Utility of sub-surface benthic foraminiferal assemblages to decipher the paleoenvironment of the north-west Kerala coast

Adarsh P, Rajeshwara Rao, N
Department of Applied Geology, University of Madras, Maraimalai Campus, Guindy, Sardar Patel Road, Chennai 600 025, India
raonandamuri@gmail.com
doi:10.6088/ijes.00202030060

ABSTRACT

Benthic foraminifera have proved to be reliable proxies for understanding paleoenvironmental changes or paleoclimatic changes in the past geological history of the Earth, especially since the Cambrian when these unicellular protozoans began to evolve. Since then, foraminifers have been recorded as fossils and their abundant occurrence in the fossil record has aided in understanding the past history of the Earth. Within the Holocene, this group of microfossils has proved to be of immense utility, as their assemblages could be utilized for understanding past environmental changes, as they are so sensitive to variations in such ecological parameters as pH, depth of the water column, salinity, dissolved oxygen content, nature of substrate calcium carbonate and organic contents, which are the primary controlling factors over their species populations and diversity. The study area is a part of Kannur District, Kerala, India, about 5–7 km from the present-day shoreline. Trench samples (sub-surface) at varying depths up to 3.6 m, at Karakkeezhu and Kuduvathala, yielded a benthic foraminiferal assemblage that is characteristic of modern estuarine/brackish water environments. This assemblage, typified by the dominance of Ammonia beccarii (Linnaeus) and its associated species, is suggestive of a shallow, probably sheltered, tidal flat environment with a possible connection to the Arabian Sea ~5,000 to 5,500 years B.P. as revealed by $^{14}$C dates of both mollusk shells and sediment samples. The study has thrown open some intriguing questions, particularly with regard to the complete absence of arenaceous, agglutinated forms (Suborder TEXTULARIINA) and the poor representation of calcareous, imperforate taxa (Suborder MILIOLINA).

Keywords: Kannur District, Ecology, Sea-level changes, Holocene, $^{14}$C dating.

1. Introduction

Analysis of the relationships between marine organisms and their environment has always served as an important and reliable tool for the understanding and management of marine communities (Hockey and Branch, 1997; Williams and Bax, 2001; Roff et al., 2003). Benthic foraminifera are a group of organisms that are ubiquitous throughout the world oceans, but the distribution of individual species is constrained by their environmental preferences. These organisms have, therefore, the potential to provide valuable information about the environment. Benthic foraminiferal species distributions are influenced by a combination of such factors as nature of the substrate, light penetration depth, water temperature, availability of food, dissolved oxygen content, salinity, tidal variations, and energy of currents (Murray, 1991). Many of these attributes vary with water depth, so depth may often provide clues to variations in these parameters as well as in species distributions. Foraminifera are essentially marine unicellular micro-organisms that secrete tests (shells); their life habits embrace...
planktic and benthic modes. Planktic forms generally inhabit the open ocean, particularly in deeper waters, and are seldom found to dwell in coastal waters. On the other hand, benthic foraminifera exist on substrates from inter-tidal areas to abyssal plains. Many species of foraminifera have narrowly defined niches, making them ideal for paleoenvironmental analysis (Murray, 1991). Analysis of foraminifera in the modern inter-tidal zone has found that species inhabit narrowly defined niches (e.g., high and low salt marshes, tidal flats and tidal creeks), and that certain assemblages are indicative of deposition in specific environments (Pearson et al., 1990; Boomer, 1998). Modern foraminifera have also been found to be stratified according to tidal levels (Scott and Medioli, 1978; Gehrels, 1994; Haslett et al., 1998). Foraminifera have, therefore, proved to be invaluable in the reconstruction of paleoenvironmental conditions (Boomer and Godwin, 1993) and as indicators of sea-level change (Scott and Medioli, 1986).

