Journal of the Palaeontological Society of India
Volume, 56(2), December 2011: 195-200

ISSN 0522-9630

BENTHIC FORAMINIFERAL ASSEMBLAGES FROM THE ESTUARY AND TIDAL ZONES ALONG THE EAST COAST OF TAMILNADU, INDIA: DECIPHERING HOLOCENE SEA-LEVEL CHANGE

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ABSTRACT

In this paper, we present down-core variations of foraminiferal assemblages from five shallow sediment cores retrieved from the present-day estuaries and tidal zones between Odinur and Cuddalore along the east coast of Tamilnadu, India. Down sediment core variations in foraminiferal assemblage supplemented by radiocarbon dates is used for interpreting the Holocene sea-level change. 432 subsamples were sorted under the binocular microscope. Sixty one species of the foraminiferal taxa belonging to 23 genera, 17 subfamilies, 14 families, 12 superfamiles and 4 suborders have been identified, among which ROTALIINA and MILIOLINA are predominant.

Down-core variation of foraminifera with depth revealed the abundant occurrence of *Ammonia beccarii*, *Elphidium* and *Quinqueloculina seminulum* with varying percentage of *Amphistegina radiata,* and *E. craticulatum* in core I, II and III, indicating, high saline conditions, while in core V the occurrence of *Ammobaculites agglutinans*, *Ammobaculites exiguus*, *Ammobaculites* sp. and *Reophax* sp. indicated marsh environment with low saline and mud flat conditions.

High organic matter content was observed in the sediment cores from Marakkanam and Odinur. Radiocarbon dates on shell, organic carbon at the base and intervals of the cores from Marakkanam (Core IV) and Odinur (Core V) are 8200±230, 9170±290, 5540±430 yrs BP, 2700±140 respectively. Radiocarbon dates indicate a more rapid relative sea-level rise (RSL) subsequent to 2500-3500 BP. The ^{14}C dates indicate tidal flat sedimentation between 3475 and 3145 yrs BP. Lithounits in the tidal zone of Marakkanam and Odinur point to a local fluctuation of sea level. The terminal Pleistocene-early Holocene period was characterized by a relative low sea level, while the early Holocene period and the mid Holocene period (~9000 yrs BP and around ~5000 yrs BP) were marked by high sea level. Reworking of the inner-shelf sediments as a result of the Terminal Pleistocene low sea level provided the ultimate sediment source for the progradation of the present coastline.

Keywords: Holocene, Radiocarbon dating, Benthic Forminifera, estuaries and tidal zones, East coast of India

INTRODUCTION

The foraminiferal assemblages from estuary and tidal zone sediments all over the world have been studied for understanding coastal geomorphic processes and Holocene sea-level changes from the variations in the preserved foraminiferal fauna (Nguyen *et al.*, 2010; Leorri *et al.*, 2010). Distribution of foraminifera along the west coast India from several sites such as the Gulf of Khambat (Nigam, 1984), the Narmada and Tapi estuaries (Ghosh *et al.*, 2009) and lower stretches of the Mandovi Rivery estuary (Nigam *et al.*, 2005) was studied to mark the benthic foraminifera assemblage, effect of environmental pollution and sea level changes in the estuarine and tidal settings. However, there are no detailed studies on benthic foraminiferal distribution from sediment cores along the east coast India; barring a few (Achyuthan and Baker, 2002; Hameed *et al.*, 2004). Earlier work on foraminifera along the East Coast of Tamilnadu has been carried out by sampling surface sediments from estuaries and tidal zones for understanding recent foraminiferal assemblages and taxonomic classification (Jayaraju and Reddy, 1995; Kathal, 1996, 1998, 2002; Kathal and Bhalla, 1998; Rao, 1998; Kumar and Srinivasan, 2004). The East Coast of Tamil Nadu is an interesting area to investigate the distribution of benthic foraminifera in recent sediments as well as in sediment cores as number of estuaries and tidal zones are connected to the mainland and the Bay of Bengal. Down-core sediment variations of foraminifera abundance will help in understanding fluctuations in salinity and palaeoenvironments and inferring the sea-level change through time.

