CHAPTER 5
RELI CT BENTHIC FORAMINIFERA:
PALEOCLIMATIC IMPLICATIONS

5.1 INTRODUCTION

As discussed in Chapter 4 (pages 73-74), a considerable number of specimens encountered in surface sediments cannot be placed under the category of Recent foraminifera. Such specimens are identified by their earthy colour, dull luster, abraded or polished surfaces and broken tests with deposition of secondary material. The term 'relict' is used for such foraminiferal specimens that remained on the seafloor for thousands of years without any major transportation (Murray, 1991).

Such specimens once identified with reference to their ecology, distribution and time of deposition can be helpful to derive inference about paleoclimatic conditions of the area in which they occur. In view of the above, such specimens encountered from the study area are identified (list of the all species identified is in Chapter 4, page 74) and their distribution pattern along with their ecology and significance are discussed in this chapter. In order to understand the comprehensive distribution of relict foraminifera off central west coast of India, 51 additional samples (Table 3.3) within the depth zone of 46 to 1330 m (Henriques, 1993) were also used along with data from 52 core top samples of the present study.

5.2 DISTRIBUTION PATTERN OF RELICT BENTHIC FORAMINIFERA

Figure 5.1: 'Relict zone' encountered off central west coast of India
In study area, within 50-135 m water depth, the abundance of relict benthic foraminifera varies from 5.35% (at station SC-51) to 18.18% (at station SC-30) of total benthic foraminifera. The fauna comprise of 32 species belonging to 14 genera and 9 families. This zone of relict fauna is referred to as a ‘relict zone’, for this study and illustrated as a shaded area in the figure 5.1.

Relict benthic foraminiferal genera encountered in this study include Alveolinella, Ammonia, Amphistegina, Elphidium, Eponides, Operculina, Quinqueloculina, Rotalinoides, Sahulia, Siphonaperta, Spiroloculina, Spiroplectinella, Textularia and Triloculina. Table 5.1 lists the species under major genera encountered off central west coast of India.

**Table 5.1: Relict benthic foraminiferal species under major genera encountered off central west coast of India**

<table>
<thead>
<tr>
<th>Sr.No.</th>
<th>Genus</th>
<th>Species</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Alveolinella</td>
<td>A. quoii</td>
</tr>
<tr>
<td>2.</td>
<td>Ammonia</td>
<td>A. tepida</td>
</tr>
<tr>
<td>3.</td>
<td>Amphistegina</td>
<td>A. lessonii, Amphistegina sp.</td>
</tr>
<tr>
<td>4.</td>
<td>Elphidium</td>
<td>E. advenum, E. craticulatum, E. crispum, E. discoidale, E. macellum</td>
</tr>
<tr>
<td>5.</td>
<td>Eponides</td>
<td>Eponides sp.</td>
</tr>
<tr>
<td>6.</td>
<td>Operculina</td>
<td>O. complanata, Operculina sp.</td>
</tr>
<tr>
<td>7.</td>
<td>Quinqueloculina</td>
<td>Q. bicarinata, Q. intricata, Q. kerimbatica, Q. ludwigi, Q. seminulum, Q. vulgaris, Quinqueloculina sp.</td>
</tr>
<tr>
<td>8.</td>
<td>Rotalinoides</td>
<td>R. papillosa</td>
</tr>
<tr>
<td>9.</td>
<td>Sahulia</td>
<td>S. conica</td>
</tr>
<tr>
<td>10.</td>
<td>Siphonaperta</td>
<td>S. agglutinans, S. horrida</td>
</tr>
<tr>
<td>11.</td>
<td>Spiroloculina</td>
<td>S. exitis, S. indica</td>
</tr>
<tr>
<td>12.</td>
<td>Spiroplectinella</td>
<td>S. sagittula</td>
</tr>
</tbody>
</table>
Depending upon the major assemblages of relict foraminifera, two distinct subzones can be delineated:

1. Agglutinated subzone – This subzone is represented by six species of agglutinated genera *Textularia, Sahulia* and *Spiroplectinella*. The representative species of these genera are *Textularia agglutinans, T. bulbosa, T. cf. pseudogramen, Textularia* sp., *Sahulia conica*, and *Spiroplectinella sagittula*. This group is predominant in relatively shallower part of the relict benthic foraminiferal zone and comprises ~45–50% of total relict fauna at ~50 to ~75 m water depth.

2. *Alveolinella–Amphistegina–Operculina* subzone – This subzone is represented by three robust genera *Alveolinella, Amphistegina* and *Operculina* with five species; namely, *Alveolinella quoii, Amphistegina lessonii, Amphistegina* sp., *Operculina complanata* and *Operculina* sp. This assemblage is predominant at relatively deeper part of the relict zone and constitutes ~13–40% of total relict fauna at ~85-135 m water depth.

