheed and Ravindran 1978, Banerji and Sastri 1979, Sundaram and Rao 1979, 1986, Ramasamy and Banerji 1991). Foraminifera, ammonites and nannofossils have been used for the biostratigraphic zonation and the age determination of these rocks (e.g. Sastri et al. 1968, Sastry et al. 1968, Banerji and Radha Mohan 1970, Banerji 1973, Chiponkar and Phansalkar 1976, Marayappan 1977, Ayvazian and Jagannatha Rao 1978, Guvindhan 1978, Rasheed and Ravindran 1978, Phansalkar and Kumar 1983a, 1983b, Chiponkar 1985, Ayvazian 1990, Ramasamy and Banerji 1991, Kale and There is, therefore, a plethora of stratigraphic terms in current usage with many authors continuing to use their own classification almost regardless of other work. A lithostratigraphic classification of these rocks was done by Sundaram and Rao in 1979 (later revised in 1986) but it was Ramasamy and Banerji (1991) who, for the first time, attempted a formal definition of lithological characteristics (for the pre-Ariyalur succession) with reference to type localities/sections in accordance with current practice (Hedberg 1976, Holland et al. 1978, Anonymous (Bulletin A.A.R.C.) 1983, Whittaker et al. 1992).

There are three key reasons for this state of affairs. While it is generally appreciated that there are major facies changes in the area there is still a reluctance to recognise this in the lithostratigraphic classifications employed. This has meant that, in some cases, natural lithological grouping have been ignored. In the lower part of the succession, therefore, one has to establish a lithostratigraphy for a more basinial succession (clay and siltstone dominant) together with a more shallow-water succession, largely composed of carbonates, calcareous sandstones and siltstones. The other problem has been the occurrence of mid-Cretaceous faulting seen at numerous localities in the basin (especially at the western end of Kovandakuruchchi quarry-2 where Archaean basement is in contact with mid-Cretaceous calcareous sandstone and in the Kallakudi quarry-2 where the shape of the pink limestone outcrop is fault controlled and not due to its "reefal" structure). Around the margin of the basin this mid-Cretaceous faulting has generated a large number of massive debris flow deposits, which mainly contain massive blocks of pink limestone (e.g. in Otipadi, Neykudam and Trinapparai quarries) together with rare (and smaller blocks of Archean...
A revised lithostratigraphic classification of the Cretaceous rocks of Cauvery Basin

LITHOSTRATIGRAPHICAL CONVENTIONS

Lithostratigraphy is the description, definition and naming of rock units. It is fundamental to all other branches of stratigraphy because accuracy in, for example, bio- and chronostratigraphy relies on the correct recognition of spatial relationships (both vertical and lateral) of rock units" (Whittaker et al. 1992). Gross lithological characters must be used but that can include petrography, geochemistry, general fossil content and ichnofossil information. Units are named according to their perceived rank at the time, though that rank can be changed subsequently. It must not be taken as a criticism if the ranking of a unit is changed; rather it must recognise changing knowledge and information about basinal history, throughout the process of revision recommendations provided by Hedberg (1976), Holland et al. (1975). Commission A.A.P.G. (1983) and Whittaker et al. (1992) are complied with. In the present work the terms Group, Formation and Member have been used, but individual beds rarely have been identified. It must be noted that a Member, which is a distinct part of a Formation, may or may not extend completely across an outcrop area. It is also unnecessary to divide a Formation completely into Members.

REVISED LITHOSTRATIGRAPHY OF THE CAVERY BASIN

As indicated above, numerous workers have contributed to the lithostratigraphical classification of the on-shore part of the Cauvery Basin succession. Following the guidelines to stratigraphical procedure and respecting the rule of priority and preservation of established names, a revision of the existing lithostratigraphic classification is proposed (table 1). The revised classification with lithofacies relationship and a comparison of it with some of the existing classification is summarised in table 1 and 2. The revised lithostratigraphy, as discussed, is presented in text-fig 2. Seven units of "Formational" status, grouped into three "Groups" are recognised.

GODAWANA GROUP

In the area studied the Godawana Group comprises of one, the Sivaganga Sandstone, formation.

SIVAGANGA FORMATION

The Sivaganga Formation represents the first phase of Cretaceous sedimentation in the basin. The formation is locally divisible into three members. Well-defined at the Kovandakuruchchi quarry is a lower Kovandakuruchchi Conglomerate Member and an overlying Kovandakuruchchi Siltstone Member. While use of the same locality name for two units is discouraged (Whittaker et al. 1992, p. 815) the name Kovandakuruchchi is used for both unit as (1) there is no other suitable location where both units are well developed, and (2) the two units grade into each other along the trench section between the two quarries (at the eastern end of Kovandakuruchchi quarry-2).

Kovandakuruchchi Conglomerate Member

The Member has a clast-supported fabric (some of the clasts being 1 m in diameter) consisting exclusively of rock to
TEXT-FIGURE 2
Geological map of the Ariyalur area with the localities mentioned in the text (based on Sundaram and Rao 1986, Ramasamy and Narasim

1. Tondi clay mine
2. 2.5 km W. of Kunnam
3. power line nr. Kukkalkalattam
4. 2 km N. of Garudamangalam
5. between Mundilippur & Garudamangalam
6. S. of Kunnam
7. between Saturan & Mungalur
8. near Saradamangalam
9. 2 km N.W. of Kukkur
10. near Kotur
11. near Saubhagam
12. near Kippur
13. near Kotur
14. Silukudi railway cutting
# PROPOSED LITHOSTRATIGRAPHIC CLASSIFICATION

<table>
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### CORRELATION WITH EXISTING LITHOSTRATIGRAPHIC CLASSIFICATION

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**TABLE**

A revised lithostratigraphic classification and the tithological classification of the Cretaceous rocks in the Ariyalur olistolith, Cauvery Basin.
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PROPOSED LITHOSTRATIGRAPHIC CLASSIFICATION

MEMBERS
FORMATION
GROUP

ARCHAEOAN

GONDWANA
GROUP

UTTATUR
GROUP

ARIALUR
GROUP

1996: Ramasamy and Rangarajen
Condition of the proposed Lithostratigraphic classification with the existing classification of Ramasamy, 1992, Sandeepan and Rana
A revised lithostratigraphic classification of the Cretaceous rocks of Cauvery Basin

The Silistone Member is an off-white to grey, fine to medium grained, horizontally bedded, graded, fining-upward sandstone-siltstone succession.

**Type locality:** A trench section in the Kovandakuruchchi quarry-2, 10° 57.523' N-78° 55.877' E.

**Environment and depositional process:** Probably represents sheet flow deposits in a retrogradational alluvial fan or density (gravity) underflows down the face of a submarine fan delta.

**Remarks:** Banerji (1982) established Sivaganga Formation (gravity) underflow-sediment face of a submarine fan delta.

Kovandakuruchchi Siltstone Member

The Siltstone Member is an off-white to grey, fine to medium grained, horizontally bedded, graded, fining-upward sandstone-siltstone succession.

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**Remarks:** Banerji (1982) established Sivaganga Formation (gravity) underflow-sediment face of a submarine fan delta.

Terani Clay Member

Type locality: In and around Karai, a third, syncline, but more basinal unit in exposed in the Terani Clay mines. This is the more argillaceous, Terani Clay Member.

**Lithology:** Dirty yellow to brown, thin to thickly bedded kaolinitic claystones with subordinate ferruginous sandstone and siltstone beds. As the Terani Clay mine the claystones have thin to medium bedded (4-30 cm), coarse-grained sandstone beds with sharp planar to erosive bases and planar upper surface. Mudstone rip-up clasts are present at the base of some sandstone beds. Box-like pyrite concretions are also reported in these sandstone beds.

**Type locality:** Terani Clay mine, 11° 07.039' N-78° 53.363' E.

**Fossils:** The clays are rich in plant fossils and plant impressions and are commonly referred to as Terani plant beds. Palynological studies show that, except for some black wood fragments (Most resistant phytoclasts), the clays are barren of palynomorphs (P. Dodsworth pers. comm.). Some bioturbation is present.

**Environment and depositional process:** A low energy, lacustrine environment with little signs of wave or current reworking or a marine basin with periodic deposition from density current (turbates).

**Remarks:** The clays are reported to be of Aptian age, but no datable fossils have been recorded, with one exception. Mannigam et al. (1973) report two Upper Neocomian (Barremian) ammonoite spp. and one *Inoceramus* sp. along with plant fossils from these clays.

**Uttattur Group**

The Uttattur, resting over the Archaean basement and/or the Gondwana Group of rocks, is divided into three formations:

1. Dalmiapuram Formation
2. Karai Formation
3. Gundasamangalam Formation.

**Dalmiapuram Formation:** Five members, of which three are new, are recognized in the Dalmiapuram Formation.

**Grey Siltstone Member:** This is the lower-most member in the Dalmiapuram Formation. Sundaran (1968) reported the occurrence of a "Grey shale" bed below the limestones. The part of the Kallakudi quarry-2 where the grey shale bed was previously exposed, along a fault, is now water-logged. Two samples of the grey shales have been provided to the authors by S. Lakshminarayanan (from Kallakudi quarry-2) and S. Ramasamy (from Perai).

**Lithology:** Dark grey, fine-grained siltstones with some pyrite and mica. **Fossils:** An impoverished foraminifera and palynomorph assemblage (P. Dodsworth pers. comm.) along with some ostracod valves and fragments of gastropod and bryozoa are reported. The limited paleontological evidence from these siltstones suggest a probable Barremian to Albian and a possible Aptian age.

**Remarks:** The so-called "Grey Shale Member" (e.g. Sundaran and Rao 1986, Ramasamy and Banerji 1991) is a siltstone. Redefining the member as "Grey Siltstone" allows a proper lithologic representation of the Member. The more calcareous beds reported by Jain (1977, p. 170) have not been seen, but this is probably due to the lack of exposed sections. Our work on the palynology (P. Dodsworth pers. comm.) of these siltstones, however, agrees with much of that reported by Jain (1977). An impoverished foraminifera and palynomorph assemblage (P. Dodsworth pers. comm.) suggests that this time marginal marine conditions were established in the basin.

**Dalmiapuram Limestone Member:** Exposed along the western margin of the basin Kallakudi quarry-2, Varugupadi, Srinakarup, Olaipadi and Govindrajpatnam.

**Lithology:** The in-situ, massive, pink to off-white/pale grey limestones are bioclastic to arenaceous bioclastic mudstone-wackestone-packstone-grainstone combinations with isolated boundstone fabric. The grainstone and wackestone fabric is dominant. Arenaceous content, mainly quartz with some feldspar, is between 2-10 percent. The limestones are characterised by dissolution vugs and cavities, geopetal structures, internal sedimentation and show small scale grading.

**Type locality:** Kallakudi quarry-2, 10° 59.412' N-78° 56.756'E.

**Fossils:** The limestones are mainly composed of red algae, bryozoans, corals, brachiopods, gastropods, echinoids, and bivalves.
and bryozoa. Other bioclasts consist of echinoid spines and plates, bivalve and gastropod fragments, brachiopods, ostracods, foraminifers, calcareous sponges and fragments of scleractinian corals.

Remarks: These limestone blocks are typically pink in colour and are commonly referred to as pink limestones or pink-reefal carbonates.

Olaipadi Conglomerate Member: Overlying the Dalmiapuram Limestone Member is the Olaipadi Conglomerate Member, well developed at Olaipadi, Tiruppattur, Neykulum and Kallakudi quarry-2.

Lithology: Massive and chaotic beds with boulders of already lithified carbonates (some of which are several meters across) with fine-to-coarse-grained, poorly sorted, clayey silicilastic matrix. Associated with the carbonate blocks are smaller fragments of Archaean basement together with brown, deep weathered silty claystones (with plant fragments) of unknown age and origin. The clay appears to be very similar to the Terani clays, but at this stage of our work it is very difficult to prove this. It is also very difficult to comprehend how these clay bands can be so intimately associated with these massive conglomerates. Relative proportion of the clastics (carbonate and Archaean basement) varies from location to location e.g. totally carbonate and quartzite clasts at Neykulum, predominantly basement clasts at the western end of the Olaipadi quarry while massive carbonate boulders in the E and carbonate boulders, overturned geopetal structures and upside down fossils within the boulders.

Type locality: Olaipadi quarry, 11° 19.063' N-79° 04.763° E.

Environment and depositional process: A rapid deposition from massive submarine debris flows or turbidites at the foot of eroding fault scarp.

Remarks: These carbonate blocks relate to the mid-Cretaceous faulting. The Kallakudi and Kovandakuruchchi quarries are clearly affected by two sets of roughly E-W and NNE-SSW trending normal fault systems. Minor, localized, faulting is witnessed all along the western margin of the basin. These faults operated during, or just after, the lithification of the Dalmiapuram Limestone and generated intraformational, boulder-conglomerate flows. This fault controlled, chaotic accumulation of massive, redeposited, carbonate block in the unit has been confused for a mound shaped, non-bedded architecture associated with "reef" bodies, with Ranaasamy and Banerji (1991) reporting them as "bioherms".

The Kallakudi Sandstone and Kovandakuruchchi Sandstone Members (as is the case with the Kovandakuruchchi Conglomerate and Kovandakuruchchi Siltstone Members) are best represented at the Kallakudi quarries-2 and 1, respectively (forcing the repetition of the "Kallakudi"). The members are present all along the western margin of the basin.

Kovandakuruchchi quarry-1 and Olaipadi, is a medium to coarse, glauconite-rich, calcareous sandstone with alternating marl and limestone beds with pebbles of Precambrian basement rock. Sharp based, 10-60 cm thick beds of sandy, bioclastic grainstones interbedded (contact sharp or gradational) with marl and sandy claystones. In some beds the siliciclastic component dominates. The fresh glauconite gives the sandstone a green to grey colour; when weathered, however, the colour changes to orange-brown. Shallow (0.4 m wide), N-S trending channels showing normal (rarely reverse) grading with rare basement clasts occur. Large channels (N-S trending) also occur within the interbedded sandy claystones and marls. These channels reach 30 m in width and are several meters deep. The tops of the channel fills appear very flat and the infill is very coarse, pebbly arenites with some basement boulders up to 50 cm across. The channels contain little bioclastic material. There are lateral variation with coarse shell-rich sandstone beds, graded beds, channel deposits, alternating massive to bedded nature with rare cross bedding, features which suggest a mode of formation closely related to turbidity currents.

Type locality: Kallakudi quarry-2, 10° 59.41' N - 79° 56.756° E.

Fossils: The marl beds report a rich fossil assemblage. Foraminiferal population of the Roaalipora appennincs (Renz) Interval Zone to R. cuschami (Morrow) Total Range Zone, ranging from the late Albian to the late Cenomanian age, are reported. Amongst the macro-fauna Agnian to Albian ranging belemnite species- Tetrabelus secturus (Blainvili), Parahelobites balfordi (Spengler) and Neseobolites spp (P. Doyle pers. comm.) and an early to mid-Cretaceous phycocarid ammonite (M. Thomson pers. comm.) along with shell debris containing Exogyra, Ostrea, Alectoroida, echinoids and bryozoa fragments.

Remarks: At the Olaipadi quarry the thick massive, coarse-grained sandy grainstones pass into very coarse bioclastic arenites with lenses of very coarse grainstones containing reworked rudists and serpulids.

Kovandakuruchchi Siltstone Member

Lithology: The overlying Siltstone Member, at Kallakudi quarry-1, Tiruppattur and Neykulum is an alternating succession of siltstone and calcareous sandstone with varying proportions of glauconite and clay. Sharp based, thin to medium bedded, coarse pebbly sandstone (commonly containing pebbles of quartz and greywacke) interbedded with beds of white silty claystones, Bases of sandstones are sharp, planar to erosional and commonly display load structures. The tops of the beds rapidly grade up into mudstones. More frequent channel flows, reverse and normal grading, Bouma divisions and rare low angle erosional structures.

Fossils: Thalassinoidea, belemnite species (not in-situ).

Type locality: Kallakudi quarry-1 (abandoned quarry).
and Silstone Members). Deposition from high concentration turbidity current. Most likely a ramp-like slope developed over the massive debris/talus flows shed from fault bounded basement/carbonate platform blocks. Talus platform created directed caibonaics by previous workers (e.g. Maruvattur Formalion of Dalmiapurain Limestone, boulder-channel orientation suggests slope was EW with broad, bypassing of turbidity currents within channels. Consistent turbidity currents as they rapidly lost competence. This resulted in the deposition of mixed carbonate and clastic turbidites on a prograding apron, such as slope with occasional by-passing of turbidity currents within channels. Consistent channel orientation suggests slope orientation was EW with flows to north or south.

Remarks: The Sandstone and Silstone Members with their regularly interbedded nature, characteristic to the turbidite beds, have been mistaken for "biostromal" reefal deposits (e.g. Madhavan Nair and Vijayan 1981, Ramasamy and Banerji 1991).

The in situ carbonates of Dalmiapuram Limestone, boulder-conglomerates of Odiyam Member and the interbedded clastic-carbonate sequence of Kallakudi Sandstone and Silstone Members (this study) have been identified as "reefal" carbonates by previous workers (e.g. Manuvattur Formation (in part) of Sundaram and Rao 1986, Limestone Member of Dalmiapuram Formation in Ramasamy and Banerji 1991).

