CHAPTER 6
6.1 INTRODUCTION

An accumulation of the greenhouse gases (viz., carbon dioxide, methane, nitrous oxide and chlorofluorocarbons etc.) in the atmosphere has lead to a rise in mean global temperatures (global warming). Though it cannot be predicted with certainty, a reasonable guess is that in response to such warming, the mean sea level in the oceans will rise owing to the thermal expansion of the oceans and the melting of continental ice. As almost two thirds of the world’s population lives in proximity of the coast, an understanding of the sea level changes is of utmost importance. For, any change in the sea level will have a profound effect on the socioeconomic conditions. As the Indian sub-continent has a long coastline (about 6,000 km) which is densely populated, an understanding of the parameters which lead to changes in the sea level is of vital importance.

In order to prepare predictive models, it is essential to study the long term sea level changes that occurred along the Indian coast in the past which can be inferred using various proxies (Chatterjee, 1961; Agrawal and Guzder, 1972; Verma and Mathur, 1979; Bruckner, 1987, 1989; De and Mathur, 1988; Nigam, 1989a; Rajamanickam, 1990; Nigam et al., 1992a, 1993; Mathur, 1993, etc.). Merh (1992) in his review article on Quaternary sea level change along the Indian coast, pointed out the need to generate more data due to the fact that very little attention is paid to study the paleosealevel along the Indian coast. Therefore, every available bit of data about the past changes
Figure 39. Generalised bathymetric relationship of various genera to principal environmental factors (vertical scale exaggerated, horizontal not to scale)
the sea level is of immense help to climatologists and oceanographers for constructing regional models of sea level behaviour and forecasting future events.

In view of this, the responses of different foraminiferal parameters have been tested in modern marine environment, to be considered as an indicator of paleoshorelines that have fluctuated in the last few thousand years. Some such evidences are discussed below which are based on ecology of foraminiferal species, relict benthic foraminifera and the barnacle fouling them.

6.2 FORAMINIFERA AS PALEOSHORELINE INDICATOR

6.2.1 SPECIES DEPTH DISTRIBUTION

As discussed earlier, paleobathymetry is of growing importance in paleooceanographic/paleoclimatic reconstructions. The distribution patterns of mainly benthic species which are roughly arranged along a depth gradient have been used extensively to reconstruct the paleobathymetry (Van der Zwaan et al., 1990).

The geographical distribution of many important genera have already been presented and discussed in Section 5.4. The results of R-mode cluster analysis have shown that fauna can be divided into shallow, deep and transitional assemblages. The Q-mode factor analysis also provided the valuable data about geographical distribution of significant foraminiferal assemblages with reference to depth. Figure 39 presents the generalised picture of bathymetric profile, sediment nature, oxygen content of overlying water and presence of dominant genera at various depth in the study area.

These observations are of immense use if one wants to reconstruct the past by using fluctuations in abundance of any above assemblage in sub-surface sediments of the same region. To make the point more clear, the combined data of this study along with the data of Nigam (1988c) and Khare (1992) for percentage distribution of
Rotalidium annectens, shows that this species is absent at the river mouth of Kali river and show abundance away from the coast (Fig. 40). Considering fresh water discharge from Kali river as limiting factor, reconstruction of paleomonsoonal precipitation over Kali catchment area has been made (Nigam, 1988c).

6.2.2 RELICT FORAMINIFERA

The problem of relict foraminiferal fauna has been recognized as a major source of error in using the present continental shelves as environmental models. Therefore, in this study the relict foraminiferal faunas have been separated on the basis of their earthy coloured, highly polished, badly abraded tests and thus distorted suture, periphery and the shape. It has been observed that the maximum abundance of the relict foraminiferal fauna is in seabed samples between 60—90 m below the present sea level. These species are mainly the larger foraminifera such as Amphi
tegina, Operculina along with species such as Elphidium, Rotalidium etc. [Plate 23 V, W, X, Y, Z]. This faunal composition of relict assemblage indicate shallow water depositional environment.