1.1 Previous studies from the Kerala coast

The entire west coast of India, including the Kerala coast, receives relatively less sediment supply owing to the fewer number of rivers flowing toward west and debouching into the Arabian Sea. The availability of fluvial sediments and large quantity of unconsolidated eolian sands in the littoral zone has contributed to the formation of well-developed beach ridges in several segments of the west coast (Narayana, 2007). Beach ridges are found in prograding shorelines having large supply of sand-sized clastic sediment available in the littoral zone. At present, the beach ridges along the Kerala coast occur as isolated outcrops inland, and major roads in the area have been constructed on top of the beach ridge morphology, running parallel to the coast. The land use is highly altered due to the increased pressure of human settlements and agricultural activities.

Evidences of variation in sea level during late Pleistocene to Holocene times have been documented all along the Indian coastline. Majority of evidences of Holocene high sea-level stands can be found as fossil coral reefs, marine terraces, beach rocks, and strand lines during recession of the seawater, while those of sea-level low stands are submerged by present day sea-level (Banerjee, 2000; Thomas et al., 2009). Hashimi et al. (1995) reported evidences of a low sea-level stand based on the presence of submarine terraces at –92, –82 and –30 m depths on the west coast of India. According to Wagle et al. (1994), a series of submarine terraces, such as wave-cut terraces, coral/algal reef terraces and paleo-beach/barrier terraces occur at depths between –50 and –115 m on the western continental shelf of India between latitudes of 11°–20°N; their observations were based on geophysical investigations.

A number of beach ridges provide field evidence for a number of marine transgressive and regressive phases along the Kerala coast (Mallik, 1986). Kunte (1994) reported shore-parallel, multiple beach ridges behind the modern beaches along the coasts of Goa on the west coast of India. According to Nielson et al. (2006), it is possible to reconstruct the spatial and temporal development of a regional coastline by isotope dating of the individual ridges makes. A sea-level curve for the period from Late Pleistocene (14,500 years) to present on the west coast of India was proposed by Hashimi et al. (1995); they postulated that the sea-level has remained more or less stable during the last 7,000 years. A detailed review of literature reveals that investigations pertaining to Holocene sea-level changes, or paleoenvironmental changes, as inferred from foraminiferal assemblages and distributions have been rather inadequate from the Indian region. An effort has, therefore, been made in this study to interpret the paleoenvironmental changes that might have taken place along a part of the Kerala Coast in south-west India, based on benthic foraminiferal assemblages. Accordingly, a part of Kannur
District in Kerala was selected for this research venture, based on the observation of shell accumulations during a reconnaissance survey in this part of the district. This reconnaissance study also involved examination of randomly selected sub-surface samples for foraminifera, and confirmation of their presence in the samples gave the impetus for this research work. Thus, two locations were selected for digging trenches – Karakkeezhu and Kuduvathala – in relatively less inhabited and stratigraphically undisturbed areas.

1.2 Study area

Kannur (Cannanore) District (between the North latitudes 11°40’00” and 12°20’27” and East longitudes 75°10’00” and 75°56’30”), is one of the 14 districts of Kerala State, and one of the several coastal districts. It encompasses an area of 2,966 km², and is characterized by low topographical relief. The summer is hot, especially during the months of April and May, with a mean daily maximum temperature of 35°C, while it is quite cool during December and January with the minimum temperature ~20°C. According to Kunte (1994), the Kerala coast, which is bounded on its west by the Arabian Sea, is influenced by two monsoons with opposing winds. This seasonal reversal of wind direction causes a strong and humid southwest (SW) monsoon in Kerala during summer months (June through September) and a less intense and dry north-east (NE) monsoon in winter (Thamban et al., 2001). Out of an average annual rainfall of 3,438 mm, >80% occurs during the SW monsoon.

