SYSTEMATICS OF BENTHIC FORAMINIFERA IN SUNDERBAN MARSHES, WEST BENGAL

THESIS

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This is to certify that Mr. Asgar Hossain has worked under the supervision of Dr. Anupam Ghosh, Assistant Professor in the Department of Geological Sciences, Jadavpur University and completed his thesis entitled "**Systematics of benthic foraminifera in Sunderban Marshes, West Bengal**" which is being submitted towards the partial fulfilment of his M.Sc. Final Examination in Applied Geology of Jadavpur University in 2019.

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Abstract

The marsh zones of Sunderban coast were examined for modern benthic foraminiferal assemblages. A total of 10 genera of foraminifera were recorded from the region. Ammonia is the most abundant genus among all other types. Agglutinated foraminifera like *Trochammina* spp., *Miliammina* spp.and *Haphlophragmoides* spp.indicate the high marsh environments. Calcareous foraminifera like *Haynesina* spp., *Cribroelphidium* spp., *Ammonia* spp., and *Quinqueloculina* sp., *Nonionella* spp., characterize low marsh conditions.

CONTENTS

CHAPTER-1

INTRODUCTION

Introduction:

1.1 Introduction:

Sunderban is a dense mangrove forest ecosystem which is unique in the world. The Sunderban mangrove wetland are share between Bangladesh and West Bengal, India. The eastern 60% is located in Bangladesh and the remaining western 40% lies in India that occupies a total area of 426000 ha (Ghosh et al. 2014). The Sunderban ecosystem experienced tropical and sub tropical climate. The mangrove vegetation considerably reduces the erosion of coastal embankment and against the cyclone act as a barrier. This mangrove ecosystem are considering the both faunal and floral species. Foraminifera is one of the characteristic faunal group. Foraminifera are single celled marine organisms which is abundant in epipelagic and benthic realms.

The various abiotic factors such as salinity, temperature, coatal geomorphology, dissolved oxygen, tidal amplitude and its duration and nutrients governs the environmental settings of the mangrove ecosystem. The biotic factors such as food supply, space, competition governs the ecosystem. These macro-level environmental factors of mangroves undergo changes in time and space. These changes are well reflected in the vegetation pattern as well as distribution of foraminifera. Hence there is a necessity to understand the development of mangrove ecosystem in the recent times that will help to reconstract the past environment conditions.

The aim of the study is to understand the foraminiferal assemblages distributions and its abundance in sunderban.

1.2 Objectives:

- ❖ To study the systematics of the benthic foraminifera in Sunderban , West Bengal.
- ❖ To compare the foraminiferal populations in terms of abundance and test type in Sunderban marshes.

1.3 Location of the Study Area:

The Sundarbans (89° 02’ to 89°55’ and 21°30’E 22°30’N) is situated on the prograding, vulnerable mega delta formed by the transboundary Ganges, Brahmaputra, and Meghna (GBM) river network. Shared by Southern Bangladesh and Southern part of West Bengal (India) spreading over the major portion of the districts of North 24-Parganas and South 24-Parganas.
The sunderban comprising 60% in Bangladesh and 40 % in India that occupies atotal area of 426000 ha (Ghosh et al. 2014).

The wetlands comprise of a network of mudflats and islands intersected by an elaborate network of rivers, channels and creeks with varying width and length.

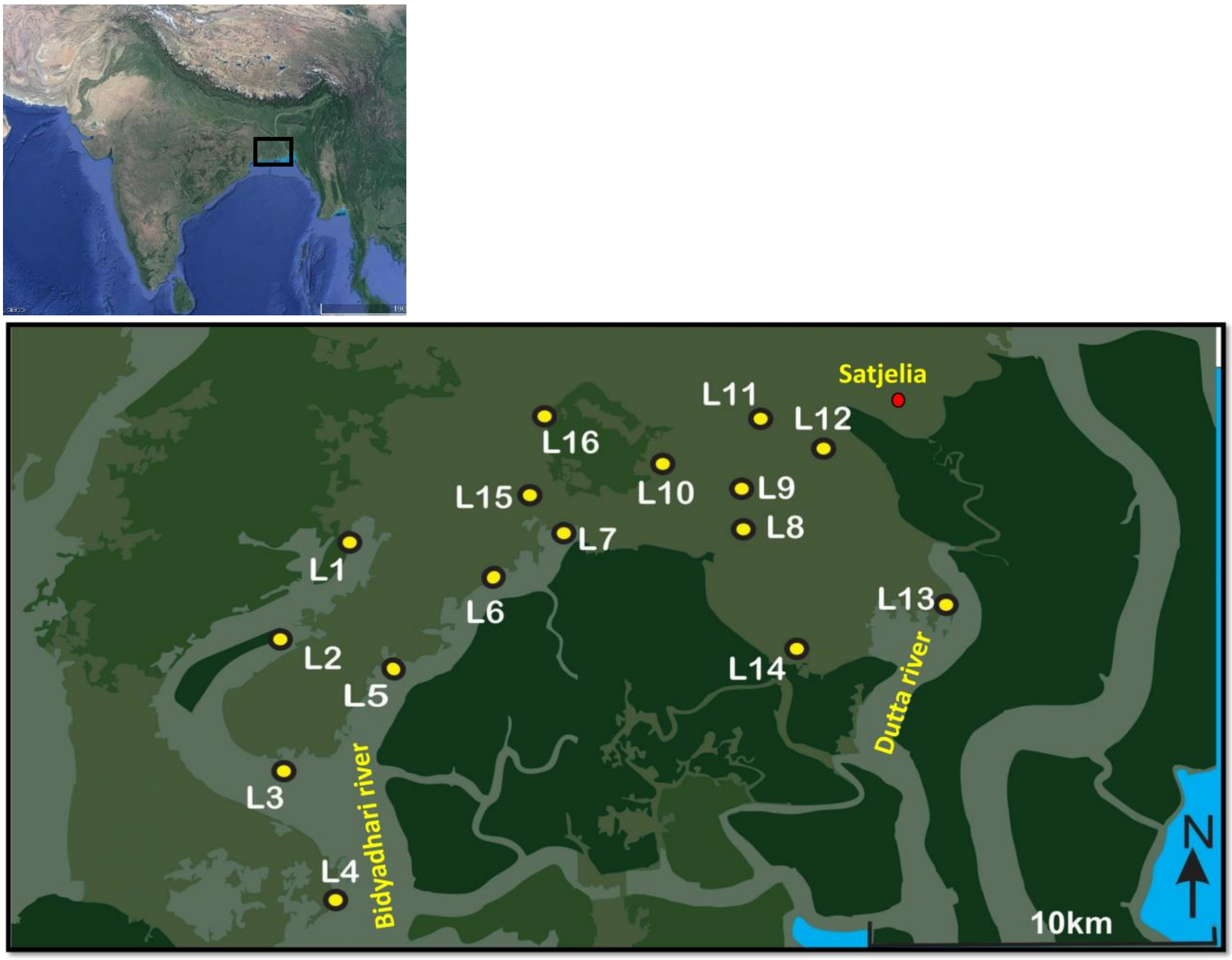


Figure 1.1: Location Map of the studied area

L1. Baalir Dweep **L2.** Bally Amalamethy Island (North) **L3.** Bally Amalamethy Island (South) **L4.** Kankmari Asram **L5.**Rangaberia **L6.** Bally 9 **L7.** Jatirampur **L8**. Jharkhali **L9.** Sonagaon **L10.** Dulki **L11.** Pakhiralay **L12**. Satjelia Sardarpara **L13**. Satjelia **L14**. Panchmukhani **L15**. Bally 6 **L16**. Ballibiraj.

1.4 Climate:

The Sunderban has a warm humid climate with an annual rainfall of about 1600 to 1800 mm (Ghosh et al. 2014). The rainfall is received during the southwest monsoon (June- October), with occasional rainfall throughout out the year. Ordinarily, the climate in Sunderbans ranges from 34 °C and 20 °C, and the rainfall is extremely high. So the weather is almost always moist and with the humid air from Bay of Bengal blowing constantly carrying 80% humidity. The mean sea level is about 3.30 m and the mean highest high water level and mean lowest high water level are 5.94 m and 0.94 respectively. The gentle slope of the low lying coast, with tidal water reaching up to 110 km inland, has facilitated the mangrove expansion (Spalding et al., 2010).The coastlines are influenced by multitude of factors which comprises wave motions, micro and macro-tidal cycles and long shore currents. The shore currents are highly influenced by cyclonic activity and the monsoons.

