CHAPTER 7
ENVIRONMENTAL SIGNIFICANCE OF DISTRIBUTIONAL PATTERNS OF FORAMINIFERA IN PALEOCLIMATOLOGY

7.1 INTRODUCTION

Paleoclimatology, the study of the earth's climatic record prior to the period of instrumental measurements, has far reaching applications. Fluctuating climates of the past have affected physical processes in the ocean as well as on land and have controlled the distribution of faunas and floras. Modern societies continue to be vulnerable to social and economic effects of droughts, storms, floods and other climatic extremes. In order to provide a framework for understanding the history of the earth and its biota, a well dated record of past climates can provide the perspective necessary for predicting future changes and for anticipating the climatic effect of rising CO₂ level and other human alterations of an increasingly overcrowded world. Foraminifera are the most important indicators of paleoclimatic/paleoceanography conditions as they are sensitive to subtle differences in water mass properties, temperature, salinity, oxygen as well as bathymetry and substratum.

Paleoecological and paleoclimatological interpretations are based directly on the responses of their modern analogs. Therefore, an attempt is made here to assess paleoclimatic potential of foraminiferal distribution pattern in modern sediments of the west coast of India. For this, i) influence of different water masses on different species of planktonic foraminifera and ii) influence of bathymetry over the morphology of benthic foraminifera are studied in detail.
Figure 25: Location map of additional samples (collected north of study area) for which data is procured.
In order to enhance the data base, the distribution patterns of planktonic and benthic foraminifer in modern sediments have not only been worked out in the study area (Mangalore-Cochin sector) but have also been considered for the unprocessed data from a number of stations procured from an earlier study (Henriques, 1993) from the Vengurla-Mangalore sector i.e., an area adjacent to present studies. Location of the additional samples have been shown in Figure 25. The grouping of different benthic species has been made for unprocessed data following the same criterion adopted for the present study.

7.2 PLANKTONIC FORAMINIFERA: INFLUENCE OF DIFFERENT WATER MASSES ON COMPOSITION

The planktonic foraminifera which are abundant in modern marine environment provide a baseline around which the fossilized remains contained in the oceanic sediments can be analysed to draw inferences about the paleooceanographic environment (Rao 1972, 1973; Zobel, 1973; Nigam, 1990; Nigam and Henriques, 1992; Divakar Naidu et al., 1992). This is governed by the interaction of biological, physical and chemical processes in determining the seasonal and geographical distribution of planktonic foraminifera in the ocean water and sediments.

The distribution of modern day planktonic foraminifera is intimately related to the distribution of specific surface water masses (Boltovskoy and Wright, 1976; Thunnel, 1978). Nevertheless, no significant attempt has been made to delineate their response to different water masses prevailing along the western continental margin of India (Section 3.6.3) with special reference to south-west and north-east monsoons. In view of this, an attempt is made in this section to study the response of different species of planktonic foraminifera to different water masses associated with monsoons. To achieve this goal, commonly occurring (i.e. > 2%) species in the surface sediments off Vengurla-Cochin sector have been illustrated graphically.
Figure 26: Distribution of
(a) Globoturborotalita rubescens,
(b) Globigerina calida,
(c) Tinophodella ambitacrena and
(d) Globigerinoides ruber
in surface sediments (Vengurla-Cochin sector).
FIGURE 27
Figure 27: Distribution of
(a) Globoquadrina conglomerata,
(b) Globoturborotalita tenella,
(c) Galliteilla vivans and
(d) Globigerina falconensis
surface sediments (Vengurla-Cochin sector).
Figure 28: Distribution of 
(a) Globigerinella aequilateralis, 
(b) Neogloboquadrina pachyderma, 
(c) Globigerina bulloides and 
(d) Neogloboquadrina hexagona 
in surface sediments (Vengurla-Cochin sector).
Figure 29: Distribution of
(a) Turborotalita quinqueloba,
(b) Neogloboquadrina dutertrei,
(c) Globorotalia menardii and
(d) Orbulina universa
in surface sediments (Vengurla-Cochin sector).
Figure 30: Distribution of 
Globigerinoides sacculifer in surface 
sediments (Vengurla-
Cochin sector).
The distribution pattern of planktonic foraminifera along the west coast (Vengurla-Cochin sector) of India suggests that the composition of the planktonic foraminifera differs in its character of relative abundance of different species. The results show that *Globoturborotalita rubescens* (> 8%) and *Globigerinoides ruber* (> 20%) are more abundant generally north of Mangalore (Figures 26a, 26d), whereas, *Globigerina calida* (upto 3%) and *Tinophedella ambitacrena* show similar trend North of Bhatkal (Figures 26b, 26c). Similarly, *Globoquadrina conglomerata* are also more abundant north of Mangalore (Figure 27a). A similar trend is exhibited by *Globoturborotalita tenella* (Figure 27b) and *Gallitellia vivans* (Figure 27c). The surficial distribution of *Globigerina falconensis* (Figure 27d) and *Globigerinella aequilateralis* (Figure 28a) show different patterns. These species are relatively more in shallow areas in the middle of study area. Furthermore, another interesting trend is noticed in the case of *Neogloboquadrina pachyderma* (Figure 28b), *Globigerina bulloides* (Figure 28c), *Neogloboquadrina hexagona* (Figure 28d) and *Turborotalita quinqueloba* (Figure 29a) which exhibit higher concentration in areas south of Karwar. However, a characteristic opposite pattern is shown by *Neogloboquadrina dutertrei* (Figure 29b). *Globorotalia menardii* (Figure 29c), *Orbulina universa* (Figure 29d) and *Globigerinoides sacculifer* (Figure 30) which are in abundance north of Karwar.