Achyuthan and Baker (2002) identified foraminifera from the core samples and radiocarbon dated organic carbon rich sediments collected from three sites at various depths along the East Coast of Tamilnadu. Until now no detailed work on the down-core variations of foraminifera from the estuaries and tidal zones has been carried out to understand Holocene environmental change. In this paper, we present the down-core variation of Holocene benthic foraminifera from the estuary and tidal zones along East Coast of Tamil Nadu, India, to infer Holocene environmental changes.

STUDY AREA

East Coast of Tamil Nadu is a narrow, sandy coastal belt extending from Odinur near Pondicherry to Cuddalore. It covers an area of approximately 120 sq. km. Geomorphologically, the area exhibits tidal flats, estuaries and marsh zones as well as linear stabilized older and younger sand dunes. Beach dunes run parallel to the sea. There are inlets of the sea at Marakkanam and Odinur and at Cuddalore, forming a tidal zone. The tidal flat exhibits four major zones: a) Outer sand flat, b) Coarse sand flat merging with beach dune complex and exposure of charnockites; c) Middle sand flat, and d) Sand to silt dominated inner flats and salt marsh (Reineck and Singh, 1980). Beach dunes run parallel to the present coastline and beach ridges inland. The dunes are stabilized at their base but are mobile on their crests.

The study area (Fig.1) experiences a tropical subhumid type of climate with an annual mean temperature of 25°C and with an average annual precipitation of 1200 mm. The geology of the study area is represented by the Archaean charnockite