The abundance of these large sized foraminiferal species (Amph
tegina and Operculina) mainly of relict nature, deposited during Late Pleistocene/Holocene with modern fauna from 60—90 m, have been reported by Nigam (1987). Sidner and Poag (1972) used the presence of these genus as an indicator of changing water depth. Seiglie (1968) used the distribution of Amphi
tegina, a shallow warm water reef dwelling benthonic genus in Pleistocene sediments off the Gulf of Mexico and the Caribbean to plot the location of fossil reefs and note the times of lower water levels. A similar relict faunal assemblage has been described from the tropical and equatorial Atlantic margins of Africa during the Late Quaternary (Barusseau et al., 1988). These relict faunal assemblages were obtained in coarse sand rich in ooids. The ooids are indicators of a high energy, carbonate rich shallow water environment.
FIGURE 40
FIGURE 41
Figure 41. Hatched area showing abundance of relict foraminifera with barnacle fouling of *T. squamosa* and locations for radiocarbon dating.
The dating of these sediments (Table 3) indicated an average of 10,000 years B.P. (Nair and Hashimi, 1980; Hashimi and Nair, 1986).

In view of the foregoing it is surmised that a paleoshore existed at 60—90 m water depth when sea level was lower than present about 10,000 years B.P.

6.2.3 BARNACLE FOULING ON RELICT FORAMINIFERA: A NEW TOOL FOR PALEOSHORE ASSESSMENT

Although the number of marine organisms used for identifying and dating ancient shorelines, yet fossil intertidal barnacles and foraminiferal association together have not so far been employed for this purpose. Jointly both these organisms can provide very useful information on sea level fluctuations during the last few thousand years. The present study is the first such attempt where this association is proposed as a new tool to demarcate paleoshoreline. This hypothesis is tested on environmental set up and foraminiferal distribution over the continental margin of Western India and the results are presented below.

While analysing the relict foraminiferal assemblage of the larger (>1000 μm) fractions of the samples, the zone 60—90 m water depth (Fig. 41) showed that the larger foraminifera, (mainly *Amphistegina* and *Operculina*) fouled by the barnacles *Tetraclita squamosa* (Pilsbury) (Plate 24). The ecology of the relict assemblage (over which barnacles are found) has already been established as an indicator of shallow water environment. The ecology of the barnacles (*T. squamosa*) is explained here.

The barnacle is the most common name for cirripedes belonging to Class Crustacea. Earlier workers have suggested that barnacles (crustaceans) inhabit predominantly rocky shorelines. Although their larval stage is planktonic, they spend their adult life as sedentary forms. Since most barnacles inhabit intertidal zones of the rocky shores, these organisms possess unusual properties apart from their sessile
characteristics. Different species also tend to proliferate in distinct zones with relation to tidal heights (Lewis, 1964). The presence of rather restricted belts of barnacles everywhere on earth marking the upper range of mean high water was noted by Kelletat (1988).

The occurrence of this barnacle species *Tetraclita squamosa* has already been reported from various parts of the world's oceans, for example from the Red Sea (Gulf of Suez), East Africa (Zanzibar and Madagascar), Arabian Coast (Gulf of Aden, Strait of Hormuz) and Northern west coast of India, Veraval (Utinomi, 1969). Daniel (1972) describes the habitat of *T. squamosa* as occurring between tide marks on rock and common in high intertidal forming distinct zones. An approximate tidal distribution of barnacles including *T. squamosa* is given below (Table 8).

*Table 8*  
**Tidal distribution of Barnacles**

<table>
<thead>
<tr>
<th></th>
<th>Chthamalus stellatus</th>
<th>Chthamalus fissus</th>
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</thead>
<tbody>
<tr>
<td>MHWS</td>
<td>Semibalanus balanoides¹</td>
<td></td>
</tr>
<tr>
<td>MHWN</td>
<td>Semibalanus balanoides²</td>
<td>Balanus glandula</td>
</tr>
<tr>
<td>MLWN</td>
<td></td>
<td>Balanus cariosus</td>
</tr>
<tr>
<td>MLWS</td>
<td></td>
<td>Chthamalus dalli</td>
</tr>
</tbody>
</table>

¹ Scotland  
² East Coast USA  
Approximate tidal distributions of barnacle species including *T. squamosa* (MHWS, mean high water spring tides; MHWN, mean high water neap tides; MLWN, mean low water neap tides; MLWS, mean low water spring tides) (after Coul and Bell, 1983).
A careful search for the presence of the living forms of *T. squamosa* (Pilsbury) in the intertidal region shows the complete absence of these forms along the Konkan coast (Wagh, 1972). He further suggested that these barnacles are well established in area of high salinity (41.5 °/o) such as the Red Sea (Ekman, 1967) whereas low salinity values in the Gulf of Khambhat (north of the study area) and further down the west coast were detrimental for their development and survival.

