

PALAEO-ECOLOGY OF MID-CRETACEOUS FORAMINIFERA IN THE CAUVERY BASIN, EAST COAST OF INDIA

R. VENKATACHALAPATHY and V. RAGOTHAMAN

DEPARTMENT OF GEOLOGY, UNIVERSITY OF MADRAS, A.C. COLLEGE CAMPUS, MADRAS- 600 025.

ABSTRACT

Foraminifera, like other marine micro fossil groups, are affected by changes in environment and palaeo-oceanographic conditions. Palaeo-ecological aspects of the mid-Cretaceous of Cauvery basin have been approached in the following ways : 1. Faunal Groups : an epicontinental Sea Fauna (ESF), an open marine Shallow Water Fauna (SWF) and an open marine Deep Water Fauna (DWF); 2. Planktic/Benthic ratio (or) P/B ratio; 3. Coiling patterns. The results are discussed and correlated.

INTRODUCTION

The Cretaceous of south India is well known for its faunal diversity and lithological associations. Here, the marine Cretaceous rocks are found in three localities separated by alluvium of the Pennar and Vellar rivers. Among these, the largest deposit occurs north-east of Thiruchirappalli District, covering an area of about 400 square kilometres. The present work is concerned with the detailed palaeoecological study of mid-Cretaceous rocks, which includes the strata from the base of Aptian to the end of Turonian (Uttattur Group), which falls within the North latitudes $10^{\circ}55'$ to $11^{\circ}25'$ and the East longitudes $78^{\circ}40'$ to $79^{\circ}10'$, forming parts of the toposheets 58 I/16, 58 M/4, 58 M/3 and 58 J/13 of the Survey of India.

Many studies have been carried out on these sediments by different workers. These contributions are based on the occurrence and distribution of mega- and microfossils, recovered from the sediment samples collected at distant spots, in a few traverses. In this area, no emphasis has so far been laid to synthesize the palaeoecology by making close sampling and using modern approaches like faunal assemblage, planktic/benthic ratio, coiling patterns, etc.

MATERIALS

For the present work, samples were collected by the senior author (R.V.) for his Doctoral programme. 227 samples were systematically collected, establishing 11 traverses covering the entire Uttattur Group. The paleoecological work incorporated in this paper is based on a study of samples collected from two traverses (namely Karai-Kulakkanatham and Terani-Garudamangalam - fig.1) and the data generated have been discussed.

FORAMINIFERAL ASSEMBLAGE

Foraminifera, like other marine microfossil groups, are affected by changes in environment and palaeo-oceanographic conditions. The prime force behind the distribution, evolution and regional extinction events of

foraminiferal fossil communities is the differential influence of depth-related factors, among which are included the stability of the environment, water temperature, dissolved oxygen concentration, salinity, availability of calcium carbonate, nutrient resources, substrate type and wave and current activity (Koutsoukos and Hart, 1990).

During the mid-Cretaceous, as is seen in the present day, the simple, inflated morphotypes inhabited the near surface waters, while the flatter, keeled forms occupied comparatively deeper habitats (Hart, 1980b). Accordingly, three faunal groups may be proposed :

- i. an Epicontinental Sea Fauna (ESF) is characterised by the species of *Guembelitra* and *Heterohelix* ;
- ii. an open marine Shallow Water Fauna (SWF) composed primarily of the species of *Hedbergella* and *Globigerinelloides* ; and
- iii. an open marine Deep Water Fauna (DWF) represented by species of *Planomalina*, *Rotalipora*, *Praeglobotruncana* and *Marginotruncana* (keeled taxa). Open ocean faunal assemblages of the study area are numerically dominated by species of the SWF, in the earlier parts i.e., pre-Cenomanian, while ESF comprises less than 3%. Biostratigraphically important DWF are generally dominant during the Cenomanian period.

Planktic foraminifera have proved to be vital in high resolution biostratigraphy of mid-Cretaceous and younger marine sequences. They are useful for ancient palaeo-oceanographic reconstructions. Since not much is known about the ecology of living foraminifera in terms of reproductive rates, ecological stress, and the ultimate destruction and sorting of their empty tests, palaeo-ecologic interpretations of extinct species and assemblages must be addressed with more care. However, when considered within a geologic framework, our basic understanding of planktic foraminiferal biology and ecology may be applied to palaeo-ecologic/palaeo-environmental interpretations. The time averaged nature of geologic samples may actually help us to understand better the long term composition of modern