**KARAI FORMATION**

The Ulatur Formation (e.g. Ramasamy and Banerji 1991) is renamed as the Karai Formation (Karai Formation of Sundaram and Rao 1986). A formation name usually consists of a geographic name, from where the unit is described, followed by a lithic designation or by word "Formation" or both. The so-called Ulatur Formation (Ramasamy and Banerji 1991) comprises predominantly of clays. The Ulatur village, after which the name was given (Blanford 1862), rests on the Archaean basement. The clays have been described from Karai and adjacent villages. This, along with priority of publication, makes it appropriate to rename the Ulatur Formation as the Karai Clay Formation. It is argillaceous unit with a local development (near Odiyam and Kuniam) of an arenaceous facies.

**Lithology:** The formation is dirty brown to rusty yellow clays, silty clays and sandy clays; glauconite and organic rich in places. Tropical weathering (high heat and humidity) has resulted in superficial gypsum concentrations. The area occupied by the formation displays a typical badlands topography.

**Type locality:** Karai-Kulakkalnattam traverse.

**Fossils:** The clays are rich in foraminifera, Foraminiferal assemblages belonging to the *R. subintertextus* (Gaud legal) Interval Zone to the *Prongilabroncron helvetica* (Belli) Interval Range Zone are identified. Palaeontological studies on 20 surface samples (foraminiferal studies on these 20 samples are currently being done) show that the clays are now barren of palynomorphs (P. Dodsworth pers. comm.). A rational explanation of this could be a high susceptibility of organic-walled palynomorphs to the tropical weathering associated with these latitudes (K. Dorning and P. Dodsworth pers. comm).

Remarks: The top of the formation is cut by a rapid regression. The event is marked by a sudden and sharp reduction in planktic foraminifera, being completely replaced by a low diversity agglutinated assemblage (see Hart et al. this volume).

**Odiyam Sandstone Member:** To the north of the basin, a locally developed arenaceous unit, the Odiyam Sandstone Member, is recognized in the otherwise argillaceous Karai Formation.

**Lithology:** Yellow, friable, silty-sands with thin impregnations of compact-grey calcareous sandstones, yellow, silty clays and calcareous clays.

**Type locality:** 2.5 km west of Kunniam, 11° 14.525' N-79° 00.416'E.

**Fossils:** A late Conomanian-early Turonian foraminiferal assemblage of *Whiteinella archaeocretacea* (Gaspasso) Partial Range Zone, ammonites of mid-Cenomanian (or younger) (M. Thomson pers. comm.) along with abundant tubular and spiral serrspills, *Thalassinoides*, *Pecten*, *Oxyura*, *Electranilla*, *Lapha*.

**GARUDAMANGALAM FORMATION**

The Karai Formation is followed (conformably in places) by the Garudamangalam Formation. Following the deposition of deep marine clays (Karai Formation) there was a major regression. This is marked by an abrupt, out of sequence shallowing. During this regressive phase, fine to coarse-grained, parallel laminated and bioturbated sandstone were deposited. In the Karai-Kulakkalnattam traverse, the clay terminates abruptly beneath a carbonate concretion unit. This nodular-concretionary unit has been reported as a concretion bed, being used to identify an unconformity between the underlying clays and the overlying sandstones (Sundaram and Rao 1986). These are carbonate concretions, however, which formed during a transgressive phase (see Hart et al. this volume). The base of Garudamangalam Formation therefore constitutes a sequence boundary caused by forced regression (sensu Posamentier et al. 1992).

**Remarks:** Sundaram and Rao (1979, 1986) recognise the Garudamangalam Formation (this study) as Trichinopoly Group (as established by Blanford 1862) with two formations - (1) Kulakkalnattam Formation and (2) Anaipadi Formation, Banerji (1973) recognised the same unit as the Garudamangalam Formation (Garudamangalam nam. corrupt of Kunniam 1871). Later Ramasamy and Banerji (1991) divided the formation into three members-Kotturai, Anaipadi, Kulathoor, in stratigraphic order. The so-described Trichinopoly Group is exposed in Garudamangalam and
adjacent villages. The Trichinopoly District, after which the name was given (Blandford 1862) rests out the Archaean rocks. Kossmat (1897) renamed the Trichinopoly Group of Blandford (1862) as Garudamangalam. While all successive workers, up to the present date, have continued using the term "Trichinopoly", Banerji (1973), for the first time, proposed the use of "Garudamangalam" as revised by Kossmat (1897).

The code on the exact location of type sections (Whittaker et al. 1992, p. 814) allows the use to term "Garudamangalam" (as revised by Kossmat and later followed by Banerji 1973)

**Kulakkalnattam Sandstone Member**

**Lithology**: Fine to coarse calcareous sandstones with two distinct layers of carbonate concretions, shell-rich sandstones, silty sandstone, ferruginous sands, argillaceous silstone, pebbly sandstones. Near the power line at Kulakkalnattam (11° 06.676' N-78° 56. 391' E), 2 km north of Garudamangalam (11° 05.630' N-78° 55.751' E) and between Alundalippur and Garudamangalam (11° 03.856' N-78° 54.963' E) is a fine-to-coarse-grained, well cemented, ferruginous sandstone member. These sandstones are massive to cross- and planar-laminated containing two distinct layers of large carbonate concretions (up to 1.5 m diameter) with vertical burrows (including *Teredolites*) penetrating these concretions. Less well indurated sandstones are highly bioturbated by feeding traces (e.g. *Thalassinoides*, etc.). Cross bedding appear to occur within shallow channels (1 m or so) above a coarse pebble (Pebbles include basement quartzite, garnet gneisses and quartz) and oyster fragment lag base. This facies appears to cut into planar horizontal laminated, medium-grained sandstones with abundant fine bioclastic material. At Garudamangalam (11° 04.562' N-78° 55.534' E), south of Kunnam (11° 13.018' N-78° 00.754'E) and Mungalpari (11° 12.235' N-78° 00.520'E) there are 1-2 m thick, compact, grey, shell-rich sandstone beds with pockets of pyrite concretions and characterised by the presence of monospecific molluscan shell banks, a typical near shore or estuarine facies. In the past this mollusc-rich unit has been identified as shell limestone (e.g. Ramasamy and Banerji 1991), the unit is, however, a fine-to medium-grained, shell-rich sandstone and not a shell limestone. There are small scale lateral variations in shell concentration, planar-and cross-laminations, load structures (lenses), normal grading and massive beds. On a larger scale a lateral variation in fossil content is observed. At Garudamangalam the shells are mainly of gastropods while at Kunnam and Mungalpari, bivalve content is observed. At Garudamangalam the shells are mainly of gastropods while at Kunnam and Mungalpari, bivalve dominance. These shell-rich sandstones are followed by a pebbly sandstone bed. Along the stream sections between Saltanur and Mungalpari (11° 02.808' N-78° 58.878' E), near Sardamangalam (11° 03.346' N-78° 55.912'E), and stream sections near Kulakkalnattam is very coarse-to-coarse-grained, pebbly, bioclastic sandstone bed with silty sandstones and argillaceous silstones. The bed contains pyrite, reworked class of shelly sandstones (up to 10 cm diameter), basement pebbles and other pebbles.

**Type locality**: Beneath the power line near Kulakkalnattam, 11° 06.976' N-78° 06.391'E (For concretionary sandstone bed); Garudamangalam, 11° 04.562' N-78° 55.534'E (for grey shell-rich sandstone); stream sections near Kulakkalnattam (for pebbly sandstone bed).

**Fossils**: Abundant wood fragments encrusted with oysters and completely bored by bivalves (Hart et al. this volume), molluscs, *Pinna* (not in situ), *Thalassinoides*, Diplorabdian *Ophiomorpha*.

**Environment and/or depositional process**: The sandstone unit (with carbonate concretions) suggests an intertidal to shallow subtidal sandflat or possible foreshore setting. Several flooding surfaces led to concretion growth (Taylor et al. 1994), boring etc. The drowning led to subtidal, burrowed sands or possible ravinement surface formation. The molluscs in the sandstone unit represents a restricted marine environment, formed by rapid deposition from supratidal current (suggested by loading, graded beds and planar horizontal beddings). An overbank of distributary channels or a high discharge or a washover event into a lagoon or tidal sandflat environment was probably responsible for these mollusc-rich sandstones. The pebbly sandstone bed appears to be a reworking (perhaps during transgression) of cemented sandstones and rarely basement rocks. The facies most likely represents some form of inlet or channel in delta plain, estuarine or within a barrier succession.

**Remarks**: The Kulakkalnattam Sandstone may represent a transgressive or lowstand systems tract above the post Karai Clay sequence boundary.

**ANAIPADI SANDSTONE**

**Lithology**: Two kilometers west and one kilometer north of Kulattur and near Kottur are dirty yellow, hard calcareous sandstone and silty-sandstones.

**Type locality**: 2 km west of Kulattur, 11° 06.882° N-78° 58.042° E.

**Fossils**: A rich assemblage of Coniacian ammonites (some of which are 1 m in diameter) represented by *Kazmaiceras gr. theobaldianum Stolicepska*, *Kazmaiceras theobaldianum var. crassicostata var. crassicostata Collignon*, *Puzosia*, *Damesites aff. sugata* (Forbes) (M. Thomson pers. comm.) along with abundant brachiopods (especially near Kottur, 11° 09.610° N-78° 00.543° E). Associated with them are nautiloids, molluscs and bored wood with encrusting oysters.

**Remarks**: A flood of large ammonites suggests a return to deeper-marine conditions in the Coniacian representing initial phase of a high stand (see Hart et al. this volume).

**ARIVALUR GROUP**

The Arylur Group is divided into three formations: (1) Siltakudi Formation, (2) Kallanakurunchchi Formation and (3) Kallamedu Formation.
SILLAKUDI FORMATION

A major unconformity, spanning post-Coniacian to late Santonian, is present between the Gandamangalam and Sillakudi Formation. During this period the basin appears to be under erosive and/or fluvial influence. At a stream section, near Saturbhagam (11° 03'188"N-78° 57'954"E), fluvial sandstones and silty-sandstones with reworked, fresh feldspar pebbles and sandstone cobbles (up to 30 cm diameter) are exposed. Very large scale trough cross-beds with sets up to 3 m wide (pale grey siltstone drape some foreset surface) occur in the unit. This is probably a fluvial channel fill. Mud drapes may indicate some marine tidal influence although this may also be the result of seasonal changes in discharge. Presence of fresh feldspar and sandstone clasts suggests incision into older facies and presence of a sequence boundary at the base of this unit. Until further work is completed the fluvial unit is recognised but not included as a formal litho-unit in the proposed classification. The Sillakudi Formation has the largest areal extent in comparison to any other formations in the outcrop. This, however, is due to the near horizontal nature of the Formation and should not be confused for a greater thickness of the unit. Lithology: Medium to coarse, off-white to grey, calcareous friable sands and hard, calcareous sandstones. There is a local development of carbonate facies (discussed later), however, in an otherwise clastic formation.

Type locality: Sillakudi railway cutting; 11° 04.887’N-79° 01.960’E.

Fossils: Except for a few inoceramid prisms and foraminifera, the sandstones are very poor in fossils. The only datable fossils reported are from subsurface material of the Sillakudi Formation.

Remarks: Rashood and Ravindran (1978) have reported a rich foraminiferal assemblage from subsurface material of the Sillakudi Formation. Kalpalvur Grainstone Member

A new (locally developed around Kilpalvur) member, the Kilpalvur Grainstone Member is proposed for the base of the Sillakudi Formation.

Lithology: Bioclastic, oolitic grainstone with oolites (probably channellite) constituting 90% of the allochems.

Type locality: well sections at Kilpalvur, 11° 04.045’N-79° 04.583’E.

Fossils: Foraminifera, inoceramid prisms and rare bivalves and echinoid fragments. Amongst the foraminifera, tiny, Globigerinelloides Cushman and Ten DAm dominate. Rare occurrences of Marginotruncana margina (Reuss), Globotruncana Cushman, Whiteinella ballica Douglas and Rankin and Archaeoglobigerina Pesagno are reported.

Remarks: The Member is exposed only in the well sections, where it is seen resting on the Arcadian basement and for the Kallanakuruchchi Formation. Full access to these wells is not possible.

KALLANAKURUCHCHI FORMATION

The Sillakudi Formation is followed unconformably by the Kallanakuruchchi Formation. At a stream section, near Kalpa (11° 08.246’N-79° 06.965’E), orange yellow, pebbly grainstone (Kallanakuruchchi Limestone) with thin, subangular to angular, pink to white quartz and feldspar pebbles to cobbles, some to which are 10 cm in diameter is exposed. Three core sections, (112 113 and 114), from the well PK3/95 at Periya-Pariakkudu (11° 01’N-79° 09’E), were made available for study (Dalmia Cement Co. pers. comm.). In PK3/95 at a depth of 34.20 m (Section 114) Sillakudi Sandstone is present. At 34.10 m (Section 113) a 5-10 cm thick gradational unit is followed by a 23 cm thick conglomerate unit (at 33.75 m, Section 112). Dark-grey sandstone pebbles, approximately 3 x 2 cm² (clasts are reworked pebbles of the underlying Sillakudi Formation) are present in orange-yellow limestone; above which the kallanakuruchchi Limestones start. The Limestones are first located at a depth of 30m (Lakshminarayanan pers. comm.). Drilling was stopped at 35 m. The presence of a conglomerate bed at a depth of 34.10 m (Section 113) is due to the near horizontal nature of the Formation and should not be confused for a greater thickness of the unit. Lithology: Medium to coarse, off-white to grey, calcareous friable sands and hard, calcareous sandstones. There is a local development of carbonate facies (discussed later), however, in an otherwise clastic formation.

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Remarks: Rashood and Ravindran (1978) have reported a rich foraminiferal assemblage from subsurface material of the Sillakudi Formation.

Type localitv. WQH pers. comm.

Three new members-(1) Tancem Limestone Member. (2) Dalmia Biotromal Member and (3) Dharni Limestone Member are proposed in the Kallanakuruchchi Formation. All facies appear to extend laterally over several hundred meters with little lateral variation. The succession represents a retrograding (transgressive) Carbonate ramp setting.

Tancem Limestone Member

Lithology: Hard, orange-yellow, coarse - to very coarse-grained, massive to thick bedded (200 to 50 cm) (some coarsening up), bioclastic to sandy bioclastic packstone-grainstone, composed mainly of larger foraminifera, bryozoa and rudist bivalves. A lateral variation in the fossil content is seen. At Tancem mines 80-90% of the bioclasis comprise larger foraminifera, with bryozoa and rudist bivalves reduced to less than 10%. On the contrary, at the Dalmia (or Fixit) mine 80-90% of the bioclasis comprise larger foraminifera with bryozoa and rudist bivalves greatly reduced. Type locality: Tancem mine, 11° 04.887’N-79° 06.965’E.

Fossils: Larger foraminifera, Ochitites spp., Siderolites calcitrapetid Lamark along with bryozoa, rudist bivalve (oyster shells and Inoceramus prisms), some red algae, ostracod valves and echinoid fragments (many of which are bored).
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Remarks: The unique feature of these limestones is the absence of Ophthalocycloids. In European and Middle Eastern Maasrichtian rocks, the Orbitoides or Orbigny are usually associated with Ophthalocycloids.

Dalmia Biostromal Member
Lithology: At Dalmia (or Fixil) mine the Tancem Member is followed by an orange-yellow, laterally extensive biostromal limestone. The limestones are sandy rudstones (characterised by large Gryphaea, terebratulids, Alcacinia/Laphia and shell-fragments of approximately 10-12 cm in size) with a coarse to very coarse, bioclastic grainstone (similar to Tancem Member) matrix.

Type locality: Dalmia or (Fixil) mine, 11° 07.997’N-79° 02.288’E.

Fossils: Gryphaea, Alcacinia/Laphia, terebratulids (many of which are broad and partially encrusted by serpulids, bryozoans and sponges), larger foraminifers e.g. Orbitoides spp., Siderolites calcitrapoides Gippilaudini degupta Marie.

Remarks: Radulovic and Ramamurthy (1992) have described dissecminated bivalves (Inoceraminid, Gryphaea) and some whole, large teratratulids.

Dherrani Limestone Member
Lithology: The member comprises of massive, orange-yellow, coarse-grained, friable, orbitoid-rich grainstone/orbitoid-rich sand.

Type locality: Dherrani quarry (near Veiliparangam village), 11° 04.006’N-79° 09.078’E.

Fossils: Larger foraminifers e.g. Orbitoides spp., Siderolites calcitrapoides, disseminated bivalves (Inoceraminid, Gryphaea) and some whole, large teratratulids.

Remarks: At Dherrani quarry the Tancem Limestone is followed by an approximately 3-4 m of friable, orbitoid-rich sands. Drilling in the quarry is still in progress and 15 m of orbitoid sand has been encountered so far (Quarry manager pers. comm.).

