Planktonic Foraminifera in Sediment Samples from the Eastern Arabian Sea

K. KAMESWARA RAO
National Institute of Oceanography, Panaji

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Twenty-two species of planktonic Foraminifera have been identified from the bottom sediments of the Arabian Sea off Bombay and their percentage occurrence has been studied. Species composition has shown that the sediments of the continental slope region off Bombay are represented by a larger number of species than the shelf sediments. The forms which are common in the eastern part of the Arabian Sea are: Globigerina bulloides, Globigerinoides ruber, G. sacculifer, Globigerinita glutinata, Globigerinella aequilateralis, Orbulina universa, P. oblifusculata, G. menardii and G. tumida. Concentration of the planktonic Foraminifera decreases from the offshore regions to regions towards the coast. In the slope sediments the per cent of CaCO₃ is proportional to the number of planktonic Foraminifera. The presence of high latitude cold water species along with the warm water species in the Arabian Sea off Bombay suggests the mixing of Antarctic water with other types of water found along the west coast of India. Similarity of the planktonic Foraminifera of the eastern Arabian Sea with that of Red Sea has been shown on the basis of species composition and dominance of certain species in both the seas. On the basis of this observation, it is concluded that Red Sea water has spread into the offshore region of Bombay.

PLANKTONIC Foraminifera in the Arabian Sea were first studied by Chapman1 who reported 17 species from the Laccadive region. Stubbings2 recorded 18 species from the Arabian Sea during John Murray Expedition. In the north-eastern part of the Arabian Sea which includes Gulf of Cambay, Kameswara Rao3,4 found 9 species. Recently Be' and McIntyre5 reported the presence of an 'extinct' subspecies, Globorotalia menardii flexuosa (Koch), from the samples collected for the present investigation. From the foregoing account it is obvious that there is no thorough quantitative documentation of various species of planktonic Foraminifera present in the west coast of India, although their presence in different regions of the Arabian Sea has been noted.

In this paper the quantitative distribution of various planktonic foraminiferal species present in the bottom sediments of the Arabian Sea off Bombay is reported. Such a study has a bearing on oceanographic conditions of the sea and also it will be useful for the comparison of the fauna with other regions.

During a cruise sponsored by the Institute on board INS 'Darshak' in January 1969 into the Arabian Sea off Bombay, several bottom sediment samples were collected using Lafond-Dietz snapper. Altogether 7 snapper samples were obtained and the sampling stations are shown in Fig. 1. The purpose of the collections of these samples is to determine species composition of planktonic Foraminifera and their quantitative distribution in the bottom sediments of the Arabian Sea off Bombay. The study area extends between longitudes 69°30'4'E and 72°22'0'E and latitudes between 18°33'5'N and 19°15'0'N. The water depths at the sites in the area range between 62 and 1820 m.

The continental shelf off Bombay coast has a maximum width of about 161 km. The inner shelf is flat whereas the outer shelf is highly irregular all the way to its edge (140 m) being formed of pinnacles and knolls with intervening depressions. The continental slope of the west coast of India is gradual.

Materials and Methods

Eight stations were covered during the said cruise. At the station 47 (lat. 19°15'0'N and long. 69°45'0'E), a pipe dredge was used and it came up with coral rocks and oolite limestones. The snapper did not get any sample at this locality and therefore for planktonic foraminiferal analysis only 7 samples were taken. The method of separating the Foraminifera from the samples is same as earlier4. Percentages of various planktonic species present in the samples have been calculated (Table 2). Station locations, sampling times and bottom character are given in Table 1 and data on water depths, salinity, temperature, calcium carbonate and total number of Foraminifera are presented in Figs. 2 to 6. Calcium carbonate content of the sediment samples was determined using the method...
of Hutchinson and Macelnnan as described by Barnes.