2. Materials and Method

Two trenches were dug up (using manual labor) at Karakkeezhu (12°04’ 36.66” N; 75°12’55.84” E) and Kuduvathala (12°04’44.2” N; 75°13’04.1” E) in a part of Kannur District, Kerala, during the month of April 2010 (Fig. 1). The depth of the trenches was variable and controlled mainly by the depth to the water table at each location. Sub-surface samples were collected at varying intervals from different layers in each trench; sampling interval was decided based on various observations in the field such as changes in color, texture, composition, and presence/absence of shell material. From the Karakkeezhu trench, sub-samples were collected at depths of 1.5–1.75, 1.75–2.00, 2.00–2.15, 2.15–2.30, 2.30–2.50, 2.50–2.70, 2.70–2.85, 2.85–3.00, 3.00–3.15, 3.15–3.25, 3.25–3.40 and 3.40–3.60 m. The trench at Kuduvathala was sub-sampled at 0.15–0.40, 0.40–0.60, 0.60–0.75, 0.75–0.90, 0.90–1.05, 1.05–1.20, 1.20–1.35, 1.35–1.50, and 1.50–1.65 m depths. Each sub-surface sediment sample collected was immediately packed in a polythene zip-lock cover and neatly labeled with all details of the location.

Portions of all sub-surface samples (21 in all) were wet-sieved using an ASTM sieve no. 230 (mesh opening of 63 microns), so that the mud (silt + clay) content was removed, and then oven-dried at 50°C. Each sediment sub-sample was cone-and-quartered (to get a representative sample), and 20 gm of each sieved sub-sample was subdivided into four fractions using ASTM sieve nos. 45, 80 and 120. Foraminifera from the +45 and +80 fractions were hand-picked using a .00 soft-bristled brush under a stereo zoom binocular microscope (NOVEX-Holland). Foraminifera from the +120 and –120 fractions were separated by flotation in CCl₄ (carbon tetrachloride). The separated foraminifers were mounted on 24-chambered micropaleontological slides genera-wise after which the hypotypes picked were identified species-wise (Loeblich and Tappan, 1987).
Utility of sub-surface benthic foraminiferal assemblages to decipher the paleoenvironment of the north-west Kerala coast

3. Results and discussion

Based on this classification, 20 foraminiferal species belonging to 15 genera and 4 suborders were identified; the distribution of species among the suborders is depicted in Figure 2.

![Figure 1: Location map of the study area showing the trench locations](image1)

**Figure 1**: Location map of the study area showing the trench locations

**Figure 2**: Pie diagram showing distribution of the suborders in the study area.
A check-list of the foraminiferal species (in alphabetical order) identified from the two trench locations at Karakkeezhu and Kuduvathala is given below:

1. *Ammonia beccarii* (Linnaeus, 1758)
2. *Ammonia dentata* (Parker and Jones, 1865)
3. *Ammonia tepida* (Cushman, 1926)
4. *Asterorotalia inflata* (Millett, 1904)
5. *Cribranonion simplex* (Cushman, 1933)
6. *Elphidium discoidale* (d’Orbigny, 1839)
7. *Elphidium norvangi* Buzas, 1977
8. *Eponides repandus* (Fichtel and Moll, 1798)
9. *Fissurina laevigata* Reuss, 1850
10. *Globigerina bulloides* d’Orbigny, 1826
11. *Globigerinoides ruber* (d’Orbigny, 1839)
12. *Helenina anderseni* (Warren, 1957)
13. *Loxostomina limbata* (Brady, 1881)
14. *Nonionella stella* Cushman and Moyer, 1930
15. *Nonionellina labradorica* (Dawson, 1860)
16. *Nonionoides boueanum* (d’Orbigny, 1846)
17. *Nonionoides elongatum* (d’Orbigny, 1826)
18. *Pararotalia calcar* (d’Orbigny, 1826)
19. *Quinqueloculina seminulum* (Linnaeus, 1758)
20. *Quinqueloculina tropicalis* Cushman, 1924

Figure 2 shows that rotaliids dominate the four suborders represented in the study area. When individual trenches are considered, however, the abundance of individual species was observed to be variable. In the Karakkeezhu trench, *Ammonia beccarii* is the dominant species, especially from a depth of 2.00 to 3.60 m, beyond which is not known as the water table was encountered. Moreover, a gradual change in color (from relatively darker to lighter) was noticed in the field, possibly indicative of the last few layers of the dark-colored sediment layers. Within these lower layers, *A. beccarii* alone accounted for 18.0 to 44.2% of the total populations counted from the various sub-surface samples. In the upper layers, though, more or less equal abundances of *A. beccarii, Pararotalia calcar, Helenina anderseni* and *Elphidium norvangi* were observed (Tables 1a, 1b). The overall benthic foraminiferal assemblage is supplemented by such taxa as *Ammonia tepida, Cribranonion simplex* and *Nonionoides elongatum*, with textulariids being completely absent. This assemblage is characteristic of modern-day inter-tidal and estuarine environments (Reddy and Reddy, 1982; Yeruku Naidu and Subba Rao, 1988).

