CHAPTER-I
CHAPTER - 1

1. INTRODUCTION

1.1 Area of Study

The area under investigation is off the coast of Rameswaram (Long. \(79°20'\) to \(79°35'\) and Lat. \(9°15'\) to \(9°17'\)) in the Palk Bay, Ramanathapuram District which lies on the east coast of Tamil Nadu forming parts of toposheet numbers 58 0/7 and 58 0/11 of the Survey of India (Fig.1).

The district is, for the most part, a plain sloping gently from west to east. The eastern and southern parts of the district are bordered by a chain of islands of which Rameswaram is the largest. These islands lie within a distance of 8 kms. from the coast and within a depth of 5 fathoms.

The geological sequence of the rock formations of Rameswaram is as follows: (IN: Geological Survey of India-125th Anniversary celebrations brochure).

<table>
<thead>
<tr>
<th>Recent</th>
<th>Alluvium</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>- Laterite</td>
</tr>
<tr>
<td>Tertiary</td>
<td>Cuddalore sandstone and Warkali beds</td>
</tr>
<tr>
<td>Palaeozoic</td>
<td>Upper Gondwana</td>
</tr>
<tr>
<td></td>
<td>Charnockite</td>
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<tr>
<td></td>
<td>Calc granulites and Crystalline limestone</td>
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<tr>
<td></td>
<td>Quartzite</td>
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<tr>
<td></td>
<td>Unclassified gneisses</td>
</tr>
<tr>
<td>Archaean</td>
<td>Granites and Syenites</td>
</tr>
</tbody>
</table>
FIG. 1 MAP SHOWING LOCATION OF SAMPLING STATIONS IN THE PALK BAY OFF RAMESWARAM, TAMIL NADU.
Exposure of marine fossiliferous Cuddalore sandstone occurs all along the coast of Rameswaram and nearby areas. This sandstone is brownish-cream to grey in colour and vary in composition from siliceous to calcareous. Corals and algae appear to have grown on these sandstones at the base of the numerous islands present. The islands are partly covered by wind-blown and wave-borne sands usually for a thickness of 3-10 feet. In some areas, the sand dunes may reach a height of 15-20 feet. The sand consists essentially of a mixture of quartz, feldspar and garnet with fragmentary material of corals, molluscs, calcareous algae and foraminifera.

Large masses of corals like Madrepora, Montipora, Pocillipora and colonies of the fragile Echinopora etc. are abundant and they are the chief reef builders. The corals afford shelter and support for a large variety of marine animals like protozoans, sponges, coelenterates, molluscs, crustaceans, etc.

In the shallower surf beaten area between high tide and low tide levels, different kinds of marine algae flourish. The important marine algae of this area (James, 1987) are as follows:

In the present area, these algae also serve as a substrate for the foraminiferal fauna.

This region is influenced by the north-east monsoon (September to November) and the south-west monsoon (June to August). The annual rainfall in this area for a period of 5 years is given in the following table:

<table>
<thead>
<tr>
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</thead>
<tbody>
<tr>
<td>January</td>
<td>31.0</td>
<td>-</td>
<td>10.0</td>
<td>205.5</td>
<td>368.6</td>
</tr>
<tr>
<td>February</td>
<td>8.8</td>
<td>-</td>
<td>-</td>
<td>307.9</td>
<td>41.3</td>
</tr>
<tr>
<td>March</td>
<td>-</td>
<td>6.2</td>
<td>-</td>
<td>106.7</td>
<td>5.5</td>
</tr>
<tr>
<td>April</td>
<td>24.3</td>
<td>31.3</td>
<td>12.6</td>
<td>173.7</td>
<td>14.7</td>
</tr>
<tr>
<td>May</td>
<td>71.2</td>
<td>15.5</td>
<td>57.2</td>
<td>2.7</td>
<td>29.8</td>
</tr>
<tr>
<td>June</td>
<td>0.4</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0.5</td>
</tr>
<tr>
<td>July</td>
<td>32.1</td>
<td>1.5</td>
<td>0.1</td>
<td>49.9</td>
<td>33.3</td>
</tr>
<tr>
<td>August</td>
<td>-</td>
<td>1.0</td>
<td>25.6</td>
<td>13.7</td>
<td>31.2</td>
</tr>
<tr>
<td>September</td>
<td>53.3</td>
<td>42.7</td>
<td>0.7</td>
<td>23.9</td>
<td>24.6</td>
</tr>
<tr>
<td>October</td>
<td>170.2</td>
<td>221.5</td>
<td>51.5</td>
<td>33.5</td>
<td>160.4</td>
</tr>
<tr>
<td>November</td>
<td>138.8</td>
<td>447.6</td>
<td>259.3</td>
<td>353.7</td>
<td>360.4</td>
</tr>
<tr>
<td>December</td>
<td>141.1</td>
<td>211.3</td>
<td>552.9</td>
<td>30.3</td>
<td>87.1</td>
</tr>
</tbody>
</table>

The bay depressions during October, November and December very frequently cross the coast in this area and during those times there is a heavy downpour.

