

Recent Marine Microfauna from the Continental Margin, West Coast of India*

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Brady's¹ monumental work on foraminifera is based upon HMS CHALLENGER (1973-76) collections of sea floor sediment samples from the three major oceans. Chapman², Heron Allen and Earland³ and Stubbings^{4,5} made specific contributions to our knowledge of foraminifera of the Arabian Sea. Earlier references to foraminifera of the Indian Ocean region date back to the times of Fichtel and Moll⁶ and d'Orbigny⁷.

The International Indian Ocean Expedition (IIOE) sponsored by UNESCO (1961-65) initiated a major thrust for a detailed, in-depth study of various aspects of the Indian Ocean. However, detailed faunal observations, distribution patterns, implication and inference studies of the shelves of India were supplemented by Indian studies. Though there have been a few occasional studies by workers from universities, Geological Survey of India, and other organizations, major contributions to our knowledge of foraminifera and other microfauna of Indian margins has been made from this Institute. The oceanographic vessels that have helped in this task are the ocean going RV INS KISTNA of India during IIOE, RV OCEANOGRAPHER of USA, RV GAVESHANI of NIO and other coastal vessels like TARINI. This paper presents a review of the status of foraminiferal studies in relation to the Arabian Sea.

Planktonic Foraminifera

Planktonic foraminifera, because they are world-wide in distribution and subject to rapid dispersal by ocean currents, are used in interpreting the Recent as well as paleoenvironments. They are frequently used as stratigraphic markers or guides in Cretaceous and Tertiary sediments.

Twenty-two planktonic species were identified from the shelf and slope of the West coast of India. Two specific features of this assemblage require special mention:

(i) *Globigerina hexagona* and *Globoquadrina conglomerata*, which apparently disappeared from the Atlantic at the end of the Last Interglacial (50,000-1,000,000 years ago), are found to be living in this region of the Indian Ocean (and also Pacific) even today⁸. Some of the associated species have a range from Miocene to Recent.

(ii) *Neogloboquadrina pachyderma*, a biopolar species, has been studied by several workers from the morphological, distributional, ecological and climatic points of view. Its coiling direction is directly related to temperature, salinity and density of the water masses. Although its occasional occurrence beyond the equator is known elsewhere, this species has been recorded from the Arabian Sea at 9, 12, 14, 19 and 23°N latitudes⁸⁻¹³. After considering the various factors, such as coiling, abundance, temperature, world distribution, upwelling and the hydrological conditions of the Indian Ocean, it was proposed that such forms that occur in the low latitudes of the northern Indian Ocean be henceforth referred to as *Neogloboquadrina pachyderma dextralis typica* Setty n. sub sp. (s.s.) if the species is right-coiled, and as *Neogloboquadrina pachyderma sinistralis typica* Setty, n. sub sp. (s.s.) if the species is left-coiled; those which occur in the mid-latitudes be referred to as *Neogloboquadrina pachyderma dextralis* Setty, n. sub sp. (s.s.), and those which occur in the high latitudes as *Neogloboquadrina pachyderma* (Ehrenberg) (s.s.). Such latitudinal zonation of the species through subspeciation may help in standardization for the Indian Ocean region¹².

Climate

Temperature influences the latitudinal depth and longitudinal distribution of foraminifera. Temperature zones in space and time are inferred on the basis of variations in test size, coiling ratio and other ecological parameters. Planktonic foraminiferal assemblages show effects of climatic control of water masses. They are best studied from cores which have stratigraphic control. But based upon the study of the distribution pattern of planktonics in the shelf sediments of the west

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coast^{4,5,8-9} and the occurrence, abundance and diversity of mixed assemblages of cold and warm water species like *Globigerina bulloides*, *Neogloboquadrina pachyderma dextralis typica*, *Globigerooides succulifer*, *G. ruber* and *Globorotalia menardii*, it is suggested that the sediments and the overlying water masses are related to the variations in climate of the region^{13,14}.