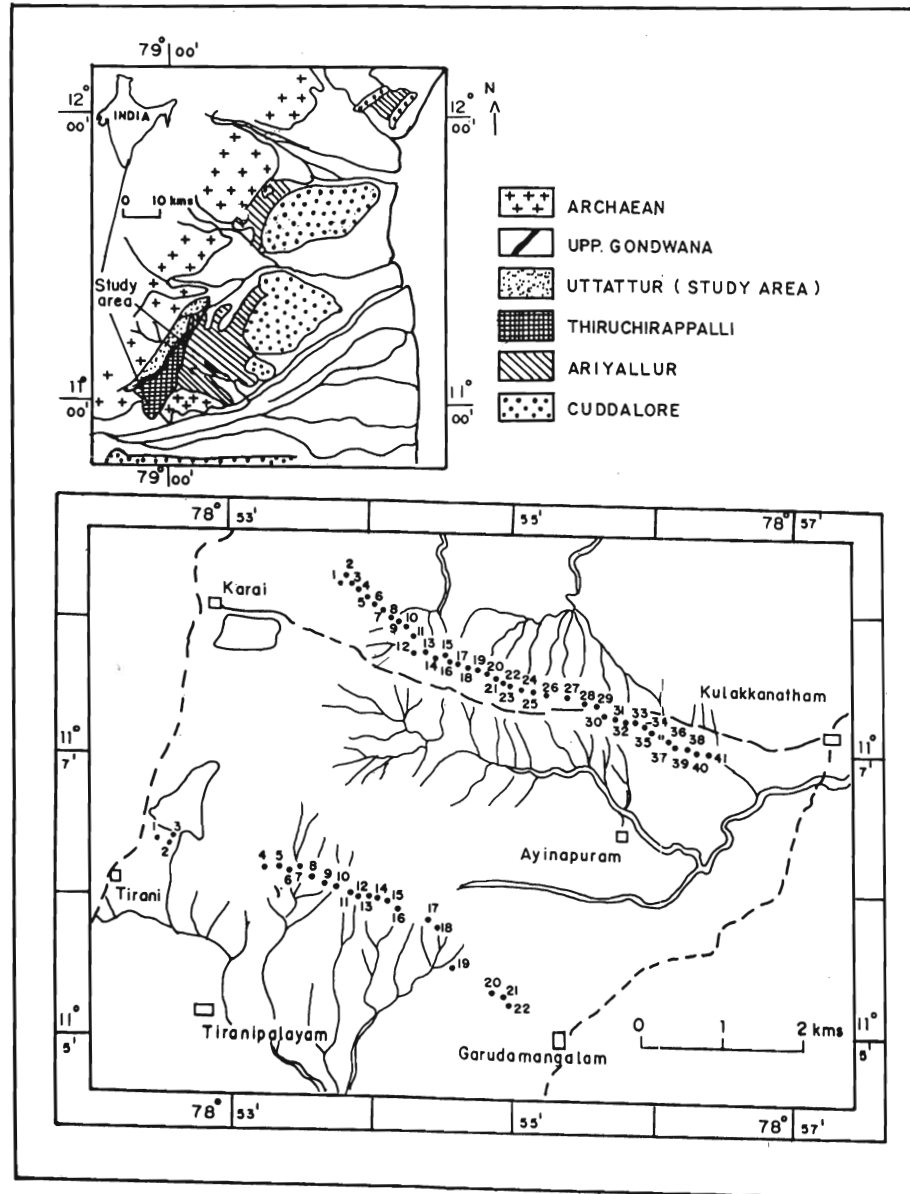


Fig. 1. Map of the Uttattur Group of the Thiruchirappalli Cretaceous showing the sample localities.

populations by hedging the problems of patchiness and seasonal variations (Leckie, 1987).

Modern planktic foraminifera are generally restricted to open marine environments of normal oceanic salinity and clear water (Leckie, 1984). In deeper waters, modern planktic foraminifera are very abundant. They live predominantly in the euphotic zone, although species-specific ecological and physiological requirements have resulted in a crude depth stratification with the spinose, symbiont-bearing species restricted to sunlit, near surface waters, while the non-spinose, symbiont-barren species tend to occupy deep waters (Be, 1982). Diversity of planktic foraminiferal assemblages in low latitude open ocean environments is probably strongly influenced by nutrient availability

and surface water fertility (Lipps, 1979). Planktic foraminifera are rare in the nearshore environments of the continental shelves but increase in abundance with increasing depth (Murray, 1976). From a study of marginal seas, Murray (1976) found a progressive increase in the population size of planktic tests as well as an increase in planktic diversity toward the open sea. Similar trends were observed by Leckie (1987) in fossil assemblages.

PALAEO-ECOLOGIC APPLICATIONS

Palaeobiogeographic distribution of Cretaceous planktic foraminifera are useful for palaeo-oceanographic reconstructions and may reflect broad

temperature gradients of the Cretaceous oceans and epicontinental seas (Douglas, 1972).

Depth distributions of Cretaceous planktic foraminifera are thought to have been similar to modern analogs with the globular (i.e., globigerine) morphotypes inhabiting the near-surface waters and the flattened, keeled biconvex and keeled planoconvex (i.e., globorotaliid-like) forms representing increasing depth habitats (Hart and Bailey, 1979; Caron and Homewood, 1983).

According to Hart and Bailey (1979), only rare individuals of the deep dwelling mid-Cretaceous species would be expected in shallow epicontinental seas, because the depth would be insufficient to support their full life cycles. Eicher (1969b) and Eicher and Worstell (1970) have shown that the globigerine and globular morphotypes (*Hedbergella*, *Heterohelix*) were the first planktics to appear during transgression and the last to disappear during the regression of shallow epicontinental seas. These data are in concurrence with the observed species distributions in modern shelf environments. Murray (1976) has shown that only rare individuals of *Globigerina* and *Globigerinoides* penetrate into the middle shelf environment, while predominantly juvenile forms are found in the inner-shelf; the bulk of the planktic tests which accumulate on the shelf have been transported by currents. He (1976) further stated that the vertical mixing and turbulence in the shelf environment reduce the settling velocities of the empty foraminiferal tests so that lateral transport and differential settling rates can yield highly variable species compositions in the residue assemblages. Caron and Homewood (1983) have suggested that deeper-dwelling morphotypes represent advanced and/or specialized taxa with longer life cycles and lower reproductive rates than the simple, surface dwelling species.

MID-CRETACEOUS DEPTH FAUNAS

As stated earlier, three faunal groups have been proposed for low-latitude, mid-Cretaceous planktic foraminiferal assemblages. They are based on recurrent faunal associations consistent with observed palaeobiogeographic distribution patterns (Tappan, 1940; Eicher and Worstell, 1970; Sliter, 1972; Hart and Bailey, 1979; Leckie, 1987).

Epicontinental Sea Fauna

The fauna is characterized by species of *Heterohelix*, a biserial form, *Guembelitra*, a triserial form and *Gubkinella*, a stout trochospiral form. Eicher (1969a) has also observed that these genera are particularly diagnostic of planktic foraminiferal assemblage from shallow marine sections of Cretaceous epicontinental seas, for example, the Western Interior Seaway of North America. They

occur in lesser abundance in open ocean pelagic sections. It is suggested that they inhabited the near-surface water (e.g., Hart and Bailey 1979) and may have had wider ecologic tolerances (i.e., eurytopic) than other mid-Cretaceous genera. Many authors Eicher, 1969b; Eicher and Worstell, 1970; Sliter, 1972; Leckie, 1987 have observed that high proportions of generally small specimens of *Hedbergella* spp. and *Globigerinelloides* spp. are associated with the Epicontinental Sea Fauna of relatively shallow epeiric or marginal seas.

Shallow Water Fauna

The major components of this faunal assemblage are *Hedbergella* spp. and *Globigerinelloides* spp. These species are dominant planktic foraminiferal elements in open marine pelagic sections. Along with these, the other associated mid-Cretaceous genus is *Clavihedbergella*.

Based on the gross morphologic characters, some authors are of the opinion that species of *Clavihedbergella* are deep-water taxa (e.g., Hart, 1980a). It is suggested that these taxa may have lived at greater depths than *Hedbergella delrioensis* (Carsey) or *H. planispira* (Tappan), based on their clavate chambers and by analogy with the living species mentioned, but close palaeobiogeographic association with *Hedbergella* sp. in Cretaceous epicontinental seas suggests that *Clavihedbergella* spp. were not deep-water forms (Eicher and Worstell, 1970). *Hedbergella* spp. are characteristic of warm, shallow-water environments such as marginal seas or carbonate platforms (Barr, 1972).

Deep-Water Fauna

The keeled genera (*Rotalipora*, *Planomalina* and *Praeglobotruncana*) are believed to have been the deepest dwelling mid-Cretaceous planktic foraminifera, based on paleogeographic distributions, oxygen-isotope data, distributions relative to eustatic changes and by analogy with the depth habitats of the living keeled globorotaliids. These taxa are believed to have been the environmentally most sensitive (i.e., stenotopic) of mid-Cretaceous planktic foraminifers (Leckie, 1987).

PALEO-ENVIRONMENTAL EVOLUTION

From an overall study of the faunal assemblage in the mid-Cretaceous of the Cauvery Basin, the under-mentioned depositional phases may be differentiated.

