Benthic foraminifera as an Environmental Proxy Linked to Monsoon Changes from Beach Sediments of Kerala Coast, India

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Abstract
The study on 290 sediment sub samples have been analyzed for benthic foraminifera from Chellanam andhakaranazhi and Azheekal beach sediments of Kerala coast, India. A total 36 species of benthic foraminifera were recorded in the study. Benthic foraminiferal faunal study, dry samples were sieved over 125 μm-size sieve and split into suitable aliquots to obtain approximately 250 specimens of benthic foraminiferal species identified and counted. The oceanographically most dominant benthic foraminiferal species are Ammonia beccarii followed by Ammonia gaimardii, Cancris oblongus, Discopulvinulina bertheloti, Gyroidinoides nitidula and Quinqueloculina seminulum were identified from the study region. The Chellanam beach sediment of benthic foraminifera species suggests that a high productivity species like Ammonia beccarii, Ammonia gaimardii, Anomalina globulosa and Quinqueloculina seminulum from 100 to 70cm and 30 to 5cm indicates of high organic productivity during the summer winds, whereas surface productivity changes may also be driven by winter winds from 70 to 30cm.

Species of Cancris oblongus from 25 to 15cm indicate by tolerance to mesotrophic-eutrophic conditions and Gyroidinoides nitidula indicates low organic carbon flux or pulsed food supply and high oxygen environment during 50 to 23cm. From Anthakaranazhi beach sediment of benthic foraminifera species are Ammonia beccarii, Ammonia gaimardii from 100 to 80cm and 20 to 5cm indicates of shallow-marine environment.

From 70 to 40cm depth, species of Gyroidinoides nitidula indicates low organic carbon flux or pulsed food supply and high oxygen environment. From Azheekal beach sediment as an instance high productivity species of Ammonia beccarii and Ammonia gaimardii shows an abrupt increase and Cancris oblongus, Gyroidinoides nitidula, Gyroidinoides neosoldanii and Miliolinella subrotunda showing abrupt decrease at 90 to 70cm and 18 to 5cm depth, suggest that rapid response of benthic foraminifera to the organic flux to the shallow seafloor.

Keywords: Benthic foraminifera, Paleoproduction changes, Indian monsoon, Kerala coast, Eastern Arabian Sea.

Introduction
Foraminifera are primarily marine organisms with a single cell enclosed in a hard protective wrap called test, depending on their mode of living. Foraminifera can be divided into two broad categories, viz. Planktic foraminifera, those that live in the upper water column and benthic foraminifera, those that live on the seafloor or within ocean sediments. Foraminifera are classified largely on the basis of the composition and morphology of the test. In generally accepted classification of the foraminifera is based on19. Foraminifera have been utilized for biostratigraphy for a number of years and have also been recognized an extremely constructive in paleoceanographic and paleoclimatological reconstruction.

Benthic foraminifera are dwelling on the sea floor and are good indicator of bottom water conditions. Changes in species diversity of benthic ratios, shell-type ratios and test morphology have all been utilized to for number of problems of modern environment, pollution monitoring, as well as an interpretation of fossil records. It is the presence of characteristic morphgroups under particular environments that has led to wide application of foraminifers for paleoclimatic reconstruction studies in different parts of the world oceans.

Understanding of the natural environmental changes of our planet on longer timescales can be achieved by the study of natural phenomena which drive climate variability. Information about past climate is obtained by piecing evidence together from various climate proxies. By analogy with the indicators of the present climate, the paleoclimatic proxies can be used to deduce past climates and climatic zones. Principal sources of proxy data for paleoclimatic reconstructions include historical records, glaciological records (e.g. ice cores), continental records (e.g. tree rings) and marine records (e.g. ocean sediments, foraminifera). For the development of a detailed and reliable paleorecord, accurate direct dating or correlation of discrete intervals with other established records is necessary for the conversion of the consistent record into the time domain.

The oceans, which cover nearly 71% of the Earth’s surface and store an immense amount of heat energy, play a fundamental and complex role in regulating climate. Billions of tonnes of sediments accumulate in the ocean basins every
year. The nature of such sediments may be indicative of climate conditions near the ocean surface or on the adjacent continents. Marine sediments preserve a wealth of information for the reconstruction of ocean and climate history in the form of their microfossil assemblage, organic matter, elemental and isotopic composition of fossils or other sediment components. Indeed, much of the recent research by geologists on modern deep-sea fauna has been driven by a desire to develop reliable tools for use in paleoceanography.