Results

The bottom sediment samples can be classified into 5 categories, viz. silty clay, silty sand, sand, sandy silt and silt. The sediments from the shore to a depth of 62 m are silty clay; from depths of 62 to 96 m the deposits are either silty sand or sand and from the outer shelf towards the sea the deposits are found to be sandy silt or silt. Seaward from 62 m to a depth of 96 m a calcareous zone is found. Evidence for this observation could be made on the basis of rock fragments and corals from 62 m to a depth of 96 m a calcareous zone has been derived largely from the flagellate species of planktonic foraminifera belonging to 9 genera and 2 families, viz. Globigerinidae and Globorotaliidae, are identified. The fauna is dominated by warm water species and with the exception of Globigerina bulloides, all other cold water species reported in this paper are uncommon. The collection of planktonic Foraminifera in the Arabian Sea off Bombay is typical of Indo-Pacific region and the list of species is as follows:

Hastigerina pelagica (d'Orbigny), Fig. 7
Orbulina universa d'Orbigny, Fig. 8
Globigerinoides conglobatus (Brady), Fig. 9
Globigerinoides ruber d'Orbigny, Fig. 11
Globigerinoides sacculifer (Brady), Fig. 10
Globigerina rubescens Hofker, Fig. 12
Globigerinella quinquedens Natland, Fig. 13
Globigerina pachyderma (Ehrenberg), Fig. 14
Globigerina falconensis Blow, Fig. 15
Globigerinoides bulloides d'Orbigny, Fig. 16
Globigerina calida Parker, Fig. 17
Globigerinella aquilispiralis (Brady), Fig. 18
Globigerinella adamsi (Banner and Blow), Fig. 20
Globigerinita glutinata (Egger), Fig. 19
Globorotalia dutertrei (d'Orbigny), Fig. 21
Globorotalia conglomerata Schwager, Fig. 22
Pulvinatina obliquiloculata (Parker and Jones), Fig. 23
Globorotalia truncatulinoides (d'Orbigny), Fig. 24
Globorotalia hirsuta (d'Orbigny), Fig. 25
Globorotalia menardii (d'Orbigny), Fig. 26
Globorotalia tumida (Brady), Fig. 27
Globorotalia menardii flexuosa (Koch), Fig. 28

The total population of planktonic Foraminifera shows greater variation in abundance at varying depths in the continental shelf region of the Bombay coast and the sediments in the slope region are quite rich in planktonic Foraminifera. The area of greatest planktonic foraminiferal abundance (34750 specimens/g dry sediment) is the site No. 44. High concentrations of planktonic Foraminifera have been observed in the slope region off Bombay. In the shelf region concentration of planktonic Foraminifera varies from 750 to 9150 specimens/g dry sediment.

Planktonic foraminiferal species found in all the samples are: Hastigerina pelagica, Orbulina universa, Globigerinoides conglobatus, G. ruber, G. sacculifer, Globigerina falconensis, G. bulloides, Globigerinella aquilispiralis, Globigerinella glutinata, Globorotalia dutertrei, Pulvinatina obliquiloculata, Globorotalia menardii and G. tumida.

Three of the 22 species recorded are found at 4 sites only, they being Globigerina quinquedens, G. calida and G. pachyderma.

Planktonic foraminiferal species found at 2 sites are: Globigerinella adamsi and Globorotalia hirsuta.

Planktonic forms observed at one station only are: Globorotalia truncatulinoides and Globorotalia menardii flexuosa.

The general relationship between planktonic foraminiferal number (number of planktonic foraminiferal specimens present in one gram of dry sediment) and depth indicated that the number increases

<table>
<thead>
<tr>
<th>Station No.</th>
<th>Date</th>
<th>Latitude</th>
<th>Longitude</th>
<th>Character</th>
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</thead>
<tbody>
<tr>
<td>40</td>
<td>7/1</td>
<td>18°34'5&quot;N</td>
<td>72°22'0&quot;E</td>
<td>Silty clay</td>
</tr>
<tr>
<td>41</td>
<td>7/1</td>
<td>18°35'7&quot;N</td>
<td>71°33'5&quot;E</td>
<td>Silty sand</td>
</tr>
<tr>
<td>42</td>
<td>8/1</td>
<td>18°36'0&quot;N</td>
<td>70°39'4&quot;E</td>
<td>Sand</td>
</tr>
<tr>
<td>43</td>
<td>8/1</td>
<td>18°35'5&quot;N</td>
<td>70°21'6&quot;E</td>
<td>Sandy silt</td>
</tr>
<tr>
<td>44</td>
<td>8/1</td>
<td>18°35'0&quot;N</td>
<td>70°03'0&quot;E</td>
<td>Silt</td>
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<tr>
<td>45</td>
<td>8/1</td>
<td>18°49'0&quot;N</td>
<td>69°47'5&quot;E</td>
<td>do</td>
</tr>
<tr>
<td>46</td>
<td>8/1</td>
<td>19°03'0&quot;N</td>
<td>69°30'4&quot;E</td>
<td>do</td>
</tr>
</tbody>
</table>