KALLAMEDU FORMATION
The formation consists of the Ottakovil Sandstone (Ottakovil Formation of Rashhoed and Ravindran 1978) that is not recognised here as it is not a mappable unit. Also in a lithostratigraphic classification separating the post-Kallanakuruchchi sandstones and unconsolidated sands as Ottakovil and Kallamedu Formations is not justifiable. The Ottakovil is a locally developed, regressive marine facies sandstone and the Kallamedu is a fluvial sandstone, but depositional process is not a criterion in lithostratigraphic classification (Commission 1983, p. 856). The Ottakovil Sandstone and the Kallamedu Sandstone are, hence included as Kallamedu Formation with a locally developed lower Ottakovil Sandstone Member. The Formation marked an end to the Cretaceous sedimentation in the basin.

Lithology: Red to green/grey variegated clayslones overlain by channel of white to pale grey, well to poorly cemented, texturally mature, fine-to-medium-grained sandstone. Channel base contain horizontal planar laminations overlain by sets of low angle planar, cross bedding. A small vertical burrow (present in one forest) and calcite cement suggests some marine influence.

Type locality: Kallamedu, 11° 11.890’N-79° 08.014’E.

Environment and/or depositional process: Variegated clays suggest soil formation in overbank muds with channelised sands showing high degree of maturity and yet appearing to indicate a rapid, shallow deposition in shallow channels. May indicate fluvial, flood plain to coastal plain environment with minor marine influence.

Ottakovil Sandstone Member
Lithology: A locally developed Member comprising grey, dirty yellow to off-white, cross-beded (beds unclear to medium bedded), medium to coarse, micaceous (predominantly biotite), friable sand and well cemented, fine-to-medium-grained sandstone. Trough cross bedding present at one horizon; sets from 15 to 20 cm thick (at one place cross sets 25 cm thick 150 cm across).

Type locality: 2 km north at a stream section near Ottakovil, 11° 11.910’N-79° 06.830’E.

Fossils: In the upstream section the sandstones are associated with echinoids, rare larger foraminifers, together with the trace fossils Thalassinoides, Ophiomorpha, Dactyliocladus. In the downstream section are echinoids, nautilids, Durania mutabilis (Stolicka) a Maasrichtian rudist bivalve (P. Skelton pers. comm.), Gunnarilcs kaktika (Stolicka) a Maasrichtian ammonite (M. Thomson pers. comm.) and Alcacinia/Laphia.

Environmental and/or depositional process: A relatively low energy, open marine, lower-upper shore face environment. Trough sets of limited lateral extent may represent rip or long shore troughs/channels. The trace fossil assemblage in indicate a marginal marine, reduced sedimentation environment of deposition. The associated ammonites are suggestive of more open marine conditions (locally developed) in an otherwise shallow basin.

CONCLUSIONS
Investigation of the Cretaceous rocks of Trichinopoly District have lead to a revision of the existing lithostratigraphy. Throughout our work the code of stratigraphical procedure, rule of priority of publication and the preservation of established names are practised. A new lithostratigraphic classification, dividing the Cretaceous rocks into three Groups, seven formations and seventeen Members (of which nine are new), is proposed.

In the light of this revised lithostratigraphy are interpretation of the basin history and its correlation with the global Cretaceous sea-level pattern will be published elsewhere.
ACKNOWLEDGEMENTS

We acknowledge the assistance of a number of geologists (Dr. Ayyasami, Prof. Dadwa, Prof. Banerji, Dr. Govindan, Dr. K. Dorning, Mr. Lakshminarayanan, Dr. M. Thomson, Dr. Narayan, Prof. P. Bhagavath, Mr. P. Dodsworth, Dr. P. Doyle, Dr. P. Skeete, Dr. Pandian, Dr. Ramachiran, Dr. Rajeshwaran, Dr. Ramamohan, Dr. Ramasamy, Dr. Ramchandran, Dr. Ramachandran, Mrs. S. Bengston, Dr. Phansalkar and Venkatachala Paty) during our work on the stratigraphy. A. Tewari acknowledges the study grant made available by the British Council and Prof. M.B. Hart and Dr. M.P. Watkins acknowledge financial assistance from The Royal Society. Mr. J. Abraham kindly provided the final versions of the figures.

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Wood boring bivalves from the Trichinopoly Sandstone of the Cauvery Basin, South-East India

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ABSTRACT: A rich assemblage of Teredolites-infested loggrounds is described from the Trichinopoly Sandstone (Late Turonian-Coniacian) of the Cauvery Basin, S.E. India. The borings, probably created by the boring bivalve Operculodonta sp., are described. The abundance of log-ground material within this part of the succession is used to assist in the determination of the sequence stratigraphy of this mid-Cretaceous succession.

INTRODUCTION
The Cretaceous sediments of the Cauvery Basin (Ariyalur-Pondicherry Depression) have been investigated for their ostracod content as part of an integrated stratigraphical analysis. The succession provides a valuable insight into the history of the eastern continental margin of India (text-fig. 1) through, from the mid-Cretaceous upwards, the sedimentary sequence records changes which appear to reflect the global sea level curve.

In the Late Turonian and Coniacian shallow-water sandstones and siltstones dominate the succession and are, collectively, known as the Trichinopoly Sandstone. This lithostratigraphical classification has recently been reassessed by the authors (Tewari et al. this volume) as part of their work in South-East India. Previous authors have reported the presence of fossil wood from this succession, including the 24m long log at Sattanur. This, and the many of the other wood fragments, are encrusted with oysters and other bivalves. Many of the wood fragments are also intensely bored by bivalve borers. Some of the logs are almost replaced by the calcareous-lined tubes of Teredolites clavatus Leymerie and T. longissimus Kelly and Bromley.

TAXONOMY
Modern teredinids are exceptionally specialised marine, woodboring bivalves. General accounts of their biology are given by Lane (1961) and Turner and Johnson (1971). Modern forms are classified according to the form and structure of the pallets (Turner 1966, 1969; Huggett and Gale 1995; Gale 1993). Fossil material pallets are quite rarely described (Wrigley, 1925; Gale, 1995), most micropalaeontologists being unaware of what these objects might be, even when they are recorded as fossils. The majority of fossil occurrences are described in the form of borings into wood (xylic) material. Recently Kelley and Bromley (1984) have attempted to rationalise the taxonomy of lithic and xylic borers.

Teredolites was first described as an ichnogenus by Leymerie (1842) but, until recently, it has rarely been used in the literature. Bromley (1972) suggested that all boring ichnogenera be included in Trypanites although this has now been accepted as impracticable. Teredolites is now restricted to clavate borings in "woodground" (Bromley et al. 1984) material. In their review Kelly and Bromley (1984) identify two ichnospieces:

Teredolites clavatus Leymerie, 1842
- clavate Teredolites, predominantly perpendicular to the grain in woody substrates having a length : width ratio usually less than 5. Lining, where present, are composed of nacreous aragonite which fuses with the valves of the bivalve.

Teredolites longissimus Kelly and Bromley, 1984
- clavate Teredolites, predominantly parallel to the grain in woody substrates having a length : width ratio usually greater than 5. Commonly sinuous to contorted with linings made of radial prismatic calcite.

STRATIGRAPHICAL SETTING
The Trichinopoly Sandstone (see Tewari et al., this volume) is exposed in the Ariyalur-Pondicherry Depression of the Cauvery Basin (text-fig. 2). The succession comprises a series of sandstones, siltstones and mudstones, together with a number of conglomerate beds and highly fossiliferous calcareous sandstones. The succession can be divided into two members (text-fig. 3); the lower Kulakkallattam Sandstone Member and an upper, Anaipadi Sandstone Member. Ramasamy and Baneiji (1991) recognised a higher unit (the "Kullatur Formation") but we have been unable to identify it as sufficiently distinctive on lithological grounds.
Wood boring bivalves from the Trichinopoly Sandstone of the Cauvery Basin

TEXT-FIGURE 1
Distribution of the Cretaceous rocks in the Indian subcontinent (after Acaryj-a and Lahiri 1991). The approximate position of the Cauvery Basin is indicated by the box.

Although - at its type locality - the characteristic fauna described by Ramasamy and Banerji has been collected, Silicified wood has been collected from a number of localities in the area around Kulakkalnaltini and Sattanur (text-fig. 4). While some specimens were in-situ, much of the fossil wood was collected from dried-up river beds and is therefore transported. The state of preservation indicates that all of the collected material comes from the Trichinopoly Sandstone.

PALEOENVIRONMENTAL SIGNIFICANCE
Woodgrind (sensu Bromley et al. 1984) are comparatively rare in the geological record and can be regarded (Savdda and King 1993) as taking two forms. Xylfic peatgrinds are laterally persistent, composite, woody substrates whereas loggrounds are relatively small, non-composite, substrates represented by isolated logs. Of the two, log-grounds are the most common, occurring in non-marine (Plint and Pickrell 1985), shallow-marine (Chamberlain 1976; Dott and Bourgeois 1982; Bromley et al. 1984; Howard and Fery 1984; Kiteley and Field 1984; Francis 1986; Lindqvist 1986; Dewey and Keady 1987; Crampton 1990; Savdda 1991a; Savdda and King 1993; Savdda et al. 1993 and deeper-water (Fery 1972; Turner 1973; Wolfl 1979; Anderson 1983) sediments.

While Euralicies - infested log-grounds are therefore, found in a wide range of environments, the majority (eg. Savdda with periods of sea level rise. In the terminology of “sequence stratigraphy” these would be Transgressive Systems Tracts (TST) which follow above sequence boundaries (SB). Following the regressive event towards the top of the Katal Formation (see Tewari et al. this volume) the planktic foraminifera were significantly reduced be a rapid shallowing of the seaway (see text-fig. 5) - being replaced by a fauna dominated by agglutinated taxa (eg. Haplophragmoides kirkii Wickenden, H. multiformis Krashceninikov, H. conicavus Chapman and other quite rare Haplophragmoides spp. and Cribrostomoides sp.). This Late Turonian event is known from a very wide geographical area (eg. Haq et al. 1987 1988; Hart and Bailey 1979; Hancox 1975, 1989; Hancox and Kaufman 1979; Raja et al. 1993) and identifies a most important sequence boundary. In the Kulakkalnaltini river section (text-figs. 4 and 5) this sequence boundary is followed by the lower part of the Kulakkalnaltini Sandstone Member of the Trichinopoly Sandstone. The justification for this lithostratigraphic nomenclature is given in Tewari et al. (this volume) but, briefly, our work has shown that the Trichinopoly Sandstones (ex-Trichinopoly Group of Blanford 1862 and subsequent authors) is best regarded as a single sequence of Late Turonian/Coniacian age based on its sedimentology, lithological character and enclosed fauna/floral (see, for example, Blanford 1902; Ravindian et al. 1993; Sundaram and Rao 1986; Phansalkar and Kumar 1983; Kale and Phansalkar 1992; Ramasamy and Banerji 1991). This stratigraphic unit is quite thin and must be sediments-starved in order to produce the abundance of fossils reported by many authors. This abundance of fossils, the log-ground material, and abundant Diplurateria and Ophiomorpha, is typical of condensed successions and the sequence, as a whole, does not enjoy “group” status. The much-quoted basal conglomerate (Sundaram and Rao 1986, p 17) is, in reality (see text-fig. 5) a line (or two lines in some places) of calcareous-cemented sandstone nodules. Some have Tertiary material within them, while others preserve in-situ cross-stratification and trace fossils (eg. Thalassinoidea). Recent work by Taylor et al. (1994) has indicated that cemented nodule layers are often to be found above sequence boundaries and represent diagenetic levels controlled by groundwater movement.

The concentration of xylfic log-grounds in the Kulakkalnaltini Sandstone are (Savdda and King 1993) thereby causing a local influx of xylfic material. This, coupled with the information from the calcareous nodules, would seem to confirm that this member is a transgressive systems tract. Included within this member are monospecific shell sandstones (eg. Kusum and Garudamangalam) and conglomerate beds containing quite fresh, pink, feldspars. The inclusion of further log-grounds (including the Sattanur tree) higher in the succession, coupled with the general abundance of fossils suggests that the Anaipadi Sandstone Member completes the sequence representing the initial regressive phase of the high-stand. This line infilled with sediments with the flocc.
Paeleolocogy of the Log-Grounds

Detailed work on the structure of the log-grounds, the mineralogy of the shells and lining tubes is continuing and will be described elsewhere (Tewari et al., in preparation). We have not observed the presence of calcareous chimney structures at the open ends of the borings as, in the majority of cases, the logs have been reworked by modern erosion which will have broken these delicate structures. Linings have been seen in a large number of specimens, the majority being radial calcite. Huggett and Gale (1995) indicate that T. clavatus
Wood boring bivalves from the Trichinopoly Sandstone of the Cauvery Basin

TEXT-Figure 3
Lithostratigraphy of the Trichinopoly Sandstone.
Wood boring bivalves from the Trichinopoly Sandstone of the Cauvery Basin

GEOL0GICAL SUCCESSION IN THE RIVER SECTION 1Km SW OF KULAKKALNAMLAM VILLAGE.

normally shows aragonitic linings while T. longissimum has prismatic calcite linings. The preservation of aragonitic linings is probably unlikely and no significance has been attached to our observations. Most Terebratulids also show prismatic calcite septa, placed across the tube when growth ceases (Haggart and Gale 1995 fig. 3 illustrates one tube with 4 septa) but this has not yet been observed in our material. In some specimens the linings are seen as a collection of broken fragments, lying in dark mudstone material that is not typical of the succession. This may indicate geologically significant reworking from a more muddy area into the present sand-dominated environment of the Kulakkalnallam Sandstone Member. Some tubes are filled with diagenetic calcite, perhaps indicating that the patters were initially in place across the entrance to the tube, thereby excluding sediment.

NATURE OF THE BORING ANIMAL.
Kelly (1988) describes *Operopholus psyche* n sp from the Lower Cretaceous of Western Antarctica, noting previous descriptions of related taxa. One such species is *Operopholus mersum* (Stolitzka 1870), initially described as *Parapholus merso* n.sp. by Stolitzka (1870) from the "Ootatoor Group" (= Uttatur Group) at Morivavator (probably Albian-Cenomanian in age). These specimens, together with *Martania timdens* Stolitzka (1870), were recovered from borings in wood. Francis (1986) has described a mixture of conifer and angiosperm wood from the Antarctic Peninsula, some of which is heavily bored (Francis 1986, text-fig 2 and pl. 51, fig. 1). Unfortunately, although there are some internal features to the borings shown in plate 51 they are very unclear due to the lightness of the photograph. Because of this little can be made of a comparison of our material. Crampin (1990) has described a new species of wood-boring bivalve from the Upper Cretaceous of New Zealand (*Pholadidea itatavia* n.ssp.) which may be an intermediate form between Cretaceous *Operopholus* and Early Cenozoic *Pholadidea* and *Martania*. This new species has been recorded from shallow water, marine, transgressive, sandstones that are very...
similar in facies to the Kuhakhandian Sandstone Member. Unfortunately all of Crampton's material is figured in 3-dimensional shelly fossils, which makes comparison to our material very difficult (if not impossible). Attempts are being made at isolating some of our shelly material but it is not possible to illustrate this at the present time. O. meroa (Stoliczka) is very close to P. (H.) meroe. 

SUMMARY

A rich assemblage of Teredolites-infested log-grounds is described from the Trichinopoly Sandstone of the Cauvery Basin, S.E. India. The log-grounds represent in situ material into the basin following an important sequence boundary in the Late Turonian. The transgressive systems tract and highstand systems tract are represented by the formation, which probably spans the Late Turonian and Coniacian interval. The presence of monospecific shell sandstones, beds of conglomerate and large accumulations of ammonites and belemnoids all indicate quite marked sediment starvation.

ACKNOWLEDGMENTS

A.T. gratefully acknowledges the support of the British Council while M.B.H. and M.P.W. acknowledge receipt of Travel Grants from the Royal Society in support of field work in India. M.Ashit, J. Abrahaim, A. Smith and D. Griffiths are thanked for their assistance with thin section preparation, cartographic work and photography. Dr. C.E. Savda (Alabama, U.S.A) is thanked for his advice on log-grounds while Dr Govindan. Ravindran, Pandian and Venkateshathapathy are thanked for their assistance in the field.

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PLATE I
Specimens 1 and 2 are polished faces of two samples collected near Kulakkalam. Both show large Teredolites borings cutting vertically through the grain of the wood. The maximum dimension of specimen 1 is xx cms and the maximum dimension of specimen 2 is xx cms.
I(Whorinn bivalves from the Trichinopoly Sandstone of the Cauvery Basin


PLATE 2
Specimens 1-3 are polished facets of specimens collected in a river section north of Kuliddakamittam Village. The maximum dimensions of each of the specimens are as follows: Specimen 1 xx cm; specimen 2 xx cm; specimen 3 xx cm. The bottom right hand corner of specimen 1 shows quite clearly the two valves of (? Opertuchasma sp., the teredinid bivalve probably responsible for the borings. Specimen 3 shows a long, fine, boring surrounded by diagnostic minerals. The initial structure of the wood can be seen at the right hand side of the specimen.
Teredolites and its palaeoenvironmental significance in the Garudamangalam Sandstone Formation (late Turonian-Coniacian) from the Cauvery Basin, southeast India.

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Suggested running header: Teredolites from South India

Key words: Teredolites, log-grounds, Cretaceous, Cauvery Basin, India, sequence stratigraphy.