The climate of the district is, on the whole, is healthy. The district enjoys, save in the hottest months, an almost equitable temperature. The monthly average temperature is generally low at the beginning of the year.
The temperature is at its peak during the summer season (March to May). Subsequently, there occurs a fall in the average temperature during the months of June and July. In general, during the months of November and December a minimum temperature prevails.

1.2 Choice of the area and purpose of Study

The author has chosen the area, inner shelf of Palk Bay, off Rameswaram for foraminiferal studies for the following reasons:

(i) The author could get the essential facilities such as motor launch, mud grab, water sampler, etc. from the Tamil Nadu State Fisheries Department, Rameswaram, for the collection of sediment and bottom water samples.

(ii) The shallow nature of the bay which never exceeded 7-8 fathoms for a long stretch from Rameswaram in the west to Sri Lanka in the east; the occurrence of many coral reefs in the area and the abundance of algal growth, seem to provide a congenial environment for the thriving of varied fauna.

(iii) So far the ecological studies of foraminiferal fauna from the Palk Bay area have not been undertaken.

The purpose of the study is i) to inventory the foraminiferal fauna of the inner shelf of Palk Bay ii) to determine quantitatively the composition of the foraminiferal population iii) to ascertain the distribution of living and total (living + dead) populations iv) to discover the seasonal variations of the foraminiferal fauna v) to attempt to correlate their distribution with observed environmental factors vi) to evaluate the ecology of the widespread
and abundant foraminiferal taxa vii) to interpret the foraminiferal population using statistical methods and viii) to compare the foraminiferal assemblage of the present area with those from off Porto Novo, the only other Indian work on Recent foraminiferal ecology in the open bay environment.

The foraminiferal taxa of the Palk Bay area was compared with that of the Coral Sea, South of Papua, New Guinea, deposited in the Department of Geology, University of Madras, Madras. The latter was studied by Prof. D.A. Rasheed (1958) and compared by him with the materials of the 'Challenger', Malaykerimba Archipelago, Delos and Palermo, deposited in the British Museum (Natural History), London. A comparison of the present fauna has also been made with those from off Mandapam (Ragothaman and Manivannan, 1985).

The available literature on Recent foraminifera in the Department of Geology, University of Madras, Madras; Geological Survey of India, Calcutta; National Institute of Oceanography, Goa as well as many personal collections from various distinguished authors have been referred.

Various analyses of the bottom water samples were carried out at the Hydrological division of the Tamil Nadu State Fisheries Department, Chetput, Madras.

Percentage distribution data of different genera were subjected to Q-mode factor analysis using FORTRAN IV 'Program package for factor analysis' (Mahadevan and Fernandes, 1983) on 'ND-100' at the Computer centre of the National Institute of Oceanography, Goa.

Photo micrographs of various views of the 108 foraminiferal taxa were
The author's present work is only an initiation of the many subsequent research work on this subject, when more facilities are available.

1.3 Methods of Study

1.3.1 Field work

The sediment samples and bottom water samples for foraminiferal studies were collected at 13 stations off Rameswaram (Fig.1), ranging in depths between less than one foot and about 43 feet. Because of the non-availability of a research vessel and since only a motor launch was available and because of the shallow nature of the Bay, the collection was restricted to a maximum depth of about 43 feet. The motor launch (about 35 feet long) belonging to the Fisheries Department of Tamil Nadu State was used. The dates of collection were generally adjusted for the day of new moon. The traverse of the sample collection is due east starting from behind the Rameswaram temple, a prominent land mark. The first station was the shore station less than a foot deep and the farthest station (number 13 station) was about 43 feet deep, the intermediary stations in the traverse being of intermediate depths. All the stations are almost equispaced, keeping up the speed and time of travel of the motor launch. The samples were collected once in 3 months for a period of one year, representing the four seasons of an year, starting from January 1985. (The four seasons of the year are - Summer -March to May; Southwest monsoon - June to August; Northeast monsoon - September to November; Winter - December to February). Thus the collections amounted to a total of 52 samples.
All the sediment samples were collected by the author himself taking necessary precautions, making use of Petersen grab (Betjeman, 1969). A unit volume of 25 ml. wet sediment taken from the top 1 cm. of sediment (making use of a plastic tube) was preserved in a 10% solution of neutralized formaldehyde for foraminiferal study. A small quantity of sodium carbonate was added in order to maintain the alkaline condition since otherwise the formalin may become acidic with time (Walton, 1964). The remaining sediment sample was preserved in a polythene bag for further laboratory investigations. Both of them were indexed. The respective depths of the water column above the sediments were noted.