| Name of the species | Trench 1 – KARAKKEEZHU |
|---------------------|------------------------|
|                     | Depth from the subsurface in m |
|                     | 1.50 to 1.75 | 1.75 to 2.00 | 2.00 to 2.15 | 2.15 to 2.30 | 2.30 to 2.50 | 2.50 to 2.70 |
| *Ammonia beccarii*  | 22.2 | 18.0 | 33.5 | 21.9 | 24.8 | 18.2 |
| *Ammonia dentata*   | 11.1 | ..... | 14.2 | ..... | 6.8 | 2.7 |

Table 1a: Individual species population percentages from Karakkeezhu trench
Utility of sub-surface benthic foraminiferal assemblages to decipher the paleoenvironment of the north-west Kerala coast

| Species              | 2.70 to 2.85 | 2.85 to 3.00 | 3.00 to 3.15 | 3.15 to 3.25 | 3.25 to 3.40 | 3.40 to 3.60 |
|----------------------|--------------|--------------|--------------|--------------|--------------|--------------|
| Ammonia beccarii     | 25.1         | 26.6         | 33.2         | 29.6         | 30.2         | 44.2         |
| Ammonia dentata      | 1.3          | 3.9          | 10.6         | 5.1          | 2.0          | 0.7          |
| Ammonia tepida       | 10.4         | 11.5         | 11.1         | 11.5         | 15.1         | 12.1         |
| Asterorotalia inflata| 2.7          | 1.9          | 6.0          | 4.3          | 4.4          | 1.7          |
| Cribronorion simplex | 10.2         | 10.6         | 5.6          | 6.1          | 7.5          | 4.4          |
| Elphidium discoidale | 5.5          | 2.9          | ..           | 1.3          | 1.8          | 0.6          |
| Elphidium norvangi   | 1.3          | 2.9          | 2.8          | 1.8          | 2.2          | 1.7          |

Table 1b: Individual species population percentages from Karakkeezhu trench (contd.)
Utility of sub-surface benthic foraminiferal assemblages to decipher the paleoenvironment of the north-west Kerala coast

| Species                  | 0.15 to 0.40 m | 0.40 to 0.60 m | 0.60 to 0.75 m | 0.75 to 0.90 m | 0.90 to 1.05 m |
|--------------------------|----------------|----------------|----------------|----------------|----------------|
| Eponides repandus        | 2.7            | ......          | 1.4            | 0.3            | 0.2            | ......          |
| Fissurina laevigata      | 5.5            | ......          | 1.1            | 0.2            | 0.3            | ......          |
| Globigerinoides ruber    | ......          | 1.0            | 0.7            | 0.2            | 0.3            | ......          |
| Helenina anderseni       | 5.5            | 3.9            | 10.9           | 13.2           | 11.6           | 15.7           |
| Loxostomina limbata      | ......          | 3.9            | ......          | 0.3            | 0.3            | ......          |
| Nonionella stella       | ......          | 2.9            | 2.5            | 2.2            | 1              | 1.3            |
| Nonionellina labradorica| 1.3            | 2.9            | ......          | 0.5            | 0.8            | ......          |
| Nonionoides boueanum     | 6.2            | 7.7            | 3.2            | 3.2            | 2.4            | 1.8            |
| Nonionoides elongatum    | 4.1            | 1.9            | 3.5            | 9.9            | 12.5           | 6.8            |
| Pararotalia calcar       | 13.1           | 10.7           | 6.0            | 9.2            | 6.5            | 8.9            |
| Quinqueloculina seminulum| 1.1            | 1.0            | 0.7            | 0.3            | 0.2            | ......          |
| Quinqueloculina tropicalis| 2.7            | 1.9            | 0.7            | 0.4            | 0.3            | ......          |
| Total counts             | 72             | 102            | 283            | 966            | 1,192          | 1,087          |