The Aptian is recognized only in a few places in the western area. Intermittent anoxic events, associated with salinity stratified water masses, occurred in the basin during the Late Aptian - Early Albian. An oxygen minimum (dysaerobic to anoxic) condition occurred during Late Aptian - Earliest Albian, in the middle - outer neritic to upper bathyal settings. In the Cauvery Basin region, the Upper Aptian-Albian succession is a carbonate-

dominated sequence of shales. This succession probably represents the first true marine sedimentation in this locality. The characteristic faunas are nodosariids and *Ticinella*.

The Middle and Late Albian period is represented by *Hedbergella planispira* Zone and *Planomalina buxtorfi* Zone. This section contains abundant, well preserved, non-keeled planktic foraminifers such as *Globigerinelloides bentonensis*, *G. caseyi*, *Hedbergella planispira*, *H. delrioensis*; and faintly keeled *Planomalina buxtorfi* in the latest Albian. It also has a diverse benthic assemblage in the form of nodosariids, *Dorothia*, *Gavelinella*, etc. which are considered characteristic of shallow water environment.

The younger Cenomanian period is represented by *Rotalipora* Zone. It is characterized by planktic foraminifers such as *Rotalipora appenninica*, *R. evoluta*, *R. greenhornensis*, *R. cushmani*, *Praeglobotruncana delrioensis* and *P. stephani* — a typical equatorial Tethyan group.

The overall foraminiferal study indicates a relatively warmer climate in Cenomanian in a depositional environment ranging from deep neritic, near the shelf edge, to middle/lower bathyal (Water depths around 1500 m) near or below the C.C.D. They also indicate oceanographic conditions with a strong increase in productivity, circulation and oxygenation, within the oceanic basin during mid-Cretaceous. The fossil content, especially the rich assemblage of planktic foraminifera associated with abundant glauconitic pellets reveal that deposition during Cenomanian period was in an open marine neritic environment.

The Late Cenomanian - Early Turonian is represented by *Rotalipora cushmani* and *Whiteinella archacocretacea* Zones. Other planktic species represented include *Rotalipora greenhornensis*, *Globigerinelloides caseyi*, *Hedbergella amabilis*, *H. delrioensis*, *H. planispira* and *Heterohelix moremani*. Benthic forms are *Dentalina* sp., *Dorothia* sp., *Eouvigerina* sp., *Nodosaria* sp., *Tappannina* sp. and *Gyroidinoides* sp. This association is indicative of a deep neritic environment, near the shelf edge (Water depth approximately 200 m), with poorly oxygenated bottom water conditions and warm temperatures.

The Middle and Late Turonian period is represented by *Helvetoglobotruncana helvetica* and *M. sigali* Zones. The fauna include *M. difformis*, *M. indica*, *M. renzi*, *Clavihedbergella simplex*, *Hedbergella delrioensis*, *H. planispira*, *Whiteinella baltica* and *W. brittonensis*. Benthics are *Nodosaria* sp., *Gyroidinoides* sp. and *Osangularia* sp.

PLANKTIC/BENTHIC RATIO (P/B RATIO)

According to Hultberg and Malmgren (1987), the planktic/benthic foraminiferal ratio may under certain assumptions be a useful palaeobathymetrical index.

This is due to the fact that there is a general decrease in the frequencies of benthic foraminifera from the outer shelf into the deep sea.

Jones (1960) defined the benthic index as the per cent of benthic foraminifera in the total foraminiferal population. This index is opined to be related to water depth in a stable, shelf-type marine environment. The change in the percentage of benthic foraminifera through a limited stratigraphic sequence is indicative of the then existing differences in environmental conditions. There is always a numerical increase of planktic foraminifera with the increase in the depth of water column.

Murray (1976, p.109) documented a ratio of planktic foraminifera to benthic foraminifera (P/B) in bottom sediments and found a progressive numerical increase of planktic foraminifera towards the open sea. Similar trend was also observed in fossil assemblages by Leckie (1987).

Since none of the earlier workers on the Cretaceous of the Thiruchirappalli area have made a study of P/B ratio as a tool for palaeoecological interpretation, an attempt of the same has been made in the present study.

Material and Methods

Leckie (1987) pointed out the importance of methodology for Planktic/Benthic ratio. He emphasised the use of 63 or 73 μm size fraction for making counts, since the finer meshes retain a better representation of ecologically significant foraminiferal assemblage.

For this study, 63 sediment samples collected in two traverses, namely Karai-Kulakkanatham and Terani - Garudamangalam have been examined quantitatively. Approximately 300 specimens of foraminifera were taken from each sample. These specimens were counted

Table 1: Planktic / Benthic Ratio (Karai - Kulakkanatham traverse)

Sample Number	P/B Ratio	Sample Number	P/B Ratio
1	83	21	35
2	80	22	31
3	77	23	28
4	75	24	27
5	71	25	25
6	68	26	29
7	67	27	35
8	65	28	42
9	63	29	48
10	61	30	57
11	58	31	69
12	53	32	77
13	50	33	82
14	51	34	70
15	50	35	65
16	48	36	50
17	45	37	46
18	43	38	43
19	40	39	40
20	39	40	36
		41	37

Table 2: Planktic/Benthic Ratio (Terani - Garudamangalam traverse)

Sample Number	P/B Ratio
1	72
2	75
3	76
4	80
5	76
6	74
7	71
8	67
9	65
10	62
11	59
12	53
13	47
14	40
15	35
16	26
17	27
18	32
19	40
20	46
21	52
22	63

numerically for estimating the planktic/benthic percentages (Tables 1 & 2). The ratios enumerated were then plotted against stratigraphic positions (Figs. 2 & 3). The change in values of P/B ratio, are, here assumed to be the fluctuations in the then prevailing environmental conditions.

Discussion

It is a known fact that the planktic foraminifera are very useful in stratigraphic correlation because of their wide geographic distribution, numerical abundance and occurrence independent of sedimentary facies. Where benthic foraminifera are abundant and pelagic

foraminifera are rare, the deposition might have taken place near the shore and or in shallow water. However, the flooding abundance of planktic foraminifera associated with a paucity of benthic forms, is indicative of a deep-water, open-ocean environment, in which adverse light, temperature and food-supply conditions inhibited the development of benthic species.

On the basis of the inference of the present study, we can demarcate three faunal assemblages:

1. The lowermost part of the Group is dominated by benthic fauna i.e., from the Late Aptian to the Middle Albian. The same condition has been noticed in the samples of the Middle to Late Turonian.

2. The planktic assemblages are more predominant between the Uppermost Albian and the Middle Cenomanian.

3. The Late Cenomanian to the earliest Turonian period records comparatively lesser population both in the planktic and benthic forms.

The fauna represented in the lower part are mostly nodosariids. Other benthics include *Dorothia*, *Gavlinella*, *Haplophragmoides* and *Trochammina*. Planktic foraminifera are poorly represented and include *Ticinnella roberti*, *Hedbergella delrioensis*, *H. planispira*, *Globigerinelloides bentonensis* and *G. caseyi*. It may be inferred that the earliest phase of marine incursions took place in the western part, near the Uttattur and Dalmiapuram areas during the Late Aptian period. The dominance of benthic foraminifera and the occurrence of reefoidal limestone in the basal parts of the basin indicate that the reefs developed along the margin of the sea which has transgressed into the land area somewhere from the northeast or east of the present study area, during the latest Aptian-Early Albian period. The coral reef developed in this area is of "fringing-reef" type.