At each station, samples of water from the sediment-water interface were collected using a Nansen water sampler. The temperature of the bottom water sample was recorded from the built-in thermometer. A portion of the sample was transferred to a 250 ml. black-coloured bottle (coated with wax and black paint) carefully avoiding air bubbles. The dissolved oxygen in it was fixed by adding 1 ml. each of Winkler 'A' and Winkler 'B' solutions, viz., manganous sulphate and alkaline potassium iodide solutions (Strickland and Parsons, 1968). The bottle was tightly fitted with a glass stopper and thoroughly shaken until the precipitated manganous hydroxide was uniformly dispersed. Then the precipitate was dissolved using concentrated H$_2$SO$_4$. This solution was preserved for estimating the dissolved oxygen content. The remaining water sample was stored in a polythene bottle and a few drops of chloroform were added to preserve it. The addition of chloroform for the preservation proved to be a satisfactory procedure and found to be better than other methods (Newcombe et al., 1939).
1.3.2 Laboratory Work

(i) Staining the living foraminifera:

'The study of living populations as well as dead populations is essential in understanding the ecology of modern foraminifera' (Phleger, 1960, p.32). Hence, the first step in the study of foraminiferal ecology is the differentiation of 'living' foraminifera from the 'dead'. Any specimen in a sample preserved in neutralized formalin is considered to be alive at the time of collection if it contained protoplasm. Recognition of the presence of the preserved cell in a specimen without use of a colour aid, such as a biologic stain, is laborious and not well-suited to rapid examination of large suites of specimens (Phleger, 1960). Different staining methods have been used for distinguishing the 'living' from the 'dead'. Rhumbler (1935) used 'Methgreosin', a mixture of 50 cc of 1% aqueous solution of methyl green, 50 cc solution of 0.8 gm. of cosin in a 50% solution of alcohol and 50 cc of absolute alcohol. (Before keeping the sample in the above solution, it is first treated with water or weak alcohol solution). The detrital and faecal materials are stained green and the organic material is stained red. Though, by this method, the living animals and other materials are differentiated colourimetrically, it is not desirable to have all the material stained.

Phleger (1945, 1951) employed Biuret test, in which an equal volume of 10% sodium hydroxide is added to a washed sample in an aqueous solution. This solution, which should be no colder than average room temperature (18°-20°C), is agitated and allowed to stand for about 10 minutes. About 30 drops of 0.5% solution of copper sulphate is added gradually, 2 to 3 drops at a time, everytime agitating the solution until a blue solution is formed.
The addition of copper sulphate either too fast or without agitation may cause a precipitate of copper hydroxide and it will creat difficulty in identification. In about 20-30 minutes a blue to pink colour is obtained on any proteinaceous material present. This reaction is relatively weak and temporary.

Phleger (1952) made use of Millon's reagent. This is prepared by digesting 1 part by weight of mercury with 2 parts by weight of nitric acid (sp.gr. 1.42) and the same is diluted with two volumes of water. After it has settled, the supernatant liquid, a solution of mercuric nitrate in nitric acid containing some nitrous acid, is used. This solution imparts a red colour to proteinaceous material in the presence of heat. In this process, the reagent contains free nitric acid and hence it can be used only for agglutinated tests.

The most positive method for identifying living foraminifera is Walton's (1952) staining technique with rose Bengal (Phleger, 1960, p.32). The rose Bengal technique was used by zoologists for staining bacteria and cytoplasm. After conducting a series of experiments to ascertain the effect of this dye with different concentrations, Walton found that worms, arthropods and those foraminiferal tests containing protoplasm were stained a deep-rose, leaving the empty shells, inorganic and organic debris unstained. He originally thought that an approximate 10 minutes time would be sufficient for staining the material, but he later (1955) found that 20-30 minutes gives good colouration to the protoplasm. This technique is equally applicable to calcareous and arenaceous - agglutinated forms since it does not involve treatment with any acid. Walton's technique has since been widely adopted.
for its obvious advantages over the earlier methods. Schafer and Sengupta (1969) employed Walton's technique with a slight modification by storing the sample itself in isoprophyl alcohol which had been mixed with rose Bengal dye. According to Ellison and Nicholos (1970), a mixture of 1 gm. rose Bengal and 5 ml. phenol dissolved in 100 ml. distilled water gives a good stain.