Submitted to Ichnos.
ABSTRACT

Teredolites-infested log-grounds are reported from the late Turonian-Coniacian Garudamangalam Sandstone Formation in the Cauvery Basin, SE India. The borings, *Teredolites clavatus* Leymerie and *T. longissimus* Kelley & Bromley, probably created by the boring bivalve *Opertochasma*, are described. The log-grounds, together with other trace fossils, are used to assess the palaeoenvironmental setting of the Garudamangalam Formation. The ichnofossil information, in conjunction with the sedimentology and palaeontology data, is applied to assess the sequence stratigraphy of the Basin.

INTRODUCTION

The Cretaceous sediments of the Cauvery Basin (Ariyalur-Pondicherry Depression) have been investigated for their microfossil content as part of an integrated stratigraphical analysis. The succession provides a valuable insight into the development of the eastern continental margin of India (Fig. 1) although, from the mid-Cretaceous upwards, the sedimentation appears to reflect the global sea-level change. Latest Jurassic to earliest Cretaceous rifting between India and Australia/Antarctica led to the development of a number of NE-SW trending basins in the Indian Precambrian crystalline basement (Powell *et al.*, 1988). The Cauvery Basin (Fig. 1) is the southernmost basin along the eastern margin of India and comprises a number of depressions (or sub-basins) developed within grabens or half-grabens. The Ariyalur-Pondicherry Depression (Ramanathan, 1968; Sastri *et al.*, 1973, 1981) is the northernmost sub-basin, containing three important outcrops at Ariyalur, Pondicherry and Vridhanchalam.

This contribution is one of a series of papers (Hart *et al.*, 1996) based on our work on the Ariyalur outcrop (Fig. 2) of the Trichinopoly District. *Teredolites*-bearing
log-grounds occur in the late Turonian-Coniacian, Garudamangalam Sandstone Formation (Fig. 3), southeast India. During the course of this research a large amount of fossilized wood has been collected from a number of localities in the area around Kulakkalnattam and Sattanur (Fig. 4). The most famous locality is Sattanur (Fig. 4, locality number 13) where a 18 m long tree trunk has been protected as a national monument. While some specimens were collected in-situ, much of the fossil wood was collected from dried-up river beds and is, therefore, transported. The preservation indicates that all of the collected material comes from the Garudamangalam Sandstone Formation. Much of the material (fossilised wood) is intensely bored by teredinid bivalves. This paper describes the morphological characteristics of the Teredolites and its palaeoenvironmental significance in the Basin. The application of sequence stratigraphic principles show that the distribution of log-grounds in the Basin is closely linked to sea-level rises (transgressive events).

LITHOSTRATIGRAPHY

The Cretaceous succession of the Cauvery Basin has been the subject of intense research since the early studies of Blanford (1862) and the production of a number of palaeontological monographs by Stoliczka (1870-1871). Since then, various workers (e.g. Banerji, 1973; Sundaraman & Rao, 1979, 1986; Ramasamy & Banerji, 1991) have subdivided the succession into stratigraphic units, although the majority of them have adhered closely to those established by Blanford (1862). A lithostratigraphical subdivision was proposed by Sundaram & Rao in 1979 and revised by the same authors seven years later (1986), but only Ramasamy & Banerji (1991) have attempted a formal definition of lithological characteristics (with reference to type sections) in line with current practice (Hedberg, 1976; Holland et al., 1978; Whittaker et al., 1992). The work of Ramasamy & Banerji (op. cit.) was, however, limited to the pre-Ariyalur Group (Fig. 3) succession. As a result of field work in the area during 1994 and 1995, the authors have attempted to address this problem. A review of the stratigraphy and a
revised lithostratigraphic classification (Fig. 3) for the Basin is proposed by the authors (see Tewari et al., 1996 for details).

Briefly our work (Tewari et al., 1996) shows that following the deposition of relatively deep-water marine clays (Karai Clay Formation, Fig. 3) there was a major regression, marked by abrupt, out-of-sequence shallowing (as discussed later). The overlying Garudamangalam Sandstone Formation is a fine to coarse-grained, calcareous sandstones containing two distinct layers of carbonate concretions, shell-rich sandstones, silty-sandstones, ferruginous sands, argillaceous silty sandstones and pebbly sandstones. The Garudamangalam Sandstone Formation is sub-divided into two members (Fig. 3), the Kulakkalnattam Sandstone Member overlain by the Anaipadi Sandstone Member. The Formation, which occupies a wide tract of the country is, in actual terms, a thin but mappable, condensed (as discussed later), shallow dipping (ca. 10°) unit. This study is based on the wood material collected from the Garudamangalam Sandstone Formation.

WOOD BORING BIVALVES

There are two families of wood-boring bivalves, the Pholadidae (piddocks) and the Teredinidae (shipworms); both belonging to the order Pholadacea (Turner & Johnson, 1971). The Pholadidae has three subfamilies of which two, Martesiinae and Xylophagainae, are wood-borers and the third, Pholadinae, normally bores into peat, firm mud, clay and soft rocks but rarely into wood. Amongst the Martesiinae only two genera, Martesia (world-wide distribution in tropical and warm temperature seas) and Lithopholas (restricted to tropical, brackish or fresh-waters of South and Central America and Indonesia) are wood-borers occurring in shallow waters, where they compete with teredinids. Species of subfamily Xylophagainae (family Pholadidae) occur world-wide in deep seas (except in higher latitudes where a few species occur in lower littoral and sublittoral) where they replace teredinids (Turner & Johnson, 1971). The family Teredinidae (shipworms) are one of the main groups of wood-boring organisms
in the marine ecosystem. Modern teredinids are exceptionally specialised marine, wood-boring bivalves. All the genera of the Teredinidae, except Kuphus, are wood borers (Turner & Johnson, 1971). They have a world-wide distribution and were first reported from the early Cretaceous. A general account of the biology of wood-boring bivalves is given by Lane (1961) and Turner & Johnson (1971). Modern forms are classified according to the form and structure of the pallets (Turner, 1966, 1969; Huggett & Gale, 1995; Gale, 1995). In fossil material pallets are quite rarely described (Wrigley, 1929; Gale, 1995), most micropaleontologists being unaware of what these objects might be, even when they are recorded in residues.

The majority of fossil occurrences of wood-borers are described in the form of borings into xylic material (Kelley, 1988; Kelley & Bromley, 1984). Wood-boring teredinid and pholadid bivalves produce club-shaped (clavate) borings that are assigned to the ichnogenus Teredolites (Kelley & Bromley, 1984). Teredolites was first described as an ichnogenus by Leymerie (1842) but, until recently, it has rarely been used in the literature. Bromley (1972) suggested that all boring ichnogenera be included in Trypanites but this has now been accepted as impractical. Recently Kelley & Bromley (1984) have attempted to rationalise the taxonomy of lithic and xylic borers. Teredolites is now restricted to borings in “woodground” (Bromley et al., 1984) material. In their review Kelley & Bromley (1984) identify two ichnospecies:

Teredolites clavatus Leymerie, 1842
- clavate Teredolites, predominantly perpendicular to the grain in woody substrate, length:width ratio usually less than 5. Linings, where present, are composed of nacreous aragonite which fuses with the valves of the bivalve. Fossil occupants of T. clavatus include Martesia and Opertochasma.

Teredolites longissimus Kelley & Bromley (1984)
- clavate Teredolites, predominantly parallel to the grain in woody substrates, length:width ratio usually greater than 5. Commonly sinuous to contorted with linings made of radial prismatic calcite. The juveniles of T. longissimus pass through a morphological phase of T. clavatus. Borings of Teredinidae fall under T. longissimus.
MORPHOLOGICAL CHARACTERISTICS OF TEREDOLITES FROM THE CAUVERY BASIN

Substrate/wood character

Fossil wood from the Garudamangalam Sandstones are riddled (Figs 5 to 10) with borings. In all of the studied material (log-ground) there is no actual wood (xylic material) preserved. This is the result of boring, petrifaction and decomposition of the substrate (wood). The wood has been intensely bored (Figs 5 to 10), from all directions, by the wood-digesting bivalves. On the same face of the wood both longitudinal and transverse sections (Figs 7, 8 & 10) of the borings are observed. The borings are closely spaced (Figs 5A, 6 & 7) and occasionally coalesce (Figs 7A & 10). This overcrowding of borings suggest that the substrate (wood) was infested by a large (abundance) community and not much xylic material was left. It also implies that either the wood was in suspension (drift stage) allowing the teredinids to attack the substrate from all directions or the wood was constantly being rolled over, exposing fresh surfaces of the substrate for the animals to attack. The xylic material that escaped the borers was lost during petrifaction. Where the replacement took place slowly the xylic fabric is preserved (Figs 5B, 7 to 10, 11A, 11D, 11F & 12A) in the fossil wood. Where the replacement process was en masse the fabric is not retained. Much of the original xylic material is replaced by silica (Fig. 7B), resulting in silicified fossil wood. In some places radial-fibrous chalcedony (Figs 9A, 10 & 11E) replaces the xylic material. Chalcedonic quartz is often a pore-fill rather than a replacement mineral (during petrifaction). The straight boundaries between adjacent growth of chalcedony and triple points can be seen in Figure 11E. These polygonal boundaries are characteristic of radial-fibrous, pore-fill chalcedonic quartz. Along with the boring and petrifaction, which were responsible for the major loss of the xylic substrate, some decomposition (mechanical disintegration, chemical dissolution and bacterial activity) of substrate would also have been responsible for the loss of the xylic material.
Borings

The borings are identified as the ichnospecies *T. clavatus* and *T. longissimus*. The borings are short with length:width ratios ranging between 3:1 to 4:1 (Figs 8B & 9B) or elongated with length:width ratio more than 8:1 (Figs 8A, 10A, 10C & 12B), straight or sinuous and contorted, abruptly changing directions (including U-turns) and have rounded anterior terminations (Figs 10A & 10C). The ichnotaxa in the Cauvery Basin do not strictly follow Kelley & Bromley's (1984) definitions for *clavatus* and *longissimus*. Small borings, with length:width ratios ranging between 3:1 to 4:1, are sinuous and contorted (Fig. 8B), something which is more characteristic of *longissimus* (Kelley & Bromley, 1984; p. 806). Elongate borings, with length:width ratio more than 8:1, are both parallel (Figs 10A & 10C) and perpendicular (Figs 8A, 10A & 10C) to the grain of the substrate (borings perpendicular to the grain are restricted to *clavatus*, Kelley & Bromley, 1984; p. 804). This deviation from the true morphological characteristics (as defined by Kelley & Bromley, 1984) of *clavatus* and *longissimus* (in the Cauvery Basin) could be explained as a response by the animal to competition for space. Ordinarily it appears that it would have been easier for the animal to bore parallel to the grain than to bore perpendicular to the grain in the substrate. This probably explains why, in Kelley & Bromley's (1984) definition, the *clavatus* borings have length:width ratio less than the *longissimus* borings. Under conditions where there is no competition for space, these morphological characters are likely to be more reliable. Things appear to be quite different where the substrate is overcrowded and the community is competing for space. The animals are then forced to attack the wood from any available direction (violating the rule of orientation with respect to the grain fabric) and change directions (regardless of the limits placed on the shape of boring under the ichnospecies definition, Kelley & Bromley, 1984) to survive. The sinuous nature of small borings (in the Cauvery Basin) could also represent the juvenile stage of *longissimus* which did not reach the adult stage because the animal died, being smothered by the sediment filling. Contemporaneous mechanical deformation of the wood, prior to any lining (to strengthen the borings, as discussed later) could also be a
possible explanation for the contorted and sinuous nature of short borings. The cross-sections of the borings are circular to oval, the diameters ranging from 2 mm to 16 mm (Figs 1A & 7 to 11). Oval cross-sections could be due to compaction of the wood or could be artifacts; the result of vertically cut slabs and thin sections meeting the boring obliquely because the borers were changing directions due to overcrowding (as discussed earlier). The majority of the borings have a calcite lining (as discussed later) with rare unlined borings observed. The borings are mostly filled with coarse-grained, unconsolidated detrital sand (Figs 8 & 10), iron (ferric) oxide (Fig. 9B) or carbonate mud (Figs 11C & 12B). Where the pallets were in place (at the posterior end of the tube) the tubes are filled with calcite (Figs 11D & 12C), which is now replaced (to quite a significant extent) by silica.

**Calcite linings in the borings**

Under normal conditions living Teredinidae may not necessarily line their borings or may do so with a very thin calcite layer. In adverse conditions, however, thick calcite linings are secreted (Grave, 1928). All borings (except for one or two) in the Garudamangalam log-grounds have thick calcite linings with several discrete calcite layers (Figs 7, 9 & 10). In some specimens the linings are seen as a collection of broken fragments (probably mechanical breakage due to overcrowding), lying in the carbonate mud (Figs 11F & 12D). The presence of such thick linings suggests that the animal was responding to some extreme conditions. Linings are a mechanism of protection against mechanical disintegration, chemical dissolution and biological threats. The linings of the borings also help in their preservation. Overpopulation amongst the Garudamangalam teredinids was perhaps the main threat. All the material studied is densely bored and the overcrowding would have been a major problem. Kelley & Bromley (1984, p. 804) and Huggett & Gale (1995, p. 121) indicate that T. clavatus show aragonitic linings while T. longissimus has prismatic calcite lining. The preservation of aragonite in geological record, however, is very unlikely. In thin sections the Garudamangalam Teredolites show tubes with distinctly layered calcite linings, most of which have undergone
diagenetic changes. Most of the original calcite in the linings is now replaced by silica. In some cases the original calcite lining has undergone micritization. The micrite carbonate linings show neomorphism to microspar. In some cross-sections, concentric layers of radial-fibrous calcite (being replaced by silica) are observed. These are interpreted to have been the originally aragonite linings in the *T. clavatus* which have now been replaced by calcite and/or silica.

Huggett & Gale (1995, p. 122) demonstrated that the sealing of the anterior wall (during the lining of the tube) marks the end of protrusive (boring) phase and beginning of the retrusive phase in the teredinids. The animal stops any further excavation of the wood once the anterior end of the boring is sealed. They (Huggett & Gale, 1995) observed the successive retrusive phases in the teredinid, when a calcite septum is placed across the tube (Huggett & Gale, 1995; fig. 3 illustrate 4 septa placed across one tube). At this stage of study calcite septa have yet not been observed. Some borings, however, have valves now present (in place) some distance away from the anterior end of the boring. This, together with thick calcite lining suggests that the teredinid had terminated its protrusive stage and was in its retrusive stage.

**Valves, pallets and calcareous chimney**

In some borings, paired valves (Figs 7, 11D & 11E) are recorded (in place) at the anterior end or some distance away from the anterior end (where the retrusive phase had started). In other cases single valves or broken pieces of valves (Figs 11A & 11C), which collapsed after the decay of soft parts, are preserved. The valves were originally aragonite in composition. The aragonite dissolved out during diagenesis leaving empty moulds (Figs 11C & 11E) which in some cases became filled with equant silica or calcite (Fig. 11D). At this stage of our work calcareous chimney structures and pallets (Huggett & Gale, 1995) have not been observed. This could be because, in the majority of cases, the logs have been reworked by modern erosion which would have broken the delicate chimney structures. Some tubes are filled with diagenetic calcite (Figs 11D &
12C) suggesting that perhaps, in some cases, the pallets were placed in place across the entrance to the tube, thereby excluding some of the sediments.

**Fossilised faecal pellets**

In five cross-sections a cluster of oval and circular structures, preserved as dark brown carbonate mud (micrite) are present. These are interpreted as possibly being fossilised faecal pellets, especially considering the feeding habit of teredinids. Teredinids depend, in part, on wood for nutrition (Turner & Johnson, 1971). The cellulose-decomposing, symbiont bacteria is found in the digestive tract, which helps in ingesting the wood. With time, as the teredinids evolved and became more specialised, wood storing caecum developed (Turner & Johnson, 1971). Allison (1988) observed similar structures from London Clay and interpreted them as fossilised gut (caecum) contents. From the London Clay teredinids Huggett & Gale (1995, figs 4A & 7F) report similar but paired, oval or circular structures as pseudofaeces.

**Nature of the boring animal**

Kelley (1988) describes *Opertochasma psyche* n.sp. from the Lower Cretaceous Western Antarctica, noting previous descriptions of related taxa. One such species is *Opertochasma mersum* (Stoliczka 1870), initially described as *Parapholas mersa* n.sp. by Stoliczka (1870) from the "Ootatoor Group" (= Uttatur Group) at Moriavatoor (probably Albian-Cenomanian in age). These specimens, together with *Martesia tundens* Stoliczka (1870), were recovered from borings in wood. Francis (1986) has described a mixture of conifer and angiosperm wood from the Antarctic Peninsula, some of which is heavily bored (Francis, 1986; text-fig. 2 and pl. 51, fig. 1). There are some internal features to the borings shown in plate 51 (Francis, 1986) but are very unclear due to the lightness of the photograph. This does not allow a proper comparison to our material. Crampton (1990) has described a new species of wood-boring bivalve from the Upper Cretaceous of New Zealand (*Pholadidea* *Hatasia*)
vffenae n.sp.) which may be an intermediate form between Cretaceous Opertochasma and Early Cenozoic Pholadidea and Martesia. This new species has been recorded from shallow-water, marine, transgressive sandstones that are very similar in facies to the Kulakkalnattam Sandstone Member. O. mersa (Stoliczka) is very close to P. (H.) vffenae, differing only in the shape of the callum. All of Crampton’s (1990) material is figured as 3-dimensional shelly fossils which makes comparison to our material very difficult. Attempts are being made at isolating some of the shelly material collected from the Garudamangalam Sandstone Formation. It is hoped that complete bivalves will allow a more direct comparison to be made.