Water Masses and Upwelling

Quantitative determination of foraminifera from plankton tows in the Arabian Sea revealed four important characteristics: (1) *Globorotalia cultrata* dominates in an assemblage that lives in water considerably admixed with Red Sea water; (2) *Globigerinoides ruber* is dominant in the waters of the Arabian Sea which contains some Persian Gulf water in it; (3) *Globigerinoides succulifer* and *Globigerinella siphonifera* are dominant in waters of the central and southern Arabian Sea that are not influenced by high salinity water masses from the north; and (4) *G. siphonifera* dominates the region where neither *Globigerinoides ruber* nor *G. succulifer* is very prominent. This indicates a close relationship and association of foraminiferal populations with the spreading of high salinity water masses from the Red Sea and Persian Gulf to the Arabian Sea¹⁵. Further, their absolute abundance is connected with and dependent upon upwelling in the coastal waters^{13,16}.

Globigerina bulloides is a temperate to cool water index species. It is abundant in the southwest Indian slope waters (off Kerala), thus indicating the occurrence of cool upwelling waters in the region.

Beach and Shelf Fauna

Recent benthic foraminifera recovered from the beach and dune regimes along parts of the west coast are characteristic warm water fauna and are essentially washed ashore from the shelf^{7,18}. Arenaceous forms were found in Bhogat area only, while claccerous forms are abundant elsewhere.

Foraminiferal assemblages from the shelf off Kerala coast, Gulf of Cambay and the northeastern Arabian Sea were studied qualitatively and quantitatively, and the various species were illustrated^{19,20}.

Estuaries

Studies on *Ammonia* spp. from the Cochin Lagoon and those from the shelf off Cochin, Kerala, revealed considerable variation in their internal structure²¹. Living benthic foraminiferal response to effluent discharges of a pesticide factory, spillage from navigational barges (fish and ore), sewage disposal and plant debris from mangroves into the estuarine environment of Mandovi-Zuari-Cumbarjua canal of

Goa as well as their response to the variation in salinity, temperature, depth, fresh water influx and desiccation leading to hypersaline conditions were studied in detail²². *Ammonia tepida*, *Elphidium clavatum*, *Bolivina lowmani*, *Florilus boueanum*, *Textularia earlandi*, *Milliammina fusca* and *Quinqueloculina seminulum* dominate in the lower reaches of Zuari, while the agglutinated species, such as *Trochammina inflata*, *T. globigeriniformis*, *Milliammina fusca*, *Ammobaculites crassus*; *Ammotium salsus*, *Arenoparella mexicana* and *Haplophragmoides wilberti*, are abundant in the canal zone, but at the junction of Mandovi river and the canal *Ammonia tepida*, *Elphidium excacatum*, *Nonion depressula* and *Trochammina inflata* predominate. *Milliammina fusca* is present throughout the estuary, as it is tolerant to extreme ecological changes. Thus, microenvironments and faunal facies were delineated based upon specific distribution patterns of selected living benthic foraminifera, which are, in turn, controlled by the nature of substrate, salinity and temperature variation caused by tides in this environment²².

Microhabitation

(a) *Substrate (Edaphic condition)*--An anomalous distribution of benthic foraminifera at a few stations within the neritic regime of Dabhol-Vengurla region of central west coast of India suggests the existence of microenvironments²³. *Cibicides* group having a depth range from 0 to >2000 m is not at all represented by living individuals at a station (No. 15) at 51 m depth. Similarly, the miliolids having a depth range of 0-40 m are exclusively confined to one location (sta. 18) at 25 m depth. This microisolation is attributed to the character of the substrate (edaphic condition) which is critical to growth and development of foraminifera. It is also observed that various species react differently to the fluctuation in organic matter of the sediment. The dominance of *Trochammina pacifica* and *Ammobaculites agglutinans* (at sta. 26), for example, is attributed to low salinity, estuarine condition and high organic content of the sediment^{23,24}.

Another example of edaphic control is noted in a tidally affected and highly energized clastic shelf area (40-43 m depth) off the Bombay-Daman coast. Here, miliolids are predominant in sand and silty-sand substrates, while *Nonion* is common in silty sand, *Nonionella* in clay and *Florilus-Elphidium* in silty-clay substrate²³.