1.5 Physiography and Geomorphology:

The mangrove-dominated Ganges delta – the Sundarbans – is a complex ecosystem comprising one of the three largest single tracts of mangrove forests of the world. The Sunderban wetland is complex delta system is surrounded by no. of rivulets and its distributaries. This is a part of Bengal basin which represents the coalescence of multi –generated deltas formed during the progradation phases of positive interglacial eustatic sea level changes of Plio-Pleistocene epoch. During this time the Bay of Bengal leaves behind the distinctive multilevel delta surfaces, terraces, palaeochannels and palaeoshorelines and migration of the successive coastline took place towards the southern sea. The mangrove vegetation is the representation of Recent-Holocene epoch which drifts down along thecoastal part of the Bengal Delta Complex. The rivers Ganga and Brahmaputra mainly drainsthis area that includes the estuaries, few hundreds of delta lobes and islands of latestgeneration with network of rivulets and tidal creeks or inlets.Towards north flat terrains are meandering tidal channels in nature. Due to rising of the sea level, the present coastline is retreating at an alarming rate. The average sedimentation of Ganga-Brahmaputra system is 900 to 1200 $\times 10^6$ t/year where the average discharge is about 970 km^3/year (Choudhuri and Choudhury,1994).The rate of sedimentation is strongly influenced by the south westerlies. Therefore the study area represents a meso-tidal delta with high discharge and monsoonal rainfall.

1.6 Geotectonic background:

Sunderban is geo-technically linked to the tectonics of the Bengal basin. It is mostly characterized by the prolific growth of rich and diversified mangrove vegetation and also rich faunas. It overlies the huge thickness of Tertiary marine sediments of the actively subsiding Bengal Basin and forms the down drifted coastal part of the Bengal Delta complex.

The Bengal Basin is one of the world's deepest, widest and most tectonically active basins, which extends upto Bay of Bengal, eastern parts of India and Bangladesh. It represents a pericratonic basin which has originated due to the effect of the different deformation phases of the Tertiary Himalayan orogeny.

The basin has a relatively stable shallow (1-8 km thick) shelf in the west and a tectonically active fore-deep in the southern and eastern part which is centered below the present Ganges–Brahmaputra river mouths. The tectonically active and stable part is separated by the hinge zone which is marked by the presence of high gravity and magnetic anomalies. The Bengal Basin is filled up by the Tertiary marine geosynclinal and shelf sedimentation (>16km thick) followed by gradual progradation of the Quaternary Ganga – Brahmaputra delta fronts towards the southern sea which lead to the formation of the Bengal Delta Complex. The recent and the sub recent part of which is popularly known as the Sunderban Delta Complex.

1.7 Flora:

The Sundarban is mostly characterized by the abundance of the following floras are: Mathgoran (*Ceriops tagal*), Peyarabain (*Avicennia marina*), Jadupalang (*Sesuvium portulacastrum*), Dhandul (*Xylocarpus granatum*), Dhanighash, Goran (*Ceriops decandra*) Sundari (*Heritiera fomes*), Genowa (*Excoecari agallocha*), Kakra (*Bruiera gymnomorrhiza*) Hental (*Phoeniz paludosa*) and Keora (*Sonneratia apetala*) all of which are found prominently throughout the area. These types of mangroves (Fig1.2) are characterised by presence of prop root and Pneumatophore . Prop root is the adventitious root whicharises from the stem; it penetrates the soil and helps to support the stem. It is also known as the brace root. Pneumatophores are the air filled roots (submerged or exposed) which worksas a respiratory organ of a marsh or swamp plant. It is also known as the air root. Thecharacteristic tree of the forest is the Sundari (*Heritiera littoralis*), from which the name Sunderban is probably been derived. It is a hard wood which is used for building houses and making boats, furniture and other things. The new forest are often conspicuously dominated by Keora (*Sonneratia apetala*) and Peyara bain(*Avicennia marina*). There are abundance of Dhundul (*Xylocarpus granatum*), and Kankra (*Bruguier gymnorrhiza*) though the distributions are discontinuous.

1.8Fauna:

There are more wildlife present here than just the endangered Royal Bengal Tiger (*Panthera tigris tigris*). Mangroves are the transitional regions from the marine to freshwater and terrestrial systems which provides critical environment for the habitat of numerous species ofsmall fish, crabs, shrimps and other crustaceans that adapt to feed and shelter and reproduce among the tangled mass of roots called the pneumatophores, which grow in upward direction from the anaerobic mud towards the open air to get the supply of oxygen. Fishing Cats, Macaques, wild boars, Common Grey Mongooses, Foxes, Jungle Cats, Flying Foxes, Pangolins, and Spotted deer are also found in abundance in the Sunderban.

Fig.1.2- mangrove vegetation in the Sunderban.

Fig.1.3- Dead roots of the mangroves in Sunderban.

Chapter – 2

Materials and Methodology

Materials and Methodology

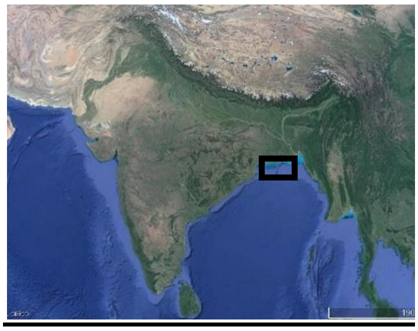
2.1 Sample Details:

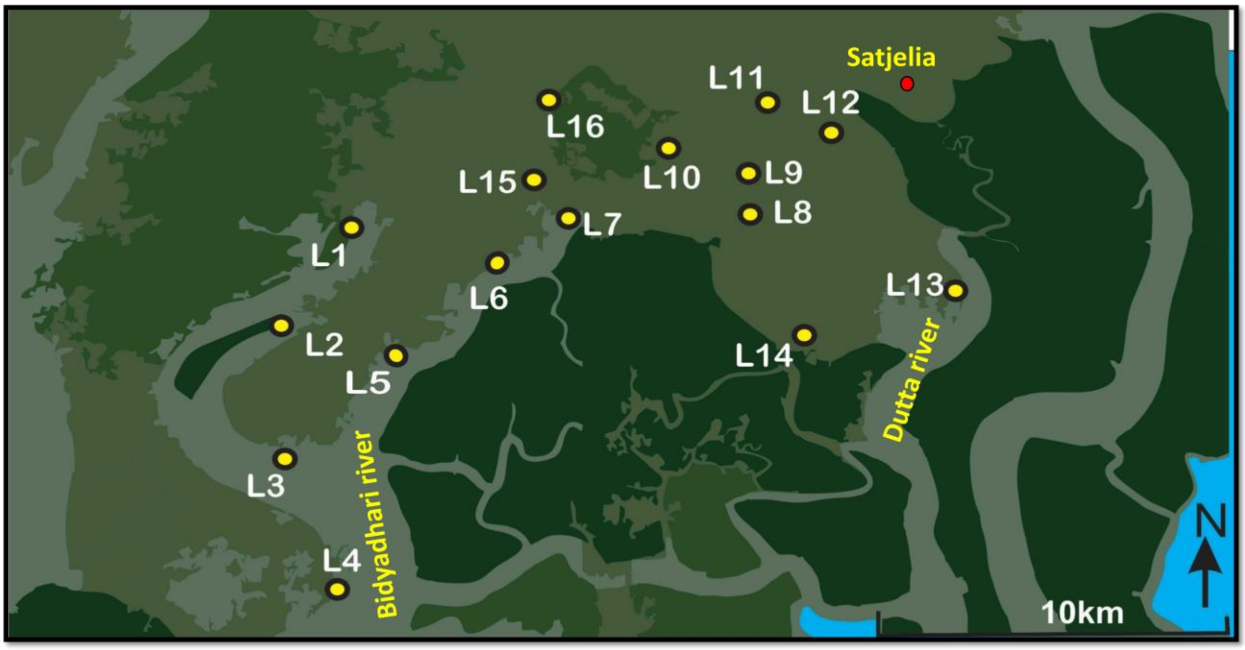
The specimens used in this study are obtained from the surface sediment samples from Sunderban along the coastline between the Latitude N-22°1´9´´ to N-22°10´33´´ and Longitude E-88°43´10´´to E-88°55´5´´. The sampling locations are given below (table 2.1) with the GPS reading.

Sl.No	Place Name	GPS Co-ordinates
1	Baalirdweep	N-22°7´22´´ E-88°44´8´´
2	Bally Amalamethy island (North)	N-22°5´56´´ E-88°43´15´´
3	Bally Amalamethy island (South)	N-22°3´11´´ E-88°43´10´´
4	KankmariAsram	N-22°1´9´´ E-88°44´22´´
5	Rangaberia	N-22°5´8´´ E-88°45´17´´
6	Bally 9	N-22°6´52´´ E-88°47´21´´
7	Jatirampur	N-22°7´55´´ E-88°48´28´´

8	Jharkhali	N-22°8´37´´ E-88°51´9´´
9	Sonagaon	N-22°9´19´´ E-88°51´21´´
10	Dulki	N-22°9´11´´ E-88°50´54´´
11	Pakhiralay	N-22°10´33´´ E-88°52´4´´
12	Satjelia Sardarpara	N-22°10´4´´ E-88°52´32´´
13	Satjelia	N-22°6´59´´ E-88°55´5´´
14	Panchmukhani	N-22°5´10´´ E-88°52´21´´
15	Bally 6	N-22°8´29´´ E-88°47´29´´
16	Ballibiraj	N-22°9´52´´ E-88°47´43´´

Table 2.1 – The details of the Sampling locations of Sunderban area.





