FORAMINIFERAL AND PTEROPOD RECORDS IN THE LATE QUATERNARY SEQUENCE OFF NORTHERN KERALA AND THEIR OCEANOGRAPHIC AND CLIMATIC SIGNIFICANCE

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CERTIFICATE

This is to certify that the thesis entitled **"FORAMINIFERAL AND PTEROPOD RECORDS IN THE LATE QUATERNARY SEQUENCE OFF NORTHERN KERALA AND THEIR OCEANOGRAPHIC AND CLIMATIC SIGNIFICANCE"** is an authentic record of research work carried out by Miss.N.R.Nisha under my supervision and guidance at the Department of Marine Geology & Geophysics, Cochin University of Science & Technology, I partial fulfillment of the requirements for the degree of Doctor of Philosophy and no part thereof has been presented for the award of any degree in any University/ Institute.

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FOREWORD

The continental shelves of India provide excellent sediment records to document changes of environments and sea level during the late Quaternary. Foraminiferal and pteropod tests preserved in shelf sediments can be used in deciphering history of the past changes with high resolution. A less effort has been made so far to analyse these microfaunal assemblages in Quaternary sedimentary record of the western continental shelf. In the present investigation, an attempt is made to study late Quaternary foraminiferal and pteropod records of the shelf of northern Kerala and to evaluate their potentiality in paleocenographic and paleoclimatic reconstruction.

The thesis is addressed in seven chapters with further subdivision. Chapter 1 comprises a general introduction on the significance of the work, a brief review of earlier investigations in Arabian Sea along with a concise account of previous work on foraminifera and pteropods of the western continental shelf. The geologic and oceanographic settings of the study area are also provided.

In Chapter 2, details of sediment cores and methodology of various analytical techniques involved in the study are discussed.

In Chapter 3, the general characteristics of foraminifera and pteropod species recorded from the examined samples and their systematic classification are given. These species are illustrated by scanning electron photomicrographs.

Chapter 4, deals with spatial distribution of Recent foraminifera and pteropods and their response to varying bathymetry, nature of substrate, organic matter content in sediment and hydrography across the shelf.

In Chapter 5, an attempt is made to establish an integrated chronostratigraphy for the examined core sections. An effort is also made to identify microfaunal criteria useful in biostratigraphic division in shallow marine core sections.

Chapter 6 deals with temporal variation in late Quaternary foraminiferal and pteropod assemblages. An attempt is made to infer various factors responsible for the change in microfaunal assemblage. Reconstruction of sea level changes during the last 36,000 years was attempted based on the pteropod record. The last chapter summarises the salient points and the conclusions arrived at from the present investigation.

Chapter 1

INTRODUCTION

1.1 General Introduction

The Quaternary period has been a time of great climatic and sea level oscillations. It is well established now that global climatic changes and sea level variations during the Quaternary had a direct impact on the circulation pattern, monsoonal system, coastal upwelling, coastal erosion and depositional processes. These changes have occurred on both the long (millennium to million years) and short (decade to century) time scales (International Geosphere-Biosphere Programme, 1990). Information related to paleoclimate and paleoceanography is stored in different forms in continental, coastal and oceanographic regimes. Depending upon the time span under consideration one can study different sources e.g. glaciers, rivers, lake-beds and deserts on the continents besides coastal and open ocean bottom sediments. The marine sediments are one of the effective archives to study the paleoclimatic and paleoceanographic changes on different time scales depending upon the place of study.

In recent years, there has been growing realisation among the Quaternary researchers to study the last glacial-Holocene shallow marine and estuarine sediments in order to have better understanding of the past oceanographic and climatic changes with high resolution on global, regional and local scales. The late Quaternary changes can be recorded using biological, biogeochemical, geochemical and sedimentological proxies preserved in the marine sediments.

The sedimentary records from the continental margins provide a better source for gathering information on past variations because their various coastal processes, sea level fluctuations, biological productivity and high sedimentation constitute sediments.