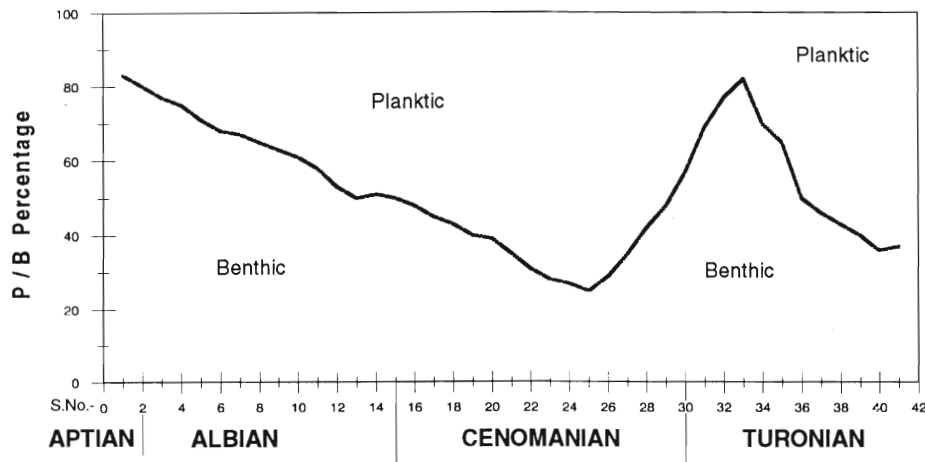


Fig. 2. Planktic/Benthic ratios plotted against stratigraphic positions indicate fluctuations in the environmental conditions in the Karai-Kulakkañatham traverse.

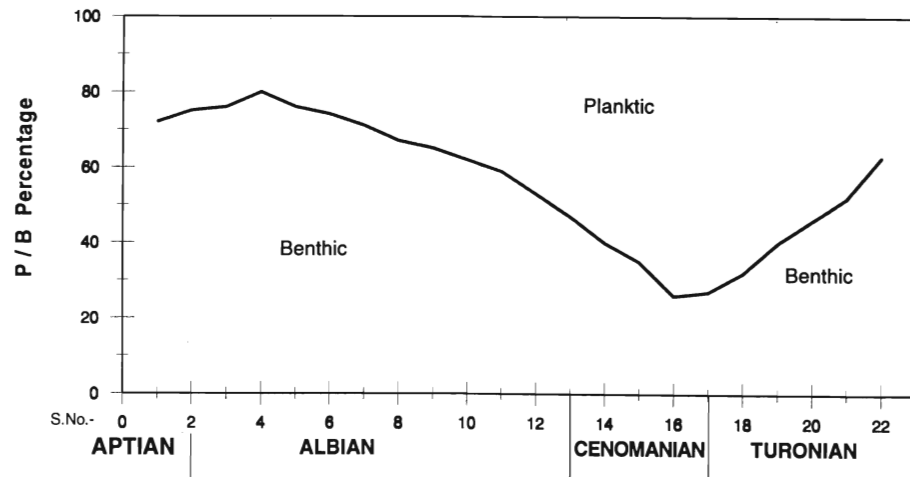


Fig. 3. Planktic/Benthic ratios plotted against stratigraphic positions indicate fluctuations in the environmental conditions in the Terani-Garudamangalam traverse.

The black shale commonly found in few places at the base indicates the then prevalent reduced environment. It was followed by open sea conditions that were favourable for the growth of reef and dominance of benthic fauna.

The Late Albian to Middle Cenomanian period was dominated by the pelagic foraminifers. The assemblage is mainly represented by *Rotalipora* spp. and *Praeglobotruncana* spp., in association with *Globigerinelloides* spp., *Hedbergella* spp. and *Planomalina* spp. The benthic foraminifera are *Lagena*, *Lenticulina*, *Dentalina*, *Nodosaria*, *Marginulina*, *Astacolus*, *Eouvigerina*, *Pleurostomella*, *Osangularia*, *Gavelinella*, and *Gyroidinoides*. The agglutinated forms include *Trochammmina*, *Dorothia*, *Ammodiscus* and *Gaudryina*. The maximum percentage of planktic foraminifera and P/B ratio of the middle sector (between the Late Albian and the Middle Cenomanian) coincides with the maximum of paleo-water depth. This view is supported by the occurrence of *Rotalipora reicheli*, which is a deep water form. Various authors (e.g., Caron and Homewood, 1983) recognised *Rotalipora reicheli* and *Helvetoglobotruncana helvetica* as deep water forms representing the Middle Cenomanian and the Early Turonian periods, respectively. From the above observation, it may be inferred that this unit was deposited in an inner neritic-middle shelf environment.

Latest Cenomanian to Late Turonian shows variation in faunal abundance. In the lower portion, the abundance of foraminifera is much less, especially that of planktic forms. The faunal evidence and P/B ratio show, a shallow water condition under regressive facies. A short regression followed by transgression created dysaerobic condition leading to the extinction of *Rotalipora* within the Cenomanian. Later on, a gradual increase in the percentage of planktic foraminifers is

noticed. The fauna is represented mostly by *Marginotruncana* spp. and *Whiteinella* spp. The benthic forms are *Nodosaria* spp., *Lenticulina* spp., *Gyroidinoides* spp. and *Osangularia* spp. An increase in the P/B ratio towards the younger beds is indicative of a rise in the water depth (shallow shelf environment) during Middle - Late Turonian period. The Latest Turonian has a poor representation of fauna. The conglomerates at the top indicate somewhat brackish to continental type of deposition for a very short period.

COILING PATTERNS

Most gastropods, some cephalopods and many families of foraminifera possess trochospirally coiled shells/tests which show easily recognizable spiral and umbilical sides. The shells of most gastropod species exhibit coiling in one preferred direction. In the case of foraminifera, within the same species occurrence of both dextrally and sinistrally coiled specimens are commonly noticed (clockwise and counter clockwise respectively).

According to Malmgren (1989), many species of Recent planktic foraminifera exhibit gradual changes in percentages of dextrally and sinistrally coiled tests over wide latitudinal belts. He further commented that, "Most species exhibiting such patterns are dominantly dextrally coiled towards warmer parts of their distributional ranges, whereas coiling preference shifts to sinistral toward cooler (higher latitudinal) parts".