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2.2 Sample collection:

The surface sediment samples of 100cm3 (10cm × 10cm × 1cm) were collected from sixteen locations covering the different marsh environments along Sunderban areas, West Bengal. The detailed sample locations are given in the Table 2.1 and Figure 2.1.

The collected sediment samples were kept into the Ziploc bags (10inch × 9inch) or wide mouth plastic bottle by using the trowel.

Fig.2.2- Sediment sample collection in the sampling locations.

2.3Washing, sieving and drying of sample:

The samples were washed by using sieves of63 μm (~230 mesh). Using the 63 micron sieve all the clay and silt particles were eliminated, leaving the fines ands and larger fraction (i.e. the fraction including size range of most foraminifera). After washing the samples, the samples are transferred into a porcelain bowl. Then the samples with porcelain bowl kept in an oven (fig.2.3) at 50°C for dry the samples. The temperature of the oven is kept about 50°C because above this temperature the foraminiferal samples would get destroyed. For 30 minuites the sample was kept in the oven to get dried off the water. The bowl which contain the sample was then removed from the oven. Then the samples were transferred into a Ziploc bag (4inch × 3inch).

Fig.2.3- Hot air oven.

The dried sample is splited by using the microsplitter and 1gm of that dried sample observed under the stereozoom microscope (fig.2.4).

Fig.2.4- The stereozoom microscope (Nikon SMZ1000) .

2.4 Picking and counting of Foraminifera:

Separationof the microfossils were done by using some accessories like finest hairbrush(#000), faunal slide made of cardboard with glass slide an aluminiumcase, micropalaeontological tray and micropalaeontological needle .(Fig 2.5). Different types of faunal slides were available for this purpose. 24- Chambered slides were used to store all the specimens, single round punch was used to store test of same specimens. On a black pickingtray which was ruled with the gridlines, the samples were scattered thinly over it.From eachsample foraminifera were picked with the help of a fine water moistened #000 hair brush observing under the stereozoom microscope (Nikon SMZ1000) (fig.2.4). The picked foraminifera were placed in the 24-chambered slides and the specimen of each species in single rounded punch slides.

Fig 2.5- Various accessories used for picking and storing of microfossils. From left to right of the picture brushes, needle, micro paleontological tray with grids, 24 and 12 chambered slides and the sieves with a lid.

2.5 Scanning Electron Microscope:

A **Scanning electron microscope** (**SEM**) is a type of electron microscope which produces images of a sample by scanning it with a beam of electrons which are focused on the sample (Fig-2.6).The focused beam of high-energy electrons helps to generate variety of signals at the surface of the solid specimens which are under observation. The signals that are derived from the interaction between the sample and electrons reveals the information about the sample including its external morphology (texture), crystalline structure, chemical composition and the orientation of the materials that makes up the sample. The electron beam is generally scanned in a raster scan pattern, and the position of the beam is combined with the detected signal to produce an image. In most of the applications, data's are collected from the surface of the sample over a selected area, and a 2-dimensional image is generated which displays the spatial variations and the other properties. Areas approximately 1 cm to 5 microns in width can be highly imaged in a scanning mode using the conventional SEM techniques (magnification ranges from 20X to approximately 30,000X and spatial resolution ranging 50 to 100 nm). The SEM is also capable of 13analyzing the selected point locations on the sample; this approach is especially useful in qualitatively or semi quantitatively determining of the chemical compositions (using EDS), crystal orientations and crystalline structure (using EBSD).

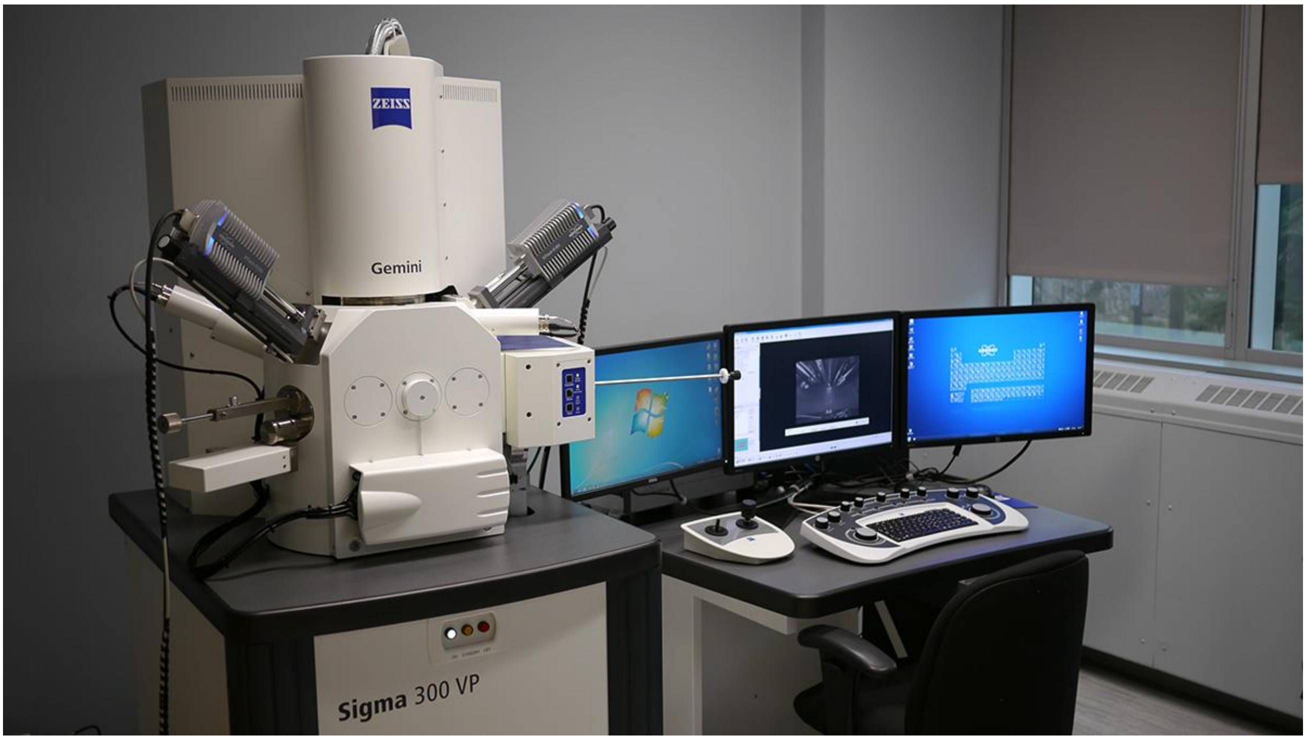

Fig 2.6- Scanning Electron Microscope (SEM) (Model-ZEISS Sigma 300 VP).
(https://www.google.com/search?q=scanning+electron+microscope&source=lnms&tbm=isch&sa=X&ved=0ahUKEwjqk6PWwMHiAhU87nMBHTBsCzQQ_AUIDigB&biw=1360&bih=625#imgrc=MZB6YSB6jD7mtM:)

Principle:

A significant amount of kinetic energy is carried by the accelerated electrons in a SEM.When the incident electrons are decelerated in the solid sample it dissipates the kinetic energy into variety of signals. These signals include secondary electrons (that helps to produce SEM images), diffracted backscattered electrons (EBSD that are used to analyse the crystal structures and orientations of minerals), backscattered electrons (BSE), photons (characteristically X-rays that are used for the elemental analysis and continuum X-rays), visible light (cathodoluminescence–CL), and heat. The secondary electrons and back scattered electrons are mostly used for imaging samples: for showing morphology and topography on the samples secondary electrons are mostly valuable and for illustrating the contrasts in composition in multiphase samples (i.e. for rapid phase discrimination) back scattered electrons are mostly used. Inelastic collision of the incident electrons with electrons indiscrete orbitals (shells) of atoms in the sample produces X-ray generation. When the excited electrons return to lower energy states, they highly yield X-rays that are of a fixed wavelength (it is related to the difference in the energy levels of electrons in different shells for a given sample). Thus, characteristic X-rays are produced by the "excited" electron beams for each element in a mineral. The analysis made by the SEM is considered to be highly "non-destructive"; that is, x-rays are generated by the electron interactions that do not lead to any volume loss of the sample, so it is possible to analyse the same materials repeatedly.

Clean foraminifera are mounted in a required orientation on a metallic stub for making the sample to be conductive. After, the metallic stub is inserted inside the microscope it produces high resolution images.

2.7 Identification:

The morphological features of the test of the foraminifera are identified from the scanning electron micro photographs. From the collected samples, the categorization of the foraminifera's are done on the basis of their external features-like shell architecture, aperture, suture, presence of some calcareous plugs or depositions, nature of the coiling etc. The taxa are identified from the help of the works of Loeblich & Tappan (1964), Barker (1960), Horton & Edwards (2006), Nomura and Seto (1992, 2002), Kathal (2002), Brasier and Armstrong (2006), Ghosh et al (2014).

The classifications given by Loeblich and Tappan (1964) are mainly followed for the study of the observed samples.