*Benthic foraminifera* are applied as proxies to understand deep-sea oxygenation (includes reconstruction of biogeochemical cycling, ocean circulation, assessment of organic pollution or estimating preservation-potential of organic matter), paleo bathymetry (geohistory analysis of sedimentary basins) and organic flux (reconstruction of bioproduction i.e. quality and quantity of organic matter). The recent *benthic foraminifera* within the sediment are controlled largely by a combination of oxygen content and organic carbon levels.\(^6,16\)

Oxygen decreases close to the sediment surface and becomes a limiting factor, favours low-oxygen species from the eutrophic regions. Benthic foraminiferal species abundance and occurrence are directly affected by organic flux\(^2,14,15\) and seasonality whereas resource and competition have long term effects on microhabitat position. The seasonal changes in the oceanographic parameters are reflected in benthic foraminiferal productivity and assemblages. *Benthic foraminifera* are controlled by biological parameters like temperature, salinity, dissolved oxygen content of the bottom water masses, surface productivity and availability of nutrients and carbonate saturation.\(^3,4,31,34\)

The study on benthic foraminiferal faunal record to understand the reconstruction of paleoceanographic and paleoclimatology changes from the Chellanam, Anthakaranazhi and Azheekal beach sediments of Kerala coast, India.

**Location map and Oceanographic setting:** The present study is an important part of the South Indian Precambrian terrain bounded by the Western Ghats on the east and Arabian Sea on the west. In the study, beach sediment samples were selected from Chellanam beach (Latitude 9\(^\circ\)47.14’N, Longitude 76\(^\circ\)16.40’E) Anthakaranazhi beach (Latitude 9\(^\circ\)44.27’N, Longitude 76\(^\circ\)17.04’E) and Azheekal beach (Latitude 9\(^\circ\)44.59’N, Longitude 76\(^\circ\)17.02’E) located in Kerala coast, India. The study area is located approximately 40 kms from fort Cochin in the north to Chellanam, Anthakaranazhi and Azheekal beach in the south for a length of approximately 26 km. The study area’s eastern side is the largest backwater system in the west coast of India and is the largest water body in Kerala.

In the region of 41 rivers brings vast amount of sediment. The deltas are not produced due to the high wave energy condition of the coast. The coastal and near shore sediments were studied over the past few decades by several researchers on various aspects of such as sea level changes, sedimentation and paleoenvironment in off-shore and on-shore region. The micropaleontological, sedimentological, stable isotope studies and calcium carbonate records in ocean sediments provide the greatest evidence of climatic changes and sea level rises from the Late-Quaternary period.\(^34,35\) (Fig. 1).

**Material and Methods**

In this study, 290 sediment sub samples have been analyzed for *Benthic foraminifera* from beach cores Chellanam, Anthakaranazhi and Azheekal beach sediments of Kerala coast, India. From Chellanam beach core (100 subsamples), Anthakaranazhi beach core (100 subsamples) and Azheekal beach core (90 subsamples) collected for the present study. The core length is (1m, 1m and 0.90cm), each sub-sampled at every 1cm intervals. The recovered core-sediment samples represent a single lithologic unit, dominantly composed of fine sand. The sediment colour varies from light grey, dark grey, brown, blackish and light brownish grey.

290 sediment sub samples were soaked in water with half a spoon of baking soda for 8 to 10 hours. Soaked samples were washed with water over 63µm-size sieve and oven-dried at ~50°C temperature. The dry samples were transferred to labeled Borosil glass vials. For benthic foraminiferal faunal study, dry samples were sieved over 125 µm-size sieve and split into suitable aliquots to obtain ~250 specimens of *Benthic foraminifera* identified and counted.

**Results**

The study is to reconstruct the paleoenvironmental circumstances in the Chellanam, Anthakaranazhi and Azheekal beach sediments of the Kerala coast, India. A total of 36 species of benthic foraminifera were recorded in this study. The distribution pattern of recent benthic foraminiferal species are *Ammonia beccarii* followed by *Ammonia gaimardii*, *Anomalina globulosa*, *Astronion umbilicatulum*, *Cancris oblongus*, *Calcarea venusta*, *Cibicides bradyi*, *Discopulvinula bertheloti*, *Discopulvinula subbertheloti*, *Elphidium advena*, *Gyroidinoides cibaoensis*, *Gyroidinoides neosoldani*, *Gyroidinoides nitidula*, *Quinqueloculina seminulum* and *Textularia* sp. as reported in this study. *Benthic foraminifera* show pronounced changes from these cores Chellanam, Anthakaranazhi and Azheekal beach sediment.