Many workers have documented distinct provinces of dextral and sinistral populations of *Globorotalia truncatulinoides* (d'Orbigny) in the major ocean basins (Ericson *et al.*, 1954; Kennett, 1967; Takayanagi *et al.*, 1968; Parker and Berger, 1971). Similar studies on the cool-water species *Neogloboquadrina pachyderma* (Ehrenberg) have been made by Ericson (1959), Bandy (1960) and Kennett (1968). Fluctuations in coiling percentages of

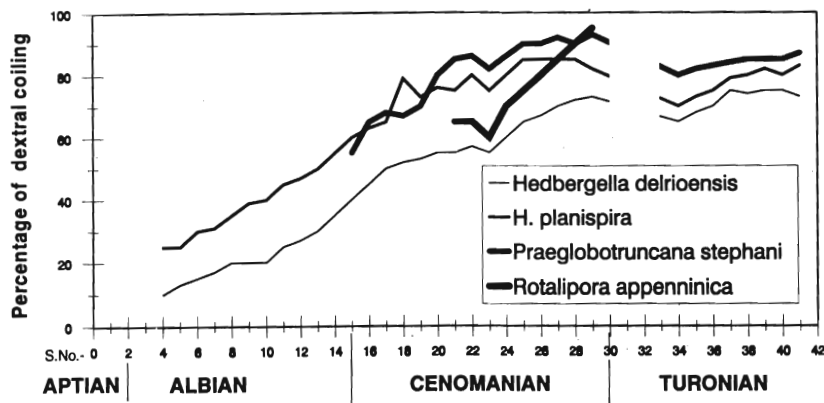


Fig. 4. Showing coiling patterns in four planktic foraminiferal species from Karai-Kulakkanatham section.

these species have been used in biostratigraphic and palaeoclimatic studies of the Late Neogene deep-sea sequences (Jenkins, 1967). The great stratigraphic and palaeoclimatic utility of coiling patterns in planktic foraminifera results from climatically induced periodic pulses of alternating equatorward and poleward migrations of coiling properties across a particular deep-sea site (Malmgren, 1989).

Gandolfi (1942) made valuable observations on the coiling of Globotruncanas (e.g., *Globotruncana appenninica* O. Renz) from a Cenomanian - Turonian section of Switzerland. He (1942) remarked, "It is a remarkable fact, that in the older beds the sinistral specimens are very frequent, nearly as numerous as the dextral ones, but in ascending stratigraphically, they gradually diminish in number until they represent only sporadic exceptions, so that it seems that coiling specializes in favour of dextral coiling".

Bolli (1950;1951;1971) suggested that phylogenetically oldest representatives of a species or a group of related species are often randomly coiled, but that they later

evolve a preference for a certain direction. This preference may either persist or shift to the opposite direction during the evolutionary history of a lineage. He noted that the Cretaceous genera like *Globotruncana* and *Rugoglobigerina* are almost exclusively dextrally coiled, whereas many species in the Tertiary developed a preference for a particular direction i.e., sinistral. He also noticed that some species (like *Globotruncana*) coiled in either direction in the early stages, but in the later stages preferred dextral coiling.

Lutze (1968) opined that a direct relationship exists between absolute abundance (number of specimens per gram sediment) and coiling percentages in the genus *Hedbergella*, recovered from the Aptian sediments of Germany.

Bandy (1960), based on his studies of the coiling ratios in *Globigerina pachyderma*, stated that, "Apparent temperature control of coiling ratios in some planktic foraminifera suggests that the biochemistry of the gene is affected by temperature. Low temperatures favour mutations toward sinistral dominance in some species;

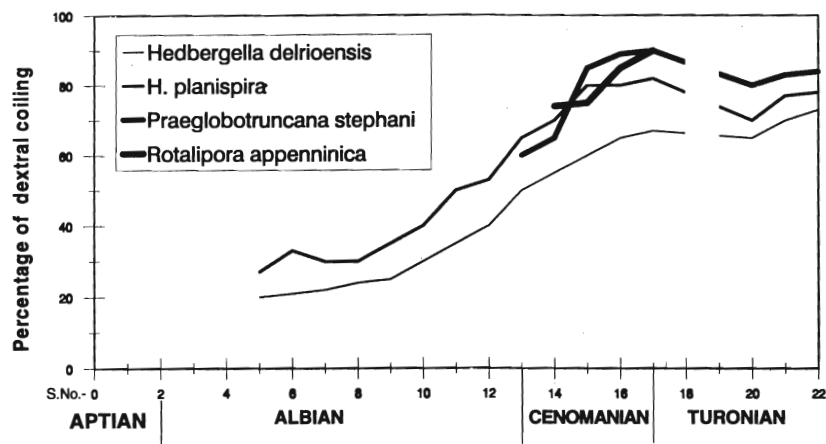


Fig. 5. Showing coiling patterns in four planktic foraminiferal species from Terani-Garudamangalam section.

Table 3: Coiling ratios of selected planktic foraminifera (Karai - Kulakkanatham traverse)

Sample Number	Hedbergella delrioensis	Hedbergella planispira	Praeglobotruncana stephani	Rotalipora appenninica
1-3	-	-	-	-
4	10	25	-	-
5	13	25	-	-
6	15	30	-	-
7	17	31	-	-
8	20	35	-	-
9	20	39	-	-
10	20	40	-	-
11	25	45	-	-
12	27	47	-	-
13	30	50	-	-
14	35	55	-	-
15	40	60	55	-
16	45	63	65	-
17	50	65	68	-
18	52	79	67	-
19	53	73	70	-
20	55	76	80	-
21	55	75	85	65
22	57	80	86	65
23	55	75	82	60
24	60	80	86	70
25	65	85	90	75
26	67	85	90	80
27	70	85	92	85
28	72	85	90	90
29	73	82	93	95
30-33	-	-	-	-
34	65	70	80	-
35	68	73	82	-
36	70	75	83	-
37	75	79	84	-
38	74	80	85	-
39	75	82	85	-
40	75	80	85	-
41	73	83	87	-

high temperature appears to favour mutations toward dextral dominance". He further stated that the planktic organisms have been considered to be among the better types of index fossils generally, because of their more rapid domination over vast areas by current.

Recently, Malmgren (1989) studied the coiling patterns in the terminal Cretaceous planktic foraminifera. From this study, he reported the geographic variability in coiling percentages of various species of rugoglobigerinids, and globotruncanids (*Rugoglobigerina rugosa* (Plummer), *R. hexacamerata* Bronnimann, *Trinitella scotti* Bronnimann, *Globotruncana arca* (Cushman), *Globotruncana stuartiformis* (Dalbiez), *Rosita contusa* (Cushman), and *Globotruncanella havanensis* (Woorwijk). He (1989) remarked that, "Most terminal Cretaceous globotruncanids and rugoglobigerinids are dominantly dextrally coiled (85-100%). The changes from dominantly dextral in low latitude to dominantly sinistral in high latitudes seen in many Pleistocene species were not found in any of terminal Cretaceous species". However, he noticed a great variability in coiling percentages in *Globotruncana havanensis*, as seen in modern species. Coiling percentage in *G. havanensis*

(Woorwijk) is potentially useful in distinguishing warm Tethyan from cool Tethyan and warm transitional waters in marine terminal Cretaceous deep-sea sequences (Malmgren, 1989).