Chapter – 3

Foraminifera

Foraminifera

3.1.Introduction:

Foraminifera (informally called "**forams**") are members of a phylum or class of amoeboid protists characterized by streaming granular ectoplasm for catching food and other uses; and commonly an external shell (called a "test") of diverse forms and materials. They derived their name from "foramen" the pores that connect the chambers in the tests. Foraminifera are unicellular animals, similar to Amoebae, and, therefore, belong to the Protista kingdom, but differ from other protists in having thread-like, anastomosing pseudopodia (granuloreticulopodia) and in possessing a shell or test . They are the most diverse group of living shelled microorganisms that dwells in the modern ocean and are found in the rocks of Phanerozoic time as fossils. The principal characteristics of this taxon are – (a) presence of the shell (test), (b) presence of long thread like projections called the pseudopodia-operated through the perforations of the test. Pseudopodia help in locomotion, selection and capturing of the food, test construction and adhering to the substratum, (c) the life history characterized by an alteration of sexual and asexual generations with meiosis associated with the asexual reproduction- a feature unique in heterotrophic eukaryotes. The shells are commonly made of calcium carbonate ($CaCO_3$) or agglutinated particles.

3.2.Systematic Position:

Superkingdom: Eukaryota

Kingdom: Protista

Phyllum: Protozoa

Subphyllum: Sarcomastigophora

Class: Sarcodina

Order: Foraminiferida.

3.3.Ecology of foraminifera:

Foraminifera occur in nearly all the marine and paralic environments. Their abundance maybe judged by a fact that about 1000 to 2, 50,000 foraminifera live per square metre in the modern marine basins. There are 4000 living species in the world's ocean among which 40species are planktonic in nature which float in the water column. The remaining species are benthic in nature which lives on shells, rock and seaweeds or in the sand and mud of the bottom oceans. In the deep sea, the bottom sediment is made up of shells of the planktonic forms because little materials come from erosion of the land. Most of the foraminifera are benthic, living upon the sea floor, within the upper few centimetres of ooze or upon the benthic algae or other organisms. Spectrum of their presence in the marine environments may be visualized by their occurrence in varying depths ranging from intertidal to the deep oceanic levels; varying salinities(brackish to hypersaline) and varying latitudes(tropics to the pole). The distributions of foraminifera are mostly controlled by the physico-chemical phenomena after time so very few species of marine foraminifera thrive in the marsh environment.

3.4 Types of Foraminifera:

Being strictly marine inhabitant foraminifera are planktonic and benthic based on their habit and mode of adaptation.

Majority of the foraminifera are bottom dwellers called the benthic foramen. They live on the bottom of the sea and they also need some substratum for being attached so that they won't get scattered by the underwater currents. Some of them move freely on the surface sediments and are called vagile and some are attached to substratum called the sessile form. The vagile benthic foraminifera are the most common than the sessile ones. Benthic foraminifera which are adapted to cold, dark, and extremely oligotrophic environment are an important component of the deep sea biomass in the present oceans. Faunas have many species showing a cosmopolitan distribution for their diversity. For the reconstruction of past environments the species living in the largest habitat on earth are used as indicators. Their tests have been extensively used in isotope and trace element analysis for the reconstruction.

Planktonic foraminifera live above the sea floor in the sea column and generally lack locomotion. They are mainly floaters or swimmers in nature. In the near-shore environment the planktonic foraminifera are less abundant because of the high energy environment prevailing here so most of the planktonic foraminifers are abundant in the deeper water regions than the shallower regions.

3.5 Test Morphology:

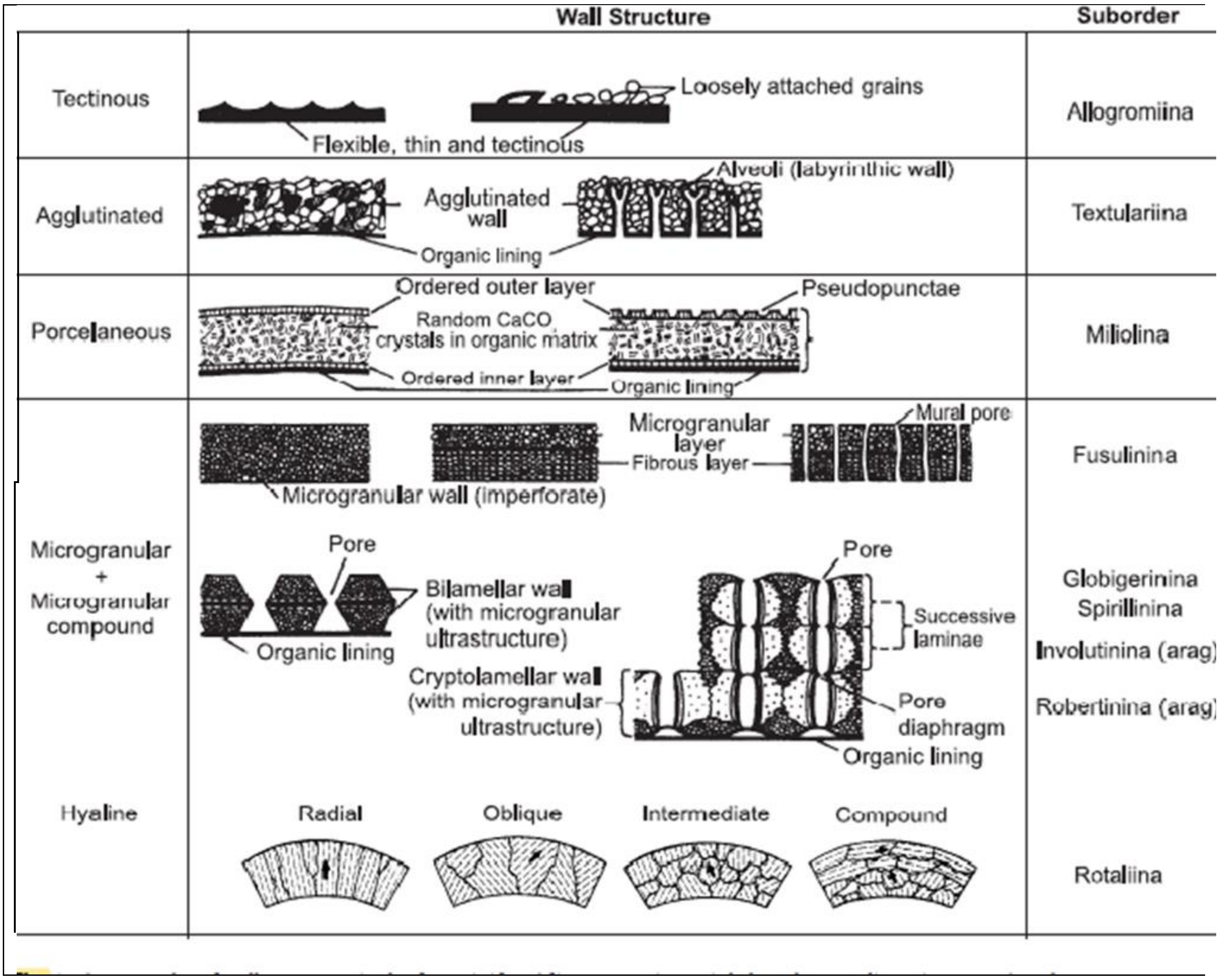

Fig 3.1– Wall structures in foraminifera (diagrammatic, mainly based on studies using SEM) (H.A. Armstrong and Martin D. Brasier, 2004).

Table 3.1 – Wall structure of various sub-orders of foraminifera.

Sub-order	**Wall Structure**	**Composition**	**Characteristics**
Allogromina	Tectinous	Organic walled	a) Flexible, thin and tectinous b) Non-linear, non-laminated imperforated test
Textularina	Agglutinated	Detrital grains of sand/shale are held in organic cement.	a) Agglutinated Wall composed of organic inorganic matter
Fusulina	Micro granular materials	$CaCO_3$ crystals	a) $CaCO_3$ grains are arranged perpendicular to the C axis. b) Some imperforate and some perforate c) Fibrous appearance helps in osmosis
Miliolina	Porcelaneous	Calcareous or Aragonite ($CaCO_3$)	a) Mural pores present. b) High Mg-Ca arrangement c) Reflected light –Milky Way colour , d)Transmitted light –Amber colour
Rotalina	Hyaline	Calcite or Aragonite Crystals	a) Different arrangement of calcite crystals b) They are perforated forms c) Many pore spaces

The test or external skeleton of foraminifera is composed of several types of material (Loeblich and Tappan, 1964). This characteristic forms the basis for defining the higher taxonomic levels of the group (Table 3.1) (Fig 3.1).