The Arabian Sea is different than other oceanic areas because of its uniqueness in geographical setting, atmosphere and oceanic circulation system bearing tremendous impact on Asian monsoonal climate. As continental margins have sedimentation rates that are an order of magnitude higher than the pelagic areas, sediment cores from the former environment would be ideal to study past variations in oceanic and climatic conditions. The continental shelves of India provide excellent sedimentary records to document changes of environments and sea level during the late Quaternary. Since last ten years, a special attention has been paid by the marine geologists and micropaleontologists to examine marine deposits along the Indian coasts. But these were mainly limited to the few locations (off Kutch-Saurashtra, Maharashtra, Karnataka and Andhra) of the continental shelves. Some stratigraphic and paleontological ~~details~~ data of the late Quaternary sediments along the Kerala coast are available based either on the inland exposed sequences or from bore wells. No serious attempt has been made so far to find out complete scenario of the oceanographic evolution along the Kerala coast during the late Quaternary.

The present micropaleontological investigation of the late Quaternary sequence off northern Kerala, employing multiple biological criteria (foraminifera and pteropods) forms a part of the ongoing research programme " Late Quaternary climatic and sea level changes along the west coast of India" in the Department of Marine Geology & Geophysics, Cochin University of Science & Technology. A systematic transect-wise core sampling across the shelf will enable to record modern distribution pattern of microfauna in order to document their response to ecological conditions and to establish new biological proxy for better deciphering of past oceanographic history (Fig.1.1). The study would also yield new insights into the last glacial-Holocene variability pattern in sea level changes along the southwestern continental margin of India.

1.2 Objectives of the study

1. To study the spatial distribution of Recent foraminifera and pteropods in order to understand the relationship between the faunal distribution pattern and environmental conditions.
2. To develop new proxies for the paleoceanographic and paleoclimatic interpretations based on the modern distribution pattern of microfauna.
3. To establish a precise chronostratigraphy for the examined core sections by integrating isotope stratigraphy, radiochronology, biostratigraphy and lithostratigraphy.
4. To study temporal distribution pattern of the foraminifera and pteropods in selected sediment cores and to assess their response to change in environment during the late Quaternary.
5. To decipher the oceanographic changes had occurred during the late Quaternary based on the integrated microfaunal records.

