Radiocarbon dates and Holocene sea-level change along the Cuddalore and Odinur Coast, Tamil Nadu

Abbas Hameed[1], Hema Achyuthan[1,*] and B. Sekhar[2]

[1]Department of Geology, Anna University, Chennai 600 025, India
[2]Birbal Sahni Institute of Paleobotany, Lucknow 226 007, India

Five sediment cores from the tidal flats and estuaries between Cuddalore and Odinur, Tamil Nadu at ~50–70 cm water depth were collected to study the down core variations in organic matter, calcium carbonate content and sediment texture. Quartz, feldspar and moderately rounded to well-round, garnet-rich sand were present in all cores except core IV collected from Marakkanam. Cuddalore (cores I–III) sediments were coarse-grained and those from Odinur (core V) varied from sand to silty sand to clay. Smectite, kaolinite, illite and vermiculite occurred as clay minerals. High content of organic matter was observed in cores from Marakkanam and Odinur. Radiocarbon dates on shell, organic carbon at the base and at intervals of the cores from Marakkanam (core IV) and Odinur (core V) are 8200 ± 230, 9170 ± 290, 5540 ± 430, 2700 ± 140 yrs BP respectively. The sea-level curve presented for the Marakkanam site indicates a gradual and slow sea-level rise since 9000 to 1800 yrs BP. Data on sediment texture, mineralogy, organic matter content supplemented by radiocarbon dates indicate that the deposition of these sediments has taken place in phases since the early Holocene. 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.

Keywords: Core sediments, organic matter, radiocarbon dates, sediment texture, tidal zones.

ALONG the east coast of India, Terminal Pleistocene to Early Holocene coastal changes have not been studied in detail and the data obtained so far are few[1]. A review of the work carried out along the East Coast of India, reveals the occurrence of Quaternary sediments in the Cauvery region of Tamil Nadu and in the Kolanka–Masulipatnam region of Andhra Pradesh[2] that indicates high sea-level during the early part of the Pleistocene followed by a lowering of sea-level. Oolitic sands at depths of 90 to 180 m off Visakhapatnam[2] are relict and were formed during low sea stand. Such deposits are scattered unevenly across the eastern shelf of India at the mouths of major rivers[2,3]. A 23 m low level oolitic surface off Visakhapatnam coast[3] was dated at 7000 to 8000 yrs BP. Subsequent to these low sea stands, sea-level rose to +2 to +5 m, as evidenced by palaeocoral reefs in the Rameshwaram peninsula[4]. These coral reefs appear to have been formed around 6000 yrs BP[4]. Hence general inferences have been drawn based on geomorphic observations in spite of lack of detailed sedimentology studies. The purpose of this communication is to report radiocarbon dates of the organic-carbon rich sediments collected in the estuary and tidal flats between Cuddalore and Odinur along the east coast of Tamil Nadu, and to decipher Holocene sea-level changes.

The east coast of Tamil Nadu is a narrow, sandy coastal belt extending from Marakkanam near Pondicherry and Cuddalore. It covers approximately 150 km^2. Geomorphology of the area exhibits tidal flats, estuaries and marsh zones as well as linear, stabilized, older and younger sand dunes. Beach dunes run practically north-south in direction and parallel to the sea. The Palar and Ponnaiyar rivers open into the Bay of Bengal forming an estuary with swash-back tidal currents affecting nearly 200 m into the river mouth during the high tides (Figure 1). There are inlets of the sea at Marakkanam, Odinur and Cuddalore forming tidal flats. These tidal flats exhibit four major zones: (a) outer sand flat, (b) coarse sand flat merging with beach dune complex and exposure of sand-stone; (c) middle sand flat and (d) sand to silt-dominated inner flats and salt marsh[5]. The salt marsh is separated from the inner flat by a narrow spit consisting of shell and shell debris. The dunes are stabilized at their base but are mobile on their crests. The study area (Figure 1) experiences a tropical sub-humid type of climate with an annual mean temperature of 25°C and average annual precipitation of 1200 mm. The geology of the study area is represented by the Archaean charnockite rocks, which are overlain by Cuddalore sandstone[6] of Eocene–Miocene age. Thick (15–20 m) mantle of Quaternary alluvium overlies the Cuddalore sandstone and the Holocene tidal flat deposits and dunes[6] in turn overlie these.

