Journal of the Palaeontological Society of India
Volume, 54(1), June 2009: 19-26

ISSN 0522-9630

FORAMINIFERA AND OSTRACODS: SIGNATURES FOR MIDDLE HOLOCENE PALAEOENVIRONMENTAL CHANGE, MUTTU KADU, CHENNAI, INDIA

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ABSTRACT

Numerous investigations have shown that foraminifera and ostracods leave a fossil record in estuarine and tidal sediments that are well suited for paleoenvironmental data collection and coastal zone monitoring ecosystems. In this study, a sediment core (~130 cm thick) was collected from Muttukadu, along the southeast coast of Chennai. This sediment core has been examined for foraminiferal and ostracods faunal assemblages. The sediment core has been dated to mid-Holocene age using radiocarbon method. The radiocarbon dates range in age from 3145 to 3475 yrs BP. 19 foraminifer and 8 ostracod species were identified. The following species of foraminifera such as *Ammonia beccarii*, *Ammonia tepida*, *Elphidium indicum*, and ostracods such as *Hemikrithe*, *Tanella gracilis* and *Paijenborchellina* sp., are abundant. It was observed that fresh water juvenile forms of ostracods and less saline foraminifer species are abundant in the upper layers; while in the lower layers of the sediment core, marine forms of foraminifera and brackish ostracod forms are dominant. Statistical data on foraminifer assemblage reveals a positive correlation and increase in the abundance of *A. tepida* with depth. The positive relation between the brackish ostracod species with depth could also be related to common habitat conditions such as increase in salinity and temperature conditions. Thus, the down core variations of the total number of foraminifera and ostracods correlate well with each other indicating shifts in the salinity and temperature conditions since the mid-Holocene period.

Keywords: Foramnifera, ostracods, sediment core, mid-Holocene, palaeoenvironments

INTRODUCTION

Foraminifera and Ostracoda are often advocated as good indicators of environmental changes in aquatic environments and have been successfully used to study salinity changes in estuary and tidal inlets (Hussain and Mohan, 2000; Kathal, 2002). This is important for monitoring environmental change over time. Numerous investigations have shown that foraminifera and ostracods which leave a fossil record in most marine and tidal sediments are well suited for this purpose. Hence, in this study a sediment core (~1m length) collected from the Muttukadu inlet along the southeast coast of Chennai (Fig.1), was examined for foraminiferal and ostracod faunal assemblages. In this paper, we present down-core distribution of foraminifera and ostracoda to understand the mid-Holocene palaeoenvironmental shifts.

MATERIAL AND METHODS

Area

Muttukadu site which has an outlet to the sea (lat. 12° 48' N and long. 80° 14' E) (Fig.1) is located 35 km south of Chennai and it branches into southern and northern wings and runs parallel to the sea coast for a distance of about 3 km. The geology of the study area is represented by the basement Archaean charnockite rocks which are overlain by a thick mantle of Quaternary alluvium and these are in turn overlain by the Holocene tidal flat deposits and coastal dunes (Achyuthan, 1997). Isolated pockets of charnockite rock exposures occur at Muttukadu. The coastal beach area at Muttukadu is characterized by salt marsh and barrier dunes forming palaeoshorelines and a spit. Linear dunes run along the shoreline, which are stabilized to a large extent. There are several inlets of tidal waters into the tidal flats and the estuary zones are salt marshes. The study area is connected to the sea by a bar mouth, the width of which is variable from a few meters to 200 m in different months. The backwaters extend for a distance of 20 km from the mouth. The width of the estuary ranges from 800 m to 1050 m. The estuary is shallow; the maximum depth being 2 m in the middle of the channel, while in most of the areas it is 1 m or less. A spit of sand protects the low-lying marshy land at Muttukadu.

Both the monsoons occur here and in summer the heat is considerably mitigated in the coastal area by sea breeze. The average annual rainfall is around ~1200 mm. The highest rainfall amount was recorded in November 1976 (Nammalawar *et al.*, 1991). The entire coast is affected by storms and cyclones during North-East monsoon. The climate is characteristically tropical, and the heat and humidity make diurnal weather quite enervating. There is an almost equitable temperature, except during the summer. During the beginning of the year, the monthly average temperature is generally low, whereas during the summer (April to June), the temperature may go up to 40°C and during winter the temperature does not fall below 18°C. The salinity fluctuation is significant, and ranges from 9.88% to 45.6%. During the month of September, the maximum salinity is 9.88%, and during the month of November, the minimum salinity is 45.6%. The dissolved oxygen content ranged from 2.92 ml l^{-1} (July) to 5.36 ml l^{-1} (May) (Nammalwar *et al.*, 1991).