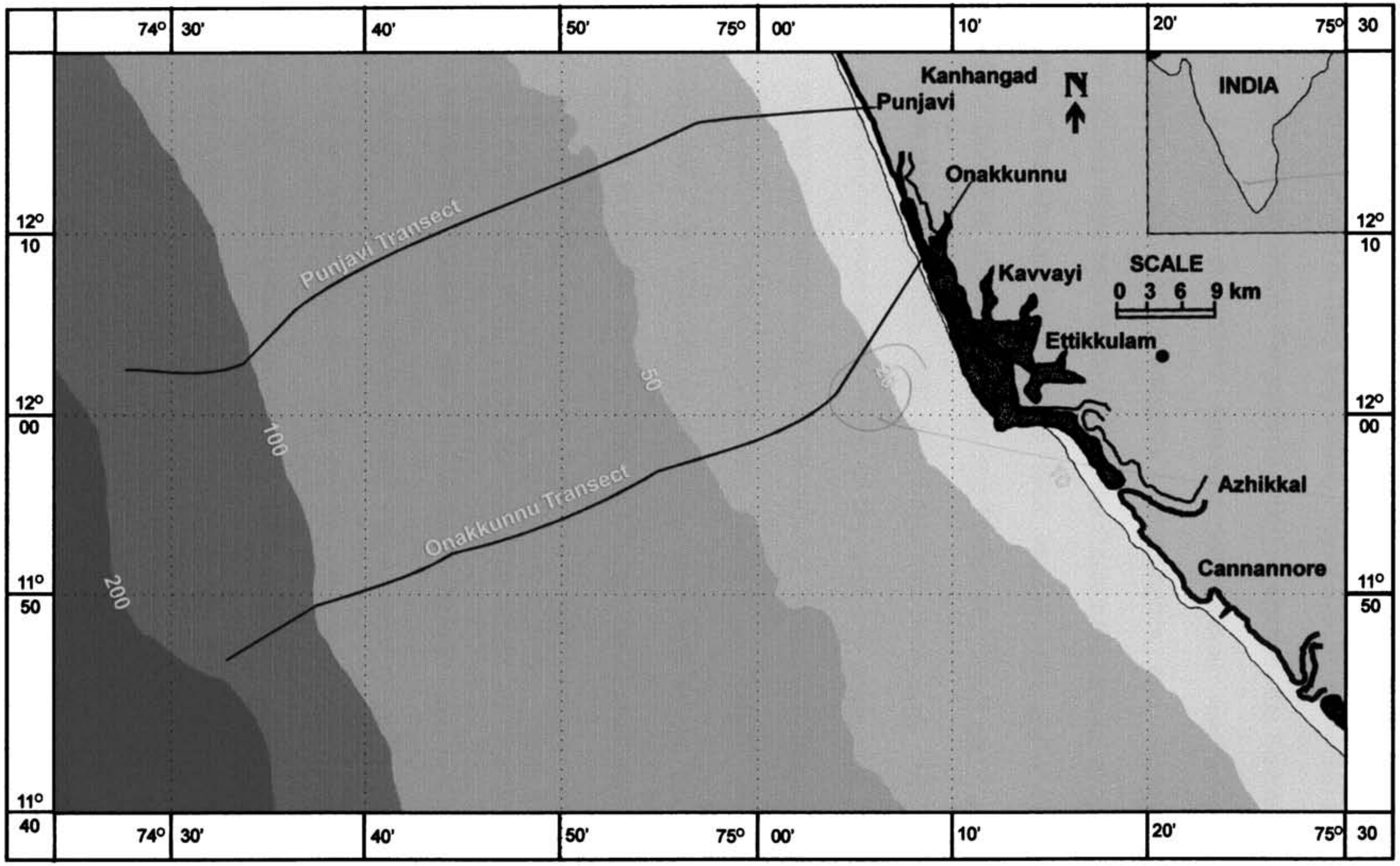

Fig. 1.1. Map of the study area showing locations of Punjavi and Onakkunnu Transects

1.3 Previous studies

With the advent of Deep Sea Drilling Project (DSDP) in the late sixties and subsequently Ocean Drilling Programme (ODP) in eighties, the Arabian Sea has become a center of activity amongst international marine geologists, micropaleontologists, sedimentologists, climatologists and oceanographers. Several studies have been carried out on the Quaternary paleoceanography and climates of the Arabian Sea (Frerichs, 1968; Vincent, 1972, 1976; Duplessy et al., 1981; Borole et al., 1982; Cullen and Prell, 1984; Prell and Van Campo, 1986; Srinivasan and Singh, 1991 and Singh and Srinivasan, 1993). Most of these investigations were based mainly on the deep-sea cores, thus providing a record of long term changes. Several international research programmes like the IGBP (International Geosphere-Biosphere Programme), PAGES (Past Global Changes), and CLIP (Climate of the Past) have emphasised the need for extensive and worldwide high-resolution study on the Quaternary (Prell and Kutzbach, 1987; Naidu, 1990; Zahn and Pedersen, 1991; Naidu et al.; 1992 and Naidu and Malmgren, 1995). These studies were based on foraminiferal data from a few sediment cores. A few significant contributions have also been made employing other sediment based climatic indices such as pollen grains (Van Campo et al., 1982; Prell and Van Campo, 1986 and Van Campo, 1991), geochemical tracers (Shimmield et al., 1990a,b; Clemens et al., 1991 and Shimmield, 1992) and isotopic composition of foraminifera (Prell and Curry, 1981; Duplessy, 1982; Kroon and Ganssen, 1989; Sirocko and Lange, 1991 and

Sirocko et al., 1991, 1993). Most of these results were derived from the western part of the Arabian Sea.