Core Chellanam beach sediment of benthic foraminiferal faunal record suggests high productivity species are *Ammonia beccarii*, *Ammonia gaimardii*, *Anomalina globulosa* and *Quinqueloculina seminulum* from 100 to 70cm and 30 to 5cm depth as an increasing trend indicate by high organic productivity during the summer winds whereas surface productivity changes may also be driven by winter winds from 70 to30cm depth (Fig. 2).
Fig. 1: Location map shows core-sediment from Chellanam and hakaranazhi and Azheekal beach sediment of Kerala coast, India. Ocean currents prevalent during summer monsoon (Jul/Aug) indicated by solid/broken lines with arrows and annual sea surface salinity indicated by dotted lines, values in psu in the Arabian Sea.

Fig. 2: Percent distribution of benthic foraminiferal species Ammonia beccarii (panel a), Ammonia gaimardii (panel b), Anomalina globulosa (panel c), Quinqueloculina seminulum (panel d), Gyroidinoides nesoldanii (panel e) and Gyroidinoides cibaoensis (panel f) at core Chellanam beach sediment located in Kerala coast, India.
Fig. 3: Percent distribution of benthic foraminiferal species *Cancris oblongus* (panel a), *Gyroidinoides nitidula* (panel b) and *Discopulvinulina bertheloti* (panel c) at core Chellanam beach sediment located in Kerala coast, India.

The moderate value of *Cancris oblongus* from 25 to 15cm depth indicates tolerance to mesotrophic-eutrophic conditions. Species of *Gyroidinoides nitidula* indicates of low organic carbon flux or pulsed food supply and high oxygen environment from 50 to 23cm depth intervals (Fig. 3). Andhakaranazhi beach sediment of benthic foraminifer *Ammonia beccarii* and *Ammonia gaimardii* from 100 to 80cm and 20 to 5cm depth shows an increasing trend indicate by shallow-marine environment (Fig. 4). The interval of 70 to 40 cm depth, species of *Gyroidinoides nitidula* indicates low organic carbon flux or pulsed food supply and high oxygen environment. From 50 to 20 cm depth, species of *Gyroidinoides cibaoensis* has been described from oxygenated deep waters of the north-western Indian Ocean receiving intermediate flux of organic matter (Fig. 5).

The Azheekal beach core-sediment for instance high productivity species like *Ammonia beccarii* and *Ammonia gaimardii* shows an abrupt increase and *Cancris oblongus*, *Gyroidinoides nitidula*, *Gyroidinoides nesoldanii* and *Miliolinella subrotunda* shows abrupt decrease at 90 to 70cm and 18 to 5cm depth (Figs. 6 and7). This suggests rapid response of Benthic foraminifera to the organic flux to the shallow seafloor when summer monsoon was stronger. The interval of 70 to 20cm depth as a decrease trend indicates of low organic productivity while summer monsoon was weakest. Species of *Cancris oblongus*, *Gyroidinoides nitidula*, *Gyroidinoides nesoldanii* and *Miliolinella subrotunda* shows an increase trend indicating of winter monsoon was stronger from 60 to 20cm depth.
Fig. 4: Percent distribution of dominant benthic foraminiferal species *Ammonia beccarii* (panel a), *Ammonia gaimardii* (panel b), *Anomalina globulosa* (panel c), *Cancris oblongus* (panel d) and *Discopulvinulina bertheloti* (panel e) at core Anthakara Nazhi beach sediment located in Kerala coast, India.
Discussion

The number of novel foraminiferal studies was established to study paleomonsoonal/paleoclimatic changes from west coast of India\textsuperscript{25,26}. Benthic foraminiferal species to survive in various microhabitats in the upper sediment layers\textsuperscript{10,16,17}. Therefore, some of them are able to precisely record bottom water characteristics, while others reveal pore water properties. This group has been found in both oxygen-depleted and oxygen-rich environments, oligotrophic and eutrophic settings, cold and warm spheres and high and low energy environments, having both epibenthic and endobenthic microhabitats. The recent studies suggest that the benthic faunal composition is strongly connected to the oxygen content of the ambient water, productivity of the overlying surface waters and the delivery of organic matter to the seafloor\textsuperscript{8,21,37}. The role of foraminifera in various issues associated to climate/environmental changes has long been established. Accordingly, these microorganisms have emerged as reliable proxy to paleoclimatic/paleoenvironmental condition\textsuperscript{32}. Benthic foraminifer’s species Ammonia beccarii indicates of euryhaline, shallow sea environment\textsuperscript{38}. Sgarrella et al\textsuperscript{33} suggested that Ammonia beccarii are indicative of a shallow-marine environment with sandy bottom. Species of Cancris oblongus indicate by tolerance to mesotrophic-eutrophic conditions and this species was maintained a high abundance along with opportunistic species as well as oxygenated bottom waters in low oxygen environments.