In view of the fact that *T. squamosa* is absent in the modern environment within this study area and only found attached to relict benthic foraminifera, but not on modern benthic foraminifera in sediments at 60—90 m water depth along the west coast of India, it is concluded that these forms lived when the sea level was low and conditions suitable for their survival. The rapid rise of sea level (and a change in the salinity pattern) and their inability to keep pace, hampered their survival, leading to their extinction.

Nair and Hashimi (1980) have drawn Holocene climatic inferences from the sediments of the western Indian continental shelf. The inferences were based on data of the distribution and abundance of two most prominent facies: the relict carbonate sediments and rocks, and modern terrigenous clastics present on the western Indian shelf (Nair et al., 1978; Hashimi et al., 1978). It was concluded that, the presence of extensive carbonate cemented rock, dead algal and coral reefs on the outer continental shelf coupled with large sized quartz, points to circumstances in which warmer climate and low terrestrial run off were dominant. Based on the occurrence of foraminifera together with bryozoans and ooids in the samples collected off the Fifty Fathom Flat (91.5 m deep) on the outer continental shelf off Bombay (India). Nair (1971) concluded that the flat stood at sea level probably during the Pleistocene. Nair (1974) further suggested that the terraces at the depth of 75, 85 and 92 m on the western Indian shelf together with the Fifty Fathom Flat off Bombay possibly corresponds to Holocene sea level stand still in the depth between 75—90 m. The age of relict carbonate facies (mostly ooids) are
9,000—11,000 years B.P. (Hashimi and Nair, 1986). They have also postulated "temperature of the water of the Arabian sea (the shelf water) was higher or that the intensity of the evaporation was greater 10,000 years ago" (Nair and Hashimi, 1980). Intensifications of the monsoon around 10,000 B.P. (Singh et al., 1972) has also been noticed over the Indian region.

Sudden changes in the climate around 11,000 years B.P. occurred on a global scale (Broecker et al., 1960) Approximately 60 m lower sea level at about 10,000 years B.P. has also been noticed elsewhere (Fairbank, 1989). He has also reported that there was a minor pause in sea level rise between 11,000—10,500 year B.P. Probably during this stand still coupled with favourable climate barnacle growth occurred on foraminferal tests as reported in this period. It is well known that afterward a rapid sea level rise occurred world wide due to ice sheet disintegration (Clark and Lingle, 1979) which must have reduced salinity. On a global scale it was noticed (Railsbeck and Anderson, 1989) that in non glacial periods, sea water was more diluted, with an average salinity of 34°/oo. The increase in precipitation around 9,000 year B.P. in this area (Prell et al., 1990) would also have contributed in lowering of salinity in coastal areas. Therefore, the salinity stress coupled with rapid rise in sea level during early Holocene might be detrimental to the growth of barnacles and caused their disappearance. Salinity stress is found to be a limiting factor in other organisms as well and subsequently used in paleosealevel studies (Van Harten, 1986).

Furthermore, changes in terrigenous supply might also be a limiting cause as the 11,000—7,000 years B.P. interval corresponding to the active sea level rise is marked by extensive development of terrigenous sediments and possible thermal effects prevented carbonate sedimentation over large areas in some parts of the world (Barusseau et al., 1988). The rapid rise in sea level during Holocene, coupled with other climatic factors not only affected the growth of barnacles, but adversely affected the formation of ooids. Reef formations (Vora and Almeida, 1990) in the
study area and all such features are generally missing in modern as well as in records over the last 6,000 year or more, which show rather stable sea level. On the western continental margin of India, after 10,000 years B.P., a rapid sea level rise was inferred from lack of evidence of stand still on a submerged shelf edge reef and from coral growth rates (Nair and Hashimi, 1988).

In view of the foregoing, it may be concluded that the presence of *Tetraclita squamosa* encrusted on foraminiferal tests indicates lowered sea level, and their inability to keep pace with rising sea level led to their extinction in the study area. Therefore, the intertidal barnacle growth on foraminifera and other sessile forms can be considered as an additional tool to decipher paleosealevel changes.

However, the traditional species indicators provide only a qualitative positioning of paleosealevel, where as the new tool proposed here can give a better resolution. The pressing need for predictive climatic models generated through quantitative paleobathymetry, required better techniques which can provide quantitative information of paleosealevel changes. In order to cater this need, planktonic percentage in surface sediments are exploited and discussed in the next chapter.