Sediment Core

One representative sediment core of approximately 1m in length was collected from Muttukadu, near Chennai, along the east coast of Tamil Nadu by puncturing PVC pipe in the spot site to a depth of nearly 130 cm with a water depth of nearly 30 cm. Extreme care was taken to retrieve the core from the site that is not presently affected by the modern-day tidal processes. The pipe was then cut open by a core cutter. The core was sub-sampled at every 2 cm interval. Within the length of the core collected, sediment layers were differentiated by depth function including sediment texture, colour, biogenic features

including occurrence of shells fragments, oxide distribution, organic carbon rich units, clay layers and concretions (Table 1). The sediment colours of the core sediments were studied using the Munsell colour System (Munsell Soil Colour Charts 1954) (Table 1). The organic carbon-rich sediment collected from the core is dated by radiocarbon method to mid-Holocene age. The radiocarbon age at 50 cm is 3145 ± 55 BP, at 70 cm is 3475 ± 55 BP (Achyuthan and Baker, 2002).

Table 1: Description of the sediment core.

Site and Core	Depth (cm)	Colour and Description	Sediment texture
Muttukadu core	0-2	2.5GY 3/1 Greenish black	Sand, sorted with Large shells
	2-7.8	N 1.5/0 Black	Sand, poorly sorted with shells
	7.8-11.3	N 3/0 Dark gray	Sand, poorly sorted with shell fragments
	11.3-26.3	N 4/0 Gray	Sand, poorly sorted with shells
	26.3-28.3	N 3/0 Dark gray	Sand, sorted with large shells
	28.3-38.3	N 4/0 Gray	Sand, moderately sorted with small shells
	38.3-40.8	N 3/0 Dark gray	Sand, moderately sorted with small shells
	40.8-45.5	N 4/0 Gray	Sand, poorly sorted with shell fragments
	45.5-50	N 3/0 Dark Gray	Sand, poorly sorted with shell fragments
	50-61.5	N 4/0 Gray	Sand, moderately sorted with small shells
	61.5-62.7	N 3/0 Dark gray	Sand, poorly sorted with shells
	62.7-64.4	N 4/0 Gray	Sand, moderately sorted with small shells
	64.4-65.6	N 3/0 Dark gray	Sand, moderately sorted with shell fragments
	65.6-116	N 4/0 Gray	Sand, moderately sorted with shell fragments

The sediment samples were analyzed for foraminiferal and ostracod assemblage. The samples were washed through an ASTM 230 mesh sieve (opening 0. 063 mm) to remove the finer (silt and clay) particles. The residue which included sand and foraminifera were collected in a china dish and dried in an oven at 50°C to 60°C. The foraminifer specimens were picked and then separated from 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. From Muttukadu sediment core, 58 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. Down-core variation of the total number of ostracod and foraminifera assemblages are presented in fig. (2a,b) (Tables 2 and 3).

R-mode Factor analyses and correlation matrix of the foraminifer and ostracod assemblages have been calculated using SPSS package and the results are given in table (4a,b). Selected specimens of each species were mounted on a double-sided adhesive tape, over brass stubs for Scanning Electron Microscope analyses. The surface of the stubs was given a thicker coating of gold (Au) and then scanned. Each species on the stub was scanned with magnification varying from 200 to 25,000 times. Significant morphological features were photographed and are presented (Pls. I-V). The preservation of the ostracods was poor as compared to the foraminifera. Few fully preserved species could be recovered and thus the counting represents the data collected on fully preserved specimens. This study was carried out at the Department of Geology, University of Madras, Chennai using the Cambridge Stereoscan 150 electron microscope at 25 KV accelerating voltage and 10 picoampere current intensity. The study on foraminifera revealed the occurrence of 19 species belonging to 6 genera, 5 families, 4 superfamilies and 2 suborders.

RESULTS

There is a distinct change in the palaeoenvironmental conditions indicated by the increase in the abundance of *Ammonia beccarii* and *A.tepida* with depth. *A.beccarii* and *A.tepida* are abundant and these two species show the salinity fluctuations, below 98 (cm). With depth, *A. tepida* increases in its abundance. Fig 3a shows the down layers to be composed of brackish water forms while the occurrences of ostracods up to 18 cm are fresh water juvenile forms. This indicates salinity fluctuations due to the freshwater run-off and precipitation; intermixing of marine with fresh water inputs in the lower part of the core.