3.6 Life cycle of foraminifera:

The foraminiferal species are vast in number but to our knowledge very little is known about their reproductive habits. Reproduction in foraminifera is accomplished by the alternation ofsexual and asexual types of reproduction. Some of the species show alternation of generations while the others show only asexual reproduction. Asexual reproduction is simple fission of the cells and is more common than the sexual type. This dual reproduction is known as dimorphism and results in the formation of the two types of test-i) Megalospheric and ii) Microspheric. In the tropical environment the alternation in two generations is completed within a year. Where as in the higher latitudes it takes two or more years. In extreme adverse conditions only one generation prevails. During the winter season the schizont generation undergoes asexual reproduction mainly in the following sequences – a) the cytoplasm is withdrawn from the test.; b) Meiosis cell division (or reduction division) takes place in which the number of chromosomes are reduced to half, which is followed by the splitting of the cytoplasm into numerous tiny daughter cells called the gamonts, each having one or more nucleus but the number of chromosome is half of the parent cell.; c) in the gamonts the process of chamber formation begins.; d) the young gamonts are released in the water for their dispersal. During the summer months the tests undergoes sexual reproduction on reaching its maturity in the sequence of – a) the cytoplasm is again withdrawn into the test.; b) Mitotic cell division(normal division without further division in the chromosome number) takes into account.; c)the cytoplasm is divided into tiny daughter cells called the gametes(bearing a pair of whiplike flagellum).; d) now are released from the mother cell ,the two gametes fuse together undergoing sexual reproduction.; e) the chromosomes are reunited and the young diploid schizonts are again released into the water.

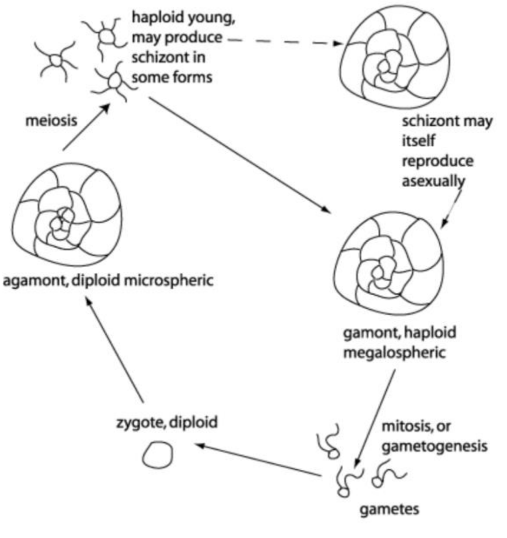

Diagram showing a generalised foraminifera life cycle note alternation between a haploid megalospheric from and a diploid microspheric form.

Redrawn from Goldstein 1999.

Fig 3.2-Life cycle of Foraminifera

The entire cytoplasm of the parent individual is highly involved in both the sexual schizogamy and asexual schizogamy, and therefore after the dispersion of the juveniles the parent test is often left empty.

Planktonic foraminifera are thought to reproduce sexually in relation to the lunar cycle after every 28 days. They do not reproduce asexually is widely taken into account. According to theory, sexual reproduction (in all foraminifera) is generally favoured in physically variable environments. It Is because wider adaptive range leads to greater genetic variety that arises from the sexual recombination of genes.

Dimorphism:

The phenomena of dimorphism are mostly pronounced in the highly evolved calcareous foraminiferal species than the others. The test of the two generations can be differentiated on the basis of test morphology:

Megalospheric test: The gamont stage is mostly recognized on the basis of the larger proloculus (first chamber) but the test size is smaller compared to it is designated as Megalospheric test. Here lesser number of chambers are present and the test morphology is less complex. It is very common and most abundant.

Microspheric test: the multinucleate schizont or a gamont (diploid) stage is marked by the presence of the smaller proloculus but the test size is much larger is designated asMicrospheric test. More number of chambers are present and the test morphology is very complex. Less abundant in nature and very few in number.

3.6 Chamber Arrangement:

Foraminiferal tests are built of hollow chambers separated by partitions, with small openings called foramina that connect the chambers. The final chamber (the last one added) has an opening or openings to the exterior, called the aperture. Most species of foraminifera build shells with multiple chambers (multilocular) but some species build shells with only a single chamber (unilocular). The most common types of chamber arrangements (Fig 3.3) are:

a) Unilocular: The test has a single chamber it is globose or flask in shape.

b) Uniserial: The chambers are arranged in a single column.

c) Biserial: The chambers are usually arranged in a linear fashion in two consecutive rows.

d) Triserial: The chambers are arranged in three consecutive columns.

e) Planispiral: The chambers are arranged in the shape of a coil within a single plane. The centre of the coil is known as the umbilicus. The coil can be either involute (where only the last chamber is visible) or evolute (here all the chambers are visible).

f) Trochospiral: The chambers coil in such a manner that it forms a spire like a snail shell shape. On the spiral side all the chambers are visible (evolute coiling). On the umbilical side only the final coil is visible (involute coiling).

g) Quinqueloculine: The chambers are 72 degree apart from each other, so characteristically four chambers are visible only from one side and three from the other side.

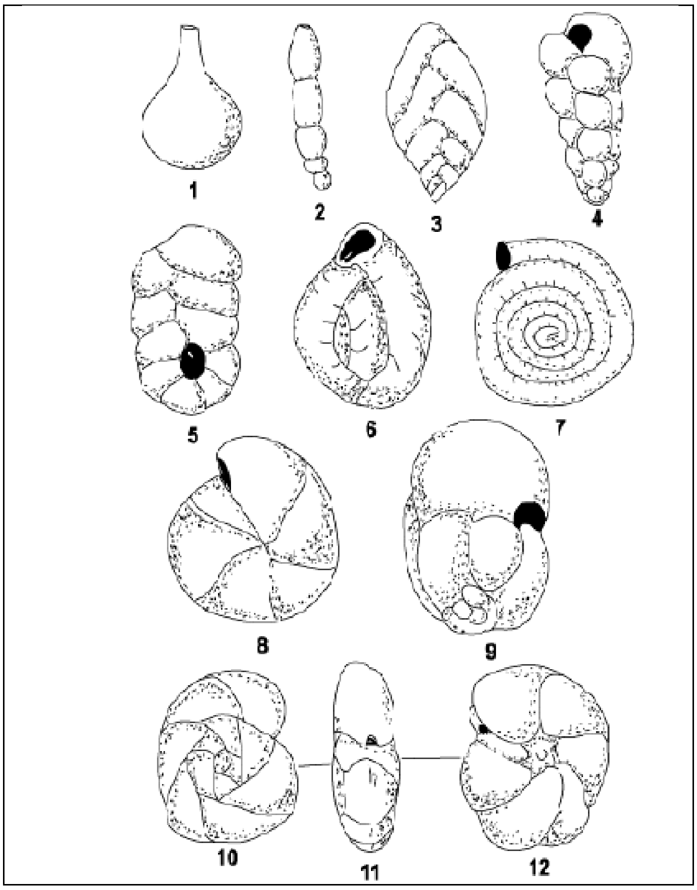

Fig 3.3-Principle types of chamber arrangement**. 1.** single chambered; **2.**uniserial; 3.biserial ; 4.triserial; **5**. Planispiral to biserial; **6**.milioline; **7**. planisopiral evolute; **8**. Planispiral involute; **9**. Streptospiral; **10-11-12**.trochospiral (10. Dorsal view;11. Edge view; 12. Ventral view). Redrawn from Leoblich and Tappan 1964.

3.8 Importance of foraminifera:

Foraminifera are in many respects for abundant, widely distributed, being small and extreamly diversity. It is very useful for paleo-ecology, paleobiogeography, oil exploration and also other hydrocarbon exploration like gas hydrate, monitoring marine pollution, study of the oceanic currents and paleo-oceanography. Foraminifera fossils also useful in the study of biostratigraphy and stratigraphic correlations.

Geological importance :

- They are useful in paleoenviromental and paleoecological reconstruction
- Excellent biostratigraphic indicator as they are abundant, widespread geographically, extensively variable and rapid in evolution.
- Sample size enables huge sample collection.
- Separation techniques are very simple.

- Huge importance in petroleum exploration and preparation of geological and hydrological maps.

Oceanographic importance:

- Recording movement of water masses
- Ecological and zoogeographic problem investigation
- Investigation problems in paleooceanography, paleoclimatology and marine geology.

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The applications of benthic foramen test:

Benthic foraminifera tend to be more restricted in distribution but provide useful schemes for local correlation (Brasier, 2006). Since benthic foraminifera shows remarkable conservative evolutionary stability for the last 14 m.y., so they can be successfully and sensitively used in the following manners as described below:

- Conservative evolution and the past areal extent of the Antarctic Bottom Water Current since Mid-Miocene.
- The tests of benthic foramens provide material for Oxygen and Carbon isotope analysis to reconstruct the bottom water history and thermo-haline structure.
- Benthic foraminifer highly indicates the depth of deposition of the sediments particularly in the Mid-Oceanic Ridge system and provides tectonic history of the basin under observation.
- Benthic foramen of near shore shallower sequence indicate paleodepth which in term provides the history of the eustatic sea level.

The applications of Planktonic foramen test:

The foramen are mostly pelagic in habitat, the planktonic foramen test are very useful for many purposes, they are described as bellow:

- They act as a tools for the palaeo-environment study because their abundance and size are increases towards the open sea. Bigger dimension of same species means they are close to the open sea i.e. Oceanicity while smaller size means close to the land i.e. confinement.
- Geographic patterns seen in the fossil records of planktonic forams are also used to reconstruct ancient ocean currents.
- Wide abundance provides inter-regional correlation and age determination.