In view of the above, it may be inferred that generally in Vengurla-Mangalore sector *i.e.*, north of study area the ambient water condition appears to be different from that which occurs south of Mangalore (the study area) which results in the different relative frequencies of planktonic species. Such characteristic distributions of different planktonic species indicate the presence of an arbitrary boundary for the abundance in planktonic species around off Mangalore. The changing ecology of these planktonic foraminifera may be interpreted in view of the hydrographic setting of this area. It is clear that the northern area is subjected to lowering of salinity once in a year whereas southern part experiences twice lowering in the salinity conditions (Figure 9).
FIGURE 31
Figure 31: Smectite weighted peak area percentage in surface sediments of Arabian Sea (after Kolla et al. 1981).
This lowering of salinity in the southern region has been attributed to intrusion of low salinity water from Bay of Bengal during north-east monsoon (Section 3.6.3). It is reported earlier by Kolla et al., (1981) that smectite along the Indian margin, derived from Narmada and Tapti rivers, show a decrease as one moves from north to south. However, near the southern tip the smectite percentage increases significantly (Figure 31) and is attributed to the influx of smectite from western Bay of Bengal, carried around the southern tip of India by relatively low salinity water from Bay of Bengal surface water currents (Wyrtki, 1971).

In view of such distinct environmental conditions north and south of Mangalore, it may further be inferred that dominance of *G. rubescens*, *G. calida*, *T. ambitacrena*, *G. ruber*, *G. conglomerata*, *G. tenella*, *N. dutertrei*, *G. menardii*, *Orbulina universa*, *G. vivans* and *G. sacculifer* in Vengurla-Mangalore sector indicate their adaptation to more saline condition, while species like *N. pachyderma*, *G. bulloides*, *N. hexagona* and *T. quinqueloba* are relatively more abundant in Mangalore-Cochin sector and thus appear to be more tolerant to low salinity water condition.

The relationship of the above mentioned planktonic species with salinity seems interesting in view of the previous workers who reported that *G. ruber* and *G. sacculifer* in the warm water of various regions is not dependent on the surface water temperature but on the salinities (Be’ and Tolderlund, 1971). Similarly, Boltovskoy (1970) observed that *N. pachyderma* and *T. quinqueloba* are capable of living in low salinity conditions.

7.2.1 Significance and Paleoclimatic Implications

As mentioned above that the lowering of salinity in the south of Mangalore region is linked with the north-east monsoon therefore, the associated frequency variations of planktonic species may be considered as a response of north-east monsoon. In view of this if we consider total number of high salinity tolerant species viz.
G. rubescens (a), G. calida (b) T. ambitacrena (c), G. ruber (d), G. conglomerata (e),
G. tenella (f), N. dutertrei (g), G. menardii (h), Orbulina universa (i), G. vivans (j) and
G. sacculifer (k) as indicator of intensity of south-west monsoon (\(I_{\text{SWM}}\)) and low
salinity tolerant species viz. N. pachyderma (1), G. bulloides (2), N. hexagona (3) and
T. quinqueloba (4) as indicator of north-east monsoon (\(I_{\text{NEM}}\)) the variations in
the intensity of south-west monsoon and north-east monsoon (\(\text{SWM/NEM}\)) may be
expressed in the form of the following equation for the present area:

\[
I_{\text{SWM}} = \frac{\sum_{i=a}^{k} N_i}{\sum_{i=a}^{k} N_i + \sum_{i=1}^{4} n_i}
\]

\[
I_{\text{NEM}} = \frac{\sum_{i=1}^{4} n_i}{\sum_{i=a}^{k} N_i + \sum_{i=1}^{4} n_i}
\]

Where \(N_i\) is total number of specimens belonging to species a to k, and
\(n_i\) is total number of specimens belonging to species 1 to 4.