Factor analysis

The R-mode factor analysis has been attempted to account for different microfaunal (foraminifera and ostracods) environments. This was performed by using programme of Klovan and Imbrie (1971). Five factors have been obtained by R-mode factor analysis that account for 62.5% of the total variance. Factor loadings revealed five distinct species assemblages that can be related to different sets of environmental parameters. It is noted that R-mode factor analysis (Table 4a,b) and the correlation matrix analysis (Table 5a,b) coincide with the vertical distribution of the species. The data collected on foraminifera supplemented by R-mode factor analyses and correlation matrix indicate that *A. tepida* shows a positive relation and an increase in its abundance with depth.

Factor 1 account for 23.2% of the total variance. The dominant species of this factor are *Globorotalia scitula, Florilus grateloupi, Q.* sp. A, *Q.* sp. B, *Q* sp. D having strong positive loadings. These species do not show any relation with depth meaning it does not have any temporal variation.

Factor 2 accounts for 20.5% variance of the total matrix. The characteristic species are *A.beccarii, E.*sp.B, *E.*sp. C, *E. indicum* that exhibit a strong positive loading on this factor along with depth. These species are present at the lower part

Table 2: Distribution of the foraminifera in actual numbers of specimens in the Muttukadu core.

Depth (cm)	*A.beccarii*	*A.tepida*	*G.bulloides*	*Globorotalia scitula*	*Globigerinoides ruber*	*Nonion* cf. *N. boueanum*	*Floritus grateloupi*	*E. crispum*	*E.* sp. A	*E. indicum*	*E.oceanensis*	*E.* sp.B	*E.* sp. C	*Q. seminulum*	*Q.* sp. A	*Q.* sp.B	*Q.* sp. C	*Q.* sp.D	*Q.* sp. E
2	15	11	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0
4	34	30	2	0	0	2	1	2	1	1	1	0	0	0	0	0	0	0	0
6	25	12	0	0	0	9	1	2	1	1	1	0	0	0	0	0	0	0	0
8	28	8	0	0	0	15	0	0	0	0	0	0	0	0	0	0	0	0	0
10	20	3	0	0	0	0	0	5	0	0	0	0	0	0	0	0	0	0	0
12	0	3	0	0	0	1	0	3	0	0	0	0	0	0	0	0	0	0	0
14	10	0	0	0	0	4	0	0	6	0	0	0	0	5	0	0	0	0	0
16	5	0	0	0	0	2	0	0	0	0	0	0	0	2	1	1	0	0	0
18	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20	3	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
22	4	3	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0
24	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
26	5	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
28	11	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
30	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32	4	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
34	3	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
36	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
38	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
40	4	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
42	20	10	0	0	0	1	2	0	1	0	0	1	2	0	0	0	0	0	0
44	10	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
46	4	3	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
48	30	10	0	2	0	12	6	0	2	0	2	0	1	4	1	3	0	2	0
50	10	9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
52	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
54	0	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
56	2	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
58	11	18	0	1	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0
60	11	31	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
62	5	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
64	6	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
66	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

68	17	19	0	0	0	1	1	0	0	0	1	0	0	0	0	0	0	0	0
70	18	10	0	1	0	2	2	0	0	0	0	3	0	0	0	0	0	0	0
72	25	15	0	0	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0
74	5	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
76	14	13	0	0	0	0	2	0	0	2	5	0	1	0	0	0	0	0	0
78	18	20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
80	10	19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
82	2	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
84	0	3	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
86	5	26	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
88	17	25	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0
90	3	25	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
92	16	16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
94	4	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
96	11	44	0	0	0	1	0	0	0	3	2	0	0	0	0	0	0	0	0
98	32	40	0	0	0	0	0	2	0	1	1	1	0	0	0	0	0	0	0
100	44	53	0	0	0	3	2	0	1	2	1	0	1	0	0	0	0	0	0
102	10	64	0	0	0	0	0	2	2	2	0	0	0	0	0	0	0	0	0
104	30	23	0	0	0	0	0	2	0	2	0	0	0	0	0	0	0	0	0
106	30	16	0	0	0	1	0	2	0	0	0	0	0	0	0	0	0	0	0
108	20	20	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0
110	45	32	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0
112	152	58	0	0	0	0	0	2	3	6	3	4	2	0	0	0	0	0	0
114	101	0	0	0	0	0	0	2	1	2	0	3	2	0	0	0	0	0	0
116	54	14	0	0	0	0	0	0	1	0	1	1	1	0	0	0	0	0	0

of the core indicating higher salinity conditions in the water column older than 3475 ± 55 yrs BP.