Tyson et al\textsuperscript{36} suggested that Cancris oblongus has been considered as a typical of well-oxygenated bottom waters and pulsed food supply with low to intermediate organic flux and high seasonality. Ecological preference of Discopulvinulina bertheloti is characteristically an
intermediate organic flux to the sea floor.\textsuperscript{11} Species \textit{Discopalvulina bertheloti} has commonly been reported as a surface dweller connected with well-aerated bottom waters and low organic flux in the Atlantic\textsuperscript{5,9,20}. \textit{Gyroidinoides nitidula}, a dominant species, was found occupying shallow infaunal microhabitats\textsuperscript{27}. Species of \textit{Gyroidinoides nitidula} indicate limited food environments in the Mediterranean Sea\textsuperscript{7} and pulsed food supply in the South Atlantic\textsuperscript{22}. Gupta et al\textsuperscript{13} suggested that \textit{Gyroidinoides nitidula} also indicates an environment with intermediate organic flux and intermediate to high seasonality during the Plio-Pleistocene.

Fig. 6: Percent distribution of benthic foraminiferal species \textit{Ammonia beccarii} (panel a) and \textit{Ammonia gaimardii} (panel b) from Chellanam Beach\textsuperscript{29}. Combined with species of \textit{Ammonia beccarii} (panel c), \textit{Ammonia gaimardii} (panel d) from Anthakara Nazhi beach sediment and \textit{Ammonia beccarii} (panel e), \textit{Ammonia gaimardii} (panel f) from Azheekal beach sediment\textsuperscript{30} located in Kerala coast, India.
Fig. 7: Percent distribution of dominant benthic foraminiferal species *Cancris oblongus* (panel a), *Gyroidinoides nitidula* (panel b), *Gyroidinoides nesoldanii* (panel c) and *Miliolinella subrotunda* (panel d) at core Azheekal beach sediment located in Kerala coast, India

This species indicate by low organic carbon flux or pulsed food supply and high oxygen content of deep-sea environment. Gupta suggested that *Gyroidinoides cibaoensis* has been described from low oxygenated deep waters of the north-western Indian Ocean with moderate flux of organic matter.

Gupta et al. suggested that genus *Quinqueloculina* has been pragmatic in cold and well-oxygenated deep waters with muscularily pulsed food supply. Species of *Quinqueloculina seminulum* indicates of near-shore shallow marine environment and is also found in outer and inner shelf in high-energy environments. Altenbach et al. and Murray suggested that genus *Textularia* prefers to lives in coarse sediments and high energy environments. Species of *Textularia* spp. has been suggested in coarse sediments and high speed of bottom currents. Species of *Sigmoilopsis schlumbergeri* populations are marked by low organic carbon flux or pulsed food supply and high oxygen content environment. *Sigmoilopsis schlumbergeri* is abundant in the top 1.5cm of sediments of the seep zone in Eel River.

Numerous recent studies indicate that benthic foraminiferal faunal assemblages are strongly correlated to the oxygen content of the ambient water, productivity of the overlying surface waters and the delivery of organic matter to the seafloor. Benthic foraminiferal fauna in the Arabian Sea are distinct than those from the southern Indian Ocean because the former is climatically and oceanographically a distinct region marked by high organic food production and flux to the sea floor causing a prominent Oxygen Minimum Zone (OMZ) at water depths ranging from 150 to 1200 m. In this study, benthic foraminiferal faunal record have been used to understand watermass changes in the southeastern Arabian Sea driven by monsoon wind impact in the surface ocean.

**Conclusion**
A total of 36 benthic foraminiferal species were identified from the study area. Benthic foraminiferal faunal records are
controlled by the quantity of organic matter getting the seafloor and revolve by the surface ocean productivity. The study area suggests that fine sediments in Chellanam andhakaranazhi and Azheekal beach are much favourable for blooming of foraminiferal species. The most relative abundance of dominated benthic foraminiferal species such as Ammonia beccarii followed by Ammonia gaimardii, Cancris oblongus, Gyroidinoides nitidula, Gyroidinoides nesolatii and Milolimella subrotunda are showing pronounced changes from the study.

The high organic productivity, the low salinity condition and fine sediment texture are the most crucial factors devious benthic foraminiferal faunal distribution from Chellanam andhakaranazhi and Azheekal beach sediment region.

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References


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