Material and Methods

An attempt has been made by the author to study the coiling patterns in planktic foraminiferal species, recovered from the stratigraphic sections of the Uttattur Group to decipher the palaeotemperature conditions. Bolli (1950) stated that, for studies on the evolution of direction of coiling during the range of a certain species, complete and undisturbed stratigraphic sections are desirable. Accordingly, 41 sediment samples from Karai-Kulakkanatham traverse and 22 from Terani - Garudamangalam traverse were examined for studying the coiling patterns in planktic foraminiferal species. In the present study, coiling patterns of *Hedbergella delrioensis* (Carsey), *H. planispira* (Tappan), *Praeglobotruncana stephani* (Gandolfi), *Rotalipora appenninica* (Renz) (Tables 3 & 4; Figs.4 & 5) were studied. Fifty specimens of each species from every sample were considered and their coiling pattern determined.

Table 4: Coiling Ratios of selected planktic foraminifera (Terani - Garudamangalam traverse)

Sample Number	<i>Hedbergella delrioensis</i>	<i>Hedbergella planispira</i>	<i>Praeglobotruncana stephani</i>	<i>Rotalipora appenninica</i>
1-4	-	-	-	-
5	20	27	-	-
6	21	33	-	-
7	22	30	-	-
8	24	30	-	-
9	25	35	-	-
10	30	40	-	-
11	35	50	-	-
12	40	53	-	-
13	50	65	60	-
14	55	70	65	74
15	60	80	85	75
16	65	80	89	85
17	67	82	90	90
18	-	-	-	-
19	-	-	-	-
20	65	70	80	-
21	70	77	83	-
22	73	78	84	-

Observations and Discussion

From the present study, it has been observed that there is a gradual increase in the percentage of dextrally coiled specimens towards the younger strata.

1. The lower Albian period consists of considerably lesser number of dextrally coiled planktic foraminifers.

2. The dextrality in the percentage of coiling has increased rapidly and reach the maximum value (90-95%) in the Late Cenomanian.

3. The Latest Cenomanian and the earliest Turonian periods in the Uttattur Group consist of low faunal diversity, and hence the coiling pattern has not been studied.

4. The percentage of dextral coiling increases slowly but gradually, during Early - Late Turonian.

5. Fluctuation in the coiling ratios may be interpreted as the result of changing environmental condition, influencing the preferred coiling direction.

Hedbergella delrioensis (Carsey) and *H. planispira* (Tappan) occur abundantly in the Uttattur Group. These two species have about 20-30% of dextrally coiled specimens in the older beds. At one point near the Albian - Cenomanian boundary, the coiling percentage of dextral and sinistral specimens are almost equal. The dextral coiling percentage of these two species increases rapidly and reach the peak value of about 70-80% in the Cenomanian period. In Turonian period, the dextral coiling percentage increases gradually towards younger strata. The primitive double keeled planktic foraminifera, *Praeglobotruncana stephani* (Gandolfi) occurs from Early Cenomanian to Late Turonian. During

its appearance, the percentage of dextral and sinistral specimens are almost equal. However, later on the percentage of dextrally coiled specimens increases rapidly.

Among the *Rotalipora* encountered in the study area, the species *Rotalipora appenninica* (Renz) is one of the long ranging. The percentage of dextrally coiled tests of this species has also been found to increase rapidly towards the stratigraphically younger beds.

While observing the changes in the percentage of coiling in *Globotruncana appenninica* Renz (= *Rotalipora appenninica* (Renz)) from Cenomanian - Turonian. of Switzerland, Gandolfi (1942) found sinistral specimens very frequently in the older beds and noticed its change towards dextral in younger beds. A similar trend in coiling percentage of *Rotalipora appenninica* (Renz) has also been noticed in the Uttattur Group.

Observations on a number of sedimentary sections in the study area show that the planktic foraminifera of the older beds exhibit coiling in both sinistral and dextral directions. A rapid change towards higher percentage of dextral coiling has been found in the younger beds. Similar observations have also been made from Trinidad by Bolli (1950) and by Jones (1960), from Eagleford Group of Texas.

Planktic foraminifers are considered valuable in determining palaeoclimate. Bandy (1960) stated that low temperatures favour mutations towards sinistral dominance; and higher temperatures appear to favour mutations towards dextral dominance. The mid-Cretaceous planktic foraminifers of the Uttattur Group reflect the trend observed by Bandy (1960). The sedimentary beds of Cenomanian period have more dextral specimens than those of the Albian.

According to Caron and Homewood (1983), many species are temperature dependent, in particular those which are restricted to temperate and warm waters. Warmer-water species are usually large, thick-walled complex morphotypes, and populations are characterized by high diversity. Colder-water species have globular chambers and populations are rather uniform. The distinction of Cretaceous planktic foraminifers within warm and cold provinces is well established (Douglas and Rankin, 1969). The restriction of keeled species to deep open seas, and the dominance of small, globular forms over shallow shelves have been demonstrated during transgressive periods (Eicher and Worstell, 1970).

In the Uttattur Group, the keeled species were restricted to Cenomanian and Turonian periods indicative of temperate province at that time. The breaks in sedimentation and local regressions during the late Cenomanian recognized in the Cauvery Basin might have proved fatal to the *Rotalipora*.

Malmgren (1989) noticed the relationship between coiling percentage and palaeolatitudes. He stated that dextrally coiled specimens are dominant towards warmer parts, whereas coiling preference shifts to sinistral towards cooler (higher latitudinal) parts. A domination of the dextrally coiled specimens of planktic foraminifera in the Cenomanian - Turonian of the Uttattur Group, indicates that the Indian subcontinent was in the temperate region (Low latitudinal) during that period. Govindan's (1980) study on palaeoclimate shows that the Uttattur was in cool temperate (non-tropical) climatic zone (Austral province) in the Albian period; in contrast to the Cenomanian-Turonian periods which are characteristic of tropical (Tethyan province). This is believed to be partly due to the northward movement of the Indian subcontinent away from the cool temperate climatic zone towards the warm tropical 'Tethyan' zone during Cenomanian - Turonian periods (Govindan, 1980).

CONCLUSIONS

From an overall study, the mid-Cretaceous of the Cauvery basin seems to have witnessed the following depositional phases.

- i. a first phase of marine transgression during the latest Aptian- Early Albian period.
- ii. a characteristic shallow water environment prevailed during the Middle Albian-Late Albian, the Late Cenomanian(?) and during the Middle to Late Turonian.
- iii. the deposition during the Early to Middle Cenomanian and the Early Turonian might have occurred in an open marine environment.

From an evaluation of coiling patterns of selected planktic foraminifera in the present area, it is inferred that a comparatively colder climate prevailed during Aptian-Albian, whereas the climate was warmer during Cenomanian-Turonian period.