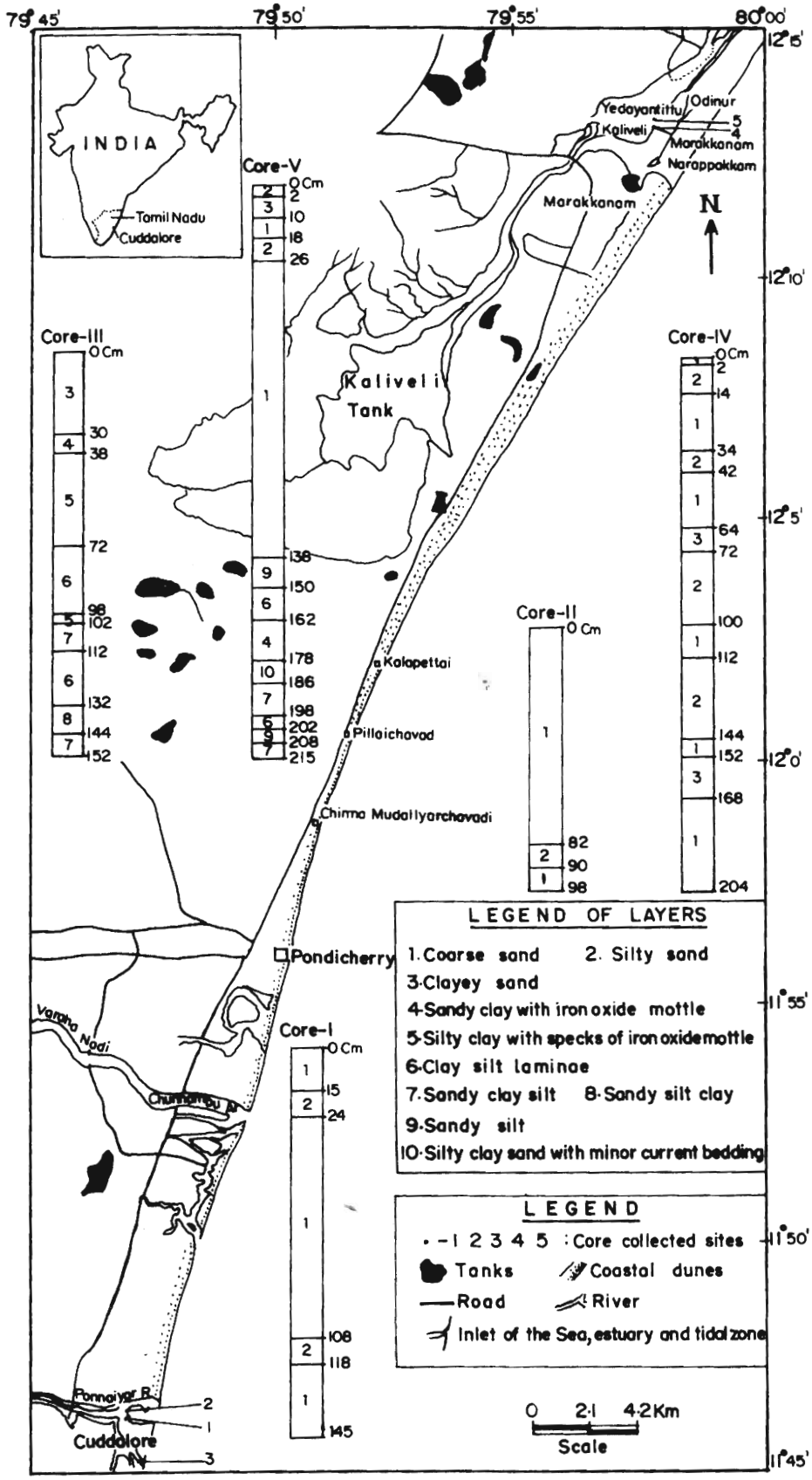

Fig. 1. Location map of the study area.