Chapter – 4

Systematics

Systematics

Order: Foraminiferida Eichwald, 1830

Suborder: TEXTULARIINA Delage and Hérouard, 1896

Superfamily: LITUOLACEA de Blainville, 1825

Family: Trochamminidae Schwager, 1877

Subfamily: Trochammininae Schwager, 1877

Genus: *Trochammina* Parker & Jones, 1859

Trochammina sp.

(pl-1, Fig.-1 and 2)

Remarks: Inflated test, trochospiral with chambers increasing in size as added. Spiral side, all chambers visible, sutures depressed and radial to slightly curved. 5-6 chambers in the outer whorl, with a deep umbilicus, agglutinated wall. Aperture on umbilical side, at the base of the final chamber forming a narrow lip.

This genus is mainly found in high amount in the high marsh region of Sunderban such as Pakhiralay, Bally 6 and Sonagaon.

Order: Foraminiferida Eichwald, 1830

Suborder: TEXTULARIINA Delage and Hérouard, 1896

Superfamily: LITUOLACEA de Blainville, 1825

Family: LITUOLACEA de Blainville, 1825

Subfamily: Haplophragmoidinae Maync, 1952

Genus: *Haplophragmoides* Cushman, 1910*Haplophragmoides* sp.

Haplophragmoides sp.

(PL-1, Fig. - 3)

Remarks: Test are planispirally coiled, involute, wall agglutinated, aperture rounded, umbilicus is not much visible with deposition of plug, an equatorial interio- marginal slit is present.

It occurs mainly in high marsh region of Sunderban such as sonagaon, and Pakhiralay.

Order: Foraminiferida   Eichwald, 1830

Suborder: TEXTULARIINA   Delage and Hérouard, 1896

Superfamily: LITUOLACEA   de Blainville, 1825

Family: Rzehakinidae   Cushman, 1933

Genus: *Miliammina*   Heron-Allen & Earland, 1930

Miliammina sp.

(PL-1, Fig.- 4)

Remarks: Test subconical, early stage is a trochospiral coil of five inflated chambers per whorl; wall finely agglutinated.

This genus is found in in the high marsh region of Sunderban such as Dulki and Balibiraj.

Order: Foraminiferida   Eichwald, 1830

Suborder: MILIOLINA   Delage and Hérouard, 1896

Superfamily: MILIOLACEA   Ehrenberg, 1839

Family: MILIOLACEA   Ehrenberg, 1839

Subfamily: Quinqueloculininae   Cushman, 1917

Genus: *Quinqueloculina*   D'Orbigny, 1826

Quinqueloculina sp.

(PL-1, Fig.-5)

Remarks: Test coiled, with chambers one half coiled in length and alternating regularly in 5 planes of coiling 72˚ apart, but with successive chambers in planes 144˚ apart, so that 3 chambers are visible from exterior side on one side of test and 4 visible from the opposite side.

This species is found mainly in middle marsh regions such as Bally amalamethy island (north) and Rangaberia

Order: Foraminiferida Eichwald, 1830

Suborder: ROTALLINA Delage and Herouard, 1896

Superfamily: CASSIDULINACEA   D'Orbigny, 1839

Subfamily: Nonioninae   Schultze, 1854

Genus: *Nonionella*   Cushman, 1926

Nonionella sp.

(PL-1, Fig.- 6and 10)

Remarks: Test free, trochospiral, slightly compressed, periphery rounded, spiral side particularly evolute with umbonal boss,broad, low, wall calcareous, perforated, granular in structure, asymmetrically trochospiral.

This genus occurs mainly in low marsh areas especially in the stations Bally Amalamethy island (north), Bally Amalamethy island (south) and ballir dweep.

Order: Foraminiferida Eichwald, 1830

Suborder: ROTALLINA Delage and Herouard, 1896

Superfamily: ROTALIACEA Ehrenberg, 1839

Family: Elphidiidae Galloway, 1933

Subfamily: Elphidiinae Galloway, 1933

Genus: *Cribroelphidium* de Montfort, 1808

Cibroelphidium sp.

(PL-1, Fig.- 7)

Remarks: Test planispiral, involute, chambers numerous, internal chamber projections along the septal borders, ending against the septal face in the final chamber, but pierced by tiny pore formed by resorption of septum, wall calcareous, finely perforated, radial in suture commonly with grooves or ridges.

This genus commonly occurs in low marsh area especially in the stations Bally Amalamethy island (north), Kankmari Asram, Jharkhali and Satjelia.

Order: Foraminiferida Eichwald, 1830

Suborder: ROTALLINA Delage and Herouard, 1896

Superfamily: ROTALIACEA Ehrenberg, 1839

Family: Rotaliidae Ehrenberg, 1839

Subfamily: Rotaliinae Ehrenberg, 1839

Genus: *Ammonia* Brünnich, 1772

Ammonia sp.

(PL- 1, Fig.- 8 and 9)

Remarks: Test free, convex, low trochospiral coiling of 2or 3 convolutions, sutures are slightly curved, large no. of sutures, thickened, depressed or umbilical side, septa primarily double, wall calcareous ,finely perforate radial in structure, umbilical surface with irregular granules along, umbilicus with bosses or plugs, aperture interiomarginal.

This genus are found almost in all the areas. It occurs abundantly in low marsh areas especially in the stations Ballir Dweep, Bally Amalamethy island (south), Bally 9, and Rangaberia.

Order: Foraminiferida Eichwald, 1830

Subroder: ROTALLINA Delage and Herouard, 1896

Superfamily: ROTALIACEA Ehrenberg, 1839

Family: Elphidiidae Galloway, 1933

Genus: *Haynesina* Banner and Culver, 1978

Haynesina sp.

(PL-1, Fig.-11)

Remarks: Test is free**,** 6 to 9 chmbers, Broadly rounded test periphery and perforated surface. The suture lines are highly curved reaching upto the periphery, large amount of calcareous deposit along the suture lines.
This genus is found mainly in low marsh areas especially in high amount in the stations Rangaberia, Satjelia Sardarpara and Kankmari Asram.

Order: Foraminiferida Eichwald, 1830

Subroder: ROTALLINA Delage and Herouard, 1896

Superfamily: ROTALIOIDEA Ehrenberg, 1839

Family: ROTALIIDAE Ehrenberg, 1839

Subfamily: PARAROTALIINAE Reiss, 1963

Genus:*Pararotalia* Le Calveg, 1949

Pararotalia sp.

(PL- 1, Fig.- 12)

Remarks: Test is a low trochospiral , planoconvex to biconvex, chambers flat to centraly elevated on the spiral side, commonly inflated and produced around the umbilicus; peripheral outline lobulate; wall calcareous, perforate; aperture interiomarginal.

This genus is found mainly in low marsh areas such as Jharkhali.

Order: Foraminiferida Eichwald, 1830

Subroder: ROTALLINA Delage and Herouard, 1896

Superfamily: CHILOSTOMELLOIDEA Brady, 1881

Family: Gavelinellidae Hofker, 1956

Subfamily: Gavelinellinae Hofker, 1951

Genus:*Cocoarota* Leoblich and Tappan,1986

Cocoarota sp.

Remarks: Test planoconvex to concavoconvex, with a low trochospiral coil, globular proloculus followed by two to three whorls, ten to thirteen chambers in the final whorl, spiral side evolute, umbilicul side involute; wall calcareous; aperture low interiomarginal.