Factor 3 accounts for 7.3% of the total variance with *E.* sp. A and *Q. seminulum* having a strong positive loading on this factor.

Factor 4 accounts for 6.3% with *G. bulloides* and *E. crispum* having positive loading. The factor 5 accounts for 5.3% with a negative loading of *Q.* sp. *E* (-0.76).

R-mode factor analysis was also performed for the ostracod assemblages. Three factors were obtained that account for 69.5% of the total variance.

Factor 1 account for 34.6% of the total variance. The dominant marine species of this factor are *Phlyctennophora* sp., *Tanella gracilis*, *Hemikrithe*, *Paijenborchellina* sp. having strong positive loadings.

Factor 2 account for 22.1% of the total variance and the ostracod marine species are *Callistocythere, Loxoconcha* with a strong positive loading with depth.

Factor 3 account for 12.7% of the total variance and the ostrocod species that show a strong positive loading are *Phlyctennophora* sp. and *Hemicytheridea* sp.

Five ostracod species show a positive correlation and these are:

Loxoconcha and Callistocythere exhibit a positive correlation (0.58).

Hemikrithe and *Tanella gracilis* show a positive correlation (0.80)

There is a positive correlation between *Paijenborchellina* sp. and *Tanella gracilis* (0.74) and *Paijenborchellina* sp. and *Hemikrithe* (0.92). The positive correlation between the ostracod species can be related to common habitat conditions such as salinity and temperature.

Depth versus ostracod assemblage (Fig.3b) reveals that fresh water juvenile forms are dominant in the upper layers while the brackish water forms occur at the lower layers of the sediment core.

DISCUSSION

Foraminifera and ostracods are often advocated as good indicators of environmental changes in aquatic environments (Hussain and Mohan, 2000) and have been successfully used to study salinity changes in Muttukadu palaeosediments (Achyuthan and Baker, 2002). In this study, we have used the fossil record of foraminifers and ostracods extracted from sediment core collected at Muttukadu to determine the history of environmental changes, such as salinity and nutrients, which

Table 3: Distribution of the ostracods in actual numbers of specimens in the Muttukadu core.

Depth (cm)	Fresh water forms	*Phlyctenno-phora* sp.	*Hemicytheridea* sp.	*Callisto -cythere*	*Loxo -concha*	*Tanella gracilis*	*Hemikrithe*	*Paijen borchellina* sp.
2	4	0	0	0	0	0	0	0
4	23	0	0	0	0	0	0	0
6	27	0	0	0	0	0	0	0
8	11	0	0	0	0	0	0	0
10	1	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0
14	1	0	0	0	0	0	0	0
16	1	0	0	0	0	0	0	0
18	1	0	0	0	0	0	0	0
20	0	1	1	0	0	0	0	0
22	0	1	1	0	0	0	0	0
24	0	0	0	0	0	0	0	0
26	0	0	0	0	0	0	0	0
28	0	0	0	0	0	0	0	0
30	0	0	0	0	0	0	0	0
32	0	0	0	0	0	0	0	0
34	0	0	0	0	0	0	0	0
36	0	0	0	0	0	0	0	0
38	0	0	0	0	0	0	0	0
40	0	0	0	0	0	0	0	0
42	0	2	0	0	0	0	0	0
44	0	1	0	0	0	0	0	0
46	0	1	0	0	0	0	0	0
48	0	3	0	0	0	0	0	0
50	0	1	0	0	0	0	0	0
52	0	0	0	0	0	0	0	0
54	0	0	0	0	0	0	0	0
56	0	0	0	0	0	0	0	0
58	0	1	0	0	0	0	0	0
60	0	0	0	0	0	0	0	0
62	0	0	0	0	0	0	0	0
64	0	0	0	0	0	0	0	0
66	0	0	0	0	0	0	0	0
68	0	0	0	0	0	0	0	0
70	0	0	0	0	1	0	0	0
72	0	0	0	0	0	0	1	0
74	0	0	0	0	0	0	0	0
76	0	0	0	0	0	0	0	0
78	0	0	0	0	0	0	0	0
80	0	0	0	0	0	0	1	0
82	0	0	0	0	0	0	0	0
84	0	0	0	0	0	0	0	0
86	0	0	0	0	0	0	1	1
88	0	0	0	0	0	0	2	1
90	0	0	0	0	0	0	0	0
92	0	0	0	0	0	0	0	0
94	0	0	0	0	0	0	0	0
96	0	0	0	1	1	0	0	0
98	0	0	0	1	1	0	0	0
100	0	0	0	1	1	0	0	0
102	0	0	0	1	0	0	0	0
104	0	0	0	1	0	0	0	0
106	0	0	0	1	0	0	0	0
108	0	1	0	0	0	0	0	0
110	0	0	0	0	0	2	1	0
112	0	3	0	0	0	3	7	5
114	0	0	0	0	0	0	1	2
116	0	0	0	0	0	1	0	1