**PALAEOENVIRONMENTAL SIGNIFICANCE**

Trace fossils (ichnofossils) record the behavioural pattern of benthonic organisms. They occupy a unique position in the sense that they contain the information on sedimentology and palaeontology of depositional environments (Pemberton et al., 1990, 1994). The ichnofossils have been grouped into nine ichnofacies; the distribution of which are not controlled by water depth (Frey & Pemberton, 1984; Pemberton et al., 1994). Ichnofacies, however, can be used (when used with caution and in conjunction with data from sedimentology and paleontology) as a mechanism for stratigraphic reconstructions. The ichno-sedimentology and ichno-paleontology studies hold a great potential for their application in sequence stratigraphic studies. Savrda (1991a,b) and Savrda & King (1993) have demonstrated the use of ichnofossils, *Teredolites* in particular, in refining the sequence stratigraphic model and interpreting sea-level changes in western and central Alabama.

Woodgrounds (sensu Bromley et al., 1984) are comparatively rare in the geological record and can be regarded as taking two forms (Savrda & King, 1993). Xylic peat grounds are laterally persistent, composite, woody substrates whereas log-grounds are relatively small, non-composite, substrates represented by isolated logs. Of the two, log-grounds are the most common, occurring in non-marine (Plint & Pickerill, 1985),
shallow-marine (Chamberlain, 1976; Dott & Bourgeois, 1982; Bromley et al., 1984; Howard & Frey, 1984; Kiteley & Field, 1984; Francis, 1986; Lindqvist, 1986; Dewey & Keady, 1987; Crampton, 1990; Savrda, 1991a; Savrda & King, 1993; Savrda et al., 1993) and deeper-water (Frey, 1972; Turner, 1973; Wolff, 1979; Anderson, 1983) sediments. While Teredolites-infested log-grounds are, therefore, found in a wide range of environments, the majority appear to be associated with periods of sea-level rise (e.g. Savrda, 1991a,b; Savrda & King, 1993). In the terminology of sequence stratigraphy these would be transgressive systems tracts (TSTs) which follow lowstand or shelf wedge systems tracts above sequence boundaries (SB). Shanley et al. (1992) have reported Teredolites log-grounds within log lags at the base of tidal influence distributary channel fills of TSTs in Cretaceous fluvial-dominated successions from the western USA.

Following the deposition of deeper-water marine clays (Karai Clay Formation) there was a major regression in the latest-mid/earliest-late Turonian. The planktonic foraminifera were significantly reduced by a rapid shallowing of the seaway. In the Kulakkalnattam river section (Fig. 4) the top of the clay succession (Karai Clay Formation) records a sharp fall in the planktonic foraminifera, from 60-65% of the total foraminiferal population to zero (Fig. 13). A diverse and high abundance planktonic assemblage is replaced by a very low diversity, but a very high abundance (99.9% of the total population) agglutinated taxa (e.g. Haplophragmoides kirki Wickenden, H. aff. multiformis Krasheninkov, H. concavus Chapman and other quite rare Haplophragmoides spp. and Cribrostomoides sp.). The regressive event, towards the top of the Karai Clay Formation, marks a very abrupt out-of-sequence shallowing. In the Kulakkanattam river section (Fig. 4) the Karai Clay terminates abruptly beneath a distinct layer (double layer in some cases) of carbonate concretions and coarse calcareous sandstones (Figs 13 & 14). The sandstone unit (including the carbonate concretions) represents the lower part of the Kulakkalnattam Sandstone Member (lower member of the Garudamangalam Sandstone Formation). Taylor et al. (1994) observe that laterally extensive, carbonate cemented horizons, often occurring as
nodule layers, are common within lowstand successions beneath marine flooding surfaces. Diagenetic studies (Taylor et al., 1994) show that this cementation was predominantly early and may be related to periods of low sediment accumulation. Marine flooding surfaces represent depositional hiatuses (low or negligible sediment accumulation) when the underlying sands remain within shallow early diagentic zones for relatively long periods. This allows early diageneric solutes that cause carbonate cementation to build up within the sediment pore spaces. The highly condensed nature (as discussed later) of the Kulakkalnattam Sandstone Member, during several transgressive phases (marine flooding events), provided conditions highly conducive to early cementation. These flooding events led to the development of the nodular-concretionary layers in the Kulakkalnattam Sandstones. Similar carbonate concretions, with fossil wood (bored by teredinids) preserved as nuclei, are reported from the Eocene London Clay (Huggett & Gale, 1995). The carbonate stable isotope studies suggest that most (if not all) of these concretions (in London Clay) formed within the sulphate reduction zone (Huggett, 1994; Huggett & Gale, 1995).

The juxtaposition of Kulakkalnattam Sandstones (coarser and more proximal facies) against the Karai Clays (distal marine facies) represents a case of forced regression (Posamentier et al., 1992). The base of the Garudamangalam Sandstone Formation constitutes, therefore, a type-1 sequence boundary (Posamentier et al., 1988), caused by forced regression (Posamentier et al., 1992). It is possible, therefore, that part of this succession corresponds to a lowstand prograding wedge (Posamentier et al., 1988) or that the lowstand systems tract is absent here and the transgressive systems tract is juxtaposed above a transgressive surface corresponding to the sequence boundary. In the latter case the top of the Karai Clay Formation (at Kulakkalnattam river section, Figs 4 & 14) marks a coincident sequence boundary-transgressive (marine flooding) surface. Either interpretation would strongly suggest that sand-prone submarine fan facies of mid-late Turonian age may occur in deeper basinal areas. This late Turonian regression is known from a very wide geographical area (e.g. Hancock, 1976; Hancock & Kauffman, 1979; Hart & Bailey, 1979; Haq et al., 1987, 1988; Hancock, 1989; Raju
et al., 1993) and identifies a most important sequence boundary in the areas in which it is described.

The Kulakkarntam Sandstone Member is quite thin (including shell-rich and conglomerate beds) and is highly condensed in nature. In sequence stratigraphy, condensed horizons are thin, marine stratigraphic units, characterised by very low sedimentation rates (Loutit et al., 1988). They correspond to marine flooding surfaces and may include the surface of maximum starvation (Loutit et al., 1988) which is the maximum flooding surface (the upper part of transgressive systems tract and basal part of highstand systems tract). The standard model of condensed transgressive lags (with reworked fossil assemblages because of its association with erosional ravinement), resulting from sediment starvation (Loutit et al., 1988) is challenged by Kidwell (1989). Kidwell (1989) has demonstrated that condensed horizons can also result from dynamic by-passing of sediments with the by-passed sediments accumulating in deeper-water environments. The condensed sections are, therefore, distinctively thin, transgressive records of low or negligible sediment accumulation and result from sediment starvation (Loutit et al., 1988) or sediment by-passing (Kidwell, 1989). These records would be even thinner if the net carbonate production (skeletal production as autochthonous sedimentation) would be low. Until a basinal picture is available it is difficult to say whether condensation in the Kulakkarntam Sandstones is due to sediment starvation or dynamic by-passing of sediments. The poorly sorted shells (with respect to size and shape) in the sandstones, however, do suggest that no significant transport of shell material took place.

The lithology and fauna/flora of the Kulakkarntam Sandstone Member has been described by a number of workers (Blanford, 1862; Phansalkar & Kumar, 1983; Sundaram & Rao, 1986; Ramasamy & Banerji, 1991; Kale & Phansalkar, 1992; Ravindran et al., 1995). The Member represents a stratigraphically condensed section (as discussed earlier), corresponding to several pulses of marine flooding. The abundance of xylic material in the Kulakkarntam Sandstone appears to be the
combined effect of two factors. The influx of xylic substrate during the flooding events (transgressions) and concentration of drifted wood during the sediment starvation (or sediment by-passing) in a shallow marine shelf setting (similar to that described from central Alabama by Savrda & King, 1993). Included within the Member are mono-specific, shell-rich (a restricted marine fauna of oysters and gastropods) sandstone beds (e.g. Kunnam and Garudamangalam) and conglomerate beds containing quite fresh, pink feldspars. The Sandstones contain either horizontal planar laminations or are highly bioturbated (e.g. Thalassinoides, Diplocraterion, Ophiomorpha) with abundant Teredolites-infested logs. When seen in-situ the Teredolites borings appear to be positioned on the top of these beds. There is no evidence of significant wave or current reworking of the sands. It is possible that xylic material may have been carried down eustarine channels and trapped on shallow flanking sandflats where colonisation by Teredolites occurred. The abundance of shelly material, log-ground and abundant trace fossils represent a low energy-reduced sedimentation environment, typical to condensed sections. The nodular-concretion horizons sit below these shell-rich, condensed beds. The concretions are either highly bioturbated (Thalassinoides) or preserve horizontal and cross laminations. Some have Teredolites material within them. Huggett & Gale (1995) report similar carbonate concretions, with bored fossil wood in the nuclei, from the Eocene London Clay.

The concentration of xylic log-ground in the Kulakkalnattam Sandstone Member suggests the link between the accumulation of Teredolites-infested logs and sea-level rises (transgressions) as proposed by Savrda (1991a). The concentration of logs in the Cauvery Basin implies that a transgressive event has inundated a coastal woodland area (similar to that reported by Savrda & King (1993) from western Alabama) thereby causing a local influx of xylic material. This, coupled with the information from the calcareous nodules, would seem to confirm that this member is a transgressive systems tract. The inclusion of further log-grounds (including the 18 m long Sattanur tree) higher in the succession, coupled with the general abundance of fossils suggests that the Anaipadi Sandstone Member (upper member of the Garudamangalam Sandstone
Formation) completes the sequence, representing the initial regressive phase of the highstand. The maximum flooding surface may equate with the floods of very large ammonites (some are about one meter in diameter) reported in the succession (approximately 2 km west of Kulattur, Fig. 4). The base of the overlying Sillakudi Sandstone Formation (especially in the stream section near Saturbhagam) shows clean, unconsolidated, fluvial sandstones and silty-siltstones which pass up into the normal marine sediments associated with the remainder of the succession. The fluvial sandstones contain reworked, fresh feldspars pebbles and cobbles (up to 30 cm diameter). The unit has very large scale trough cross-beds (sets up to 3 m wide) with pale grey mud drapes in some foresets. Mud drapes may indicate some marine tidal influence although this may also be the result of seasonal changes in discharge. Presence of fresh feldspar and sandstone clasts suggests incursion into older facies and presence of a sequence boundary at the base of Sillakudi Formation. The hiatus (? post-Coniacian to late Santonian) between the Garudamangalam Sandstone Formation and the overlying Sillakudi Sandstone Formation is stratigraphically very similar to a major hiatus in the successions on the Brazilian coastal margin (Koutsoukos & Hart, 1990).

**SUMMARY**

Teredolites-infested log-grounds are reported from the Garudamangalam Sandstone Formation of the Cauvery Basin, S.E. India. The borings *T. clavatus* and *T. longissimus*, probably created by *Opertochasma* sp., are described. The abundance of log-grounds represents an influx of xylic material into the Basin during a transgressive event. Ichnofossils information, used in conjunction with the data from sedimentology and palaeontology, is used to assess the sequence stratigraphy of the Basin. The transgressive systems tract and highstand systems tract are represented by the Garudamangalam Sandstone Formation.
ACKNOWLEDGEMENTS

AT gratefully acknowledges the support of the British Council while MBH and MPW acknowledge receipt of Travel Grants from the Royal Society in support of field work in India. The ONGC Madras, University of Madras and Dalmia Mine are thanked for their assistance in the field. Travel funds from the University of Plymouth assisted MBH in attending the 1995 SEPM Conference in Florida. M. Ashton, J. Abraham, A. Smith and D. Griffiths are thanked for their assistance with thin section preparation, cartographic work and photography. Dr. Savrda (Alabama, USA) is thanked for his advice on log-grounds.

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FIGURE CAPTIONS

Figure 1: Distribution of the Cretaceous rocks in the Indian sub-continent (after Acharyya & Lahiri, 1991). The approximate position of the Cauvery Basin is shown in the box.
Figure 2: Geological map of the exposed part of the Cauvery Basin (based on the work of Sundaram & Rao, 1986; Ramasamy & Banerji, 1991 and the Geological Survey of India). Lithostratigraphy is based on Tewari et al. 1996.

Figure 3: The revised lithostratigraphical classification and lithofacies relationships of the Cretaceous rocks of the Ariyalur outcrop, Cauvery Basin (Tewari et al., 1996). It must be noted that:-

1. the carbonates of the Kallankuruchchi Limestone Formation were deposited in a carbonate ramp environment and that the detailed relationships of the facies present cannot be accurately displayed on a diagram at this scale.

2. the positions of the stage boundaries follow current European usage, including some of the decisions taken in Brussels (September 1995) at the meeting of the international Subcommission on Cretaceous Stratigraphy.

Figure 4: Localities mentioned in the text and those from which samples of bored wood have been collected. (1. Kulakkalnattam stream section-concretions, 2. Kuthoor-small ammonites and brachiopods, 3. river section between Mungalpadi and Sattanur-conglomerate, 4. west of Kulattur-large ammonites, 5. north of Kulattur-pebbles, 6. between Anaipadi and Garudamangalam-two rows of concretions, 7. Kunnam-shell sandstones, 8. Mungalpadi-conglomerate, 9. near Garudamangalam-garnet and feldspar pebbles, 10. Garudamangalam quarries-shell-rich sandstones, 11. gully section near Saradamangalam-ammonites and conglomerate, 12. stream section near Saturbhagam-fluvial sandstones, 13. the Sattanur tree-protected locality).

Figure 5: Two unpolished pieces of wood. (A) Surface riddled with borings made by the wood-boring teredinids. (B) Silicified log-wood. The xylic fabric in the wood is preserved due to petrifaction. Much of the wood is replaced by silica.

Figure 6: Unpolished piece of log-wood (the coin is approximately 17 mm in diameter). Surface bored by teredinids; xylic fabric in the wood (that escaped boring) preserved
due to petrifaction. The xylic fabric (fibrous nature of wood) is retained during the slow replacement of wood by silica.

Figure 7: Polished surfaces of specimens collected in a river section, north of Kulakkalnattam village. (A) Maximum dimension 10 cms. Densely packed cross-sections of borings (often coalescing) with thick calcite linings, showing layers of successive secretion to strengthen the tubes. Top right hand corner shows a cross-section of the tube with valves placed in-situ. (B) Maximum dimension is 8 cms. The top left hand corner shows the two valves (preserved in-situ) of (?) Opertochasma sp., the teredinid bivalve probably responsible for the boring. (C) Closer view of Figure 5B showing the two valves (top right hand corner); thick calcite lining suggesting that the animal was in a retrusive phase; borings filled with detrital, unconsolidated sands (right hand side) and chalcedonic quartz, a pore-filling (top right hand, to the left of the two valves).

Figure 8: Polished surfaces of two samples (maximum dimension 10 cms) collected near Kulakkalnattam village. (A) The fabric of the substrate (wood) is seen preserved with the T. longissimus boring cutting vertically through the grain of the substrate, something more characteristic of clavatus ichnospecies. (B) T. clavatus boring cutting perpendicular to the grain of the substrate. The clavatus boring is very sinuous, a feature more characteristic of T. longissimus. Most of the borings are filled with coarse, unconsolidated, detritus sediments.

Figure 9: Unpolished pieces of log-wood (the coin is approximately 17 mm in diameter). (A) Xylic-fabric can be clearly seen on the right hand side, well preserved due to slow replacement of wood by silica. Some chalcedonic-quartz (to the centre) a pore-filling mineral. Thick calcite lining of the tube seen in the cross-sections. (B) Two T. clavatus boring (in the centre) filled with iron (ferric) oxide; xylic fabric preserved,
Figure 10: Polished surfaces of three samples (maximum dimensions 15 cm) showing the fibrous nature of the wood (xylic fabric) preserved (A, B & C) in the substrate during petrifaction. *T. longissimus* seen boring both perpendicular to the grain (centre of the specimens A and C) and parallel to the grain (two borings each on the top of the specimen A bottom of the specimen C) to the grain of the wood. Closely spaced, often coalescing cross-sections of the borings with thick calcite tube linings; detrital sands and/or carbonate mud filling the tubes and white, chalcedonic quartz (a pore-filling) are seen in all three specimens.

Figure 11: Thin sections (field of view 6 mm) of the bored-wood showing xylic fabric (A, D & F) of the substrate; the borings either with a thick calcite lining (B) or unlined (A & E); broken pieces of calcite lining in carbonate mud (B); valves either placed in-situ (C, D & E) or single, broken pieces (A) and chalcedonic quartz, a pore-filling (E).