This genus found in high marsh areas such as Balibiraj areas

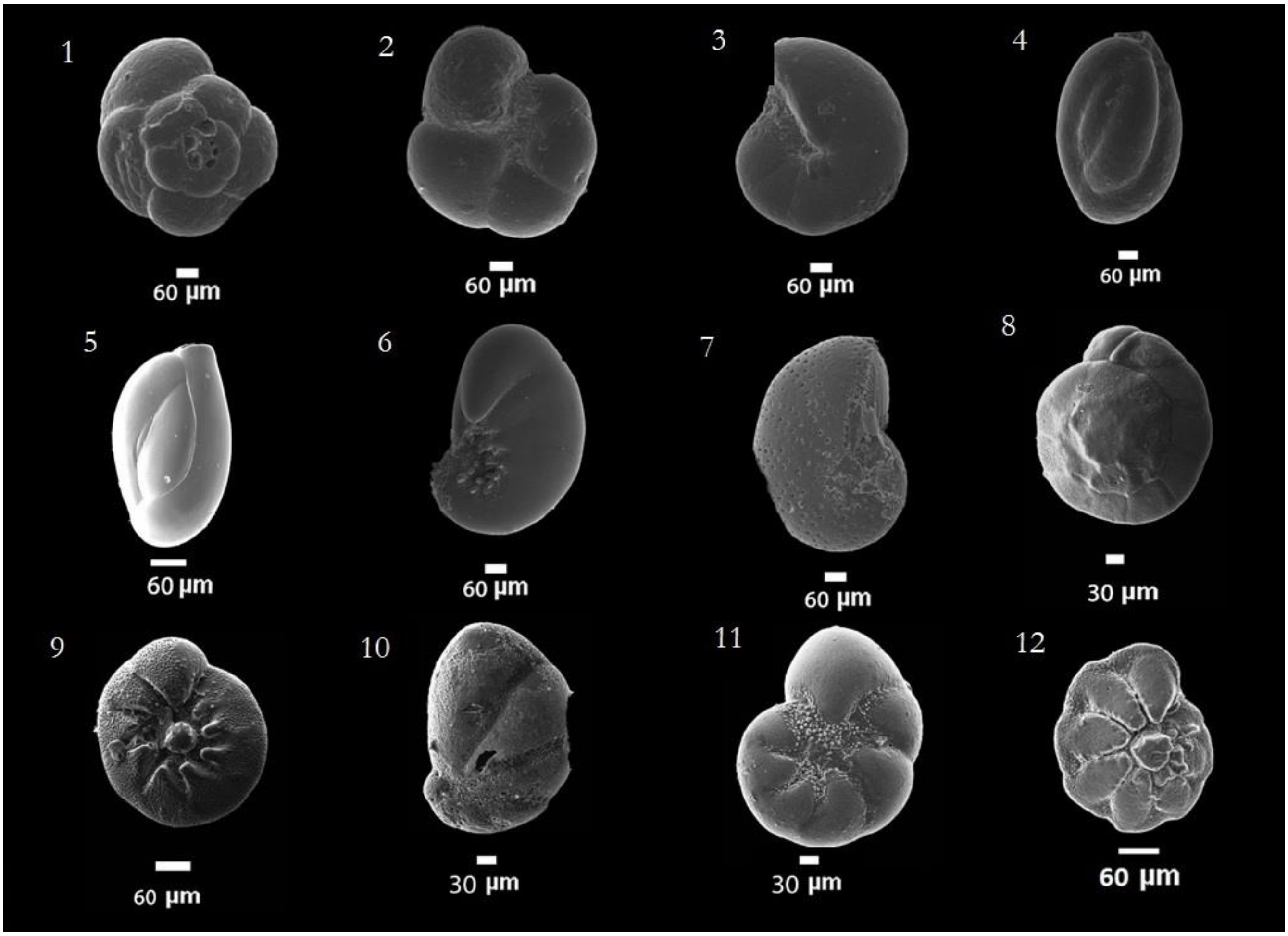

Plate 1. 1)*Trochammina*sp.(S); **2)** *Trochammina* sp. (U); **3)** *Haplophragmoides* sp. (U); **4)***Miliammina* sp. (Si); **5)** *Quinqueloculina* sp. (Si); **6)** *Nonionella* sp.(si); **7)***Cribroelphidium* sp. (Si); **8)** *Ammonia* sp.(S); **9)** *Ammonia* sp.(U); **10)** *Nonionella* sp. (Si); **11)** *Haynesina* sp. (Si); **12)***Pararotalia*sp. (U).

Legends: (Si)- Side view; (S)- Spiral view; (U)- Umbilcal view.

Chapter – 5

Results and Discussion

Results and Discussion

Result and Discussion:

The analysis of distribution pattern of foraminifera indicates that benthic foraminifera are widely distributed along the Sunderban areas from where sample has been collected.

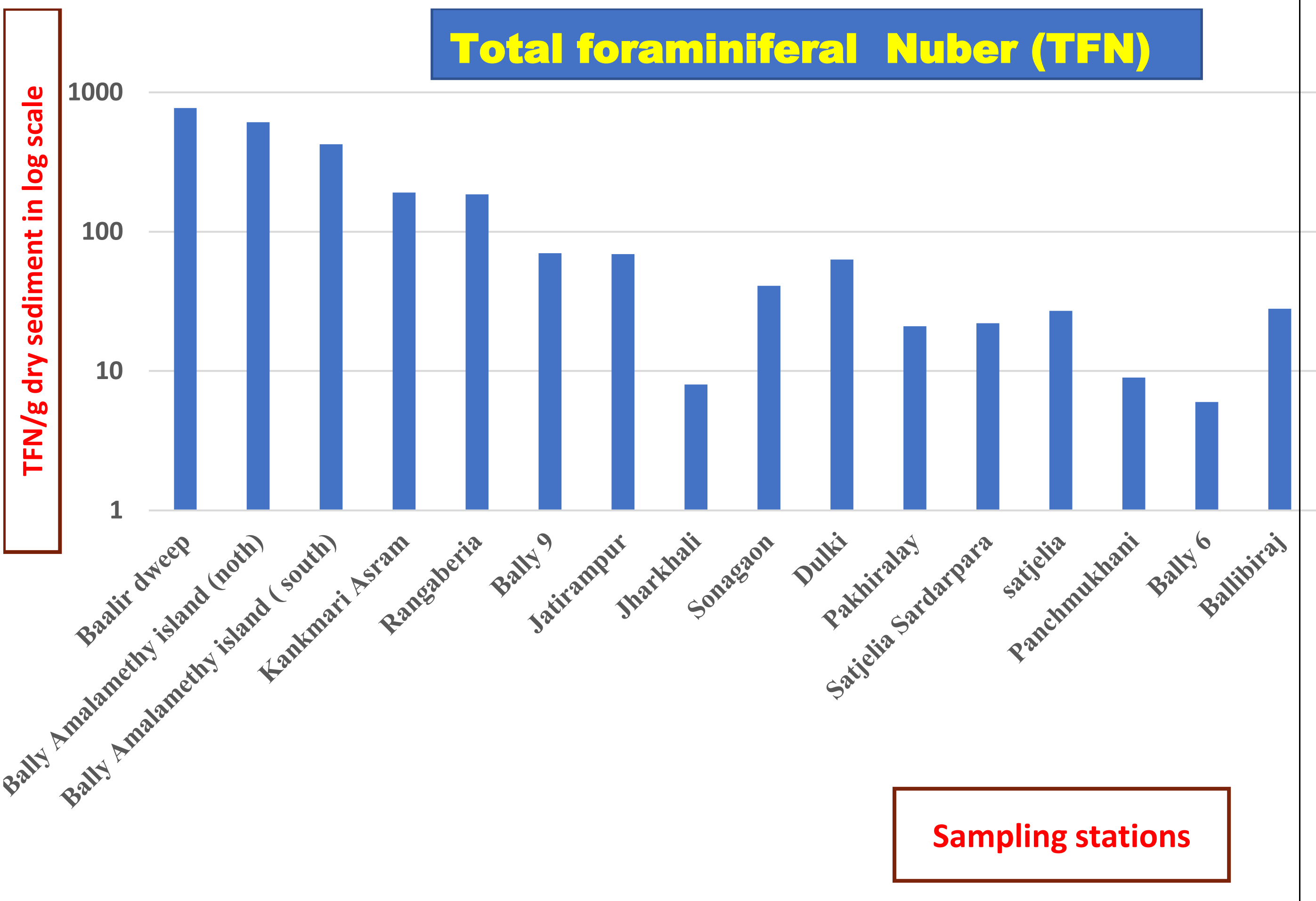

Fig.6.1-Total number of foraminifera along sampling locations, Sunderban.

This Total Foraminiferal Number (TFN) shows the variation of the abundance of foraminifera from western to eastern part of the sampling locations, Sunderban. The western region of Sunderban such as Baalir dweep, Bally Amalamethy island (north), Bally Amalamethy (south), Kankmari Asram and Rangaberia shows more abundance of foraminifera compare to the eastern region. The eastern region of Sunderban such as Jharkhali, Pakhiralay, Satjelia, Satjelia Sardarpara, Panchmukhani etc shows less abundance of foraminifera.

The possible reason of this variation is: 1) the western part has more marine infuelnce and eastern part are towards the interior side of the tidal creek. 2) May be the salinity is higher in western part than eastern part as salinity increases the abundance of foraminifer increases with salinity.

The foraminiferal genus also widely distributed in Sunderban areasfrom where sample has been collected (fig.6.2). The ten genus have been identified such as *Ammonia spp.*, *Cribroelphidium* spp., *Haplophraqgmoides* spp., *Hynesina* spp., *Trochamina* spp., *Nonionella* spp., *Quinqueloculina* spp., *Pararotalia* spp., *Miliammina*spp., *Cocoarota* spp.