The denominator \(\sum_{i=a}^{k} N_i + \sum_{i=1}^{4} n_i\) represents the total number of
planktonic foraminifera (a to k and 1 to 4) in a standard sample.

It will not be out of place to mention here that the previous workers have shown
that during the Last Glacial Maxima (LGM) north-eastern monsoon intensity was
higher (Duplessy et al., 1981; Sarkar et al., 1990). However, during Holocene,
fluctuations and/or gradual weakening of north-east monsoon is yet to be studied.

Hence the study of relative frequency variations of planktonic species in the
subsurface sediment around Mangalore may prove its utility to understand the
changes in intensity of north-east monsoon in the past.
7.3 BENTHIC FORAMINIFERA: INFLUENCE OF BATHYMETRY ON DIFFERENT MORPHO-GROUPS

Morphological variability in foraminifera has been related to various environmental properties (Bandy, 1959; Lutze, 1962; Hermelin, 1983; Nigam and Rao, 1987; Wetmore, 1987; Spencer, 1987; Nigam, 1988b, etc.). Pronounced intraspecific morphological variability can lead to erroneous taxonomy and misleading ecological and evolutionary interpretations (Collins, 1989). Therefore, it was suggested that reliance should not be placed only on a single species but efforts should be made to recognised an indexing assemblage (Sahni in Nigam, 1989b).

In view of this, an attempt has been made in this section to study the response of coarser taxonomic morphological groups (morpho-groups) to different environmental changes.

The significance of these morpho-groups is initially recognised by Chamny (1976), Severin (1983), Jones and Charnock (1985) and Bernhard (1986). Corliss and his co-workers studied the morphological differences between epifaunal and infaunal foraminiferal assemblages in deep sea sediments and use them to study paleoproductivity (Corliss, 1985; Corliss and Chen, 1988; Corliss and Emerson, 1990). This is further confirmed by Widmark and Malmgren (1992). However, depth linked variations in the morpho-groups have been considered in this section. While grouping the foraminiferal individuals, the criterion of Nigam et al. (1992b; modified version of Severin, 1983) has been taken into account.

7.3.1 DEPTH AND MORPHO-GROUPS

The water depth not only influences different species of benthic foraminifera (Bandy and Arnal, 1960; Hermelin and Malmgren, 1980; Drooger, 1983; Spencer, 1987), but also controls the external test morphology, resulting in distinct morpho-groups.
FIGURE 32
Figure 32: Distribution of angular-asymmetrical morpho-groups in surface sediments (Vengurla-Cochin sector).
Figure 33: Distribution of rounded-symmetrical morpho-groups in surface sediments (Vengurla-Cochin sector).
Following the criterion of Nigam et al. (1992b) whole foraminiferal population is clubbed into two morpho-groups namely angular-asymmetrical and rounded-symmetrical (Section 4.4.2.1). The distribution of these morpho-groups in the surface sediments off Vengurla-Cochin sector revealed that angular-asymmetrical forms varied from 11.85% to 87.75% whereas rounded-symmetrical forms fluctuated between 12.25% to 88.15%. In general the distribution patterns apparently show that angular-asymmetrical morpho-group is by and large abundant in deeper regions (Figure 32) while, rounded-symmetrical morpho-group tend to flourish in relatively shallow regions (Figure 33). Such characteristic distribution could be attributed to the sediment turbulence. Severin (1983) observed that sediment turbulence may govern the overall morphology and geometry of the epibenthic foraminiferal species. He further observed that during periods of higher turbulence, species tend to develop more symmetry.

The role of turbulence is also suggested by Nigam and Khare (In press) who found less abundance of angular-asymmetrical forms in the regions affected by the river discharge and explained it due to the influence of river borne turbulence over these morpho-groups. This observation is also in agreement with Nigam et al., (1992b) who studied the frequency variations of these morpho-groups in a shallow water sediment core from the inner shelf region off Karwar, where turbulence is linked with monsoonal precipitation. Their study established an inverse relationship between variations in angular-asymmetrical forms and rainfall data of the catchment area of Kali river whereas, a direct relationship was observed between rounded-symmetrical forms and rainfall.