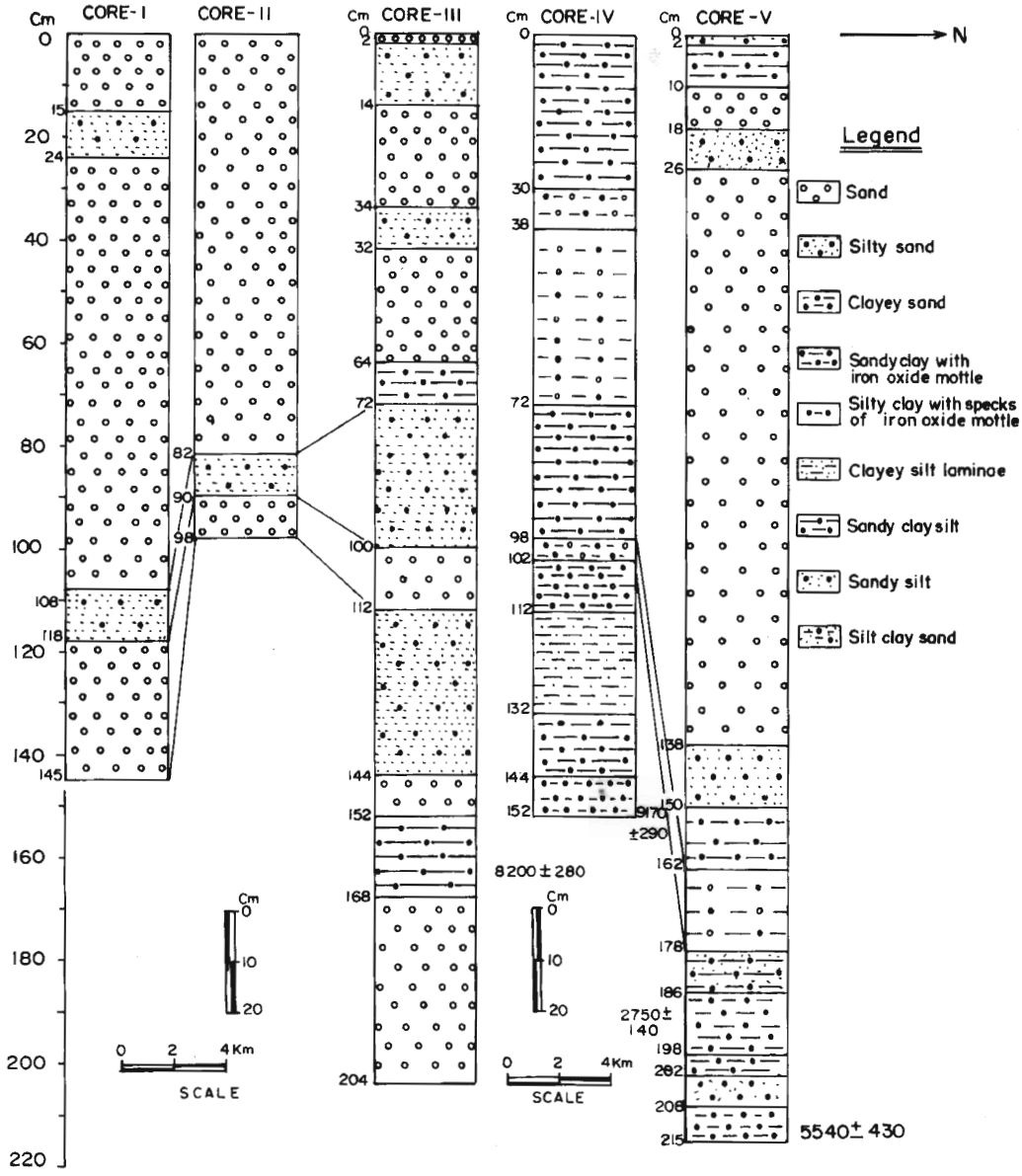

Fig. 2. Lithounits of five cores studied with radiocarbon dates.

rocks which are overlain by the Cuddalore Sandstone. Thick mantle of Quaternary alluvium overlies the Cuddalore Sandstone and these are in turn overlain by the Holocene tidal flat deposits and dunes (Achyuthan, 1997).

MATERIALS AND METHODS

Five *in situ* sediment cores were collected in April 2003 along the East Coast of Tamilnadu between Odinur and Cuddalore. The sediment cores were collected by puncturing PVC pipes (2-inch diameter) in the spot sites to a depth of nearly 100-215 cm with a water depth of nearly 30 cm. Extreme care was taken to retrieve the cores from sites that are not presently affected by the modern day tidal processes. These pipes with the core samples were then cut open. The cores were subsampled every 2 cm interval except core I which was sampled at every 1.5 cm for various analyses. Within the length of the core collected, sediment layers were differentiated by depth function including sediment texture, colour, biogenic features such as occurrence of shell fragments, oxide distribution, organic carbon rich units, clay layers and concretions. The colour of the core logs was studied using the Munsell colour System (Munsell Soil Colour Charts 1954). The samples were radiocarbon dated at the Birbal Sahni Institute of Palaeobotany, Lucknow and the dates are presented in Table 1, Fig. 3.

The foraminiferal samples were washed through an ASTM 230 mesh sieve (opening 0. 063 mm) to remove the finer (silt and clay) particles for examination under the light microscope. The residue which included sand and foraminifera were collected in a china dish and dried in an oven at 50°C to 60°C. Benthic foraminifera specimens were picked and then separated from the residue under a light zoom, binocular microscope, using 0.001mm Winder and Newton sable hairbrush. The foraminifera were spread carefully on a 24-chamberd sorting tray, observed under the microscope and identified to generic and species level. 432 subsamples from these five cores