Figure 12: Thin sections (field of view 6 mm) of bored-wood showing the xylic fabric (A & B) of the substrate preserved during petrifaction (slow replacement of wood by silica). *T. longissimus* with a calcite lining and the valve placed at the anterior end of the tube (B); broken pieces of calcite lining in carbonate mud (C); tubes filled with diagenetic calcite (C), carbonate mud (B) or coarse, detritus sands (A & B).

Figure 13: Geological succession in the river section 1 km SW of Kulakkalnattam village (Locality 1 on Figure 4).

Figure 14: Lithostratigraphy of the Garudamangalam Sandstone Formation.
Figure 1
Figure 2
Figure 3

FACIES RELATIONSHIPS

REVISED LITHOSTRATIGRAPHIC CLASSIFICATION, Tewari et al. 1996

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<td>Kallakudi Siltstone Member</td>
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<td>Dalmapuram Formation</td>
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ARCHEAN

ARCHAEOAN

Sivaganga Formation

Gondwana Group

UTTATUR

Kovandakuruvi Conglomerate Member

Teranl Clay Member

Sivaganga Formation

Gondwana Group

Kovandakuruvi Conglomerate Member

Kovandakuruvi Siltstone Member

Kovandakuruvi Siltstone Member

Kovandakuruvi Siltstone Member

Otiyakadu Cong. Mbr.

Dalmiapuram Limestone Member

Grey Siltstone Member

Dalmapuram Formation

Karai Clay Mbr.

Karai Clay Fm.

ARCHAEOAN

Otiyakadu Cong. Mbr.

Dalmiapuram Limestone Member

Grey Siltstone Member

Dalmapuram Formation

Karai Clay Mbr.

Karai Clay Fm.

ARCHAEOAN
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**Legend:**
- terebratulids
- small ammonites
- large ammonites
- log ground (xylic) material
- calcareous sandstone nodules
- rhynchonellids
- Garudamangalam Shell Sandstone Bed(s)
Appendix 2

Plates
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16. Spiral view x150
17. Umbilical view x150

18. *Cribrostomoides sp. 1*, spiral view x200, Upper Albian, Karai-Kulakkalnattam traverse

19. *Glomospira charoides* (Jones & Parker), side view x350, Upper Albian, Karai-4

20. *Glomospira charoides* (Jones & Parker), side view x350, Lower Turonian, Karai-Kulakkalnattam traverse

21. *Glomospira sp. aff. G. gordialis* (Jones & Parker), side view x350, Upper Albian, Karai-4
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1. *Haplophragmoides chapmani* Morozova, spiral view x200, Lower Turonian, Karai-Kulakkalnattam traverse

2. *Haplophragmoides concavus* (Chapman), spiral view x150, Middle Turonian, Karai-Kulakkalnattam traverse

3. *Haplophragmoides concavus* (Chapman), umbilical view x150, Middle Turonian, Karai-Kulakkalnattam traverse

4. *Haplophragmoides hagni* (Bhalla), spiral view x200, Lower Turonian, Karai-4

5. *Haplophragmoides horridus* (Grzybowski), spiral view x100, Lower Turonian, Karai-4

6. *Haplophragmoides horridus* (Grzybowski), umbilical view x100, Lower Turonian, Karai-4

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8. *Haplophragmoides kirki* Wickenden, umbilical view x150, Lower Turonian, Karai-4

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9-10. *Haplophragmoides sp. aff. H. multiformis* (Krasheninnikov) var. A, side view x150, Upper Cenomanian, Karai-Kulakkalnattam traverse

12. *Haplophragmoides nonioninoides* (Reuss) var. *angulosa* Magniez-Jannin, spiral view x150, Lower Turonian, Karai-6

13. *Haplophragmoides nonioninoides* (Reuss) var. *rotunda* Magniez-Jannin, spiral view x150, Upper Cenomanian, Karai-6

14. *Haplophragmoides nonioninoides* (Reuss) var. *rotunda* Magniez-Jannin, umbilical view x150, Lower Turonian, Karai-6
15. **Haplophragmoides walteri** (Grzybowski), spiral view x200, Lower Cenomanian, Karai-4

16. **Haplophragmoides sp. 1**, umbilical view x150, Lower Cenomanian, Karai-4
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2. Haplophragmoides sp. 3, side view x100, Upper Albian, Karai-Kulakkanattam traverse
3. Ammobaculites hofkeri Bhalla, side view x75, Cenomanian, Karai-4
4. Ammobaculites hofkeri Bhalla, side view x150, Lower Turonian, Karai-Kulakkanattam traverse
5. Ammobaculites sp. cf. A. minimus Crespin, side view x150, Cenomanian, Karai-4
6. Ammobaculites parvispira ten Dam, side view x100, Cenomanian, Karai-4
7. Ammobaculites sp. aff. A. parvispira ten Dam, side view x100, Upper Albian, Karai-4
8. Ammobaculites reophacoides Bartenstein, side view x150, Lower Turonian, Karai-4
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10. Ammobaculites subcretacea Cushman & Alexander, side view x100, Cenomanian, Karai-4
11. Spiroplectammina latickeri Albritton & Phleger, side view x150, Upper Albian, Karai-4
12. Spiroplectammina sp. aff. S. semicomplanata (Carsey) var. juncea Cushman, side view x200, Lower Cenomanian, Karai-3
13. Spiroplectammina sp. 1, side view x200, Upper Albian, Karai-4
14. Recurvoides gerochi Pflaumann, spiral view x150, Upper Albian, Karai-Kulakkanattam traverse
15. Recurvoides sp. 1, spiral side x100, Upper Cenomanian, Karai-Kulakkanattam traverse
16. **Bulbophragmium aequalle** Maync, side view x200, Cenomanian, Karai-6

17. **Bulbophragmium sp. 1**, side view x150, Upper Albian, Karai-Kulakkalanattam traverse

18. **Spiroplectammina sp. 2**, side view x200, Lower Cenomanian, Karai-4

19. **Ammobaculoides mosbyensis** Eicher, side view x100, Lower Turonian Karai-4

20. **Ammobaculoides mosbyensis** Eicher, side view x100, Lower Turonian Karai-4

21. **Ammobaculoides mosbyensis** Eicher, side view x200, Upper Albian, Karai-Kulakkalanattam traverse

22. **Bulbophragmium cylindraceum** (Chapman), side view x100, Upper Albian, Karai-Kulakkalanattam traverse

23. **Pseudobolivina variana** (Eicher), side view x100, Cenomanian, Karai-6
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1. **Pseudobolivina sp. aff. P. variana** (Eicher), side view x200, Lower Turonian, Karai-4

2. **Trochammina wetteri** Stelck & Wall, spiral view x150, Cenomanian, Karai-4

3-4. **Gaudryina pyramidata** Cushman, Middle Cenomanian, Karai-6
   3. side view x350
   4. apertural view x200

5. **Gaudryina pyramidata** Cushman, side view x200, Lower Turonian, Karai-3

6. **Uvigerinammina sp. 1**, side view x350, Upper Cenomanian, Karai-6

7. **Verneuilina muensteri** Reuss, side view x350, Middle Turonian, Karai-3

8. **Tritaxia pyramidata** Reuss, side view x100, Upper Albian, Karai-4

9. **Tritaxia pyramidata** Reuss, side view x100, Upper Cenomanian, Karai-4

10. **Tritaxia pyramidata** Reuss, side view x100, Upper Cenomanian, Karai-Kulakkalnattam traverse

11. **Tritaxia sp. aff. T. ellisorae** Cushman, side view x150, Cenomanian, Karai-Kulakkalnattam traverse

12. **Tritaxia sp. aff. T. ellisorae** Cushman, side view x100, Lower Turonian, Karai-Kulakkalnattam traverse

13. **Tritaxia sp. 1**, side view x100, Campanian, Sillakudi railway cutting section

14. **Dorothia filiformis** (Berthelin), side view x150, Upper Albian, Karai-4

15. **Dorothia filiformis** (Berthelin), side view x150, Upper Albian, Karai-4

16. **Dorothia filiformis** (Berthelin), side view x150, Cenomanian, Karai-Kulakkalnattam traverse

17. **Dorothia sp. 2**, side view x100, Maastrichtian, Dherani quarry

18. **Dorothia sp. 2**, side view x50, Maastrichtian, Dherani quarry
19. **Remesella** sp. 1, side view x200, Upper Albian, Karai-4

20. **Tritaxia tricarinata** Reuss, side view x200, Lower Turonian, Karai-3

21. **Tritaxia tricarinata** Reuss, side view x100, Lower Turonian, Karai-Kulakkalnattam traverse
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1. *Marssonella oxycona* (Reuss), side view x200, Middle Turonian, Karai-Kulakkalnattam traverse

2. *Marssonella* sp. cf. *M. trochus* (d’Orbigny), side view x100, Upper Campanian, Dherani quarry

3. *Marssonella turris* (d’Orbigny), side view x75, Upper Campanian, Dherani quarry

4. *Textularia* sp. aff. *chapmani* Lalicker, side view x200, Lower Cenomanian, Karai-4

5. *Textularia* sp. aff. *T. wilgunyaensis* Crespin, side view x200, Upper Albian, Karai-4

6. *Textularia* sp. 1, side view x100, Upper Albian, Karai-Kulakkalnattam traverse

7. *Textularia* sp. 4, side view x150, Upper Campanian, Dherani quarry

8. *Pseudochrysalidina* sp. 1, side view x200, Upper Albian, Karai-4

9. *Cribrobigenerina* sp. 1, side view x150, Middle Cenomanian, Karai-6

10. *Olssonina* sp. 1, side view x200, Upper Albian, Karai-4

11. *Olssonina* sp. 2, side view x200, Upper Albian, Karai-Kulakkalnattam traverse

12. *Planctostoma* sp. 1, side view x200, Upper Cenomanian, Karai-4

13. *Siphotextularia* sp. 1, side view x200, Upper Cenomanian, Karai-4
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1. **Dentalina communis** (d'Orbigny), side view x100, Upper Albian, Karai-4

2. **Dentalina catenula** Reuss, side view x100, Cenomanian, Karai-Kulakkalnattam traverse

3. **Dentalina cylindroides** Reuss, side view x150, Cenomanian, Karai-Kulakkalnattam traverse

4. **Dentalina cylindroides** Reuss, side view x150, Upper Albian, Karai-Kulakkalnattam traverse

5. **Dentalina distincta** (Reuss), side view x100, Cenomanian, Karai-Kulakkalnattam traverse

6. **Dentalina distincta** (Reuss), side view x75, Upper Albian, Karai-Kulakkalnattam traverse

7. **Dentalina gracilis** d'Orbigny, side view x50, Upper Albian, Karai-Kulakkalnattam traverse

8. **Dentalina sp. aff. D. hammensis** (Franke), side view x150, Cenomanian, Karai-4

9. **Dentalina lorneiana** d'Orbigny, side view x200, Upper Cenomanian, Karai-6

10. **Dentalina nana** Reuss, side view x100, Upper Albian, Karai-Kulakkalnattam traverse

11. **Dentalina strangulata** Reuss, side view x100, Upper Albian, Karai-4

12. **Dentalina strangulata** Reuss, side view x100, Lower Cenomanian, Karai-Kulakkalnattam traverse

13. **Dentalina trujilloi** Loeblich & Tappan, side view x150, Middle Cenomanian, Karai-6

14. **Dentalina sp. 1**, side view x75, Cenomanian, Karai-Kulakkalnattam traverse

15. **Dentalina sp. 2**, side view x100, Cenomanian, Karai-Kulakkalnattam traverse
16. **Dentalina sp. 3**, side view x200, Upper Albian, Karai-4

17. **Dentalina sp. 5**, side view x150, Lower Turonian, Karai-Kulakkalnattam traverse

18. **Dentalina sp. 6**, side view x100, Cenomanian, Karai-Kulakkalnattam traverse

19. **Dentalina sp. 8**, side view x75, Upper Cenomanian, Karai-3

20. **Enantioldentalina sp. 1**, side view x100, Cenomanian, Karai-Kulakkalnattam traverse

21. **Nodosaria affinis** Reuss, side view x200, Upper Albian, Karai-4

22. **Nodosaria lamellosocostata** Reuss, side view x75, Cenomanian, Karai-6

23. **Nodosaria monile** Hagenow, side view x150, Lower Turonian, Karai-4

24. **Nodosaria orthopleura** Reuss, side view x75, Middle Cenomanian, Karai-Kulakkalnattam traverse

25. **Nodosaria paupercula** Reuss, side view x150, Middle Turonian, Karai-6

26. **Nodosaria sceptrum** Reuss, side view x200, Upper Cenomanian, Karai-Kulakkalnattam traverse

27. **Nodosaria zippei** Reuss, side view x35, Upper Albian, Karai-Kulakkalnattam traverse

28. **Nodosaria sp. 6**, side view x350, Upper Cenomanian, Karai-Kulakkalnattam traverse

29. **Nodosaria rugosa** ten Dam, side view x150, Upper Cenomanian, Karai-Kulakkalnattam traverse

30. **Nodosaria prismatica** Reuss, side view x200, Upper Albian, Karai-Kulakkalnattam traverse

31. **Nodosaria sp. 1**, side view x150, Upper Albian, Karai-4

32. **Nodosaria sp. 1**, side view x100, Upper Cenomanian, Karai-Kulakkalnattam traverse
33. *Nodosaria* sp. 4, side view x150, Upper Albian, Karai-Kulakkalnattam traverse

34. *Nodosaria* sp. 5, side view x100, Middle Cenomanian, Karai-Kulakkalnattam traverse
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1. *Pseudonodosaria cylindracea* (Reuss), side view x100, Upper Cenomanian, Karai-3

2. *Pseudonodosaria humilis* (Roemer), side view x150, Lower Turonian, Karai-Kulakalmattam traverse

3. *Pseudonodosaria mutabilis* (Reuss), side view x350, Cenomanian, Karai-Kulakalmattam traverse

4. *Pseudonodosaria* sp. 1, side view x350, Middle Turonian, Karai-4

5. *Pseudonodosaria* sp. 4, side view x200, Lower Turonian, Karai-Kulakalmattam traverse

6. *Pseudonodosaria* sp. 2, side view x200, Upper Albian, Karai-4

7. *Pseudonodosaria* sp. 3, side view x75, Cenomanian, Karai-4

8. *Lingulina* sp. aff. *L. serrata* (Tappan), side view x350, Upper Cenomanian, Karai-6

9. *Frondicularia angulosa* (d’Orbigny), side view x200, Cenomanian, Karai-6

10. *Frondicularia filocincta* Reuss var. aff. *filocincta* Magniez-Jannin, side view x100, Upper Albian, Karai-4

11. *Frondicularia filocincta* Reuss var. aff. *filocincta* Magniez-Jannin, side view x50, Middle Turonian, Karai-Kulakalmattam traverse

12. *Frondicularia* sp. 4, side view x100, Lower Cenomanian, Karai-Kulakalmattam traverse

13. *Frondicularia gaultina* Reuss, side view x75, Upper Albian, Karai-4

14. *Frondicularia gaultina* Reuss, side view x75, Lower Turonian, Karai-Kulakalmattam traverse

15. *Frondicularia archiaciana* d’Orbigny, side view x50, Cenomanian, Karai-6

16. *Frondicularia* sp. 1, side view x100, Upper Albian, Karai-4
17. *Tristix excavata* (Reuss), side view x100, Cenomanian, Karai-Kulakalnattam traverse

18. *Lenticulina cephalotes* (Reuss) var. A, side view x100, Cenomanian, Karai-4

19. *Frondicularia* sp. 7, side view x200, Lower Turonian, Karai-Kulakalnattam traverse

20. *Frondicularia* sp. 7, side view x200, Middle Turonian, Karai-Kulakalnattam traverse

21. *Frondicularia* sp. 6, side view x200, Upper Cenomanian, Karai-6

22. *Lenticulina cephalotes* (Reuss), side view x150, Upper Albian, Karai-4

23. *Lenticulina cephalotes* (Reuss), side view x100, Cenomanian, Karai-Kulakalnattam traverse

24. *Lenticulina cephalotes* (Reuss) var. A, side view x150, Middle Turonian, Karai-Kulakalnattam traverse
Plate 8

1. **Lenticulina circumcidanea** (Berthelin), side view x200, Middle Cenomanian, Karai-Kulakkalnattam traverse

2. **Lenticulina sp. aff. L. frankei** (ten Dam), side view x100, Cenomanian, Karai-4

3. **Lenticulina gaultina** (Berthelin), side view x100, Cenomanian, Karai-4

4. **Lenticulina ingenua** (Berthelin), side view x150, Middle Turonian, Karai-Kulakkalnattam traverse

5. **Lenticulina lanceolata** Magniez-Jannin, side view x150, Cenomanian, Karai-4

6. **Lenticulina macrodisca** (Reuss), side view x150, Middle Turonian, Karai-3

7. **Lenticulina nodosa** (Reuss), side view x100, Middle Turonian, Karai-Kulakkalnattam traverse

8. **Lenticulina planiuscula** (Reuss), side view x100, Upper Albian, Karai-Kulakkalnattam traverse