(b) *Salinity*--*Globorotalia inflata*, *G. pumilio*, *Globigerinita iota* and *G. uvala* are not known from the Bay of Bengal. Further, planktonic foraminiferal diversity is much higher off the Kerala coast than in the Bay of Bengal⁸⁻¹³. These two features are attributed to the relatively high salinity of the Arabian Sea waters.

(c) *Rate of Sedimentation*—It is well known that living/total population ratios of foraminifera indicate the relative rate of sedimentation in a given area. Using this criterion, it was observed that sedimentation rate was higher in the upper reaches than in the lower reaches of Mandovi and Zuari estuaries of Goa²²⁻²⁶. A similar conclusion was reached by a statistical study of the L/T ratios of *Ammonia beccarii* and its variants and *Trochammina* independently.

Faunal Affinities

Many of the Recent foraminifera recorded from Juhu, Chowpatty and Bhogat beaches are considered to have Indo-Pacific affinity¹⁷. Several species, including *Quinqueloculina seminulum*, *Q. tropicalis*, *Triloculina trigonula*, *T. tricarinata*, *Spiroloculina communis*, *Elphidium crispum*, *E. advenum* and *Ammonia dentata*, occur in the shelf sediments of Gulf of Kutch²⁷, of Dabhol-Vengurla^{13,23,28} and of Kerala¹⁶. *Q. venusta*, *S. excavata* and *Ammonia papillosus* occur in the beach facies of Goa²⁹. All these and a majority of the other reported species are considered to have Indo-Pacific affinity. *Hyalinea balthica*, a Plio-Pleistocene boundary marker, is reported from the shelf of Gulf of Kutch²⁷ and of Kerala along with *Neogloboquadrina pachyderma dextralis typica*¹². Some of the associated benthonic foraminifera, such as *Pararotalia lateralis*, *Quinqueloculina antillarum*, *Pseudorotalia lateralis* and *Elphidium indicum*, which occur in the Kerala and Dabhol-Vengurla shelf sediments^{13,28,16}, belong to the East African Zoogeographic province.

Reworked Fauna

The first record of Paleogene reworked foraminiferal species has been made in the Recent sediments off the coast of Bombay-Daman from a depth of 43 m³⁰. Among others, *Quadriformina advena*, *Uvigerina minuta*, *Gyroidinoides soldani*, *Bulimina aquafrescanensis* and *Alabamina atlantisae*, which are characteristic of Paleogene, are encountered as earthy coloured, highly polished rounded grains filled with secondary material. *Biloculina lobata*, *Bolivina serrula*, *Discorbis giganticus*, *Quinqueloculina triangularis* and *Rectobolivina* cf. *R. oribrata*, which are known from the Paleogene strata of Surat and Broach area, are found here mixed with the Recent fauna of the inner neritic shelf³⁰.

Larger Foraminifera

Larger foraminifera recovered from the relict shelf sediments of Karwar region include *Amphistegina papillosa*, *Borelis schlumbergeri*, *Cellanthus* sp., *Gypsina globula*, *Heterostegina suborbicularis*, *Operculina ammonoides* and *Operculinoides* sp.³¹. Some of them have also been noticed from the shelf off

Mangalore and Trivandrum shelf areas. Some of their tests are well preserved and white in colour and translucent, while others are broken, abraded and iron-stained. It is considered that they represent a reworked assemblage of Recent forms. However, some of the species are known to have a range from Miocene to Recent (Setty, unpublished data)³².