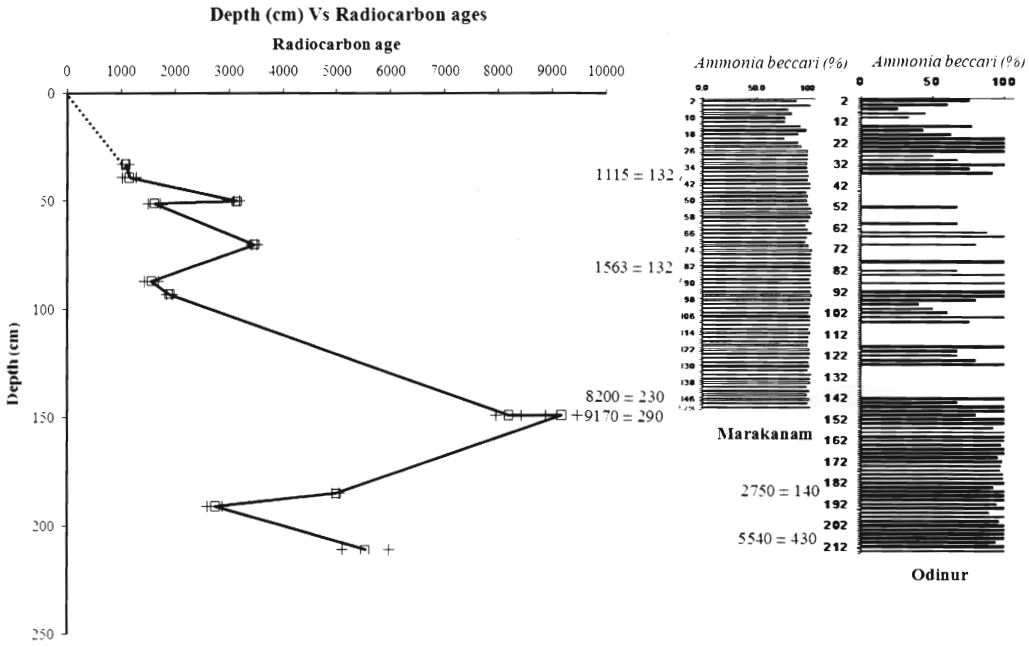

Fig. 3. The figure shows rapid sea level rise since 3500 yrs BP (Achyuthan and Baker, 2002; Hameed *et al.*, 2004). The adjacent panel exhibits the down core sediment fluctuations in *Ammonia beccari* abundance.

(Cuddalore core I-97 subsamples; Cuddalore core II-50 subsamples; Cuddalore core III-102 sub samples; Marakkanam core IV- 78 subsamples; and Odinur core V- 105 subsamples) were processed for foraminiferal study. The species were identified and arranged according to the classification proposed by Loeblich and Tappan (1988). All species have been housed in the Quaternary Lab., Department of Geology, Anna University, Chennai-600 025. Based on the total foraminifera number (TFN), percentages were calculated for each group of foraminifera viz. Milioliina, Rotaliina and Textulariina.

RESULTS

The foraminifers identified in the present study can be grouped into four suborders: Textulariina, Milioliina, Rotaliina and Lagenina. Percentage wise, the benthic foraminifera are the most dominant group and form 44% of the bulk assemblage followed by miliolids 39%. Only two species *Q. seminulum* and *Q. tropicalis* are present in core IV but are few. *Ammonia beccarii* is abundant and occurs since the early Holocene period, *Elphidium* species vary in their abundance. In present study, *Operculina ammonides*, *Quinqueloculina incisa*, *Quinqueloculina striatula*, *Quinqueloculina tenuicollis* also occur in abundance.

Down-core variation of foraminifera with depth revealed the abundant occurrence of *Ammonia beccarii*, *Elphidium* and *Quinqueloculina seminulum* with varying percentage of *Amphistegina radiata, E. craticulatum* in core I, II and III indicating high saline conditions. However, in core V the occurrence of *Ammobaculites agglutinans*, *Ammobaculites exiguus*, *Ammobaculites* sp. and *Reophax* sp. indicated marsh environment with low saline and mud flat conditions. Four benthic foraminiferal species *Ammonia beccarii*, *Ammonia tepida*, *Elphidium advenum* and *Elphidium crispum* were found in all the cores. The benthic foraminifera have been abundant in four cores and these are:

Core I: *Ammonia beccarii*, *Elphidium craticulatum*, *Quinqueloculina seminulum*, and *Quinqueloculina tenuicollis*

Core II: *Ammonia beccarii*, *Elphidium* sp1, *Quinqueloculina seminulum*,

Core III: *Ammonia beccarii*, *Elphidium advenum*, *Elphidium* sp, *Nonionoides elongatum* and *Quinqueloculina seminulum*,
Core IV: *Ammonia beccarii*, *Elphidium hispidulum* and *Elphidium* sp.

CoreV: *Ammonia beccarii*, *Elphidium hispidulum* and *Elphidium excavatum*.

However, the foraminiferal assemblages do not exhibit high diversity. The agglutinated group is shared by 10% of the total fauna. In general the calcareous group is dominant (51%) over the Miliolid (39%) and aggulinated (10%) group of fossils. The radiocarbon dates range in age from 9170±290 to 2750±140Yrs BP (Table 1)

DISCUSSION

Foraminifera in Cuddalore are different both in size and in the types of the species from those observed from Marakkanam and Odinur. Foraminifera from Cuddalore (Core I, II and III) are larger in size, while in other cores (Core IV and V) the foraminifer size is small. Different foraminifer species exhibit response to change in salinity, for example, *Ammonia beccarii* has been reported from very low salinity pools or lakes to higher salinity marine environment. Phleger and Parkar (1951) report *Ammonia beccarii* living at salinity between 44% and 46‰. Certain forms of foraminifera, especially agglutinated foraminiferal genera,

Table 1: Radiocarbon dates obtained from shell and sediments from Marakkanam (Core IV) and Odinur (Core V).