In the present study, following Walton's (1952) technique, the sediment sample preserved in neutralised formalin was subjected to laboratory treatment. The preserved sample was washed over an ASTM 230 mesh sieve (opening = 0.063 mm) to remove the silt and clay. The sieve with the residue was kept for about an hour in a tray containing an aqueous solution of rose Bengal (1 gm. of rose Bengal dye in 1 litre of distilled water) insuring that the residue on the sieve mesh was fully covered by the solution. Then the material on the sieve was washed to remove the excess stain and dried.

The foraminiferal tests were then separated from the residue by using carbon tetrachloride (Cushman, 1959, p.27). As a check, the residue after floatation was re-examined under a stereomicroscope for any foraminiferal tests left unconcentrated. They were hand-picked using 'OO' Windsor-Newton sable-hair brush.

(ii) Counting, Mounting and Photography:

The faunal specimens thus obtained were spread over a picking tray. The different genera and species were identified. The living and dead populations were counted. Where the population size was considerably large, it was split to obtain a workable population.

Selected specimens of each species were mounted on micropala-
eontological slides, according to the family, genus and species, over a thin layer of tragacanth gum. Before the gum gets dried up each specimen was oriented to the desired position, for further study.

Selected specimens were mounted on a double side adhesive tape over a specified stub. Making use of the same, a series of Scanning Electron microscope photomicrographs were taken to illustrate the various views of the 108 foraminiferal taxa.

(iii) Sand-silt-clay ratio estimation:

The off-shore shallow water sediments are, in general, composite types consisting particles of size range from sand to clay with their different combinations. In order to find out the percentages of sand, silt and clay, firstly, each sample was completely dried in a hot-air-oven to eliminate the moisture content. Then, a suitable quantity of each sample was dispersed overnight with sodium hexametaphosphate solution of 0.025 N for disaggregation. The material thus disaggregated was washed through a 230 ASTM sieve mesh (opening = 0.063) made of phosphor-bronze wiremesh until clear water passed through, taking care that the washings did not exceed 1000 cc. The material retained on the sieve was dried and weighed for obtaining the weight of the material coarser than 1/16 mm., ie., sand. The fine material (silt and clay) in the washings was analysed by the pipette method in accordance with the procedure adopted by Krumbein and Pettijohn (1938, pp.166-168). The suspension passing through the sieve was collected in a 1 litre graduated measuring jar. If the suspension collected in the jar, after complete washing, is less than 1000 cc', the already prepared sodium-hexametaphosphate solution was added to make it up to 1000 cc. Then,
the suspension in the measuring jar was well agitated using a stirring device, inorder to have a uniform distribution of the particles in suspension. As soon as the agitation stopped, the time was noted. Exactly after 2 hours and 3 minutes, a 20 cc pipette was slowly inserted upto a depth of 10 cms. in the solution and the sample was withdrawn from the place with uniform suction. The pipetted out sample was transferred to a 50 cc beaker and dried in an oven. Care was taken to prevent boiling and splintering. After complete drying, the weight of the residue was found out. The respective weights of sand, silt and clay were converted into weight percentages and plotted on a trilinear diagram. Trefethen's (1950) textural nomenclature has been used to describe the sediments, in the present study.

(iv) Organic matter:

Organic matter is that portion of a sediment which has arisen through organic activity and contains carbon in any form other than mineral carbonate (Sverdrup et al., 1942 ; Trask, 1939). It consists mainly of carbon, oxygen, hydrogen and nitrogen and also several others such as phosphorous, sulphur, silica, potassium and iron in small quantities (Trask, op. cit.) It is determined indirectly by estimating its carbon, nitrogen or phosphate content. The organic matter of soils and sediments is generally estimated by determining the organic carbon. A multiplying factor 1.72 is preferred by soil chemists on the assumption that organic matter contains 58% carbon. Texture serves as an index of organic content, the finer sediments containing more organic matter than the coarse-grained sediments.

The only method available for directly determining organic matter is
that in which the soil organic matter is oxidised by a concentrated solution of hydrogen peroxide, the resultant loss being taken as a measure of organic matter. But, the organic matter is usually calculated from the content of organic carbon. This can be determined with considerable accuracy by dry combustion methods, wet combustion methods and titrometric methods. The dry combustion methods are too expensive and cannot distinguish between the different forms of carbon such as coal, charcoal, graphite etc. The wet combustion methods are too time-consuming.

