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

Abbas Hameed, Hema Achyuthan* and B. Sekhar

1Department of Geology, Anna University, Chennai 600 025, India
2Bibirbal 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-rounded, 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. Smeectite, 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. 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 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 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. A 23 m low level oolitic surface off Visakhapatnam coast 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.

These coral reefs appear to have been formed around 6000 yrs BP. 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 km². 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. 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 of Eocene–Miocene age. Thick (15–20 m) mantle of Quaternary alluvium overlies the Cuddalore sandstone and the Holocene tidal flat deposits and dunes in turn overlie these.

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

Figure 1. Location map of the study area.
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 and grain size variation. 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...
Odinur V-23). Down-core variation and concentration of these parameters are presented in Figure 3a 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. Four samples from Marakkannam (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 Marakkannam and Odinur contained organic carbon-rich sediments suitable for radiocarbon dating, while the sediment cores from Cuddalore contained coarse terrigenous 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, Marakkannam 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. Marakkannam (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 Marakkannam (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 3a). In Odinur (core V), the organic matter concentration varies from 1.1
Table 2. Radiocarbon dates obtained from shell and sediments at Marakkamam (core IV) and Odinur (core V)

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

*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 Marakkamam (core IV) and Odinur (core V) reveal higher organic matter content (Figure 3a). 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, 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 4a–d) for the Cuddalore and Marakkamam core samples. A positive correlation is only noted between organic matter and silt fraction (R^2 value of 0.795; Figure 4e) 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 terrigenous origin that accumulates in shallow water environments. 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. High values of organic matter in the core sediments from Marakkamam 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 matter and trapping of fine inorganic material by the marsh vegetation.

Similarly, CaCO₃ content in Cuddalore sediments (cores I–III) is low. CaCO₃ content in core III is approximately similar to that at core II and ranges from 4.7 to 7.9% (Figure 3b). Two cores from Marakkamam (core IV) and Odinur (core V) reveal relatively high calcium carbonate percentage (Figure 3b). 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 terrigenous or high rate of sedimentation. 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.

14C dates of shell and organic carbon-rich sediments from Marakkamam (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 4a–e. Correlation between organic matter and silt fraction of the five cores respectively.

Figure 5. Depth vs radiocarbon age of Marakkam site.

from Odinar 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. 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 Marakkkanam, 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.\(^{11}\) 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. Marakkkanam (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. Re-working 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 Marakkkanam 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 Marakkkanam site indicate a gradual and slow sea-level rise since 9000 to 1115 yrs BP, and these data are site-specific.


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.