In contrast, the sub-samples from the trench at Kuduvathala yielded very high abundances of *Ammonia beccarii*, with its population percentages ranging from 62.4 to 78.0%; other such species as *Ammonia tepida*, *Helenina anderseni* and *Pararotalia calcar* are just secondary taxa constituting the benthic foraminiferal assemblage (Table 2). The predominance of a single species in the entire depth range of 0.15 to 1.65 m below the surface suggests paleoenvironmental conditions that should have been favorable for a highly adaptable species as *A. beccarii*, but not favorable enough for other species to inhabit the sediment substrate, as revealed by the population percentages of its associated taxa, particularly in the uppermost sub-sample (0.15 to 0.40 m). The vertical distribution of the other species in this trench is indicative of conditions changing from an initial, considerably reduced-salinity (hyposaline) paleoenvironment, to a more euhaline environment favoring inhabitation of other species composing the benthic foraminiferal assemblage at this location. The general increase in the total number of tests counted in the sub-samples of this trench supports this interpretation as well.

**Table 2a:** Individual species population percentages from Kuduvathala trench

| Name of the species | Trench – KUDUVATHALA |
|---------------------|-----------------------|
|                     | Depth from the subsurface in m |
|                     | 0.15 to 0.40 m | 0.40 to 0.60 m | 0.60 to 0.75 m | 0.75 to 0.90 m | 0.90 to 1.05 m |
| Ammonia beccarii    | 76.9            | 74.2            | 78.0            | 63.3            | 62.4            |
| Ammonia dentata     | ......          | ......          | ......          | 1.0             | ......          |
| Name of the species         | Trench – KUDUVATHALA |
|----------------------------|----------------------|
|                            | Depth from the subsurface in m |
|                            | 1.05 to 1.20 | 1.20 to 1.35 | 1.35 to 1.50 | 1.50 to 1.65 |
| Ammonia beccarii           | 69.6          | 69.8          | 74.6          | 77.5          |
| Ammonia dentata            | 0.6           | 0.7           | 0.7           | 0.3           |
| Ammonia tepida             | 14.3          | 12.5          | 8.7           | 8.2           |
| Asterorotalia inflata      | 0.4           | 1.1           | 0.9           | 0.6           |
| Cribriconion simplex      | 1.3           | 0.9           | 0.7           | 1.0           |
| Elphidium discoidale       | 0.4           | 0.7           | 0.7           | 1.0           |
| Elphidium norvangi         | .....          | 0.9           | 0.3           | 1.4           |
It is evident from Tables 1 and 2 that the overall dominance of *Ammonia beccarii*, which is a cosmopolitan species with records world over (Murray, 1991), and the associated taxa constituting the assemblages from these two trenches suggest a nearshore inter-tidal environment possibly connected with the Arabian Sea. The presence of few tests of planktic species such as *Globigerina bulloides* and *Globigerinoides ruber*, suggests that should have drifted in due to the action of tidal currents; both are essentially marine taxa and hence support the marine connection. Few tests of *Ammonia dentata*, a nearshore species with short, blunt spines, also lend sufficient credentials to this interpretation. According to Ragothaman (1974) and Rajeshwara Rao (1998), tests of *A. dentata* with short, blunt spines are characteristic of nearshore waters; these should have drifted towards inland along with the globigerinids. The poor representation of miliolids could be attributed to reduced salinities, while the complete absence of arenaceous, agglutinated forms could be due to their breakdown either during processing as most of them are quite fragile, or due to the action of currents (M.D.Brasier, 2011; personal communication). Carbon isotopic dating of sediment and mollusk shell samples has yielded $^{14}$C dates of 5,100±100 years and 5,600±80 and B.P., respectively. This implies that around 5,000 to 5,500 years B.P., the region around Karakkeezhu and Kuduvathala in Kannur District, North Kerala, was initially a brackish water, hyposaline environment that gradually changed into a mid-tidal to shallow tidal, sheltered, near-normal salinity environment that was connected to the Arabian Sea (B.W.Hayward, 2011; personal communication).