In the present study, organic matter was determined by the method of Walkley and Black as detailed out by Jackson (1967, pp. 219-221). This is a chromic acid method based on spontaneous heating by dilution of sulphuric acid. The procedure is as follows: First, the sediment sample was dried in a hot-air-oven to remove the moisture content. Some quantity of the sample was crushed to fine particles and from it 0.5 gm. of sediment was transferred to a 500 ml. conical flask. Then, exactly 10 ml. of 1 N potassium dichromate solution was added to it and the two were mixed well by swirling the flask. Later, 20 ml. of conc. sulphuric acid containing 0.1 gm. of silver sulphate was added. The contents were mixed well by gentle rotation of the flask for one minute to insure complete contact of the reagents with the soil containing organic matter, with care to avoid throwing up of the soil on to the sides of the flask out of contact with the reagents. The mixture was allowed to cool for 30 minutes. A standardization blank (without soil) was made in the same way. This solution was diluted to 200 ml. with distilled water and 10 ml. of 85% phosphoric acid, 0.2 gm. of sodium flouride and 30 drops of diphynylamine indicator were added. The solution was blank titrated with 0.5 N ferrous ammonium sulphate solution. The colour was dull green with chromous ion at the beginning, then shifts
to a turbid blue as the titration proceeds. At the end-point, this colour shifts to a brilliant green giving one drop end point.

The organic matter was calculated by the following equation:

\[
\% \text{ OM} = 10 \left(1 - \frac{T}{S}\right) \times 1.34
\]

where \( S \) = Standardisation blank titration
ml. ferrous solution.

\( T \) = Sample titration ml. ferrous solution

The factor 1.34 was derived as follows:

\[
(1.0 \text{ N}) \times \frac{12}{4000} \times \frac{1.72}{0.77} \times \frac{100}{0.5} = 1.34 \text{ in which } 0.5 \text{ is the sample weight, } 1.72 \text{ the factor for OM from carbon and } \frac{12}{4000} \text{ the meq. wt. of carbon. The 77% recovery factor found by Walkley was used.}
\]

(v) Calcium carbonate:

Determination of calcium carbonate content of the sediments was made in order to find out its influence over the fauna.

In the present study, calcium carbonate was determined by the author using rapid titration method (after Piper, 1947). The carbonates determined by this method includes other carbonates such as magnesium which is negligible and hence for all practical purposes the total carbonate is referred to as calcium carbonate in the present investigation.

The procedure for determining the calcium carbonate content in sediments is as follows: 5.0 gms. of soil was weighed and transferred to a tall 150 ml. beaker (For soils with approximately more than 30% of calcium carbonate, 2.5 gms. of soil sample is enough). Then, 100 ml. of N hydro-
chloric acid was added to it making use of a pipette with an enlarged jet. The beaker was covered with a watch glass and stirred vigorously several times for a period of one hour. After allowing the mixture to settle, 20 ml. of supernatant liquid was pipetted out and transferred to a small erlenmeyer flask. To it was added 6-8 drops of bromothymal blue indicator and titrated with N sodium hydroxide. With some soils, the colour of the indicator may fade as the end point—blue colour—is approached. In such cases more indicator is added and the titration completed. A blank titration is carried out to obtain the titre of hydrochloric acid. The percentage of calcium carbonate is known by the equation

\[% \text{CaCO}_3 = (\text{Blank titration} - \text{Actual titration}) \times 5.\]

(vi) Dissolved Oxygen:

The concentration of dissolved oxygen in sea water varies from 0 to in excess of 10 ml./l. of sea water. The former value would be found in stagnant waters and the latter in a region of supersaturation at the surface and in the presence of great photosynthetic activity.

There are physico-chemical, electrochemical and pure chemical methods for the evaluation of dissolved oxygen in sea water. In the present study, Winkler's method (Strickland and Parsons, 1968) was employed, in which, any dissolved oxygen present (fixed during the time of sample collection) rapidly oxidises an equivalent amount of divalent manganese to basic hydroxide of higher valency states. When the solution was acidified in the presence of iodide, the oxidised manganese again reverts to the divalent state and iodine, equivalent to the original dissolved oxygen content of water was liberated, which was titrated against sodium thiosulphate solution.
\[
\begin{align*}
\text{Mn}^{2+} + 2(\text{OH})^- & \rightarrow \text{Mn(OH)}_2 \\
2\text{Mn(OH)}_2 + \text{O}_2 & \rightarrow 2\text{MnO(OH)}_2 \\
\text{MnO(OH)}_2 + 4\text{H}^+ + 3\text{I}^- & \rightarrow \text{Mn}^{2+} + 3\text{I}^- + 3\text{H}_2\text{O} \\
\text{I}_3^- + 2\text{S}_2\text{O}_3^{2-} & \rightarrow 3\text{I}^- + \text{S}_4\text{O}_6^{2-}
\end{align*}
\]