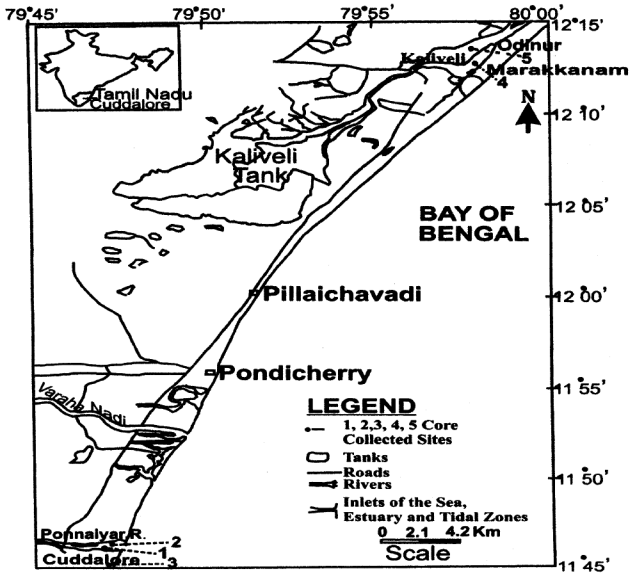

Figure 1. Location map of the study area.

*For correspondence. (e-mail: hachyuthan@yahoo.com)

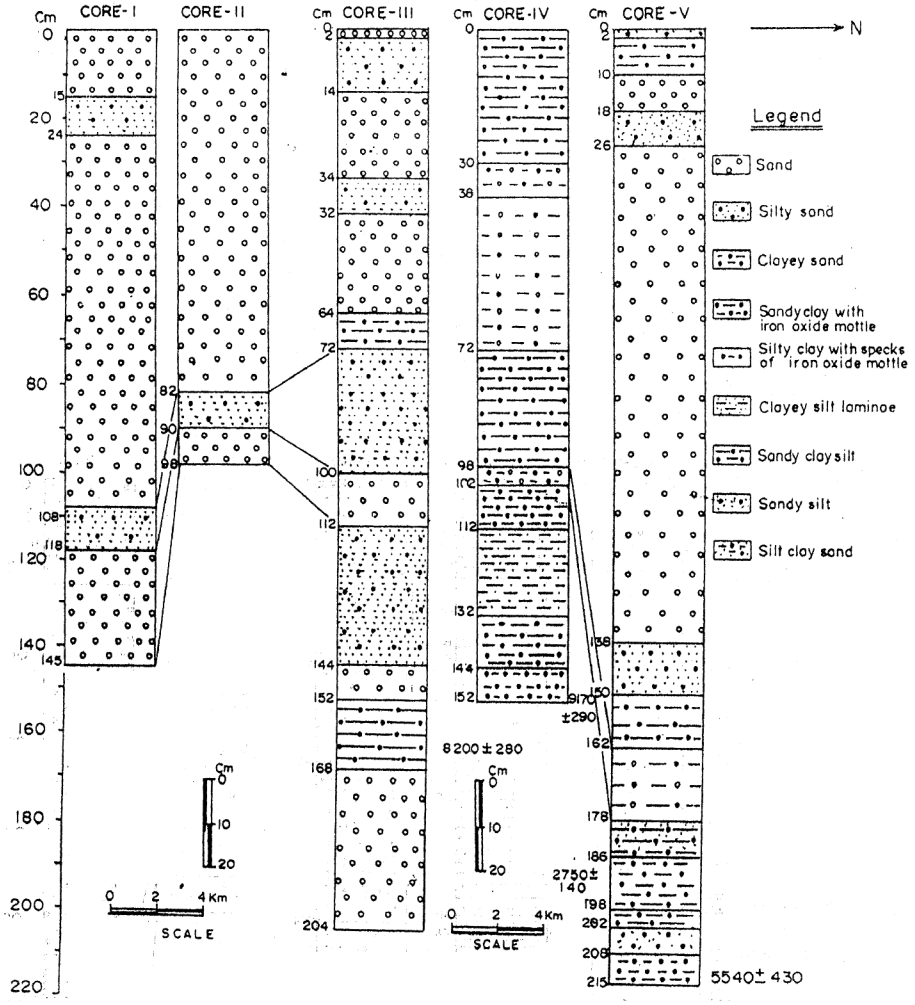

Figure 2. Litho units in five sediment cores.