The region between agglutinated and *Alveolinella–Amphistegina–Operculina* subzone is marked by the presence of a transitional zone characterized by relict foraminifera fouled by barnacles (sessile cirripedes; Figure 3.3), and this subzone partially overlaps the agglutinated and *Alveolinella–Amphistegina–Operculina* subzones. This barnacle fouled relict foraminifera subzone extends from a water depth of 60 m to 90 m. Figure 5.2 shows the schematic depth zonation of two different relict benthic foraminiferal assemblages along with the overlapping barnacle zone.

In order to assess the paleoclimatic significance of relict assemblage, the chronology to the relict assemblage was assigned on the basis of radiocarbon dating of surface sediments associated with relict foraminifera from the depth of ~100 m, which gives an age of 12,000-10,000yr BP (Nigam *et al.*, 1993).

5.3 DISCUSSION

Relict foraminifera have been encountered from numerous parts of world oceans and have been applied to solve diverse geological problems. Here we show how relict foraminifera can help indicate the presence of ancient coral reef and its destruction with reference to sea level changes and associated phenomena.

Figure 5.2 Schematic representations of three relict zones. The elongated conical tests represent the agglutinated subzone; deformed polygonal tests show the barnacle subzone while rounded tests represent *Amphistegina-Alveolinella-Operculina* subzone.
Amphistegina, Alveolinella, Operculina, Quinqueloculina, Spiroloculina, Triloculina, Elphidium and Textularia dominating the relict assemblage in the deeper part of the relict zone from the study area are amongst the important benthic foraminiferal genera reported from world’s famous reef systems, with first three genera being considered as the index fauna for coral reef (Venne-Peyre, 1985; Hart and Kaeuler, 1986; Martin and Right, 1988; Hallock, 1995; Hohenegger, 1998; Yordanova and Hohengger, 1998; Langer and Lipps, 2003).

Figure 5.2: Schematic representation of three relict zones. The elongated conical tests represent the Agglutinated subzone; deformed polygonal tests show the Barnacle subzone while rounded tests represent Amphistegina-Alveolinella-Operculina subzone.

Based on the high abundance of relict Amphistegina, Alveolinella and Operculina, the presence of a paleo-reef environment is postulated within the depth range of 85-135 m in the study area. Similar conditions have also been reported from other parts of the world and have been used to understand past sea level variations (Stoddart, 1971; MacIntyre, 1972).

To infer the paleoenvironmental significance of paleo-reef, it is necessary to understand physico-chemical preferences of modern day reefs. Modern coral reefs are restricted within the tropical region with temperature and salinity range of 17-34°C and 30-38‰ respectively; normally marine water with considerably low turbidity with the maximum water depth of
30m is most congenial for a coral reef to flourish (Guilcher, 1988). As the paleo-reef environment in the study area is inferred at a depth range of 85 to 135 m, the paleo-sea level (at 12,000-10,000 yr BP) can approximately be fixed at a water depth ~80 m lower than present.

The conclusion regarding the presence of a paleo-reef and thus the lowered sea level are in agreement with the geomorphological/geophysical and bathymetric studies (Fig. 5.3, 5.4 and 5.5) carried out in this region (Vora and Almeida, 1990; Vora et al., 1996; Wagle et al., 2002; Rao et al., 2003). These studies indicated the existence of a 1300 km long shelf edge barrier reef system of 9,200 to 11,330 yr BP age at a water depth of 85-136 m. Figure 5.3 shows the presence of early Holocene reef system postulated by the aforesaid authors.

Figure 5.3: Postulated early Holocene reef system along west coast (modified after Vora et al., 1996); straight lines represent the line of echo sounding and side scan sonar data, while black dots represent the presence of past reef.
The inference regarding lowered sea level, based on the presence of a paleo-reef also gets credence from the abundance of relict barnacle at a water depth of 60 m to 90 m (Figure 5.6). Nigam et al. (1993) and Henriques (1993) reported the abundance of relict barnacle, *Tetraclita squamosa*, attached to the relict foraminifera, at a depth of 60-90 m in the study area. Ecologically *T. squamosa* represents high salinity and high-energy intertidal depth zone environment (Ekman, 1967). *T. squamosa rufotincta* (Pilsbury) has been reported within tidemarks on rock (Daniel, 1972). However, this species is totally absent in the modern environment of the west coast of India (Wagh, 1972). The relict presence of *T. squamosa* can be explained by the fact that it resided in this area and got encrusted on foraminiferal tests when the sea level was lower ~10,000 yr BP, thus indicating that at ~10,000 yr BP, the shore line was ~80 m lower than that at present.