### 4. Conclusions

Sub-surface sediment samples from two onshore trenches dug up at Karakkeezhu and Kuduvathala in Kannur District of North Kerala yielded a benthic foraminiferal assemblage...
Utility of sub-surface benthic foraminiferal assemblages to decipher the paleoenvironment of the north-west Kerala coast

Adarsh P, Rajeshwara Rao

International Journal of Environmental Sciences Volume 2 No.3, 2012

dominated by *Ammonia beccarii*, and complemented by other species such as *Ammonia tepida, Helenina anderseni, Pararotalia calcar* and *Nonionoides elongatum*, all of which are typical of modern-day brackish to estuarine settings. All the trenches are ~5 to 7 km onshore from the present-day shoreline on the south-west coast of India. $^{14}$C dates of mollusk shells and sediment samples, and the distribution of benthic foraminiferal species in the trenches examined reveal that ~5,000 to 5,500 years B.P., this region was initially a brackish water, hyposaline environment, but gradually became a mid-tidal to shallow tidal, sheltered, near-normal salinity environment connected with the Arabian Sea.

Acknowledgement

The authors are extremely grateful to Prof. R. Ramesh, PRL, Ahmedabad, for providing the $^{14}$C dates for the sediment and shell samples. PA is thankful to the Rajiv Gandhi National Fellowship, University Grants Commission, Government of India, for funding this research endeavor (F.14-2(SC)/2008(SA-III), dated 31.03.2009).

5. References

1. Banerjee, P.K., (2000), Holocene and Late Pleistocene relative sea level fluctuations along the east coast of India, Marine Geology, 167(3–4), pp 243-260.

2. Boomer, I., (1998), The relationship between meiofauna (ostracoda, foraminifera) and tidal levels in modern inter-tidal environments of north Norfolk: A tool for paleoenvironmental reconstruction, Bulletin of the Geological Society of Norfolk, 46, pp 17-26.

3. Boomer, I. and Godwin, M., (1993), Paleoenvironmental reconstruction in the Breydon Formation, Holocene of East Anglia, Journal of Micropaleontology, 12(1), pp 35-46.

4. Gehrels, W.R., (1994), Determining relative sea-level change from salt marsh foraminifera and plant zones on the coast of Maine, USA, Journal of Coastal Research, 10(4), pp 990-1009.

5. Hashimi, N.H., Nigam, R., Nair, R.R. and Rajagopalan, G., (1995), Holocene sea level fluctuations on western Indian continental margin: An update, Journal of the Geological Society of India, 46(2), pp 157-162.

6. Haslett, S.K., Davies, P. and Strawbridge, F., (1998), Reconstructing Holocene sea-level change in the Severn Estuary and Somerset Levels: The foraminifera connection, Archaeology in the Severn Estuary, 8, pp 29-40.

7. Hockey, P.A.R. and Branch, G.M., (1997), Criteria, objectives and methodology for evaluating marine protected areas in South Africa, South African Journal of Marine Science, 18(1), pp 369-383.

8. Kunte, P.D., (1994), Sediment transport along the Goa-north Karnataka coast, western India, Marine Geology, 118(3–4), pp 207-216.

9. Lambeck, K., Esat, T.M. and Potter, E–K., (2002), Links between climate and sea levels for the past three million years, Nature, 419(6903), pp 199-206.
Utility of sub-surface benthic foraminiferal assemblages to decipher the paleoenvironment of the north-west Kerala coast

10. A.R. Loeblich, Jr. and H. Tappan, (1987). Foraminiferal Genera and their Classification, Von Nostrand Reinhold, New York, 970 p.

11. Mallik, T.K., (1986), Micromorphology of some placer minerals from Kerala beach, India, Marine Geology, 71(3–4), pp 371-381.