Table 1. Location of core site, water depth and salinity

Site and core no.	Location (GPS)	Water depth (cm)	Salinity (ppt)
Cuddalore (Core I)	79°47′E; 11°46′N	50	31
Cuddalore (Core II)	79°47′E; 11°48′N	60	31
Cuddalore (Core III)	79°47′E; 11°45′N	70	30
Marakkanam (Core IV)	79°58′E; 12°13′N	50	34
Odinur (Core V)	79°58′E; 12°16′N	50	32

The outer sandy flat and the beach dune complex are characterized by sand waves (wavelength approximately 5–8 m), in which amplitude (maximum approximately 0.5–1.0 m) decreases landward. The inner sand flat consists of elevated grounds (fine sand mixed with algal material) surrounded by shallow (2–5 m) pools of water with soft substrate. Shell mounds are at or above mean high water level (MHWL) and are scattered at the points of small headlands near Marakkanam and Odinur. The bathymetry of the East Coast, Tamil Nadu is presented in Figure 1.

Five sediment cores were collected at ~50–70 cm water depth (Table 1) from the estuary and tidal zones at Cuddalore, Marakkanam and Odinur along the East Coast of Tamil Nadu (Figure 1). The core samples were collected using PVC pipe of 2 inches diameter. The PVC pipes were punctured into the ground manually at the selected spots using geographical positioning system (GPS) and also noting that the surface of the sediment core is equivalent to the present-day mean sea-level. After closing the mouth of the pipe, the core pipe was retrieved immediately. The core samples were frozen at –20°C and later cut open using a core-cutter to be sub-sampled every 2 cm. The cores varied in length (100–215 cm). Litho units within the core were differentiated on the basis of colour, sediment texture, shell fragments, mottle distribution and organic carbon layers and concretions (Figure 2). The representative sediment samples were analysed for organic matter[7] and grain size variation[8]. Totally, 93 sub-samples were selected from these five cores and analysed for grain size, organic matter and calcium carbonate content (Cuddalore I-20; Cuddalore II-13; Cuddalore III-21; Marakkanam IV-16 and