Among these genus *Ammonia* are in higher abundance and widely distributed along all the sampling locations of Sunderban such as Baalir Dweep, Bally Amalamethy island (south), Kaqnkmari Asram, Rangaberia etc (fig.6.2). There may be the possible reasons of higher abundance of *Ammonia* is: it has higher tollerent capacity of salinity and temperature

The higher abundance of foraminiferal genus also found in western region of Sunderban such as Baalir dweep, Bally Amalamethy island (north), Bally Amalamethy (south), Kankmari Asram, Rangaberia and Bally 9. The eastern region has lower abundance of foraminiferal genus than western part such as Jharkhali, Satjelia, Panchmukhani, Bally 6, Pakhiralay (fig.6.2)

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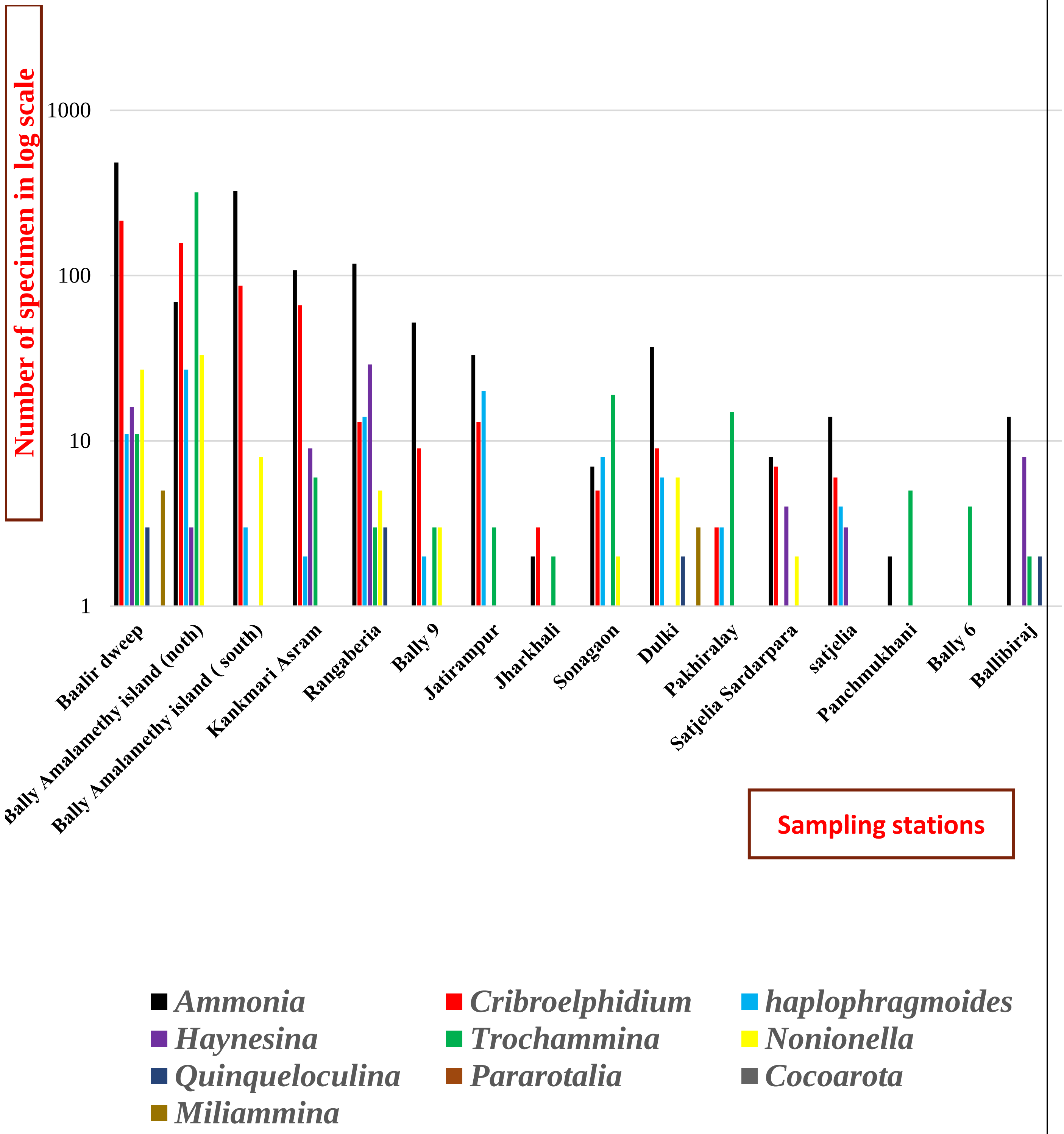

Fig.6.2-Variations of foraminiferal genus along the sampling stations, Sunderban.

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The Sunderban area is characterized by high marsh zone, middle marsh zone and low marsh zone. The marsh zonations are recognized on the basis of tide positions. The high marsh zone is dominated by agglutinated foraminiferal assemblages such as *Trochammina* spp., *Haplophragmoides* spp., *miliammina* spp., and few calcareous taxa *Ammonia* spp., *Cribroelphidium* spp. in northen part of the Sunderban. Foraminiferal assemblages of nothern most side of the Sunderban are cluster in the right sideof the Murray's Ternary diagram (fig.6.3, cluster 2). So northern side of the Sunderban such as Pakhiralay, Bally 6, and Sonagaon has dominated by agglutinated form because of high marsh zonation.

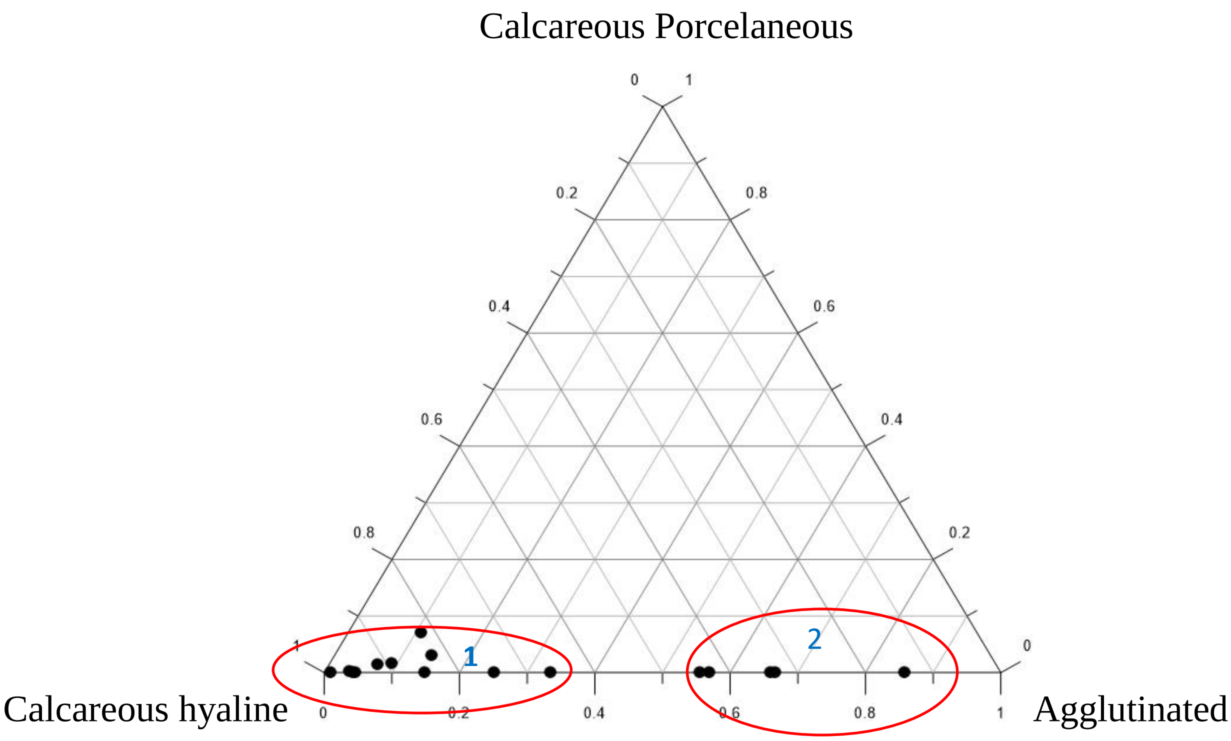

Fig.6.3-Murray's Ternary Diagram. Shows the percentage of wall type of foraminiferal assemblages, more dominantly showing the calcareous and agglutinated forms forms which are denoted by the two circles – **1**.Calcareous dominated stations (southern side of Sunderban) and **2** .Agglutinated dominated stations (northern side of Sunderban).

The calcareous hyaline foraminiferal assemblages like *Ammonia* spp., *Haynesina* spp., *Cribroelphidium* spp., *Nonionella* spp., dominate in low marsh zone i.e. southern part of the Sunderban such as Baalir Dweep, Bally Amalamethy island (south), Rangaberia, Bally 9 etc (fig.6.3, cluster 1). So southern part of the sunderban has dominated by calcareous hyaline form because of low marsh zonation.

CHAPTER-6

CONCLUSIONS

CONCLUSIONS

6.2 Conclusions:

a)A total of 10 benthic foraminiferal genus are recorded from the study area.

b)*Ammonia* spp. is the most abundant genus among all other types.

c)Western side showed the highest abundance of foraminiferal population and Eastern side showed the lowest.

d)Western side showed the highest abundance of foraminiferal genus and Eastern side showed the lowest.

e)The agglutinated foraminifera are *Trochammina* spp., *Haplophragmoides* spp., *Miliammina* spp. characterized the high marsh zones of the Sunderban and differentiate it from the calcareous hyaline foraminiferal assemblages such as *Ammonia* spp., *Haynesina* spp., *Nonionella* spp.,*Cribroelphidium* spp., *Pararptalia* spp. and *Cocoarota* spp. characterised the low marsh zonal environments and one calcareous porcelaneous form is *Quinqeuloculina* spp.

f)Southern part consists of most calcareous and Northern part consists of most agglutinated forms.

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