In view of the fact that such turbulence, which shows a gradient from greater in shallow water to lesser in deep water, it may be inferred that an increase in the abundance of angular-asymmetrical forms in the deeper portion is perhaps due to low turbulence in the ambient water. A reverse explanation holds good for rounded-symmetrical forms. This sort of relationship may be explained by the fact
Figure 34: Surficial distribution (Vengurla-Cochin) of benthic genera whose abundance indicates low oxygen concentration
(a) Bolivina, (b) Bulimina, (c) Uvigerina and (d) Globobulimina.
that in undisturbed sediment/ambient water an individual can easily occupy a preferred microhabitat. On the other hand, in turbulent conditions, its position and orientation would be controlled largely by the motion of the sediment. Foraminifera with symmetrical tests are able to move more easily through the sediment and hence are able to regain their preferred microhabitat following disturbance of the sediment by turbulence (Severin, 1983) whereas, the pre-requisite for asymmetrical forms is quiescent conditions. However, it is interesting to note that rounded-symmetrical morpho-group incorporates mostly epifaunal forms whereas angular-asymmetrical morpho-groups mainly constitute infaunal forms of Corliss and Chen (1988). It is reported that epifaunal shapes may be advantageous for attachment at the surface during the time of turbulence (Corliss and Emerson, 1990; Corliss and Fois, 1990; Corliss, 1991; Rosoff and Corliss, 1992).

7.3.2 Oxygen Content and Morpho-groups

In addition to this it can also be noticed that infaunal forms are dominating in angular-asymmetrical morpho-groups which show relatively higher concentration beyond 150 m water depth whereas, a reverse trend is noticed in the case of epifaunal forms in rounded-symmetrical morpho-groups. As stated earlier that in the Arabian Sea from 150 m to 1,500 m depth the dissolved oxygen content is low creating an Oxygen Minima Zone (OMZ) (Section 3.6.1). Taking this fact into consideration it is significant to note that infaunal forms relatively are more abundant in OMZ whereas, the same has an adverse effect on the epifaunal forms. Therefore, it may be inferred that low oxygen conditions are better suited to infaunal forms of benthic foraminifera. Our inference is in agreement with Rosoff and Corliss (1992) who reported that the dominance of infaunal test was associated with depletion of dissolved oxygen due to the oxidation of organic matter. However, the dominance of few indicators forms of low oxygen conditions like Bolivina, Bulimina, Uvigerina and Globobulimina (Katz and Thunell, 1984; Boltovskoy and Wright, 1976) in the oxygen mimima zone assemblage (Figures 34a–34d respectively) may further
intuitively suggest a preferential adaption of infaunal forms in angular-asymmetrical morpho-group to oxygen poor water. This inference suits well with work done by previous workers elsewhere (Mc Gowran and Beecroft, 1986; Sengupta and Machain-Castillo, 1993).

7.3.3 ORGANIC CARBON AND MORPHO-GROUPE

The relative abundance of infaunal forms in angular-asymmetrical morpho-groups beyond 150 m can also be interpreted in the light of organic carbon (Section 3.7). Paropkari et al. (1992) reported "that high concentration (> 4%) of organic carbon exactly coincides with the oxygen minima (150–1500 m water depth)". In view of this it may be inferred that infaunal angular-asymmetrical forms of benthic foraminifera usually flourish perhaps due to the anoxic bottom water which is conducive for such forms, the reasoning which also plays a crucial role in preservation of organic carbon in oxygen minima zone.

7.3.4 SIGNIFICANCE AND PALEOCLIMATIC IMPLICATIONS

In view of the foregoing account, it may be concluded that depth linked factors such as low oxygen conditions high organic carbon content seem to be conducive for infaunal forms in angular-asymmetrical morpho-groups whereas, same conditions have an adverse effect over epifaunal forms in rounded-symmetrical morpho-group of benthic foraminifera. Therefore by studying these morpho-groups in subsurface sediments paleoceanographic reconstruction might be made (Mc Corkle and Emerson, 1988; Bernhard, 1989).

The results of the present study show that besides other methods frequency of distribution of morpho-groups may be used as an additional tool for quick easy and preliminary estimates of paleoclimate as:
1. Morpho-groups are independent of taxonomic difference that arises among the authors regarding synonymy.

2. No modern counterpart of such group is required as in case of species.

3. Species taxonomy need not be determined, much time can be saved in the sorting of the foraminifera in sediment samples.

4. Data handling is also simplified because number of morpho-groups is much smaller than number of species.

5. Computer aided image analyser can also be used for grouping the foraminiferal assemblage thus saves time.

In order to confirm further the depth related variations in the foraminiferal population a number of statistical analyses have been performed on the raw data of 32 samples from the study area (Mangalore-Cochin sector), which include Q-mode and R-mode cluster analyses.