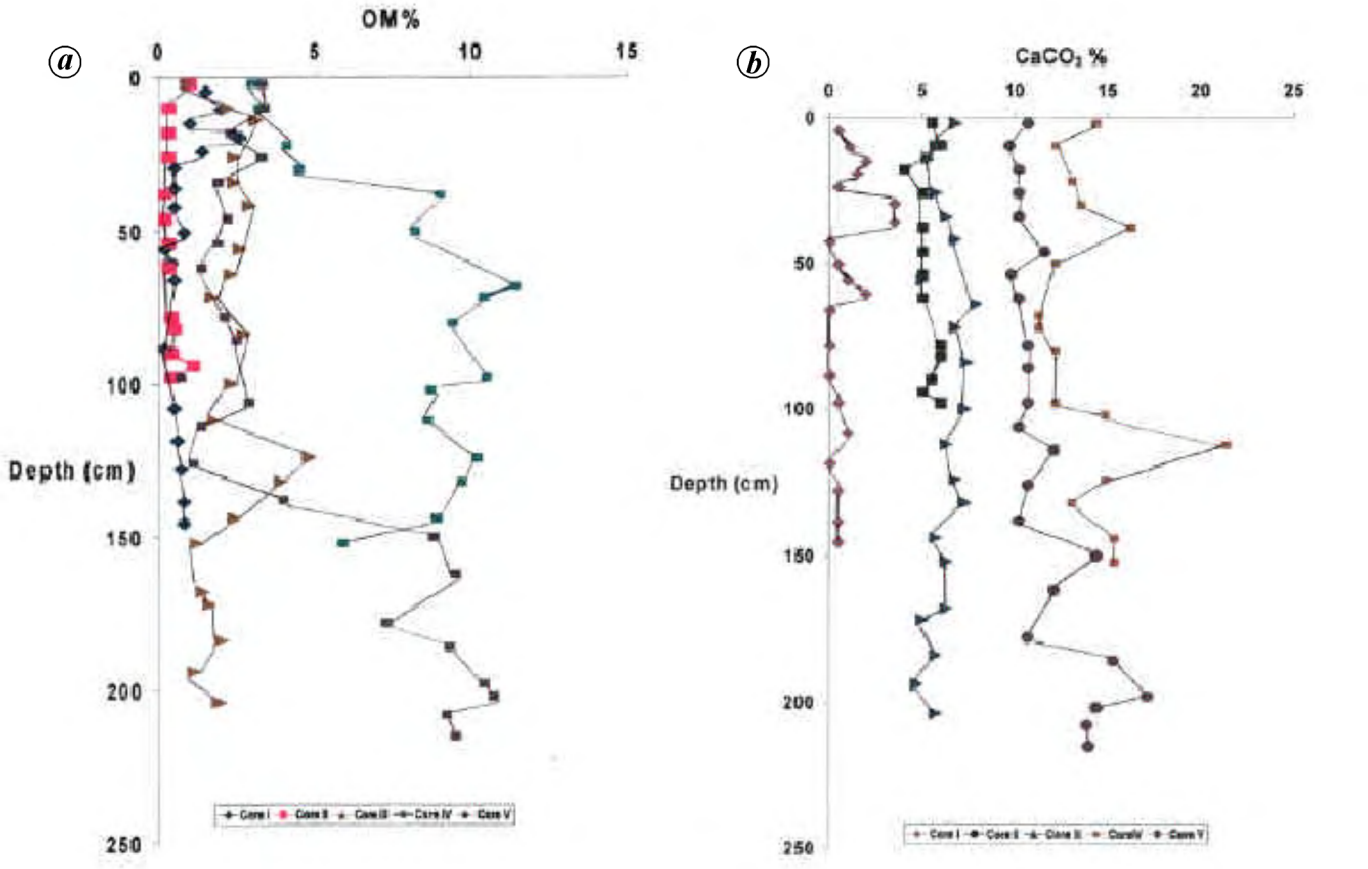

Figure 3. Depth (cm) vs organic matter (%) (***a***) and depth (cm) vs $CaCO_3$ (%) (***b***) of the five cores analysed.

Odinur V-23). Down-core variation and concentration of these parameters are presented in Figure 3 *a* and *b*. The analytical accuracy for organic matter and calcium carbonate is within 5% and the precision is of three replicate measurements for all the core samples.

Calcium carbonate was determined by rapid titration method[9]. Four samples from Marakkanam (core IV) and two samples from Odinur (core V) were radiocarbon-dated by analysing shell and organic carbon-rich sediments at Birbal Sahni Institute of Paleobotany, Lucknow. The half-life was 5730 ± 40 yrs (Table 2). Sediment cores from Marakkanam and Odinur contained organic carbon-rich sediments suitable for radiocarbon dating, while the sediment cores from Cuddalore contained coarse terrigeneous sand.

All the cores revealed multicolour layers, but predominantly 2.5YR4/2 (dark reddish-grey), 7.5Y4/1 (grey) and 2.5Y2/1 (black; Munsell colour chart) and were compact. The sediment texture differs considerably at these three sites (Figure 2). At Cuddalore, Marakkanam and Odinur, the coarser sand is mainly quartz with small amounts (<3–4%) of feldspar, sillimanite, hypersthene, garnet and traces of mica, rock fragment, including carbonized material. Admixed with these are molluscan shell debris, carbonaceous wood and root fragments, foraminifer, and various aggregates including faecal pellets and other minor components. The fine fractions were identified using X-ray diffractogram analyses and were found to contain smectite, kaolinite, aragonite, illite and vermiculite that occurred as clay minerals.

Down-core variation of sediment texture observed within three cores collected around Cuddalore at different sites comprises coarse sand content with varying percentages of silt and clay. The relative high abundance of sand within the sediment cores indicates high depositional wave-energy conditions. Marakkanam (core IV) reveals varying sand content from 9.2 to 62.9% and silt content from 0.2 to 56.4%. Clay content varies from 33.3 to 63.2%. Odinur (core V) exhibits high sand percentage ranging from 14.4 to 92.2 except at a depth of 200–202 cm in which the sand percentage is very low (0.4%) compared to other core samples analysed. At a depth of 176–178 cm, the clay content is high (56.4%). High percentage of clay content is also recorded at the depth interval of 200–202 cm. This may be due to dry conditions, less turbulence and stagnant water pool environment within the estuary zone.