Table 4a: Rotated component matrix for foraminifera.

Rotated Component Matrix					
	Component				
	1	2	3	4	5
Depth	-0.12	**0.61**	-0.33	-0.26	0.41
A.beccarii	-0.01	**0.89**	0.20	0.12	0.02
A.tepida	-0.03	**0.63**	-0.21	0.36	0.30
G.bulloides	0.01	-0.06	0.02	**0.78**	-0.07
Globorotalia scitula	**0.79**	0.08	-0.04	-0.11	0.06
Globigerinoides ruber	-0.08	-0.12	0.06	-0.22	0.37
Nonion cf. *N.boueanum*	0.58	-0.06	0.31	0.24	-0.06
Florilus grateloupi	**0.79**	0.15	-0.04	0.09	-0.05
E. crispum	-0.18	0.21	0.10	**0.51**	0.20
E. sp. A	0.12	0.34	**0.84**	0.12	0.09
E. indicum	-0.07	**0.82**	0.01	0.27	0.08
E.oceanensis	0.32	**0.59**	-0.11	0.26	-0.02
E. sp.B	-0.08	**0.78**	0.17	-0.12	-0.08
E. sp. C	0.14	**0.76**	0.12	-0.17	-0.07
Q. seminulum	**0.56**	-0.08	**0.74**	-0.07	0.08
Q. sp. A	**0.79**	-0.06	0.19	-0.08	0.04
Q. sp. B	**0.94**	0.00	0.15	-0.06	0.04
Q. sp. C	-0.07	-0.09	-0.02	-0.11	-0.26
Q. sp. D	**0.80**	-0.04	0.06	-0.06	0.00
Q. sp. E	-0.04	-0.01	-0.02	-0.06	**-0.76**

Extraction Method: Principal Component Analysis.
Rotation Method: Varimax with Kaiser Normalization.
a. Rotation converged in 6 iterations.

Table 4b: Rotated component matrix (ostracods).

Rotated Component Matrix			
	Component		
	1	2	3
Depth	0.41	**0.71**	-0.12
Fresh water forms	-0.1	-0.45	-0.41
Phlyctennophora sp.	**0.55**	-0.13	**0.52**
Hemicytheridea sp.	-0.11	-0.11	**0.86**
Callistocythere	-0.12	**0.82**	-0.07
Loxoconcha	-0.13	**0.74**	-0.04
Tanella gracilis	**0.88**	0.02	-0.01
Hemikrithe	**0.95**	0.00	0.01
Paijenborchellina sp.	**0.94**	0.01	0.00

Extraction Method: Principal Component Analysis.
Rotation Method: Varimax with Kaiser normalization and rotation converged in 4 iterations

took place over the last several thousands of years.

Sediments and environment of deposition

Geomorphologically, the Muttukadu area can be classified into six different depositional facies based on Reineck and Singh (1980).