In recent years international scientific community paid special attention to understand the pattern of past sea level changes mainly on the local scale. The main focus of Quaternary sea level research has been on the continental shelves (Devoy, 1985; Belderson et al., 1986; Peterson, 1986; Fairbanks, 1989 and Austin, 1991) and information on former sea level stands can be derived from several established biological tools besides archeological, geological and geomorphological indicators (Wright, 1977; Singh et al; 1998).

Micropaleontological and paleoceanographic studies on coastal eastern Arabian Sea sediments are still in infancy. Several investigations on the carbonate sediments of the western continental shelf of India have been made in the last few decades. But, previous studies were mainly focused to record distribution of Recent foraminifera along the Indian west coast (Antony, 1968; Seibold, 1972; Setty, 1973, 1974; Guptha, 1974; Rao, 1974; Bhatia and Kumar, 1976; Nigam and Sarupriya, 1981; Setty and Nigam, 1982; Nigam, 1986,1987; Nigam and Rao, 1987; Naidu, 1990; Nigam and Henriques, 1992; Nigam and Sarkar, 1993 and Nigam and Khare, 1999). A few papers have been published on the late Quaternary biological and lithological response to climatic fluctuations and sea level changes in northern and central part of the western continental shelf (Nair, 1974; Nair and Hashmi, 1980; Nigam, 1986, 1988, 1989; Nigam and Nair, 1989; Nigam and Khare, 1992a,b and Rao et al., 1996). No serious attempt was made to study foraminiferal assemblages from subsurface sediments of the shelf of Kerala and their response to the late Quaternary oceanographic changes occurred along the cost. Besides foraminifera, pteropods that have been known to be very sensitive to a change in environmental condition also represent a significant biogenic component of the sediments of Indian margins. Surprisingly, study of pteropods from the marginal sediments of the Arabian Sea had been neglected until recently (Singh and Rajarama, 1997; Singh, 1998; Singh et al., 1998, 2000).

1.4 Geologic setting

The width of the western continental shelf of India is about 30Km off Bombay and narrows down to about 60 km near 10°N latitude (Shrivastava and Chandra, 1993). The southwestern shelf decreases southward from 75km to 55km (Shrivastava and Chandra, 1993). The Western Ghats mountain chains are the major physiographic features along the southwest coast with elevations up to ~1000m. The coastal region consists of Plio-Miocene Warkalli and Quilon Formations and Recent alluvium. The coastline of Kerala is an emergent type and is formed by several long narrow banks running parallel to the shoreline. There are often several rows of these and between them is a complicated system of channels or backwaters. Although no major river traverses through this area, there are several minor rivers and streams, seasonal in nature. Similar to the northern part, the southwestern shelf of India is covered by three different types of sediments (i) near-shore sand zone extending from shoreline to 5-10m depth,

(ii) silt and clay (muds) extending to depth of 50m (iii) biogenic carbonate rich sediments of the outershelf (beyond >50 - 60m water depth).

1.5 Oceanographic setting

The strong seasonal variability in the monsoonal climate invokes large oceanographic changes in the Arabian Sea. During the southwestern monsoon, surface water flows from west to east and Equatorial Current (EC) shifts northward to join the Monsoon Current (MC). Southwesterly winds during the summer monsoon cause coastal upwelling offshore Somali, Oman and Yemen and open ocean upwelling to the northeast of Findlater Jet axis. A weak upwelling has been reported in certain areas off southwestern India (Wyrtki, 1973 and Singh and Rajarama, 1997). The northeastern monsoon is characterized by east to west water movement and highly variable airflow from the northeast. These northeastern winds produce weak upwelling and greater surface mixing in the northeastern Arabian Sea (Wyrtki, 1973).