S. No	Samples reference No BSIP	Samples dated	Depth (cm)	Radiocarbon age (Half Life = 5730± 40 yrs BP.)	Calibrated age range yrs BP.
1	BS-2270, Marakkanam	Shell	Core IV 146-152	8200± 230	9230-8460
2	BS-2275, Marakkanam	Organic carbon	Core IV 146-152	9170 ±290	10360-9550
3	BS-2398 Odinur	Organic carbon	Core V 188-194	2750±140	2920-2710
4	BS-2272, Odinur	Organic carbon	Core V 208-214	5540±430	6640-5660

like *Trochammina* and calcareous genera like *Elphidium*, are much more tolerant to low salinity conditions. Miliolid species that are found in the present study occur in Cuddalore (Core I, II and III), but are absent in core IV and core V. This may be due to the coarse grain nature of the sediments and that the sediment core was collected very close to the sea. Very few species such as *Quinqueloculina seminulum* and *Quinqueloculina tropicalis* are found in Marakkanam (Core IV).

The generic composition of agglutinated foraminifera such as *Reophax*, *Ammobaculites* and *Trochammina* do not exhibit any variation in the palaeoecological conditions. Their occurrence indicates hyposaline to normal marine environment of deposition ranging from marsh to intertidal marine settings. In general, they are assigned to the foraminiferal assemblage generally associated with the marginal marine environment. The above-mentioned genera also indicate the type of substrate that existed to reflect the muddy layers. The generic composition further reflects the tropical waters. Thus, the agglutinated foraminifera characterize the studied sediments from the hypo-saline to normal marine water regime assignable to the tropical marginal marine environment of deposition. The calcareous group shows high diversity as compared to the other two groups and is represented by *Hanzawaia, Pararotalia, Operculina, Ammonia, Asterorotalia, Elphidium, Cribrononion, Amphistegina, Rectobolivina, Baggina, Eponides, Glandulina, Oolina and Globulina*. Out of these, *Amphistegina* represents a saline environment characterised by >34‰ of salinity, sea grass, sediments associated with coral reef and its depth of occurrence ranges from 5 to 20 m typical of inner-shelf conditions. The occurrence of this genus in estuary clearly indicates its non-indigenous form and that it has been transported from the shoreface by storms in the studied locations at the time of their deposition. Further, the occurrence of *Amphistegina* is common along with smaller miliolids and rotaliids in the Indo-Pacific and Atlantic Ocean (Murray, 1971).

In the present study, the calcareous foraminifera form the most dominant percentage of the fauna studied. Among these, the genus *Elphidium* has a maximum number of species. The genus *Elphidium* is the most common shallow water marine foraminifer occurring throughout the world. It occurs in almost all the shallow water marine environments from supratidal region to shelf encompassing tropical, subtropical and temperate environments. *Elphidium* has two principal forms. In the studied assemblage, keeled and nonkeeled forms were observed. According to Murray (1973), keeled forms occur mostly in the inner shelf with salinity 35.50‰, while the nonkeeled forms occur in hyposaline to hypersaline tidal marshes, lagoons and near shore environments. Bathymetrically, both the forms and the their species exhibit a depth range of 0 to 50 m. Frerichs (1970) has noted the depth range of *Elphidium crispum* between 77 and 225 m in the Andaman Sea and Bay of Bengal. The species presented in this study are typical of Indo-Pacific species commonly found along the East Coast and West Coast and point towards a relatively more stable environment. The occurrence of these tests in this area is due to the transportation by waves and tidal currents and for the benthic foraminiferal production, oxygen was always available at the sediment water interface.

The high percentage of Rotaliina and Miliolina indicates the proximity of the studied sites very close to the mouth of the estuary. The absence *of Milliammina fusca*, other characteristic foraminifers and the high percentage of calcareous and porcellaneous species from the four sites indicate that the sites were very near to the mouth of the estuary and rules out its position faraway inland from the mouth.