1. Estuarine
2. Stagnant brackish water zone (isolated)
3. Tidal zone with exposed basement rock
4. Oxic tidal zone (organic activity)
5. Saline water and
6. Oxic brackish water zone (Recent condition)

The sediment core collected from Muttukadu reveals that the tidal sediment is multicolored and compact with shell fragments and pieces of charnockite rocks. The sediments in the core are predominantly sandy intermittently intermixed with silt and clay sediments. The coarser sediments are mainly quartz with small amount of feldspar, sillimanite, hypersthene, garnet, traces of mica and rock fragments, including carbonized material. Admixed with these are molluscan shell debris, plant and root fragments, foraminifer tests, and various aggregates including fecal pellets and other minor components. The sand is very similar in composition to those supplied by the neighboring coasts and adjacent seafloor. Integration of sediment texture and benthic foraminifer and ostracod assemblages from the core studied, following observations have been made:

The 58 samples sorted under the microscope yielded 19 species of foraminifer taxa belonging to 6 genera, 5 families, 4 superfamilies and 2 suborders, among which ROTALIINA is predominant. Eight species of ostracod taxa belonging to 8 genera, 6 families, 2 superfamilies, and 1 suborder have been identified, among which PODOCOPIDA is predominant.

Two benthic foraminifer species, *Ammonia beccarii* and *Ammonia tepida*, are occurring abundantly in the core, and continuous occurrence of *Ammonia beccarii* is observed in the core since the mid-Holocene Period. These two species exhibit high tolerance to variations in salinity that varies from as low as 8 ppt to 30 ppt. Their tolerance to variation in temperature is also from 20° to 38° C.

In depths 24-40, 60-68, 90-94 cms, incursions of freshwater input or flood of very short duration occurred; this is revealed by a sandy unit and insignificant assemblage of foraminifera. From the depths between 18 and 116 cms brackish water forms occur and the salinity ranges from 15 to 25 ppt. This indicates salinity fluctuations due to freshwater run-off and precipitation; interaction of marine water inputs.

The data collected on foraminifers and supplemented by R-mode factor analyses and correlation matrix indicate that *A.tepida* shows a positive relation and an increase in its abundance with depth. Depth versus ostracod assemblage reveals that fresh water forms are dominant in the upper layers.

From the sediment core study, it is observed that the mid Holocene transgression that flooded the deeper waters before the shallower ones, allowed a longer colonization period, may have contributed to the higher species richness of foraminifera within them such as *A. beccarii* and *A. tepida*. This also allowed temporal inverse relationship between the relative abundance of particular species and increasing salinity to hypersaline (40 ‰) conditions. The benthic foraminifera community is predominately represented by *Ammonia* sp. *Q.*spp. *Ammonia* sp. These are predominant in low saline to hyper saline conditions while *Elphidium* spp. decrease in their abundance with increasing saline conditions.

In this study, the representative sediment core has been divided into two distinct major bio-zones and several sub-zones using stratigraphically constrained factor analysis. Each of these zones is composed of distinct foraminifer and ostracod assemblages. Uppermost sediments, from the late Holocene are less marked by marine epiphytic benthic species, while the lower layers of the sediment core are predominantly characterized by species of foraminifer and brackish water ostracods tolerant of higher salinity conditions. This also indicates episodes of freshwater incursions within broader marine transgression. Beneath this upper zone is an ostracod community with little compositional overlap, being dominated by *Hemikrithe, Tanella gracilis* and *Paijenborchellina* sp. In general, changes in foraminifer and ostracod communities