The procedure adopted is as follows:

100 ml. of sample (already fixed for dissolved oxygen in the field) was taken in a conical flask and to it was added 2 or 3 drops of starch indicator. A blue colour will develop. This was titrated with N/40 sodium thiosulphate till the colour was discharged. By calculation,

\[
1 \text{ ml. of N/40 Na}_2\text{S}_2\text{O}_3 = 0.2 \text{ ml. of dissolved oxygen.}
\]

\[
\text{ml/L dissolved oxygen present} = \frac{0.2 \times 1000}{\text{Vol. of fixed solution}} = \frac{0.2 \times 1000}{100} = 2
\]

So, burette reading \(\times 2\) = ml/L. of dissolved oxygen when 100 ml. of fixed solution was taken.

(vii) Salinity:

Salinity is a measure of total salt content of water. To determine the salinity of water, chlorinity has to be estimated. Salinity and chlorinity are related by Knudsen equation -

\[
\text{Salinity} = 0.03 + 1.805 \text{ cl. where,}
\]

\[
\text{cl} = \text{the chloride content in 1cc of water.}
\]

Chlorinity can be estimated both by chemical and physical methods. Physical methods are based mainly upon the determination of either density, RI or conductivity. Presently, conductivity salinometers are widely employed.
This is based on the principle that conductivity of sea water is proportional to the salinity.

In the present study, chlorinity was estimated employing the standard titration method of Knudsen. The precipitable halide halogens in a 10 ml. volume of sea water sample were determined by titration with silver nitrate solution using a chromate end point, the Mohr titration. Silver nitrate solution was standardized against 10 ml. of sea-water-standard of known chlorinity (Eau de Mer Normale). After the correction of the titration value to obtain chlorinity, the salinity value was estimated.

**Procedure**: Exactly 10 ml. of sea water sample was taken in a conical flask and 3-4 drops of potassium chromate indicator solution was added to it. The solution will become yellowish in colour. This was titrated with standard AgNO₃ with vigorous shaking of the conical flask. Appearance of a definite pale red colour indicates the end point.

\[
\text{Mg/L (ppt. of chloride): } \frac{\text{Vol. of AgNO}_3 \text{ used} \times 1000}{\text{Vol. of sample taken}}
\]

**(viii)** \(P^H\) (Hydrogen ion concentration):

\(P^H\) of the water sample was measured by a glass electrode and electrometer type \(P^H\) meter after taking necessary precautions in sampling and standardisation.

**(ix)** Nutrients:

All estimations of dissolved nutrients in sea water were carried out in filtered water samples. (The analysis were made almost immediately after bringing the sample to the laboratory to avoid any possible bio-chemical
changes in the stored water. A UNICOM 500 spectrophotometer was used.

a) Reactive silicate:

The reactive silicate was estimated by adopting the method described by Mullin and Riley (1955) in which the filtered water sample was allowed to react with molybdate under conditions which result in the formation of silicomolybdate, phosphomolybdate and arsenomolybdate complexes. The interference from phosphate and arsenic was eliminated by adding reducing solution containing metol and oxalic acid which reduces the silicomolybdate complex alone to give a blue reduction compound. The extinction of the resulting solution was measured at 812 m\(\mu\).

b) Inorganic phosphate:

The sea water sample was allowed to react with a composite reagent containing molybdic acid, ascorbic acid and trivalent antimony. The resulting complex heteropoly acid was reduced in situ to give a blue solution. The extinction of this blue solution was measured at a wavelength of 885 m\(\mu\) (Strickland and Parsons, 1968).

c) Nitrate:

Nitrate of sea water was determined by the method described by Strickland and Parsons (1968). A copperised cadmium column was used in reducing nitrate into nitrite as given by Wood et al., (1967). The nitrate present was reduced quantitatively into nitrite when the water sample was run through the column containing cadmium fillings loosely coated with metallic copper. The nitrite produced was then determined by the method of Bandschneider and Robinson (1952) as applied to sea water in which the
nitrite was diazotised with N-(1-naphthyl)-ethylene diamine to form a highly
coloured azo dye. The extinction of the coloured solution was measured
at 543 m\textmu.