REFERENCES

- Bandy, O.L. 1960. The geologic significance of coiling ratios in the foraminifer *Globigerina pachyderma* (Ehrenberg). *Jour. Pal.*, **34**(4) : 671-681.
- Barr, F.T. 1968. Late Cretaceous planktic foraminifera from the coastal area east of Susa (Apollonia), Northeastern Libya. *Jour. Pal.*, **42**(2) : 308-321.
- Barr, F.T. 1972. Cretaceous biostratigraphy and planktic foraminifera of Libya. *Micropal.*, **18**(1) : 1-46, pls.1-10.
- Be, A.W.H. 1982. Biology of planktic foraminifera, p. : 51-89. In: Ed., Broadhead, T.W., *Foraminifera, notes for a short course. Univ. of Tennessee, Studies in Geology*, **6**.
- Bolli, H.M. 1950. The direction of coiling in the evolution of some Globorotaliidae. *Contr. Cushman Found. Foram. Res.*, **1** : 82-89.
- Bolli, H.M. 1951. Notes on the direction of coiling of Rotalid foraminifera. *Contr. Cushman Found. Foram. Res.*, **2** : 139-143.
- Bolli, H.M. 1971. The direction of coiling in planktic foraminifera, p. 639-648. In: (Eds.) B.M.Funnell and W.R.Reidel. *The Micropalaontology of Oceans*, Cambridge Univ. Press.
- Caron, M. and Homewood, P. 1983. Evolution of early planktic foraminifers. *Mar. Micropal.*, **7** : 453-462.
- Douglas, R.G. 1972. Paleozoogeography of Late Cretaceous planktic foraminifera in North America. *Jour. Foram. Res.*, **2**(1) : 14-34.
- Douglas, R.G. and Rankin, C. 1969. Cretaceous planktic foraminifera from Bornholm and their zoogeographic significance. *Lethaia*, **2** : 185-217.
- Eicher, D.L. 1969a. Paleobathymetry of Cretaceous Greenhorn Sea in Eastern Colorado. *APPG. Bull.*, **53** : 1075-1090.
- Eicher, D.L. 1969b. Cenomanian and Turonian planktic foraminifera from the Western Interior of the United States, p. : 163-174. In: (Eds.) Bronnimann, P., and Renz, H.H. *Proc. 1st. Internat. Conf. Plankt. Microfossils*, **2**.
- Eicher, D.L. and Worstell, P. 1970. Cenomanian and Turonian foraminifera from the Great Plains, United States. *Micropal.*, **6**(3) : 269-324, pls.1-13.
- Ericson, D.B. 1959. Coiling direction of *Globigerina pachyderma* as a climatic index. *Science*, **130** : 219-220.
- Ericson, D.B., Wollin, G. and Wollin, J. 1954. Coiling direction of *Globorotalia truncatulinoides* in Deep-Sea cores. *Deep-Sea Res.*, **2** : 152-158.
- Gandolfi, R. 1942. Ricerche micropaleontologiche e stratigrafiche sulla Scaglia e sul Flysch Cretacici dei Dintorni di Balerna (Canton Ticino). *Riv. Ital. Pal.*, **48**(4) : 1-160, pls.1-14.
- Govindan, A. 1980. Cretaceous foraminifera from the eastern part of Indian Peninsula and their palaeoclimatological significance. *Bull. ONGC.*, **17**(1): 35-43.
- Hart, M.B. 1980a. The recognition of mid-Cretaceous sea-level changes by means of foraminifera. *Cret. Res.*, **1** : 289-298.
- Hart, M.B. 1980b. A water depth model for the evolution of the planktic foraminifera. *Nature*, **286** : 252-254.
- Hart, M.B. and Bailey, H.W. 1979. The distribution of planktic foraminifera in the mid-Cretaceous of NW Europe, p. : 527-542. In: Aspekte der Kreide Europas (Wiedmann, J., Ed.). *Internat. Union of Geol. Sci.*, **6**.
- Hultberg, S.U. and Malmgren, B.A. 1987. Quantitative biostratigraphy based on Late Maestrichtian Dinoflagellates and planktic foraminifera from Southern Scandinavia. *Cret. Res.*, **8** : 211-228.