Table 5a: Correlation matrix of foraminifera (a) and ostracod (b) data

Correlation	**Depth (cm)**	*A.beccarii*	*A.tepida*	*G.bulloides*	*Globorotalia scitula*	*G. ruber*	*Nonion* cf *N. boueanum*	*Florilus grateloupi*	*E. crispum*	*E.* sp. A	*E. indicum*	*E. oceanensis*	*E.* sp.B	*E.* sp. C	*Q. seminulum*	*Q.*sp. A	*Q.* sp. B	*Q.* sp. C	*Q.* sp. D	*Q.* sp. E
Depth (cm)	1																			
A.beccarii	0.42	1																		
A.tepida	**0.55**	0.47	1																	
G.bulloides	-0.22	0.09	0.15	1																
Globorotalia scitula	0.02	0.02	0.02	-0.03	1															
G. ruber	0.02	-0.10	-0.12	-0.02	-0.03	1														
Nonion cf.N. boueanum	-0.32	0.12	-0.02	0.04	0.38	-0.05	1													
Florilus grateloupi	-0.04	0.11	0.06	0.07	**0.58**	-0.05	0.05	1												
E. crispum	0.09	0.34	0.24	0.18	-0.12	-0.06	-0.03	-0.11	1											
E. sp. A	0.00	0.39	0.21	0.09	0.12	-0.05	0.27	0.17	0.1	1										
E. indicum	0.39	**0.71**	**0.66**	0.07	-0.01	-0.06	-0.04	0.00	0.27	0.34	1									
E.oceanensis	0.22	0.42	0.39	0.10	0.14	-0.05	0.15	0.37	0.05	0.22	**0.62**	1								
E.sp.B	0.35	**0.77**	0.25	-0.04	0.12	-0.04	-0.07	0.05	0.18	0.28	**0.56**	0.27	1							
E.sp. C	0.36	**0.72**	0.31	-0.05	0.08	-0.05	0.03	0.26	0.04	0.31	0.43	0.39	**0.55**	1						
Q. seminulum	-0.21	0.00	-0.14	-0.03	0.42	-0.03	0.43	0.37	-0.10	**0.72**	-0.09	0.10	-0.07	0.06	1					
Q.sp. A	-0.15	0.01	-0.11	-0.03	**0.51**	-0.03	0.40	0.46	-0.09	0.13	-0.08	0.15	-0.06	0.09	**0.62**	1				
Q. sp.B	-0.10	0.05	-0.07	-0.02	**0.71**	-0.02	**0.51**	**0.65**	-0.08	0.20	-0.07	0.23	-0.05	0.16	**0.65**	**0.89**	1			
Q. sp. C	-0.11	-0.10	-0.09	-0.03	-0.05	-0.03	-0.07	-0.07	-0.09	-0.07	-0.08	-0.07	-0.06	-0.08	-0.04	-0.04	-0.03	1		
Q. sp.D	-0.15	0.00	-0.10	-0.03	**0.60**	-0.03	0.38	**0.54**	-0.10	0.15	-0.09	0.17	-0.07	0.11	0.46	**0.56**	**0.77**	-0.04	1	
Q. sp. E	-0.14	-0.10	-0.11	-0.02	-0.03	-0.02	-0.05	-0.05	-0.06	-0.05	-0.06	-0.05	-0.04	-0.05	-0.03	-0.03	-0.02	-0.03	-0.03	1

Table 5 b: Correlation matrix of ostracode data.

	Depth (cm)	Fresh water forms	*Phlyctennophora* sp.	*Hemicytheridea* sp.	*Callistocythere*	*Loxoconcha*	*Tanella gracilis*	*Hemikrithe*	*Paijenborchellina* sp.
Depth (cm)	1								
Fresh water forms	-0.04	1							
Phlyctennophora sp.	0.02	-0.1	1						
Hemicytheridea sp.	-0.21	-0.05	0.21	1					
Callistocythere	0.43	-0.08	-0.13	-0.06	1				
Loxoconcha	0.26	-0.07	-0.11	-0.05	**0.58**	1			
Tanella gracilis	0.34	-0.05	0.41	-0.04	-0.07	-0.06	1		
Hemikrithe	0.32	-0.06	0.47	-0.05	-0.08	-0.07	**0.8**	1	
Paijenborchellina sp.	0.35	-0.06	0.45	-0.05	-0.08	-0.06	**0.74**	**0.92**	1

preserved in the sediment core indicate fluctuations in abundance of macrophyte communities and predominant marine and brackish conditions in the lower part of the core.

Appearances of freshwater juvenile taxa among typical marine species in the upper part of the core indicate freshwater inflow/flood at this site and strong marine incursion in the lower part of the core during the mid Holocene. The ecology of Muttukadu has been greatly affected by natural as well as human activities in the adjacent landscape.

The importance of this study lies in the fact that a detailed study of middle Holocene sea-level fluctuation, environmental change and micropalaeontology will assist in understanding the various phases of erosion, deposition and mass wasting processes which operate over a long period of time in the coastal zones. There are several estuaries, tidal zones and Quaternary surfaces exposed along the southern stretch of the East Coast of India. These landforms bear signatures of sea-level changes and contain abundant micropalaeontological material that holds signatures of erosion and deposition. There is a need to determine the causes for the shifts in sea level since the Holocene Period. In keeping with this aim, an extension of the study is suggested to investigate the nature of palaeoenvironment since the early Quaternary period along the east Coast, Tamil Nadu, as well as the adjacent inland region to understand sea-level changes and Man-land relationship.

ACKNOWLEDGEMENTS

This work was supported by the UGC DRS programme of the Department of Geology, Anna University. The authors thank the reviewers for their constructive suggestions that helped in the improvement of the manuscript.

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Manuscript Accepted January 2009