TABLE 1 - DATA ON BOTTOM SEDIMENTS FROM THE ARABIAN SEA OFF BOMBAY

Figs. 2-6 - Ecological data and distributional trend of planktonic foraminiferal fauna
The planktonic foraminiferal species from the eastern part of the Arabian Sea can be classified into two categories: warm and cold water species. Some dominant warm water species in the Arabian Sea off Bombay are: *Hastigerina pelagica*, *Globigerinoides ruber*, *G. sacculifer*, *Globigerinella aequilateralis*, *Orbulina universa* and *Globorotalia tumida*. All the cold water species which are rare with the exception of *Globigerina bulloides* are *Globigerina pachyderma* and *G. quinqueloba*. The occurrence of cold water species with warm water species in the bottom sediments of the Arabian Sea off Bombay is an indication of the mixing of the Antarctic water with other types of water, viz. the Indian equatorial water, the Red Sea water and the Indian central water found along the west coast of India. It is also known that the upwelling of the cold bottom waters of the Antarctic comes to the surface in the Arabian Sea when confronted with the Carlsberg Ridge.

In connection with the mixing of the two types of faunal elements, it is worth mentioning about an interesting species, namely *Globorotalia menardii flexuosa* (Koch). Ericson et al. observed specimens of *G. m. flexuosa* at certain Quaternary levels of Atlantic deep-sea cores and it was considered by these authors on the basis of this observation that this subspecies became extinct after having lived about 90000 to 125000 years ago in a circumtropical belt in the Atlantic, Indian and Pacific Oceans during the warm Interstadial of the Wisconsin and the Sargamon Interglacial.

Quantitative analysis of planktonic Foraminifera from the shelf sediments has shown that the silty sand and sand deposits contain only a few forms whereas the sandy silt and silt deposits are fairly rich in variety and numerical abundance. The sediments of the continental slope region are represented by a larger number of specimens of planktonic Foraminifera than those of the shelf. It can be inferred that low concentrations of planktonic Foraminifera in the shelf region is due to low productivity of this group in the shelf waters. The sediments in the shelf region off Bombay are fairly rich in CaCO₃ and the content of CaCO₃ varies from 38 to 66%. Seaward from 62 m to a depth of 96 m, a calcareous sand zone exists and in this area CaCO₃ varies from 52 to 66% and the calcareous material is largely derived from the coral rocks and oolite limestones. From the edge of the continental shelf and continuing into the slope, CaCO₃ content in the deposits varies from 30 to 48%. The content of CaCO₃ in the pelagic sediments is actually the balance of the two processes, viz. productivity of calcareous organisms and the reaction of water on the deposited calcareous remains. It has been found that in this region the source of calcareous material is dominantly from floating calcareous organisms, namely planktonic Foraminifera, and in the deposits of this area CaCO₃ content increases with the number of planktonic Foraminifera (Fig. 5). This confirms the observation of Correns that the amount of CaCO₃ in the silt is proportional to the number of foraminiferal tests.