In Marakkanam (core IV) the organic matter concentration varies from 3 to 11.4%. The higher concentration value of 11.4% was recorded at a depth interval of 68 cm only, which is a carbonaceous wood piece (Figure 3 *a*). In Odinur (core V), the organic matter concentration varies from 1.1

Table 2. Radiocarbon dates obtained from shell and sediments at Marakkanam (core IV) and Odinur (core V)

Site and laboratory code*	Depth (cm) and sample type	^{14}C age yrs BP	Calibrated age range	Clay mineral	Coarse mineral fraction >80 μm
Marakkanam BS-1605	38–40, shell	1115 ± 132	AD 612–1082	Kaolinite, vermiculite, illite and aragonite	Quartz, K-feldspar, rutile (>2%), mica, garnet, sillimanite, hypersthene and quartzite grain
Marakkanam BS-1608	86–88, shell	1563 ± 132	136–680 BC	Kaolinite, illite and aragonite	Quartz, K-feldspar, rutile (>2%), mica, garnet, sillimanite, hypersthene and quartzite grain
Marakkanam BS-2270	146–152, shell	8200 ± 230	9230–8460 BC	Kaolinite, aragonite and illite	Quartz, K-feldspar, garnet (>2%), mica, sillimanite, hypersthene and quartzite grain
Marakkanam BS-2275	146–152, sediment	9170 ± 290	10360–8460 BC	Kaolinite, smectite, vermiculite and illite	Quartz, K-feldspar, garnet (2%), mica, sillimanite, hypersthene and quartzite grain
Odinur BS-2398	188–194, sediment	2750 ± 140	2920–2710 BC	Kaolinite, smectite, vermiculite and illite	Quartz, K-feldspar, sillimanite, garnet, mica and hypersthene
Odinur BS-2272	208–214, sediment	5540 ± 430	6640–5660 BC	Kaolinite, smectite and illite	Quartz, K-feldspar, sillimanite, garnet, hypersthene and mica

*BS, Birbal Sahni Radiocarbon Laboratory number.

to 10.7%. Higher concentration of 10.7% was observed at depth interval of 202 cm. In comparison with Cuddalore (cores I–III), sediment cores from Marakkanam (core IV) and Odinur (core V) reveal higher organic matter content (Figure 3 *a*). This is probably also due to the adsorption and incorporation of organic materials from the overlying polluted water column and fine fragments of wood.

Fine fractions such as fine silt and silty clay sediments are considered to be major sinks for organic matter. Organic matter often shows a positive correlation with weight percentage of silt and clay[10] but our data reveal negative correlation between fine fractions such as silt with organic matter (correlation R^2 value varies from 0.003 to 0.558; Figure 4 *a–d*) for the Cuddalore and Marakkanam core samples. A positive correlation is only noted between organic matter and silt fraction (R^2 value of 0.795; Figure 4 *e*) for the Odinur core samples. This indicates that the Odinur samples differ in their characters from those at other locations. Textural analyses also point towards higher, finer fraction content and these finer fractions form a major sink for the organic matter. This is probably due to inland, less turbulent conditions in the Odinur site than at other locations from where the core samples were retrieved.

Most of the organic matter in coastal sediments is derived from plant material of terrigeneous origin that accumulates in shallow water environments[11]. The amount of sedimentary organic matter depends upon the rate of deposition of organic matter, rate of deposition of inorganic matter and rate of decomposition of organic matter following its deposition[11]. High values of organic matter in the core sediments from Marakkanam and Odinur are due to the presence of carbonaceous wood/peat and occurrence of fine sediments. In general, higher organic matter at the surface is attributed to the abundance of fresh plant material, while the decrease with depth is due to degradation of organic material and trapping of fine inorganic material by the marsh vegetation.

Similarly, $CaCO_3$ content in Cuddalore sediments (cores I–III) is low. $CaCO_3$ content in core III is approximately similar to that at core II and ranges from 4.7 to 7.9% (Figure 3 *b*). Two cores from Marakkanam (core IV) and Odinur (core V) reveal relatively high calcium carbonate percentage (Figure 3 *b*). This is due to increase in shell fragments and also due to sediment texture variation. The lower values of calcium carbonate in the Cuddalore (cores II, III and I) estuary are due to greater dilution from terrigeneous or high rate of sedimentation[12]. High rate of sedimentation and fine nature of substratum, in general, do not support bioorganic activity and hence low carbonate values. Slightly higher carbonate percentage in core IV is due to the dominance of sand with shells.