SEA-LEVEL CHANGE AND RADIOCARBON DATES

Radiocarbon dates revealed an early Holocene-late Holocene age (fig. 2 and 3). Based on the nine ^{14}C dates presented by Achyuthan and Baker (2002) and the four radiocarbon dates from the present study, the data indicate a more rapid relative sea-level rise (RSL) subsequent to 2500-3500 BP. The ^{14}C dates indicate tidal flat sedimentation between 3475 and 3145 yrs BP. The discrepancies in the radiocarbon ages between Muthukadu and the other three sites (Mammallapuram, Marakkanam, and Odinur) indicate probable neotectonic activity or coastal configuration shift. The likely cause is the reactivation of the fault line east of Muthukadu, trending north-south, and projecting into the sea near Mamallapuram, consequently drowning the beach system south of Muthukadu. This resulted in the short removal of marine conditions and ample supply of sediment in the tidal zones.

Lithounits in the tidal zone of Marakkanam and Odinur point to a local fluctuation of sea level. Probably, the terminal Pleistocene-early Holocene period was characterized by a relative low sea level with high saline conditions (Achyuthan, 1997). The early Holocene period and the mid Holocene period (~9000 yrs BP and around ~5000 yrs BP) were marked by high sea level due to intense warm conditions. This probably resulted in an increased availability of sand in the shore zone. Large pulses of sand were supplied to the beach by southward-running coastal currents with returning NE monsoons. Short period of decreased storminess is recorded by the occurrence of immature soil formation in the bordering beach dunes (Achyuthan and Baker,

2002). The low sea level partly eroded the terminal Pleistocene-early Holocene coastal tract. It is important to note that reworking of the inner-shelf sediments as a result of the dropping sea level provided the ultimate sediment source for the progradation of the present coastline. The area seems to have experienced intense warm and humid conditions around early Holocene period (~9000 yrs BP), 5,500 yrs BP and around 1100 yrs BP. Along the East Coast between Cuddalore and Odinur, the sea level fluctuated locally and the amount of rise and fall of sea level has been small since the middle Holocene ~5500 to 1100 yrs BP. The deltas started probably building around 6,000 years ago, when ocean levels became more stable. Most of them are still growing.

The position of the tidal and estuary zones altered drastically subsequent to ~5500 yrs BP. The amplitude of the shoreline moved both horizontally and vertically, as revealed by the occurrence of the sand and fine silt since the last ~5000 yrs BP, due to neotectonic activity.

This study points that transgression events did take place probably due to neotectonism and coastal configurational processes during the early Holocene and late Holocene periods. These facts, along with the characteristics and spatial distribution and microfossils of marine sediments, reveal that the early Holocene and the late Holocene periods have been times of rapid eustatic changes which have kept pace with the NE monsoon cycles and fluctuated with small amplitudes. Similar observations at the Mahi estuary on the west coast of India (4000-1700 BP) have been made by Kusumgar *et al.* (1998) based on ^{14}C dates and foraminiferal assemblage and Raj and Chamyal (1998). The lack of lengthy Holocene tidal and estuarine sequence from different parts of the eastern coastline makes it difficult to recognize inter-site correlation and the abrupt changes in coastal stratigraphy. Although it is possible to offer a first-order interpretation of the data, in terms of the sedimentation it makes such inferences all the more difficult.

CONCLUSIONS

Integration of benthic foraminiferal assemblage and radiocarbon dates from the five cores studied allows to draw the following conclusions:

- Five sediment cores were analysed for foraminiferal assemblage variations and the study yielded 61 species of foraminifera belonging to 23 genera, 17 subfamilies, 14 families, 12 superfamilies, and 4 suborders, among which ROTALIINA and MILIOLINA are predominant.
- Four benthic foraminiferal species *Ammonia beccarii*, *Ammonia tepida*, *Elphidium advenum* and *Elphidium crispum* occur in all the five cores since the early Holocene period.
- The present study reveals that the east coast Tamilnadu sea level fluctuated locally and that the rise and fall of sea level has been much small since the middle Holocene ~5000 yrs BP and ~11000 yrs BP. Current estuaries and tidal zones date from the Holocene, and they overlie the older accumulation in the subsidence zones.

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Manuscript Accepted June 2011