Foraminifera-Organic Matter Relationship

The relationship between organic matter and the foraminiferal assemblages of different types of substrate (and possibly environments) of the western continental shelf of India (Gulf of Kutch, shallow neritic areas of Bombay-Daman, Dabhol-Vengurla and inshore areas of Cola Bay, Goa and Karwar) was investigated³³. In the shelf areas of Bombay-Daman, Dabhol-Vengurla and Karwar, *Ammobaculites* and *Ammonia* have a positive correlation, while miliolids, *Florilus-Nonion*, *Nonionella* and *Astrorotalia* have a negative correlation. But the values become significant only for *Ammobaculites* in Karwar, and for *Florilus-Nonion* and miliolids in Karwar and Bombay-Daman areas. A qualitative analysis showed that the total foraminiferal number (TFN) is inversely proportional to the organic matter in the Cola Bay, but is inconsistent in the Gulf of Kutch due to very low values of organic matter. The organic matter-foraminifera relationship appears to be governed by a combination of factors like the nature of the substrate (controlling the retention of organic matter), salinity (influenced by inflow), depth (affecting sedimentation rate), and input (terrigenous) through various pathways³³.

Foraminifera as Indicators of Pollution

Introduction of pollutants, such as discharge of sewage, toxic effluents from industrial plants, highly toxic nuclear waste without pretreatment and even hot water and non-recycled water rich in ammonia, arsenic, etc., disturbs the natural balance in a marine environment. Widespread mortality of fish and other biotic communities and imbalance in water masses and their heat budget are caused resulting in an ecological shift in the biotic set-up. This leads to a polluted environment or pollution. This pollution or environmental stress gradient can be measured by monitoring the relative sensitivity of tolerance of the biota, particularly of the benthic foraminifera. In the polluted environments, the tests of foraminifera are affected in several ways. When quantitative faunal data are compared with the time integrated data of the Recent top layer of the sediment, the degree of pollution can be estimated. Further, the live/dead ratios of the benthic fauna are used in delineating the zones of effects of pollution³⁵.

Pollution effects on benthonic foraminifera have been investigated in Thana Creek, Bombay, Cola Bay, Goa and in the offshore areas of Karwar, Karnataka, and of Trivandrum, Kerala.

In the Thana creek, three zones of pollution of various degrees are delineated based upon the foraminiferal population and test morphology. The innermost zone surrounding the outfall point is a zone of abiotic condition where discharge causes a total destruction of the biota. Some of the foraminiferal tests are encrusted or have infillings, while some others are represented only by casts of infillings. The succeeding transitional zone, where toxicity is somewhat reduced, contains foraminiferal tests, many of which show less erosion, while the distal zone where pollutants are sufficiently diluted is characterized by increased populations and species diversity^{35,36}.

In the Cola Bay, Goa region, the pollutant is composed of hot ammoniacal waters and arsenic and the pollution effect is variable from the proximal to the distal end. The foraminiferal abundance trends which are usually parallel to the shoreline have been altered at the discharge site. The intertidal and the very shallow nearshore environment (nearest the discharge site) is marked by high productivity of *Ammonia-Florilus-Elphidium* suit. *Ammonia beccarii* and its variants are most predominant^{34,35}. Agglutinated species like *Milliammina fusca*, *Textularia agglutinans* and *Trochammina* sp., which are less tolerant to the effluents, are absent from the proximity of the discharge point. On the other hand, these appear in good number along with *Nonion*, *Fursenkoina*, *Bulimina* and *Brizalina* at the distal end, where dispersion and dilution of the effluent by water movement have suppressed the toxic effect³⁴. The relative sensitivity of the benthonics nearer this outfall area is positive³⁵.

The effluent discharge in the region of Karwar, Karnataka, is alkaline and in the outfall area the species diversity and the total foraminiferal population are markedly low compared to the distal area where there is an increase of the same due to dilution and dispersion caused by longshore currents. The size of the individual specimens of *Florilus boueanum*, *F. scaphum*, *Ammonia beccarii* and *A. annectans* is reduced at the site of discharge and in the succeeding transitional zone, but then resumes normalcy, and the diversity and abundance also increase at the distal zone³⁵. *Ammonia* and its variants seem to favour alkaline conditions, as they are most abundant near the discharge point. Similarly, *Eggerella advena* and *Trochammina inflata* seem to favour the modified environment as evidenced by their large size tests and increased populations³³. In contrast, *Florilus scaphum* is adversely affected by pollution. For, this species,

which during normal marine conditions constituted 58.95% of the population^{37,38}, presently accounts for only 15.36%^{33,35}.