1.4 Review of previous researches from India

The contributions pertaining to the study of Recent Foraminifera from
the Indian sub-continent may be dealt with under two heads:

1. Recent foraminifera from the East coast and
2. Recent foraminifera from the West coast

The studies under each category may be classified into two divisions -
(i) Foraminifera of the shelf and slope regions and (ii) Foraminifera of the
beaches, estuaries and other marine marginal water bodies.

1.4.1 Recent foraminifera from the East coast

(i) Shelf and slope regions:

From the Indian sub-continent, the foremost contribution to fora­
miniferal knowledge is that of Carter (1880) who worked on specimens
dredged up from the Gulf of Mannar.

Gnanamuthu (1943) illustrated and described 47 species of foraminifera
from the littoral zones of Krusadi Island in the Gulf of Mannar and pointed
out the similarity of the assemblage to those of Laccadive and Maldive
islands. Ganapati and Satyavati (1958) reported about 103 species of
foraminifera belonging to 65 general from the samples collected from 111
stations scattered in the littoral zone along the east coast extending from
Calcutta in the north to Madras in the south, with concentration of stations
off Visakhapatnam. In the subsequent year, Ganapati and Sarojini (1959) made
some quantitative study of the foraminifera from the same material and reported 57 additional foraminiferal species. Subba Rao and Vedantam (1968) examined sediment samples from 22 stations located off Visakhapatnam, ranging in depth from 11 to 104 fathoms. They dealt mainly with the distribution of foraminiferal population giving more importance to 32 commonly occurring species, their distribution pattern and their relation to the different sedimentary size fractions. A study of the distribution of foraminiferal fauna of the shelf sediments off Pentakota, 90 kms. southwest of Visakhapatnam was made by Vedantam and Subba Rao (1970). The role played by 18 agglutinated foraminiferal species in a depth zone of 35-222 meters off the east coast of India in terms of lithology and faunal assemblage was given by Almeida and Setty (1972). Rasheed and Ragothaman (1978) recorded the occurrence of 70 foraminiferal species from off Porto Novo and discussed their distribution in relation to various ecological factors. Subba Rao, Vedantam and Nageswara Rao (1979) gave the distribution and ecology of 124 species of benthonic foraminifera of the sediments from the Visakhapatnam shelf. A systematic account of 52 foraminiferal taxa from the inner shelf of Rameswaram was given by Ragothaman and Kumar (1985). In the same year, Ragothaman and Manivannan (1985) reported 56 species of foraminifera from of Mandapam.

(ii) Beaches, estuaries and other marine marginal water bodies:

Bhatia and Bhalla (1959) described and illustrated 14 species of foraminifera from the shore sands of Puri. The species Asterorotalia trispinosa (Thalmann) was reported by Ghose (1966) from the Digha beach of southern Bengal, with a statistical analysis. Bhalla (1968) studied and described 16 species of foraminifera from the beach sands of Visakhapatnam.
of foraminiferal assemblages from the Godavari and Krishna river estuaries was given by Narappa et al. (1982). Reddy, A.N. et al. (1983) gave a systematic account on the living and dead foraminifera in the Araniar river estuary. Reddy, K.R. and Rao, R.J. (1983) gave a qualitative study on the frequency distribution of Recent foraminiferal species from the Pennar river estuary. The same authors (op. cit.) gave a quantitative study of the distribution of Recent foraminifera from 180 sediment samples collected from the same area.

1.4.2 Recent foraminifera from the West coast

(i) Shelf and slope regions:

Chapman (1895) studied foraminifera from the investigator collections made off Laccadives. Stubbings (1939) recorded about 300 species from the sediments collected by the John Murray expeditions off the Arabian Sea. Kurian (1953) studied foraminifera from the Travancore coast, which revealed the occurrence of about 25 genera and the existence of a definite relationship between the bottom fauna and the texture of the soil in which they occur. Sethulakshmiamma (1958) recorded 114 foraminiferal species from off Travancore coast and its back waters. Kameswara Rao (1970 a,b; 1971 a) contributed to our knowledge of foraminifera, for the first time from the Gulf of Cambay, describing 84 species belonging to 34 genera. He (1971 b) reported 92 species belonging to 40 genera from the northeastern part of the Arabian sea. Nigam, Setty, M.G.A.P. and Ambre (1979) reported 64 benthonic foraminiferids from Dabhol-Vengurla inner shore neritic environment. Graphic pattern of the foraminiferal dominance in near-shore region of central west coast of India was given by Setty, (1979) et al. Cluster analysis and ecology of living benthonic foraminifera from 23 samples collected from the inner shelf, off Ratnagiri, west coast of India was