12. J.W. Murray, (1991). Ecology and Palaeoecology of Benthic Foraminifera, Longman Scientific and Technical, Harlow, U.K., 397 p.

13. Narayana, A.C., (2007). Peat deposits of the west coast of India: Implications for environmental and climate changes during late Quaternary, Journal of Coastal Research, SI 50 (Proceedings of IX International Coastal Symposium), pp 683-687.

14. Nielsen, A., Murray, A.S., Pejrup, M. and Elberling, B., (2006), Optically simulated luminescence dating of a Holocene beach ridge plain in Northern Jutland, Denmark, Quaternary Geochronology, 1(4), pp 305-312.

15. Pearson, I., Funnell, B.M. and McCave, I.N., (1990), Sedimentary environments of the sandy barrier/tidal marsh coastline of north Norfolk, Bulletin of the Geological Society of Norfolk, 39, pp 3-44.

16. Peltier, W.R., (2002), On eustatic sea level history: Last Glacial Maximum to Holocene, Quaternary Science Reviews, 21(1–3), pp 377-396.

17. Ragothaman, V., (1974). The study of foraminifera from off Porto Novo, Tamil Nadu State, Unpublished Ph.D. thesis, University of Madras, Madras, India.

18. Rajeshwara Rao, N., (1998). Recent foraminifera from inner shelf sediments of the Bay of Bengal, off Karikkattukuppam, near Madras, South India, Unpublished Ph.D. thesis, University of Madras, Chennai, India.

19. Reddy, A.N. and Reddy, K.R., (1982), Recent benthonic foraminifera from the Araniyar River estuary, Tamil Nadu, India, Indian Journal of Marine Sciences, 11, pp 249-250.

20. Roff, J.C., Taylor, M.E. and Laughren, J., (2003), Geophysical approaches to the classification, delineation and monitoring of marine habitats and their communities, Aquatic Conservation: Marine and Freshwater Ecosystems, 13(1), pp 77-90.

21. Scott, D.B. and Medioli, F.S., (1978), Vertical zonation of marsh foraminifera as accurate indicators of former sea levels, Nature, 272(5653), pp 528-531.

22. Scott, D.B. and Medioli, F.S., (1986). Foraminifera as sea-level indicators, In: Van de Plassche, O. (Ed.), Sea-Level Research: A Manual for the Collection and Evaluation of Data, Geo-Books, Norwich, 435-456.

23. Shennan, I., Peltier, W.R., Drummond, R. and Horton, B.P., (2002), Global to local-scale parameters determining relative sea-level changes and the post-glacial isostatic adjustment of Great Britain, Quaternary Science Reviews, 21(1–3), pp 397-408.

24. Thamban, M., Rao, V.P., Schneider, R.R. and Grootes, P.M., (2001), Glacial to Holocene fluctuations in hydrography and productivity along the southwestern
Utility of sub-surface benthic foraminiferal assemblages to decipher the paleoenvironment of the north-west Kerala coast

continental margin of India, Palaeogeography, Palaeoclimatology, Palaeoecology, 165(1–2), pp 113-127.

25. Thomas, A.L., Henderson, G.M., Deschamps, P., Yokoyama, Y., Mason, A.J., Bard, E., Hamelin, B., Durand, N. and Camoin, G., (2009), Penultimate deglacial sea-level timing from uranium/thorium dating of Tahitian corals, Science, 324(5931), pp 1186-1189.

26. Wagle, B.G., Vora, K.H., Karisiddaiah, S.M., Veerayya, M. and Almeida, F., (1994), Holocene submarine terraces on the western continental shelf of India: Implications for sea-level changes, Marine Geology, 117(1–4), pp 207-225.

27. Williams, A. and Bax, N.J., (2001), Delineating fish-habitat associations for spatially based management: An example from the south-eastern Australian continental shelf, Marine and Freshwater Research, 52(4), pp 513-536.

28. Yeruku Naidu, T. and Subba Rao, M., (1988), Foraminiferal ecology of Bendi Lagoon, east coast of India, Revue de Paleobiologie, 2(2), pp 851-858.