Microscopic observations of the sediments revealed the occurrence of pyrite at depth intervals 10, 22, 90, 98, 124 and 132 cm in core IV and at 18, 162 and 202 cm in core V. This is due to decomposition of organic matter under sulphate-reducing conditions. Clay minerals such as kaolinite, illite, vermiculite and smectite are similar in composition to those supplied by the rivers draining into the area and to those being eroded from the neighbouring coasts and adjacent seafloor. Hence it is difficult to assign a definite source to them[13].

^{14}C dates of shell and organic carbon-rich sediments from Marakkanam (146–152 cm depth) range from 8200 ± 230 to 9170 ± 290 yrs BP (Table 2) and reveal a relative low sea-level (~ –24 to –37 m) during the early Holocene age. The organic-rich sediment at the depth of 208–214 cm

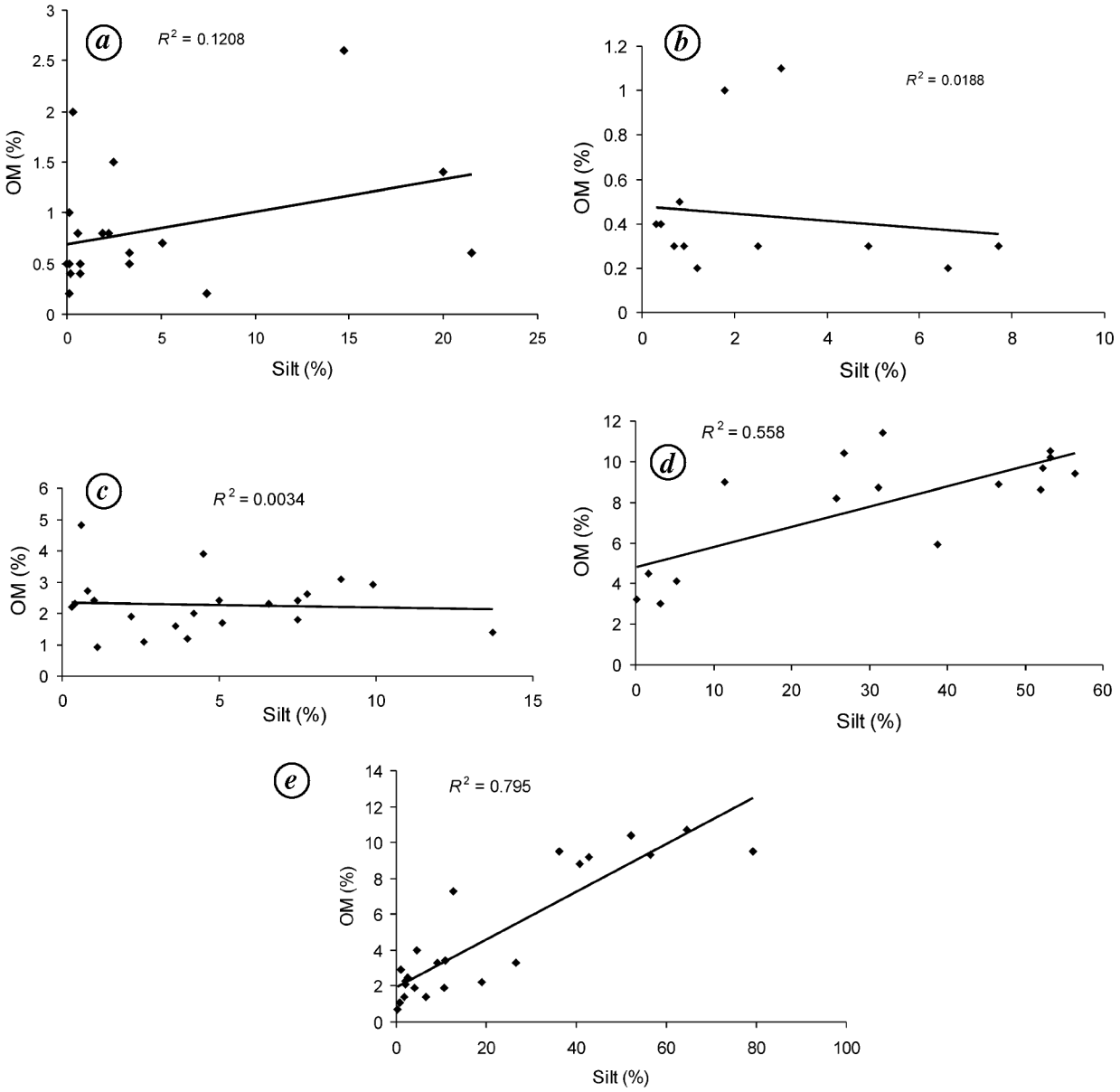

Figure 4*a–e*. Correlation between organic matter and silt fraction of the five cores respectively.

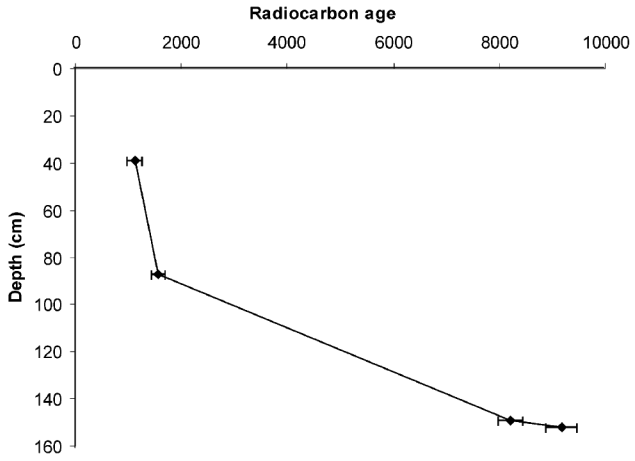

Figure 5. Depth vs radiocarbon age of Marakkanam site.

from Odinur is dated to 5540 ± 430 yrs BP of mid-Holocene age. The present data indicate a gradual and slow sea-level rise since 9000 to 1115 yrs BP (Figure 5), with a sedimentation rate of ~0.7 mm yr^{-1} between 1500 and 1115 yrs BP. The younger date indicates that the present-day sea-level attained its current position around 1100 yrs BP with minor oscillations. Figure 5 represents the sea-level curve for a small stretch of the east coast and is site-specific. High-resolution analyses using stable isotopes on ice cores, coral reefs, deep sea ocean sediments reveal that globally sea level has risen rapidly since the early Holocene, with smaller oscillations approximately around 9000–8200, 6000, 4200–3500 and 2000–1600 yrs BP[14–16]. Data from the present study corroborate the earlier view.

The clay units are devoid of shells. The fine silt and clay units record short period of decreased storminess.