- Jenkins, D.G. 1967. Recent distribution, origin and coiling ratio changes in *Globorotalia pachyderma* (Ehrenberg). *Micropal.*, 13 : 195-203.
- Jones, J.I. 1960. The significance of variability in *Praeglobotruncana gaultierensis* (Brönnimann), 1952, from the Cretaceous Eagleford Group of Texas. *Contr. Cushman Found. Foram Res.*, 11 (3) : 89-103.
- Kennett, J.P. 1967. Distribution of planktic foraminifera in surface sediments southwest of New Zealand, p. : 307-322. In: Bronnimann, P., and Renz., H.H. (Eds.). *Proc. 1st Internat. Conf. Plankt. Microfossils*, 2.
- Kennett, J.P. 1968. Latitudinal variation in *Globigerina pachyderma* (Ehrenberg) in surface sediments of the southwest Pacific Ocean. *Micropal.*, 14 : 305-318.
- Koutsoukos, E.A.M. and Hart, M.B. 1990. Cretaceous foraminiferal morphogroup distribution patterns, paleocommunities and trophic structures: a case study from the Sergipe Basin, Brazil. *Trans. Roy. Soc. Edinburg: Earth Sciences*, 81 : 221-226.
- Leckie, R.M. 1984. Mid-Cretaceous planktic foraminiferal biostratigraphy off Central Morocco, DSDP LEG 79, Sites 545 and 547. *Init. Repts. DSDP.*, 79: 579-620, pls. 1-17.
- Leckie, R.M. 1987. Paleocology of mid-Cretaceous planktic foraminifera : A comparison of Open Ocean and Epicontinental Sea assemblages. *Micropal.*, 33 : 164-177.
- Lipps, J.H. 1979. Ecology and paleoecology of planktic foraminifera. In: Lipps, J.H., et al., (Eds.) *Foraminiferal ecology and paleoecology*, p. : 62-104. *Soc. Econ. Pal. and Min. Short Course no.6* (Houston).
- Lutze, G.F. 1968. Okoanalyse der Mikrofauna des Aptium von Sarstedt Dei Hannover. *Berichte der Naturhistorischen Gesellschaft in Hannover, Beiheft*, 5 : 427-443.
- Malmgren, B.A. 1989. Coiling patterns in Terminal Cretaceous planktic foraminifera. *Jour. foram. Res.*, 19(4) : 311-323.
- Murray, J.W. 1976. A method of determining proximity of marginal seas to an ocean. *Marine Geol.*, 22 : 103-119.
- Parker, F.L. and Berger, W.H. 1971. Faunal and solution patterns of planktic foraminifera in surface sediments of the South Pacific. *Deep-Sea Res.*, 18 : 73-107.
- Sliter, W.V. 1972. Upper Cretaceous planktic foraminiferal zoogeography and ecology — Eastern Pacific margin. *Palaeogeogr. Palaeoclimatol, Palaeoecol.*, 12 : 15-31.
- Takayanagi, Y. Niitsuma, N. and Sakai, T., 1968. Wall microstructure of *Globorotalia truncatulinoides* (d'Orbigny). *Sci. Repts. Tohoku Univ., Sendai*, 40 : 141-170.
- Tappan, H. 1940. Foraminifera from the Grayson Formation of Northern Texas. *Jour. Pal.*, 14(2) : 93-126, pls.14-19.
- Venkatachalapathy, R. 1993. *Mid-Cretaceous foraminiferal biostratigraphy, paleoecology and the boundary events in the Cauvery Basin, India*. Ph.D. Thesis (M.S), Madras University, 230 pp.
- hispidus* Cushman, *E. srinivasanii* n. sp., *E. uttatturensis* Narayanan, *Fronicularia* aff. *F.aclis* Morrow, *F. filocincta* Reuss, *F. goldfussi* Reuss, *F. mucronata* Reuss, *F. striatula* Reuss, *F. pattiensis* Rasheed and Govindan, *Gaudryina tailluri* (Tappan), *Gavelinella baltica* Brotzen, *G. cenomanica* (Brotzen), *G. intermedia* (Berthelin), *G. plummerae* (Tappan), *G. simionescui* (Neagu), *Globulina lacrima* (Reuss), *G. prisca* Reuss, *Glomospirella gaultina* (Berthelin), *Gyroidinoides depressa* (Alth), *G. globosa* (Hagenow), *G. nitidus* (Reuss), *Haplophragmoides concavus* (Chapman), *H. kirki* Wickenden, *H. sp.*, *Lagena globosa* (Montagu), *L. hauteriviana* Bartenstein and Brand, *L. hispidus* Reuss, *L. sulcata* (Wlaker and Jacob), *L. sp.*, *Lenticulina alexanderi* (Sandidge), *L. circumcidanea* (Berthelin), *L. gaultina* (Berthelin), *L. grata* (Reuss), *L. macrodisca* (Reuss), *L. navarroensis* (Plummer), *L. nuda* (Reuss), *L. oblongus* (Takayanagi), *L. ovalis* (Reuss), *L. polygona* (Perner), *L. rotulata* Lamarck, *L. saxocertacea* Bartenstein, *L. secans* (Reuss), *L. stephensoni* (Cushman), *L. sulcifera* (Reuss), *L. warregoensis* (Crespin), *Lingulina nodosaria* (Reuss), *Lingulogavelinella marksi* Narayanan, *Marginulina aequivoca* (Reuss), *M. bullata* Reuss, *M. compressa* d'Orbigny, *M. directa* (Cushman), *M. glabra* d'Orbigny, *M. hamuloides* Brotzen, *M. hamulus* chapman, *M. jonesi* (Reuss), *M. linearis* (Carsey), *M. munieri* Berthelin, *M. navarroana* Cushman, *M. perobliqua* (Reuss), *M. trocdssoni* Brotzen, *Nodosaria chapmani* Tappan, *N. distans* Reuss, *N. limbata* d'Orbigny, *N. mutabilis* Terquem, *N. obscura* Reuss, *N. orthopleura* Reuss, *N. paucicosta* Roemer, *Nodogenerina* sp., *Oolina apiculata* Reuss, *O. simplex* Reuss, *Osangularia navarrona* (Cushman), *Pattellina subcretacea* Cushman and Alexander, *Praebulimina reussi* (Morrow), *Planulina schloenbachi* (Reuss), *Pleurostomella cullygoodiensis* Rasheed, *P. nitida* Morrow, *P. obtusa* Berthelin, *P. reussi* Berthelin, *Pseudonodosaria cylindracea* (Reuss), *P. manifesta* (Reuss), *P. mutabilis* (Reuss), *Pseudotextulariella cretosa* Cushman, *Pyrolina cylindroides* (Roemer), *Quadriformina allomorphinoides* (Reuss), *Q. camerata* (Brotzen), *Quinqueloculina antiqua angusta* Franke, *Q. moremani* Cushman, *Ramulina aculeata* (d'Orbigny), *R. globulifera* Brady, *R. spandeli* Paalzow, *Saracenaria bononiensis* (Berthelin), *S. frankei* (ten Dam), *S. sp.*, *Spirillina minima* Schacko, *Spiroplectinata jagapathyii* Rasheed, *Tappanina rasheedii* Narayanan, *Tristix excavata* (Reuss), *T. tricarinarum acutangulam* (Reuss), *Tritaxia pyramidata* Reuss, *Trochammina* cf. *T. globosa* Bolin, *T. sp.* *Trocholina raoii* Rasheed, *Vaginulina debilis* (Berthelin), *V. kochii* Roemer, *V. plummerae* (Cushman), *V. recta* Reuss, *V. striolata* Reuss, *V. tenuistriata* Chapman, *Verneuilinoides chapmani* (ten Dam), *V. schizeus* (Cushman and Alexander), *Vidalina hispanica* Schlumberger.

Checklist of foraminiferal fauna identified in the mid- Cretaceous of Cauvery Basin, India.

Benthic foraminifera

Ammobaculites torosus Loeblich and Tappan, *Amodiscus cretaceous* (Reuss), *A. Planus* Loeblich, *Anomalinoidea indica* (Sastry and Sastri), *Astacolus calliopsis* (Reuss), *A. complanatus* (Reuss), *A. jarvisi* (Cushman), *Citharina barcoensis* (Cushman and Hedberg), *C. multicostrata* (Cushman), *C. sp.*, *Conorboides minutissima* (Tappan), *Dentalina alternata* (Jones), *D. basiplanata* Cushman, *D. catenula* Reuss, *D. cylindroides* Reuss, *D. lorneiana* d'Orbigny, *D. marginuloides* Reuss, *D. trujilloi* Loeblich and Tappan, *D. xiphoides* Reuss, *Dorothia ellisorae* (Cushman), *D. filiformis* (Berthelin), *D. oxycona* (Reuss), *Eouvigerina*

Planktic foraminifera

Clavihedbergella simplex (Moreman), *Globigerinelloides bentonensis* (Morrow), *G. caseyi* (Bolli, Loeblich and Tappan), *G. ultramicra* (Subbotina), *Guembelitra cenomana* (Keller), *Hedbergella amabilis* Loeblich and Tappan, *H. delrioensis* (Carsey), *H. planispira* (Tappan), *Helvetoglobotruncana helvetica* (Bolli), *Heterohelix globosa* (Ehrenberg), *H. moremani* (Cushman), *H. pulchra* (Brotzen), *Marginotruncana difformis* (Gandolfi), *M. indica* (Jacob

and Sastry), *M. renzi* (Gandolfi), *M. sigali* (Reichel), *Planomalina buxtorfi* (Gandolfi), *Praeglobotruncana delrioensis* (Plummer), *P. stephani* (Gandolfi), *Rotalipora appenninica* (Renz), *R. balernaensis* (Gandolfi), *R. cushmani* (Morrow), *R. evoluta* Sigal, *R. greenhornensis* (Morrow), *R. reicheli* (Mornod), *Ticinella roberti* (Gandolfi), *Whiteinella archaeocretacea* Pessagno, *W. baltica* Douglas and Rankin, *W. brittonensis* (Loeblich and Tappan).