The effluent discharge in the Trivandrum, Kerala, area is acidic. Only a few benthonics are present and invariably their tests show morphological abnormalities. Smaller benthonics are quickly removed by dissolution, while the larger foraminifera like *Operculina*, *Amphistegina*, *Heterostegina* and *Borelis* show a high degree of corrosion, pitting, thinning, enlargement of apertural faces and chamber walls, abrasion of ornamentation and chalky appearance. The differential acidic action gives rise to various shapes and sizes and modern sculptural features. In *Hanzawaia*, the last two chambers show aberrations, while *Elphidium* exhibits wide sutural flutes; *Textularia* is left behind with a pyritized cast only³⁵. Dissolution effects on the tests were observed not only at the outfall area, but also on the polluted parts of the beach³⁹.

Test Aberrations

Pollution in the marine environment sometimes causes bloom (sudden high biological productivity), bizzare growth in the test chambers, and morphological abnormalities on the one hand and mortality and sometimes total elimination of the entire population on the other.

Among the living foraminifera in Trivandrum region, *Cibicides refulgens* and *Elphidium opima* exhibit induced growth in their last two chambers, which become characteristically large and broad. *Operculina complanata* adds four highly abnormal chambers at the end. *Hanzawaia* shows unusual enlargement in size and distortion in its coiling symmetry³⁵. *Virgulinea pertusa* shows three cases of eccentric growth in its last three chambers. As observed, in one case, it shows a sudden spurt of development; in the second, there is a case of bizarre growth of chambers in the test, and in the third, it results in abnormality in the chamber size by inflation. Further, a case of twinning is also seen⁴⁰.

Microdistribution

Two species of *Virgulinea* (*V. pertusa* and *V. gunteri*) in two different types (opaque and transparent, but thin-walled) are encountered at 10-60 m depth range, chiefly in clayey-silt sediments. Their distribution thins out north and south of the Mangalore region (where they are highly concentrated), but they totally disappear south of Cochin⁴¹. This suggests microdistribution of the species.

Core Studies

Long sediment cores were obtained from the Arabian Sea off Bombay and Gujarat coasts on board

R V OCEANOGRAPHER; the core from the abyssal plain (190 cm long) is largely composed of Globigerina ooze, with limy marl and turbidite intercalations of fine grained oolites. Pteropods and embryonic gastropods and pelecypods are found in the turbidite layers of the core. The core from the slope (175 cm long) is a soft, gray, calcareous clay with white and gray oolites. Planktonic foraminifera are dominant, but pteropods, otoliths and fish scales and teeth as also embryonic bivalves and gastropods occur. Slump deposits containing mixed fauna are also observed as intercalations. The shelf cores (50-235 cm long) are dominated by foraminifera and oolites; pteropods, otoliths, fish scales and teeth and embryonic and fragmented bivalves and gastropods are common. Sapropelitic layers occur as intercalations⁴².

Spores, pollen and acritarchs are present in the cores of the slope and the basin. However, they are abundant in the turbidite segments. Diatoms are considerable in the ooze layer. The cores from the shelf region contain, in addition to pollen and spores, hystriospherids and dinoflagellates. *Laricoidites* (a gymnospermous spore), *Rhizophora*, *Palmidites*, *Phragmothyrites*, *Inapertusporites*, *Diporicellesporites*, *Monoporites* (fungal spore) and *Chenopodium* are the common species of this assemblage⁴³. The estimate of the top of a core from the shelf gave an age of 9830 ± 180 years, while that of a segment of the basin core gave an age of $20,940 \pm 450$ years⁴⁴. These ages signify the presence of relict sediments and indirectly the rate of sedimentation.

Acritarchs and dinoflagellate cysts were recovered from the five cores. Among dinoflagellate cysts, *Hystriospheraeridium* (3 spp), *Surculosphaeridium* (2 spp), *Tuberculodinium* (1 sp) and *Lingulodinium* (1 sp) and among acritarchs *Baltisphaerium* and *Ornatosphaera* are the major elements. One acritarch genus *Ornatosphaera* and three species, *O. globata*, *O. reticulata* and *O. elliptica* are new⁴⁵.