Litho units in the tidal zone of Marakkanam, Cuddalore and Odinur point to a local fluctuation of sea-level and do not conform to the mid-Holocene eustatic high sea-level change. This was probably due to an overall intense aridity and low sea-level with high saline conditions[6,13] that characterized mid-Holocene environment of the study area. This 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 and long shore drifts. Lowering of the sea level during the mid-Holocene period 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 progradation of the present coastline. Since the early Holocene period, the east coast has changed due to coastal configuration processes. These include effects of subduction earthquakes, coastal processes such as waves, tides, rip currents, storm surges, shoreline weathering, coastal erosion, sediment transportation and deposition, organic activity and beach nourishment. Similar observations at the Mahi estuary on the west coast of India (4000–1700 yrs BP) have been made by Kusumgar *et al.*[17] based on ^{14}C dates and foraminifer assemblage. Our interpretation is based on a few radiocarbon dates and published data[13].

The present communication is an exercise that indicates the complicated nature of sea-level rise and changes during the Holocene period along the east coast of Tamil Nadu. Application of higher resolution dating methods, supported by bathymetry data and rigorous sediment analyses will help in better understanding of sea-level change and presenting a Holocene sea-level curve for the east coast of Tamil Nadu.

In conclusion, all the five cores reveal changes in sediment texture predominantly with coarse sand from the Cuddalore site. Marakkanam (core IV) and Odinur (core V) are dominantly silty sand and clay silt. This may be due to different source material from the hinterland and coastal processes, reflecting changes in energy conditions. Reworking of the shore and the inner-shelf sediments has been an important source for the present coastline configuration.