### Table 2 — Percentage Occurrences of Planktonic Foraminiferal Species

<table>
<thead>
<tr>
<th>Planktonic species</th>
<th>Station number</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>40</td>
</tr>
<tr>
<td></td>
<td>Depth, m:</td>
</tr>
<tr>
<td><em>Hastigerina pelagica</em></td>
<td>1-2</td>
</tr>
<tr>
<td><em>Orbulina universa</em></td>
<td>9-6</td>
</tr>
<tr>
<td><em>Globigerinoides conglobatus</em></td>
<td>3-2</td>
</tr>
<tr>
<td><em>Globigerinoides ruber</em></td>
<td>30-8</td>
</tr>
<tr>
<td><em>G. sacculifer</em></td>
<td>4-6</td>
</tr>
<tr>
<td><em>Globigerina rubescens</em></td>
<td>0-6</td>
</tr>
<tr>
<td><em>Globigerina quinqueloba</em></td>
<td>—</td>
</tr>
<tr>
<td><em>Globigerina pachyderma</em></td>
<td>0-2</td>
</tr>
<tr>
<td><em>Globigerinella falcomensis</em></td>
<td>2-8</td>
</tr>
<tr>
<td><em>Globigerina bulloides</em></td>
<td>15-8</td>
</tr>
<tr>
<td><em>Globigerina calida</em></td>
<td>—</td>
</tr>
<tr>
<td><em>Globigerinella aequilateralis</em></td>
<td>4-8</td>
</tr>
<tr>
<td><em>Globigerinella adamsi</em></td>
<td>1-0</td>
</tr>
<tr>
<td><em>Globigerinella glutinata</em></td>
<td>14-8</td>
</tr>
<tr>
<td><em>Globorotalia dutertrei</em></td>
<td>5-2</td>
</tr>
<tr>
<td><em>Globorotalia conglomerata</em></td>
<td>1-6</td>
</tr>
<tr>
<td><em>Pulvinaria obliquiloculata</em></td>
<td>0-8</td>
</tr>
<tr>
<td><em>Globorotalia truncatuloides</em></td>
<td>—</td>
</tr>
<tr>
<td><em>Globorotalia hirsuta</em></td>
<td>2-5</td>
</tr>
<tr>
<td><em>Globorotalia menardii</em></td>
<td>1-2</td>
</tr>
<tr>
<td><em>Globorotalia menardii flexuosa</em></td>
<td>—</td>
</tr>
</tbody>
</table>

with depth and distance from the shore (Fig. 6). The slope sediments are represented by larger number of species. Studies on this group have shown that in the slope sediments the percentage of CaCO₃ increases with the abundance of planktonic Foraminifera.

**Discussion**

The planktonic foraminiferal species from the eastern part of the Arabian Sea can be classified into two categories: warm and cold water species. Some dominant warm water species in the Arabian Sea off Bombay are: *Hastigerina pelagica*, *Globigerinoides ruber*, *G. sacculifer*, *Globigerinella aequilateralis*, *Orbulina universa* and *Globorotalia tumida*. All the cold water species which are rare with the exception of *Globigerina bulloides* are *Globigerina pachyderma* and *G. quinqueloba*. The occurrence of cold water species with warm water species in the bottom sediments of the Arabian Sea off Bombay is an indication of the mixing of the Antarctic water with other types of water, viz. the Indian equatorial water, the Red Sea water and the Indian central water found along the west coast of India. It is also known that the upwelling of the cold bottom waters of the Antarctic comes to the surface in the Arabian Sea when confronted with the Carlsberg Ridge.
that the mixing of the two faunal categories is 'relict' in nature but this conclusion is not true in view of the fact that Be' and McIntyre\(^5\) could discover living specimens of the same species in the northern Indian Ocean which includes Bay of Bengal and Arabian Sea. From this report we can conclude that it is still living since its inception. Report of Be' and McIntyre\(^5\) about the presence of *Gl. m. flexuosa* from the sediment samples of the present investigation is further an evidence of its presence in the Arabian Sea besides Bay of Bengal and other adjacent seas of northern Indian Ocean.

Our knowledge of planktonic Foraminifera present in the Red Sea is mainly from the contributions of Said\(^12\), Herman\(^13\) and Berggren and Boersma\(^14\). Said\(^12\) recorded 5 planktonic forms. Herman\(^13\) reported 16 species from the samples of the Red Sea. Further studies on this group from the Red Sea by Berggren and Boersma\(^14\) have shown that some species like *Orbulina universa*, *Globigerinella aequilateralis*, *Globigerinoides ruber* and *G. sacculifer* are dominant. In the offshore region of Bombay, the above-mentioned species are quite abundant. *Globigerinoides ruber* which is known to tolerate high salinity conditions in the Red Sea is very dominant in the offshore region of Bombay. Out of the 16 species reported by Herman\(^13\), 14 of them are encountered in the samples of the study area. From the results of the present investigation and those of earlier studies by Chapman\(^1\) and Stubbings\(^3\) it is seen that there is some identity of the planktonic foraminiferal fauna of the Red Sea with that of Arabian Sea. This similarity of planktonic foraminiferal fauna in both the seas suggests that the Red Sea water has spread into the offshore region of Bombay. This finding is of importance as it is the only available biological evidence so far for the mixing of Red Sea water with that of Arabian Sea. Physical evidence for this phenomenon is that of Rochford\(^3\) who has shown the presence of Red Sea water along the west coast of India on the basis of *T-S* characteristics.

**Acknowledgement**

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**References**