A third zone dominated by agglutinated foraminifera, mainly *Textularia* towards the shallower depths, follows the zone of ‘barnacle encrusted relict foraminifera’. *Textularia*, agglutinated rectilinear biserial benthic foraminifer is a well-known genus indicating “shallow water low salinity condition” (Kaminski et al., 2002). Presence of six relict species of *Textularia* and other agglutinated genera at the water depth of 50-75 m with an abundance of ~55.0% of total relict benthic foraminifera, indicate the decline of salinity, most probably due to high influx of fresh water.
The fresh water influx probably resulted in increased turbidity as well as sea level rise, which eventually destroyed the coral reef. The barnacle species *Tetraclita squamosa* (now relict) could not keep pace with the sudden fall in salinity below its tolerant limit due to freshwater influx, and subsequent sea level rise, and hence disappeared in the course of time from this area.

The findings of the present study can also be discussed with reference to the Holocene sea level fluctuation curve (Figure 5.7) from the western Indian continental margin (Hashimi et al., 1995). The figure 5.7 places the paleo-shoreline at 80-90 m depth around 12,000 yr BP, followed by a stand-still for about 2000 years and then a rapid sea level rise up to 7000 yr BP (Hashimi et al., 1995). During 12,000-10,000 yr BP, when the paleo-shoreline was at a standstill at 80 m depth or was on a very slow rise, the reef formed and flourished at the water depth of 85 m to 135 m under conditions favorable for its growth. The rapid sea level rise between ~10,000 to ~7,000 yr BP probably caused the extinction of the barnacle and increase in the abundance of *Textularia*.

![Figure 5.5](image)

*Figure 5.5:* Echo sounding and side scan sonar profile for the lines a to f respectively of figures 5.3 (modified after Vora et al., 1996); R = reef; BR = buried reef; T = terrace; V = valley/depression; S = scarp; P = pinnacle.
Figure 5.6: Schematic representation of paleoclimatic scenario at ~10,000 BP; (A) Ancient coral reef at early Holocene based on the coral reef indicator fauna; (B) Barnacle zone, supporting the paleo-sea level at 80m; (C) Agglutinated zone, representing the freshwater influx; (D) Freshwater influx, sea level rise, destruction of coral reef, extinction of *T. squamosa*
5.4 CONCLUSIONS

After summarizing the distribution of relict benthic foraminifers off central west coast of India and the ecological preferences of the modern day counterparts of the relict benthic foraminiferal species, we conclude that (vide Figure 5.6):

1. The presence of the coral reef indicators *Amphistegina-Alveolinella-Operculina* assemblage proves the presence of a coral reef prior to Holocene, within the depth zone of 85m to 135m (Figure 5.6A). Depending upon the present day coral ecology the paleo-sea level is fixed at ~80 m water depth at ~12,000 to 10,000 yr BP.

2. The presence of relict barnacle zone within the depth of 60-90 m supports the postulation of 80 m lowered sea level (Figure 5.6B) and decline of salinity probably because of fresh water influx and resultant increased sea level.

3. The presence of agglutinated (mostly represented by *Textularia*) zone at 50-75 m water depth indicates freshwater influx (probably from landward side) (Figure 5.6C).
4. Freshwater influx increased the sea level from 80 m to the present day level (Figure 5.6D). This affected both, the barnacle and the coral reef. Increased fresh water influx lowered the salinity in the present area, thus adversely affecting *T. squamosa*, which eventually got extinct. Coral reef also, could not cope up with the rapid sea level rise and was destroyed just after ~10,000 yr BP.

5.5 IMPLICATIONS

This study documents the presence of a late Pleistocene-Holocene reef system along with the then shoreline at 80 m lower than present on the basis of presence of relict coral-reef foraminiferal assemblage at the present day water depth of 50-135m. The reason for destruction of the reef is suggested to be the rise of sea level during early Holocene due to rise in global temperature, as it is reported that with the onset of Holocene the global temperature rose by ~4°C (Coughan and Neyenzi, 1991). Increased temperature resulted in thermal expansion of seawater and melting of the glacial ice. This eventually increased the sea level rapidly, so much so that the reef could not cope up with the sudden rise of sea level. Thus, this study shows how rapid sea level change associated with early Holocene warming adversely affected the flourishing reef system in the region off west coast of India. The present study has made a pioneering but modest beginning in this direction. Trust this will pave the way for more such studies from the Indian waters.