9. **Lenticulina pseudolinearis** (Magniez-Jannin), side view x150, Cenomanian, Karai-4

10. **Lenticulina sp. aff. tripleura** (Berthelin), side view x150, Lower Turonian, Karai-4

11. **Lenticulina ex gr. oligostegia** (Reuss), side view x150, Upper Albian, Karai-4

12. **Lenticulina ex gr. oligostegia** (Reuss), side view x150, Upper Albian, Karai-4

13. **Lenticulina ex gr. oligostegia** (Reuss), side view x150, Cenomanian, Karai-4

14. **Lenticulina ex gr. rotulata** (Lamarck), side view x100, Cenomanian, Karai-4

15. **Lenticulina saxocretacea** Bartenstein, side view x100, Cenomanian, Karai-6
16. *Lenticulina sternalis* (Berthelin), side view x100, Upper Albian, Karai-Kulakkalnattam traverse

17. *Lenticulina variata* (Magniez-Jannin), side view x150, Lower Turonian, Karai-Kulakkalnattam traverse

18. *Lenticulina warregoensis* Crespin, side view x150, Cenomanian, Karai-4

19. *Lenticulina sp. 2*, side view x100, Middle Turonian, Karai-6

20. *Lenticulina sp. 1*, side view x350, Middle Turonian, Karai-Kulakkalnattam traverse
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1. Lenticulina sp. 4, side view x150, Upper Albian, Karai-4
2. Lenticulina sp. 5, side view x150, Cenomanian, Karai-Kulakkalnattam traverse
3. Lenticulina sp. 6, side view x100, Upper Albian, Karai-6
4. Lenticulina sp. 6, side view x150, Cenomanian, Karai-6
5. Neoflabellina sp. 1, side view x75, Upper Albian, Karai-Kulakkalnattam traverse
6. Lenticulina sp. 8, side view x200, Middle Turonian, Karai-Kulakkalnattam traverse
7. Astacolus sp. 1, side view x100, Lower Turonian, Karai-6
8. Marginulina acuticostata (Reuss) var. acuticostata (Magniez-Jannin), side view x100, Lower Turonian, Karai-4
9. Marginulina acuticostata (Reuss) var. robusta (Magniez-Jannin), side view x150, Cenomanian, Karai-4
10. Marginulina bullata Reuss, side view x150, Upper Albian, Karai-Kulakkalnattam traverse
11. Marginulina costulata (Chapman), side view x100, Upper Cenomanian, Karai-Kulakkalnattam traverse
12. Marginulina curvatura Cushman, side view x150, Upper Albian, Karai-4
13. Marginulina directa Cushman, side view x150, Upper Albian, Karai-4
14. Marginulina inaequalis Reuss, side view x200, Middle Cenomanian, Karai-6
15. Marginulina jarvisi Cushman, side view x100, Lower Turonian, Karai-4
16. Marginulina jonesi Reuss, side view x200, Middle Turonian, Karai-Kulakkalnattam traverse
17. *Marginulina* sp. 1, side view x150, Upper Albian, Karai-Kulakkalnattam traverse

18. *Marginulina* sp. 2, side view x200, Cenomanian, Karai-Kulakkalnattam traverse

19. *Citharina* sp. 2, side view x100, Lower Cenomanian, Karai-Kulakkalnattam traverse

20. *Planularia complanata* (Reuss), side view x150, Lower Turonian, Karai-6

21. *Vaginulina daini* (Schijfsma), side view x75, Campanian, Sillakudi railway cutting section

22. *Vaginulina daini* (Schijfsma), side view x50, Campanian, Sillakudi railway cutting section

23. *Vaginulina kochii* Roemer, side view x75, Middle Turonian, Karai-4

24. *Vaginulina marginuloides* Reuss, side view x100, Upper Cenomanian, Karai-Kulakkalnattam traverse

25. *Vaginulina* sp. 1, side view x100, Middle Cenomanian, Karai-4
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<tr>
<td>1. <strong>Vaginulina sp. 2</strong>, side view x100, Lower Turonian, Karai-4</td>
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<td>2. <strong>Vaginulina sp. 3</strong>, side view x100, Cenomanian, Karai-Kulakkalnattam traverse</td>
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<td>3. <strong>Vaginulina sp. 5</strong>, side view x150, Upper Albian, Karai-Kulakkalnattam traverse</td>
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<td>4. <strong>Vaginulina sp. 5</strong>, side view x200, Lower Turonian, Karai-Kulakkalnattam traverse</td>
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<td>5. <strong>Vaginulina sp. 6</strong>, side view x75, Middle Turonian, Karai-Kulakkalnattam traverse</td>
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<td>6. <strong>Vaginulina sp. 7</strong>, side view x150, Upper Albian, Karai-Kulakkalnattam traverse</td>
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<td>7. <strong>Lagenula acuticosta</strong> Reuss, side view x200, Middle Turonian, Karai-Kulakkalnattam traverse</td>
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<td>8. <strong>Lagenula globosa</strong> (Montagu), side view x200, Upper Albian, Karai-Kulakkalnattam traverse</td>
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<td>9. <strong>Lagenula hispida</strong> Reuss, side view x150, Lower Turonian, Karai-4</td>
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<td>10. <strong>Vaginulina sp. 4</strong>, side view x100, Middle Cenomanian, Karai-6</td>
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<td>11. <strong>Lagenula sp. aff. L. oxystoma</strong> Reuss, side view x350, Upper Cenomanian, Karai-4</td>
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<td>12. <strong>Lagenula striatifera</strong> Tappan, side view x350, Middle Turonian, Karai-Kulakkalnattam traverse</td>
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<td>13. <strong>Globulina lacrima</strong> Reuss, side view x200, Upper Albian, Karai-Kulakkalnattam traverse</td>
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<td>14. <strong>Tobolina sp. 1</strong>, side view x500, Lower Turonian, Karai-4</td>
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<tr>
<td>15. <strong>Globulina prisca</strong> Reuss, side view x150, Middle Turonian, Karai-Kulakkalnattam traverse</td>
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16. *Globulina subsphaerica* (Berthelin), side view x200, Upper Albian, Karai-Kulakkalnattam traverse

17. *Ramulina aculeata* Wright, side view x150, Upper Albian, Karai-6

18. *Ramulina sp. 1*, side view x100, Upper Cenomanian, Karai-6

19. *Ramulina globotubulosa* Cushman, side view x150, Upper Albian, Karai-Kulakkalnattam traverse

20. *Oolina sp. 1*, side view x100, Middle Cenomanian, Karai-4

21. *Ramulina arkadelphiana* Cushman, side view x150, Cenomanian, Karai-4

22. *Ramulina fusiformis* Khan, side view x100, Lower Cenomanian, Karai-Kulakkalnattam traverse

23. *Guttulina adhaerens* (Olszewski), side view x200, Lower Turonian, Karai-3
Plate 11

1. *Oolina* sp. 2, side view x200, Upper Cenomanian, Karai-4
2. *Oolina* sp. 3, side view x200, Lower Turonian, Karai-Kulakkalnattam traverse
3. *Fissurina* sp. 1, side view x200, Upper Cenomanian, Karai-4
4. *Fissurina* sp. 2, side view x100, Upper Albian, Karai-Kulakkalnattam traverse
5. *Fissurina* sp. 3, side view x150, Lower Turonian, Karai-Kulakkalnattam traverse
6. *Fissurina* sp. 2, apertural view x200, Upper Albian, Karai-Kulakkalnattam traverse
7. *Fissurina* sp. 4, side view x150, Upper Albian, Karai-Kulakkalnattam traverse
8. *Ceratolamarckina* sp. 1, spiral view x200, Middle Turonian, Karai-3
9. *Ceratolamarckina* sp. 1, spiral view x200, Middle Turonian, Karai-3
10. *Parafissurina* sp. 1, side view x200, Upper Albian, Karai-Kulakkalnattam traverse
11. *Hoeglundina* sp. 1, spiral view x100, Lower Turonian, Karai-6
12. *Hoeglundina* sp. 1, spiral view x150, Lower Turonian, Karai-6
13. *Conorboides* sp. 3, umbilical view x500, Upper Albian, Karai-Kulakkalnattam traverse
14. *Conorboides* sp. 1, spiral view x100, Lower Turonian, Karai-6
15. *Conorboides* sp. 1, umbilical view x100, Lower Turonian, Karai-6
16. *Conorboides* sp. 2, umbilical view x150, Middle Turonian, Karai-3
17. *Conorboides* sp. 2, spiral view x150, Middle Turonian, Karai-3
1. **Guembelitria sp. 1**, side view x750, Middle Cenomanian, Karai-Kulakkalnattam traverse

2. **Heterohelix globulosa** (Ehrenberg), side view x350, Middle Turonian, Karai-3

3. **Heterohelix moremani** (Cushman), side view x500, Middle Turonian, Karai-Kulakkalnattam traverse

4-5. **Bifarina sp. 1**, Cenomanian, Karai-Kulakkalnattam traverse
   4. side view x350
   5. side view x500

6-7. **Bifarina sp. 2**, Middle Turonian, Karai-Kulakkalnattam traverse
   6. side view x200
   7. side view x500

8. **Globigerinelloides bentonensis** (Morrow), spiral view x350, Upper Albian, Karai-Kulakkalnattam traverse

9. **Globigerinelloides sp. aff. G. maridalensis** (Bolli), spiral view x200, Middle Cenomanian, Karai-Kulakkalnattam traverse

10. **Hedbergella planispira** Tappan, spiral view x200, Middle Turonian, Karai-Kulakkalnattam traverse

11. **Globigerinelloides ultramicra** (Subbotina), spiral view x350, Lower Cenomanian, Karai-4

12. **Hedbergella delrioensis** (Carsey), spiral view x200, Lower Turonian, Karai-Kulakkalnattam traverse

13. **Hedbergella sp. aff. H. globigerinelloides** (Subbotina), spiral view x350, Upper Albian, Karai-4

14. **Hedbergella infracretacea** (Glaessner), spiral view x350, Lower Cenomanian, Karai-4

15. **Hedbergella simplex** (Morrow), spiral view x200, Middle Turonian, Karai-3

16. **Planomalina buxtorfi** (Gandolfi), spiral view x200, Upper Albian, Karai-4
17. *Whiteinella aprica* (Loeblich & Tappan), spiral view x200, Middle Turonian, Karai-3

18-19. *Whiteinella aprica* (Loeblich & Tappan), spiral view x200, Middle Turonian, Karai-3
   18. umbilical view x200
   19. side view x200
Plate 13

1-2, 5. **Whiteinella archaeocretacea** Pessagno, Middle Turonian, Karai-3
   1. spiral view x200
   2. umbilical view x200
   5. side view x200

3-4. **Whiteinella baltica** (Douglas & Rankin) type **baltica** (Douglas & Rankin)
   (form with 4 chambers in the final whorl, see Chapter 4 for details), Middle Turonian, Karai-3
   3. spiral view x200
   4. umbilical view x200

6. **Whiteinella baltica** (Douglas & Rankin) type **alpina** (Porthault) (form with 5 chambers in the final whorl, see Chapter 4 for details), spiral view x200, Middle Turonian, Karai-3

7. **Whiteinella baltica** (Douglas & Rankin) type **bornholmensis** (Douglas & Rankin) (form with 3½ chambers in the final whorl and a trilobate periphery, see Chapter 4 for details), spiral view x200 Upper Albian, Karai-Kulakkalnattam traverse

8. **Whiteinella brittonensis** (Loeblich & Tappan), spiral view x200, Middle Turonian, Karai-3

9-10. **Whiteinella brittonensis** (Loeblich & Tappan), Middle Turonian, Karai-3
   9. side view x200
   10. spiral view x200

11. **Praeglobotruncana aumalensis** (Sigal), spiral view x150, Middle Turonian, Karai-3

12-13. **Praeglobotruncana aumalensis** (Sigal), Middle Turonian, Karai-3
   12. side view x200
   13. umbilical view x150

14. **Praeglobotruncana delrioensis** (Plummer), spiral view x200, Upper Albian, Karai-Kulakkalnattam traverse

15. **Praeglobotruncana gibba** Klaus, spiral view x200 (2½ whorls with a highly developed beaded ornamentation, see Chapters 4 & 6 for details), Middle Turonian, Karai-3
16-17. **Praeglobotruncana gibba** Klaus, Lower Turonian, Karai-6
16. spiral view x200 (2½ to (?)3 whorls with a beaded ornamentation)
17. side view x200 (a block-shaped high trochospire with the inner whorls sitting like a lobe on the final whorl, see Chapters 4 & 6 for details)

18. **Praeglobotruncana gibba** Klaus, side view x200 (highly developed rows of pustules which could be referred to two closely spaced keels, see Chapters 4 & 6 for details), Lower Cenomanian, Karai-4
1.4. Praeglobotruncana helvetica (Bolli), Lower Turonian, Karai-3
   1. spiral view x200 (unlike the typical Tethyan helvetica (7 chambers in the final whorl) only 4 to (?\(4^{1/2}\) chambers in the last whorl, see Chapters 4, 5 & 6 for details)
   4. side view x150

2.5. Praeglobotruncana helvetica (Bolli), Middle Turonian, Karai-3
   1. spiral view x200 (well developed single keel but, unlike the typical Tethyan helvetica (7 chambers in the final whorl) only \(4^{1/2}\) chambers in the last whorl, see Chapters 4, 5 & 6 for details)
   4. side view x200 (a very prominent, beaded, single keel)

3. Praeglobotruncana helvetica (Bolli), spiral view x200 (rare occurrence, in the Middle Turonian, of forms with 5 chambers in the final whorl, see Chapter 4 for detail), Middle Turonian, Karai-3

6, 8. Praeglobotruncana praehelvetica (Trujillo), Middle Turonian, Karai-3
   6. spiral view x150
   8. side view x150

7. Praeglobotruncana praehelvetica (Trujillo), spiral view x200, Middle Turonian, Karai-3

9. Praeglobotruncana stephani (Gandolfi), spiral view x200 (strongly beaded ornamentation, see Chapters 4 & 6 for details), Lower Cenomanian, Karai-Kulakkalnattam traverse

10-12. Praeglobotruncana stephani (Gandolfi), Middle Turonian, Karai-3
   10. spiral view x200
   11. umbilical view x200
   12. side view x200

13,15. Rotalipora appenninica (Renz), Upper Cenomanian, Karai-4
   13. umbilical view x200
   15. side view x200

14. Rotalipora appenninica (Renz), spiral view x150, Upper Albian, Karai-4

16. Rotalipora brotzeni (Sigal), spiral view x200, Upper Albian, Karai-4
Plate 15

1. **Rotalipora brotzeni** (Sigal), umbilical view x200, Upper Albian, Karai-4

2-3. **Rotalipora brotzeni** (Sigal), Upper Albian, Karai-4
   2. spiral view x200
   3. umbilical view x200

4-6. **Rotalipora cushmani** (Morrow), Upper Cenomanian, Karai-4
   4. side view x150
   5. spiral view x150
   6. umbilical view x150

7-8. **Rotalipora sp. aff. R. deeckeii** (Franke), Upper Cenomanian, Karai-4
   7. spiral view x200
   8. umbilical view x200

9-10. **Rotalipora gandolfii** Luterbacher & Premoli-Silvia, Upper Cenomanian, Karai-Kulakkalnattam traverse
   9. spiral view x200
   10. umbilical view x200

11-13. **Rotalipora micheli** (Sacal & Debourle), Middle Cenomanian, Karai-4
   11. spiral view x200
   12. umbilical view x200
   13. side view x200

14-15. **Rotalipora greenhornensis** (Morrow), Upper Cenomanian, Karai-Kulakkalnattam traverse
   14. spiral view x200
   15. umbilical view x200

16. **Rotalipora montsalvensis** Mornod, umbilical view x150, Cenomanian, Karai-Kulakkalnattam traverse
Plate 16

1. *Rotalipora montsalvensis* Mornod, spiral view x150, Cenomanian, Karai-Kulakkalnattam traverse

2-3. *Rotalipora reicheli* Mornod, Upper Cenomanian, Karai-Kulakkalnattam traverse
   2. spiral view x150
   3. side view x150

4-7. *Rotalipora reicheli* Mornod, Lower Cenomanian, Karai-Kulakkalnattam traverse
   4. umbilical view x150
   7. side view x150

5-6. *Rotalipora reicheli* Mornod, Lower Cenomanian, Karai-Kulakkalnattam traverse
   5. spiral view x200
   6. umbilical view x200

8-10. *Rotalipora subticinensis* (Gandolfi), Upper Albian, Karai-Kulakkalnattam traverse
   8. spiral view x200
   9. umbilical view x200
   10. side view x200 (unlike the *R. subticinensis* reported from Europe (Robaszynski & Caron 1979), which lack keel on the last 3 to 4 chambers, the specimen shows a single keel present in the final 3 chambers, see Chapter 4 for details)

11. *Rotalipora subticinensis* (Gandolfi), spiral view x200 Upper Albian, Karai-Kulakkalnattam traverse

12-14. *Rotalipora ticinensis* (Gandolfi), Upper Albian, Karai-Kulakkalnattam traverse
   12. spiral view x200
   13. umbilical view x200
   14. side view x200
Plate 17