Organic matter content in the sediment cores from Marakkanam and Odinur is due to carbonaceous wood and organic carbon-rich fine sediments. Decrease in organic matter with depth is due to diagenesis and compaction of organic material in fine sediments.

Sediment texture, mineralogy, organic matter content, supplemented by radiocarbon dates indicate that the deposition between Cuddalore and Odinur has taken place in phases. Sediment data and radiocarbon dates indicate that since the early Holocene period, the east coast has been modified due to coastal processes. The radiocarbon dates and the Holocene sea-level curve presented for the Marakkanam site indicate a gradual and slow sea-level rise since 9000 to 1115 yrs BP, and these data are site-specific.

1. Vaz, G. G., Age of relict coral reef from the continental shelf off Karaikal, Bay of Bengal: evidence of last glacial maximum. *Curr. Sci.*, 2000, **79**, 228–230.
2. Subba Rao, M., Some aspects of continental shelf sediments of the East Coast of India. *Mar. Geol.*, 1964, **1**, 59–87.
3. Prudhvi Raju, K. N. and Vaidyanadhan, R., Geomorphology and evolution of Sarda river basin, Visakhapatnam District, AP. *Ann. Natl. Assoc. Geol.*, 1981, **1**, 1–17.
4. Rajamanickam, G. V. and Tooley, M. J., *Quaternary Sea Level Variation, Shoreline Displacement and Coastal Environment*, New Academic Publishers, Laxmi Nagar, New Delhi, 2001.
5. Reineck, G. and Singh I .B., *Depositional Sedimentary Environment*, Springer-Verlag, New York, 1980.
6. Achyuthan, H., Age and formation of oyster beds of Mutthukadu tidal flat zone, Chennai, Tamil Nadu. *Curr. Sci.*, 1997, **73**, 450–453.
7. Dean, Jr. W. E., Determination of carbonate and organic matter in calcareous sediment and sedimentary rocks by loss on ignition: Comparison with other methods. *J. Sediment. Petrol.*, 1974, **44**, 242–248.
8. Carver, R. E., *Procedures in Sedimentary Petrography*, Wiley International Science, New York, 1971, pp. 47–86.
9. Piper, C. S., *Soil and Plant Analysis*, University of Adelaide Press, Adelaide, 1947, p. 368.
10. Subba Rao, M., Organic matter in marine sediment off East Coast of India. *Am. Assoc. Petrol. Geol. Bull.*, 1960, **44**, 1705–1712.
11. Mackereth, F. J. H., Chemical investigation of lake sediments and their interpretation. *Proc. R. Soc. London Ser.*, 1965, **161**, 295.
12. Achyuthan, H., Richardmohan, R., Srinivasalu, S. and Selvaraj, K., Trace metals concentrations in the sediment cores of estuary and tidal zones between Chennai and Pondicherry, along the East Coast of India. *Indian J. Mar. Sci.*, 2002, **31**, 141–149.
13. Achyuthan, H. and Baker, V. R., Coastal response to changes in sea level since the last 4500 year BP on the East Coast Tamil Nadu, India. *Radiocarbon*, 2002, **44**, 137–144.
14. Fairbridge, R. W., Eustatic changes in sea level. In *Physics and Chemistry of the Earth*, Pergamon Press, London, 1961, vol. 4, pp. 99–185.
15. Broecker, W. S., Absolute dating and the astronomical theory of glaciation. *Science*, 1966, **151**, 299–301.
16. Mesollela, R. K., Matthews, R. K., Broecker, D. L. and Thurber, B. L., Astronomical theory of climate change. *J. Geol.*, 1969, **77**, 250–274.
17. Kusumgar, S., Raj, R., Chamyal, L. S. and Yadav, G. N., Holocene palaeoenvironment changes in the Mahi river basin, Gujarat, Western India. *Radiocarbon*, 1998, **40**, 319–323.

ACKNOWLEDGEMENTS. We thank the Head, Department of Geology, Anna University, Chennai for providing necessary facilities. This work was carried out under the UGC DRS Phase I programme of the Department of Geology, Anna University, Chennai. H.A. is grateful to BSIP, Lucknow, for radiocarbon dating of the samples and to Dr M. N. Balasubramanian, Retd. DyDG, GSI for reading this manuscript.

Received 10 August 2005; revised accepted 23 March 2006