Eustatic Movements

The beach rock is formed a few metres beneath the loose surface of the beach within the tidal range or spray zone. In Goa and Madh island near Bombay²⁹, beach rock is found at higher elevations than the present beach. It shows signs of weathering. This beach rock contains foraminifera (*Ammonia* and its variants, *Elphidium crispum*, *E. indicum*, *Quinqueloculina semimulum*, *Q. venusta*, *Triloculina tricarinata*, *T. terquemiana*, *Milliammina fusca* and *Amphistegina* sp.), pelecypods, gastropods and other remains. This implies definite coastal uplift along the west coast of India²⁹. The uplift of the Goa coast is considered to be of middle Miocene to Pleistocene period²⁹.

Foraminifera in Engineering Problems

The mass properties of marine sediments are affected

by the amount of biogenous skeletal remains incorporated in them. Foraminiferal tests abound among such skeletal remains. A marine engineer concerned with erection of offshore structures and platforms has invariably to reckon with the foraminiferal content of the sediment (characters such as size, sphericity, roundness, ornamentation and shell thickness as directly related to the grain size, mineralogy and organic matter content) while determining their mass properties⁴⁶.

X-Ray Diffraction Studies

Living foraminifera secrete calcium carbonate (CaCO_3) from the sea water to form their tests. Whether this carbonate is aragonitic or calcitic in nature is not very clear. In case it is aragonitic to begin with, when and how it inverts to calcite (or vice versa) is also not clear. X-ray diffraction studies of tests of known planktonic and benthonic forms are in progress.

It is known that traces of magnesium and strontium are also found in the composition of some of the test walls of foraminifera. X-ray diffraction studies will help in identifying the Mg-Sr- CaCO_3 ratios and work in this direction is also in progress. This study will assist in understanding the paleotemperature and paleosalinity of the former oceans.

Culture Studies

Laboratory culture of living foraminifera is being attempted. Besides understanding the ontogeny of the different species, various types of pollutants will be used to identify their effects on the living forms.

Foraminifera and Computer

Q-mode cluster analysis explains the spatial distribution of living foraminifera. Using this method, two main biotopes and two sub-biotopes are recognized in the Ratnagiri inner shelf⁴⁷. *Trochammina inflata* characterizes the inner shelf north of Ratnagiri and demarcates the zone influenced by fresh water. *Nonion* and *Ammonia* demarcate the inner shelf south of Ratnagiri. Similar work in other areas is in progress.

Summary

Recent sediments of the continental margin of West Coast of India yielded *Globigerina hexagona* and *Globoquadrina conglomerata* which disappeared from the Atlantic 50,000 to 1 million years ago. The bipolar species *Neogloboquadrina pachyderma* occurs as far north of equator as 23°N in the Arabian Sea. Similarly, high salinity indicating planktonic assemblages of Red Sea and Persian Gulf is also observed near Kerala Coast. The edaphic state of some benthonic species on the shelf (Dabhol-Vengurla sector) indicated their

microenvironments. Living/dead ratios of *Ammonia* and certain agglutinated species are used in estimating the relative rates of sedimentation.

Intertidal fauna of beach rock found at higher elevations indicated eustatic movement of the coast, while relict and reworked fauna of the Tertiary was observed from Karwar and Bombay-Daman shelf. Sediment cores taken from the shelf to basin off Bombay-Gujarat reveal a distinct pattern of faunal assemblage and lithological composition spanning an estimated age of 9840 ± 180 to $20,940 \pm 450$ years B.P.

The relative sensitivity of tolerance of foraminifera to pollutants results in their sudden bloom, bizarre growth in size of chambers and morphological abnormalities on the one hand to effects of corrosion, dissolution and thinning of tests, encrustations and infillings in the dead fauna and extensive mortality on the other. XRD techniques to determine Sr-Mg-CaCO₃ ratios in foraminiferal tests are being tried to determine paleosalinity and paleotemperature of ancient basins.

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