(ii) Beaches, estuaries and other marine marginal water bodies:

The report on Elphidium indicum from the shore sands of Bombay harbour by Cushman (1936) was the earliest on foraminifera recovered from beach sands. Subsequently, Chaudhury and Biswas (1954) described 12 perforate species from the Juhu beach sands. After a systematic study of 46 species of foraminifera from the Juhu (Bombay) and Bhogat (Gujarat) beaches, Bhatia (1956) found a majority of them to be characteristic of Indopacific. Rocha and Ubaldo (1964 a, b) have reported 52 species from the beach sands and dunes of Diu, Gogola and Simbor in Gujarat and 25 species from Jampor(Damon) and Boga (Goa) area. Seibold (1971) studied the foraminiferal fauna from a lagoon of Cochin and concluded that the foraminiferal species were transported into the lagoon by the tidal currents.
Venkatachalapathy and Shareef (1976) reported some smaller foraminifera from the shore sediments of Mangalore area and explained their morphologic and microstructural characteristic features. Also, they (1978) made SEM studies on some rotaliid foraminifera of the Mangalore coast. A report of 36 species of foraminifera from the Calangute beach sand (Goa) was given by Bhalla and Nigam (1979). Shareef and Venkatachalapathy (1988) have studied the foraminifera from the shore sands of Bhatkal and Devagad islands and stated that *Edentostomina cultrata*, *Spiroloculina angulata* and *Pararotalia ozawai* are recorded for the first time from Indian waters.

1.4.3 Hydrological and Sedimentological studies

Many workers in the past have attempted to study the nature of the deep sea deposits, temperature and salinity of sea water and the different parameters of sediments such as particle size, calcium carbonate, organic matter, etc., off the east coast of India. Most of the work pertain to depths greater than 36 feet, but not much work had been done on deposits occurring in depths less than 36 feet.

The earliest work is that of Sewell (1929) who made extensive observations on the seasonal variations of surface temperature and salinity of Bay of Bengal. Jayaraman (1951, 1954) studied the chemistry of waters off Madras city (during the period 1948-1949) and off Mandapam (for the years 1951 and 1952). La Fond reported the seasonal cycle of sea-surface temperatures and salinities along the east coast of India. Subba Rao (1956) reported the sedimentary environments off Kalingapatnam-Gopalpur coast by coarse-fraction studies. Raghu Prasad (1957) dealt in detail with the seasonal variations observed in the surface temperature of sea water at Mandapam,
from January 1950 to December 1954. Subba Rao (1957) gave an account of the distribution of calcium carbonate in the sediments off Visakhapatnam, in relation to the distance from the coast, configuration of the shelf and silty and clayey material of the sediments. He (1958, 1960) made an exhaustive study on the calcium carbonate and on the organic matter content of the shelf sediments of the east coast of India, to the north of Madras. He is of the view that the sediments from depths of less than 20 fathoms are generally poor in calcium carbonate content and that the fine-grained sediments are generally richer in organic matter content than the coarse-grained. Muthu (1965) investigated the various physico-chemical factors of the sea water off Madras beach, where the average depth is about 48 feet. Freda Chandrasekaran, Isac Rajendran and Malu Pillai (1968) studied the salinity and temperature variations of the surface waters over Pearl and Chunk beds off Tuticorin for a period of 5 years from January 1959 to December 1963.

Madhusudana Rao and Murthy (1968) studied the texture of bottom sediments and calcium carbonate content of the shelf sediments off Madras coast and off Karaikal. Out of the 21 samples drawn from the continental shelf and upper part of the continental slope, they studied four samples only from depths less than 96 feet - two from off Madras and two from off Karaikal. They found that the calcium carbonate content shows a steady increase with depth. Seasonal variations of foraminiferal abundance and their relation to substrate in the Vellar estuary was studied by Ramanathan (1969). He found that the silty-clayey-sand substratum in which silt is the dominating factor, has more abundance of benthic foraminifera. Reddy, A.N. and Reddy, K.R. (1981) gave an account of the seasonal variations in the size
distribution of sediments in Pulicat estuary. Setty and Nigam (1982) reported
the foraminiferal assemblages in the sediments and their relation to organic
carbon in selected near shore areas from the Gulf of Kutch, Bombay -
Daman sector, Vengurla - Dabhol sector, Cola bay and Karwar area, of the
west coast of India.