1-2. **Rotalipora ticinensis** (Gandolfi), Upper Albian, Karai-Kulakkalnattam traverse
   1. spiral view x200
   2. umbilical view x200

3-5. **Rotalipora sp. 2**, Middle Cenomanian, Karai-Kulakkalnattam traverse
   3. spiral view x200
   4. umbilical view x200
   5. side view x200

6. **Rotalipora sp. 1**, spiral side x200, Upper Albian, Karai-4

7. **Dicarinella algeriana** (Caron), spiral view x150, Cenomanian, Karai-4

8. **Dicarinella algeriana** (Caron), umbilical view x150, Cenomanian, Karai-4

9. **Dicarinella algeriana** (Caron), side view x150, Cenomanian, Karai-4

10-12. **Dicarinella canaliculata** (Reuss), Upper Cenomanian, Karai-Kulakalnattam traverse
   10. side view x350
   11. spiral view x350
   12. umbilical view x350

13-14. **Dicarinella hagni** (Scheibnerova), Upper Cenomanian, Karai-4
   13. spiral view x150
   14. side view x150 (high trochospire)

15-16. **Dicarinella hagni** (Scheibnerova), Upper Cenomanian, Karai-4
   15. spiral view x150
   16. side view x150 (high trochospire)

17-18. **Dicarinella hagni** (Scheibnerova), Upper Cenomanian, Karai-4
   17. spiral view x150
   18. side view x150 (moderate trochospire)
**Plate 18**

1-3. **Dicarinella hagni** (Scheibnerova), Lower Turonian, Karai-4
   1. spiral view x200 (flat to gently concave test)
   2. umbilical view x150
   3. side view x200 (plano-convex)

4-9. **Dicarinella hagni** (Scheibnerova), Middle Cenomanian, Karai-Kulakkanattam traverse
   4. spiral view x150 (low trochospire)
   5. side view x150 (plano-convex profile).
   9. umbilical view x150

5. **Dicarinella hagni** (Scheibnerova), side view x150 (plano-convex profile), Lower Turonian, Karai-3

6-8. **Dicarinella hagni** (Scheibnerova), Middle Turonian, Karai-3
   6. spiral view x150 (flat to gently concave test)
   7. umbilical view x150 (a prominent periumbilical ridge developed in the final 3 chambers)
   8. side view x150 (plano/concavo-convex profile)

10. **Dicarinella hagni** (Scheibnerova), umbilical view x150 (weakly developed periumbilical thickening in all the chambers) Upper Cenomanian, Karai-4

11. **Dicarinella hagni** (Scheibnerova), umbilical view x200 (periumbilical thickening in all the chambers becoming more prominent in the final two chambers) Upper Cenomanian, Karai-4

12. **Dicarinella hagni** (Scheibnerova), umbilical view x200 (weakly developed periumbilical ridge) Lower Turonian, Karai-Kulakkanattam traverse

13. **Dicarinella hagni** (Scheibnerova), umbilical view x150 (periumbilical thickening becoming more prominent in the final two chambers) Lower Turonian, Karai-4

14. **Dicarinella imbricata** (Mornod), spiral view x350, Lower Turonian, Karai-4

15, 17. **Dicarinella imbricata** (Mornod), Lower Turonian, Karai-4
   15. side view x200
   17. side view x350

16. **Dicarinella imbricata** (Mornod), side view x200, Upper Cenomanian, Karai-4
18. *Dicarinella imbricata* (Mornod), spiral view x200, Upper Cenomanian, Karai-4
Plate 19

1, 5. *Globotruncana area* (Cushman), Campanian, Sillakudi railway cutting section
   1. spiral view x200
   5. side view x200

2-4. *Marginotruncana marginata* Reuss, Middle Turonian, Karai-3
   2. spiral view x150
   3. umbilical view x150 (U-shaped sigmoidal rim)
   4. side view x150 (asymmetrical biconvex (spiral side slightly more convex), low trochospire test with two well developed keels separated by a wide imperforate band with the spiral keel slightly diverging obliquely per chamber, see Chapter 4 for details)

6-8. *Marginotruncana marginata* Reuss, Lower Turonian, Karai-3
   6. spiral view x200 (nearly flat trochospire)
   7. umbilical view x200 (U-shaped sigmoidal rim)
   8. side view x200 (low to flat trochospire, equally biconvex test with two well developed keels separated by a wide imperforate band, see Chapter 4 for details)

9-11. *Marginotruncana marginata* Reuss, Lower Turonian, Karai-3
   9. spiral view x150 (beaded ornamentation)
   10. umbilical view x150 (U-shaped sigmoidal rim)
   11. side view x150 (asymmetrical, moderately high trochospire with two well developed keels separated by a narrow peripheral band, see Chapter 4 for details)

12-14. *Marginotruncana marginata* Reuss, Middle Turonian, Karai-3
   12. spiral view x150 (heavily beaded ornamentation)
   13. umbilical view x150 (U-shaped sigmoidal rim)
   14. side view x150 (asymmetrical, high trochospire with two well developed keels separated by a narrow peripheral band, see Chapter 4 for details)
Plate 20

1-3. Marginotruncana schneegansi (Sigal) (similar to that described from Europe (Robaszynski & Caron 1979), see Chapter 4 for details), Middle Turonian, Karai-3. These forms are rare in the Cauvery Basin.
1. spiral side x150
2. umbilical side x150
3. side view x150 (low trochospire, almost symmetrical biconvex test)

4, 8. Marginotruncana schneegansi (Sigal) (similar to that reported from Europe (Robaszynski & Caron 1979), see Chapter 4 for details), Middle Turonian, Karai-3. These forms are rare in the Cauvery Basin.
4. spiral side x150
8. side view x200

5-7. Marginotruncana schneegansi (Sigal) (high trochospire form, a type more frequent in the Cauvery Basin, but contrary, in terms of morphology, to the European counterparts (Robaszynski & Caron 1979), see Chapter 4 for details), Middle Turonian, Karai-3
5. spiral view x100
6. umbilical view x100
7. side view x150 (very high trochospire, asymmetrical biconvex test)

9-10. Marginotruncana schneegansi (Sigal) (high trochospire forms, a type more frequent in the Cauvery Basin, but contrary, in terms of morphology, to the European counterparts (Robaszynski & Caron 1979), see Chapter 4 for details), Middle Turonian, Karai-3
9. spiral view x100
10. side view x150 (high trochospire, asymmetrical biconvex test)

11-12. Marginotruncana schneegansi-Dicarinella hagni intermediate form (flat to low trochospire form), Middle Turonian, Karai-Kulakkalanattam traverse
11. spiral view x100 (flat to concave spiral side)
12. side view x100 (plano/concavo-convex profile)

13-14. Marginotruncana schneegansi-Dicarinella hagni intermediate form (low to moderate trochospire form), Middle Turonian, Karai-3
11. spiral view x100
12. side view x100

15. Marginotruncana schneegansi-Dicarinella hagni intermediate form, side view x100 (plano-convex profile), Middle Turonian, Karai-3
Plate 21

1. **Bolivina** sp. aff. *B. incrassata* Reuss, side view x200, Middle Turonian, Karai-3

2. **Bolivina textilaroides** Reuss, side view x350, Upper Albian, Karai-Kulakkalnattam traverse

3. **Bolivina** sp. 1, side view x500, Lower Turonian, Karai-Kulakkalnattam traverse

4. **Tappanina** sp. 1, side view x350, Lower Turonian, Karai-3

5. **Praebulimina nannina** (Tappan), side view x500, Lower Turonian, Karai-4

6. **Praebulimina elata** Magniez-Jannin, side view x200, Lower Turonian, Karai-6

7. **Coryphostoma** sp. 1, side view x200, Upper Albian, Karai-Kulakkalnattam traverse

8. **Coryphostoma** sp. 2, side view x200, Lower Turonian, Karai-6

9. **Coryphostoma** sp. 3, side view x200, Middle Cenomanian, Karai-Kulakkalnattam traverse

10. **Ellipsoglandulina concinna** (Olbertz), side view x200, Upper Albian, Karai-Kulakkalnattam traverse

11. **Ellipsoglandulina** sp. 1, side view x150, Upper Albian, Karai-Kulakkalnattam traverse

12. **Ellipsoglandulina** sp. 2, side view x100, Upper Albian, Karai-Kulakkalnattam traverse

13. **Pleurostomella nitida** Morrow, side view x150, Cenomanian, Karai-Kulakkalnattam traverse

14. **Pleurostomella obtusa** Berthelin, side view x100, Upper Albian, Karai-4

15. **Pleurostomella reussi** Berthelin, side view x100, Lower Turonian, Karai-Kulakkalnattam traverse
16. *Pleurostomella reussi* Berthelin var. A, side view x200, Lower Turonian, Karai-4

17. *Stilostomella sp.* 1, side view x350, Middle Turonian, Karai-Kulakalnattam traverse

18. *Stilostomella sp.* 2, side view x150, Middle Turonian, Karai-3

19-20. *Epistomaroides indica* (Sastry & Sastri), Lower Turonian, Karai-4
   (umbilical view of the specimen in Plate 22, Figure 1)
   19. spiral view x150
   20. side view x150

21-22. *Conorbina sp.* 1, Lower Turonian, Karai-6
   21. spiral view x150
   22. umbilical view x100

23-24. *Conorbina sp.* 2, Lower Turonian, Karai-6
   21. spiral view x150
   22. umbilical view x100
Plate 22

1. *Epistomaroides indica* (Sastry & Sastri), umbilical view x150 Lower Turonian, Karai-4 (spiral and side views of the specimen in Plate 21 Figures 19 & 20 respectively)

2-4. *Epistomaroides sp. 1*, Lower Turonian, Karai-4
   2. spiral view x200
   3. umbilical view x200
   4. side view x200

5-6. *Quadririmorphina camerata* (Brotzen), Lower Turonian, Karai-6
   5. spiral view x200
   6. umbilical view x200

7. *Globorotalites sp. 2*, spiral view x150, Lower Turonian, Karai-4

8-9. *Globorotalites sp. 2*, Lower Turonian, Karai-4
   8. umbilical view x200
   9. side view x200

10-11. *Globorotalites sp. 1*, Upper Albian, Karai-Kulakkalnattam traverse
   10. umbilical view x350
   11. side view x350

12. *Goupillaudina daguini* Marie, spiral view x75, Upper Campanian, Dalmia quarry

13. *Osangularia sp. 1*, side view x100, Upper Albian, Karai-4

14-15. *Heterolepa sp. 1*, Cenomanian, Karai-4
   14. spiral view x500
   15. umbilical view x350

16. *Heterolepa sp. 2*, spiral view x200 Middle Cenomanian, Karai-Kulakkalnattam traverse

17. *Gyroidinoides sp. 1*, spiral view x200, Upper Albian, Karai-4 (umbilical and side views of the specimen in Plate 23 Figures 1 & 2 respectively)
Plate 23

1-2. **Gyroidinoides** sp. 1, Upper Albian, Karai-4 (spiral view of the specimen in Plate 22 Figure 17)
   1. umbilical view x200
   2. side view x200

3-5. **Gyroidinoides** sp. 2, Upper Albian, Karai-4
   3. spiral view x200
   4. umbilical view x200
   5. side view x200

6-7. **Gyroidinoides** sp. 3, Lower Cenomanian, Karai-Kulakkalnattam traverse
   6. spiral view x200
   7. umbilical view x150

8-9. **Gyroidinoides** sp. 5, Middle Turonian, Karai-Kulakkalnattam traverse
   8. spiral view x200
   9. umbilical view x200

10-12. **Gyroidinoides** sp. 4, Middle Turonian, Karai-Kulakkalnattam traverse
   10. spiral view x200
   11. umbilical view x200
   12. side view x200

13-14. **Gyroidinoides** sp. 6, Upper Albian, Karai-4
   13. umbilical view x200
   14. side view x200

15-16. **Gyroidinoides** sp. 7, Cenomanian, Karai-Kulakkalnattam traverse
   15. spiral view x200
   16. side view x200

17-18. **Gyroidinoides** sp. 8, Upper Albian, Karai-4 (side view of the specimen in Plate 24 Figure 1)
   17. spiral view x200
   18. umbilical view x150
Plate 24

1. **Gyroidinoides** sp. 8, side view x150, Upper Albian, Karai-4 (spiral and umbilical view of the specimen in Plate 23 Figures 17 & 18 respectively)

2-4. **Gyroidinoides** sp. 9, Lower Turonian, Karai-4
2. spiral view x200
3. umbilical view x200
4. side view x350

5. **Gavelinella cenomanica** (Brotzen), spiral view x200, Upper Albian, Karai-Kulakkalnattam traverse

6-8. **Gavelinella baltica** Brotzen, Lower Turonian, Karai-4
6. spiral view x100
7. umbilical view x100
8. side view x100

9. **Gavelinella cenomanica** (Brotzen), spiral view x150, Upper Albian, Karai-Kulakkalnattam traverse

10, 14, 18. **Gavelinella reussi** (Khan), Upper Albian, Karai-Kulakkalnattam traverse
10. spiral view x150
14. umbilical view x150
18. side view x150

11-13. **Gavelinella berthelini** (Keller), Lower Turonian, Karai-4
11. spiral view x150
12. umbilical view x150
13. side view x150

15-17. **Gavelinella intermedia** (Berthelin), Lower Turonian, Karai-4
15. spiral view x150
16. umbilical view x150
17. side view x150
Plate 25

1-2. *Gavelinella rudis* (Reuss), Lower Turonian, Karai-Kulakkalnattam traverse
   1. spiral view x150
   2. umbilical view x150

3-5. *Gavelinella rudis* (Reuss), Lower Turonian, Karai-Kulakkalnattam traverse
   3. spiral view x150
   4. umbilical view x150
   5. side view x150

6, 9. *Gavelinella schloenbachi* (Reuss), Upper Albian, Karai-Kulakkalnattam traverse
   6. spiral view x200 (inner whorls sitting like a block on a very flat final whorl)
   9. side view x200 (high trochospire with a concavo-convex profile, umbilical side concave)

7, 8, 10. *Gavelinella schloenbachi* (Reuss), Lower Cenomanian, Karai-Kulakkalnattam traverse
   7. spiral view x200 (a steady and gradual rise in the spire)
   8. umbilical view x200
   10. side view x200 (low trochospire test with an asymmetrical biconvex profile)

11-13. *Gavelinella tourainensis* Butt, Turonian, Karai-Kulakkalnattam traverse
   11. spiral view x150
   12. umbilical view x150
   13. side view x150

14. *Gavelinella* sp. 1, spiral view x100, Campanian, Sillakudi railway cutting section

15-16. *Gavelinella* sp. 2, Campanian, Sillakudi railway cutting section
   15. spiral view x100
   16. umbilical view x100

17-18. *Gavelinella* sp. 3, Campanian, Sillakudi railway cutting section
   17. umbilical view x200
   18. spiral view x200
Plate 26

1. *Gavelinella sp. 4*, spiral view x100, Campanian, Sillakudi railway cutting section

2-3. *Gavelinella sp. 5*, Upper Albian, Karai-Kulakalmattam traverse
   2. spiral view x350
   3. umbilical view x350

4. *Gavelinella sp. 6*, spiral view x150, Upper Albian, Karai-Kulakalmattam traverse

5-6. *Lingulogavelinella albiensis* Malapris, Upper Albian, Karai-Kulakalmattam traverse
   5. spiral view x200
   6. side view x200

7-9. *Lingulogavelinella globosa* (Brotzen), Lower Turonian, Karai-3
   7. spiral view x200
   8. umbilical view x200
   9. side view x200

10-12. *Lingulogavelinella jarzevae* (Vasilenko), Upper Albian, Karai-4
   10. spiral view x200
   11. umbilical view x200
   12. side view x200

13, 17. *Orithostella viriola* Eicher & Worstell, Upper Albian, Karai-4
   13. spiral view x200
   17. side view x200

14. *Orithostella indica* Scheibnerova, spiral view x150, Lower Turonian, Karai-4

15-16. *Orithostella indica* Scheibnerova, spiral view x150, Lower Turonian, Karai-4
   15. umbilical view x150
   16. side view x150
Plate 27

1. **Lepidortbitoides socialis** Leymerie, x100, Upper Campanian-Maastrichtian, Dherani quarry

2. **Lepidortbitoides socialis** Leymerie, x40, Upper Campanian-Maastrichtian, Tancem quarry

3. **Lepidortbitoides socialis** Leymerie, x40, Upper Campanian-Maastrichtian, Tancem quarry

4. **Lepidortbitoides socialis** Leymerie, x40, Upper Campanian-Maastrichtian, Tancem quarry

5. **Siderolites calcitrapoides** Lamarck, x40, Upper Campanian-Maastrichtian, Tancem quarry

6. **Siderolites calcitrapoides** Lamarck, x75, Upper Campanian-Maastrichtian, Dherani quarry

7. **Siderolites calcitrapoides** Lamarck, x40, Upper Campanian-Maastrichtian, Tancem quarry

8. **Siderolites calcitrapoides** Lamarck, x40, Upper Campanian-Maastrichtian, Tancem quarry

9. **Siderolites calcitrapoides** Lamarck, x40, Upper Campanian-Maastrichtian, Tancem quarry