The surface waters off the Kerala coast show a seasonal variation in hydrographic parameters. During the southwest monsoon from May to September, a season of heavy rainfall, strong winds and severe storm at sea prevail. During this season, surface temperature remains high and the thermocline (the greatest temperature with depth) extends almost to the surface. The salinity gradient in the top 100m decreases significantly. The coastal current flows southward associated with the Equatorial Surface Water (ESW) retreat and an upward movement of Arabian Sea Water (ASW) (Darbyshire, 1967). Between

July to August, the backwaters discharge very low salinity water and this extends seawards as low –salinity front at the surface. With the onset of winter monsoon (NE monsoon), the coastal current starts flowing northward bringing less saline Equatorial Surface Water and resulting sinking of the Arabian Sea Water and deepening of the thermocline. During the months of November to January, a weak coastal upwelling occurs (Darbyshire, 1967). Isohaline conditions are formed in February to April months. February to April is characterised by relatively stable hydrographic conditions. The thermocline remains between 100 and 200m. The current system becomes weak and condition remains similar to those in January.

Due to the high biological productivity, a pronounced mid-depth Oxygen Minimum Zone (OMZ) prevails in the Arabian Sea. The OMZ is recorded strongest between 300 and 700m water depth in the northeastern part of the Arabian Sea (Wyrtki, 1973). Along the southwest coast of India, extremely low oxygen concentration (<0.2ml/l) occurs approximately at 200m water depth downwards in the water column. The hydrographic data (temperature, salinity and dissolved oxygen: DO) recorded during the Sagar Sampada Cruise 162 from the study area and around are presented in Table. 1.1

Table.1.1 Hydrographical parameters recorded during Sagar Sampada Cruise 162 from the study area and around

Depth (m)	Latitude °N	Longitude °E	Surface waters			Bottom waters		
			Temp. (°C)	Salinity (‰)	D O ml/l	Temp. (°C)	Salinity (‰)	DO ml/l
30	11°21.20	75°34.28	29°2512	34.6001	3.310	29°2410	34.5991	3.196
50	11°19.50	75°21.28	29°0968	34.4171	3.369	29°0635	34.4759	3.069
100	11°18.15	74°57.25	29°1366	34.2924	3.411	27°4268	37.3080	1.701
200	11°19.37	74°52.23	29°1915	34.2913	3.442	12°9040	35.2095	0.153
30	11°59.11	75°05.09	29°0506	34.6964	3.237	29°0674	34.6989	3.169
50	11°56.14	75°01.26	28°9515	34.4664	3.401	29°1167	34.8345	3.103
75	11°49.32	74°53.18	28°9804	34.3069	3.412	29°0350	34.9961	2.984
100	11°45.37	74°41.21	29°0438	34.2932	3.327	27°7281	36.3091	2.920
200	11°43.19	74°34.04	29°0825	34.2684	3.315	14°3094	35.2088	0.061
30	12°53.08	74°41.07	29°3769	35.0301	3.530	29°1301	35.0285	3.697
50	12°49.20	74°32.49	29°1559	34.9699	2.064	29°1524	35.0965	3.109
100	12°44.14	74°14.02	29°1355	34.6260	3.313	26°7445	35.8112	2.056
200	12°44.29	74°06.45	29°0893	34.6291	3.364	13°7467	35.2730	0.035

Chapter 2

MATERIALS AND METHODS

To accomplish the scientific objectives enumerated in Chapter 1, a detailed micropaleontological investigation using multiple biological proxies on several cores recovered from the shelf off northern Kerala was carried out. Various procedures and analytical techniques employed in the study are briefly discussed below.

2.1 SEDIMENT CORES

Thirteen gravity cores used in this study were collected from the shelf off northern Kerala during FORV Sagar Sampada cruise No.119 (under a collaborative research programme of Centre for Earth Science Studies, Thiruvananthapuram and Cochin University of Science and Technology). These cores were recovered along the two transects covering inner to outershelf areas (transect 1 (off Punjavi): S5, S4, S3, S2 and S1; transect 2 (off Onakkunnu) : S10, S11, S9, S8, S7, S12, S6, S13) (Fig.2.1). In addition, one piston core SS125 was also collected (Fig.2.1). Details of the examined cores are provided in Table 2.1. Colour and lithology of the sediments were noted shortly after the recovery of the core onboard. Careful visual examinations were also made for identifying the presence of turbidites and sediment slumping.

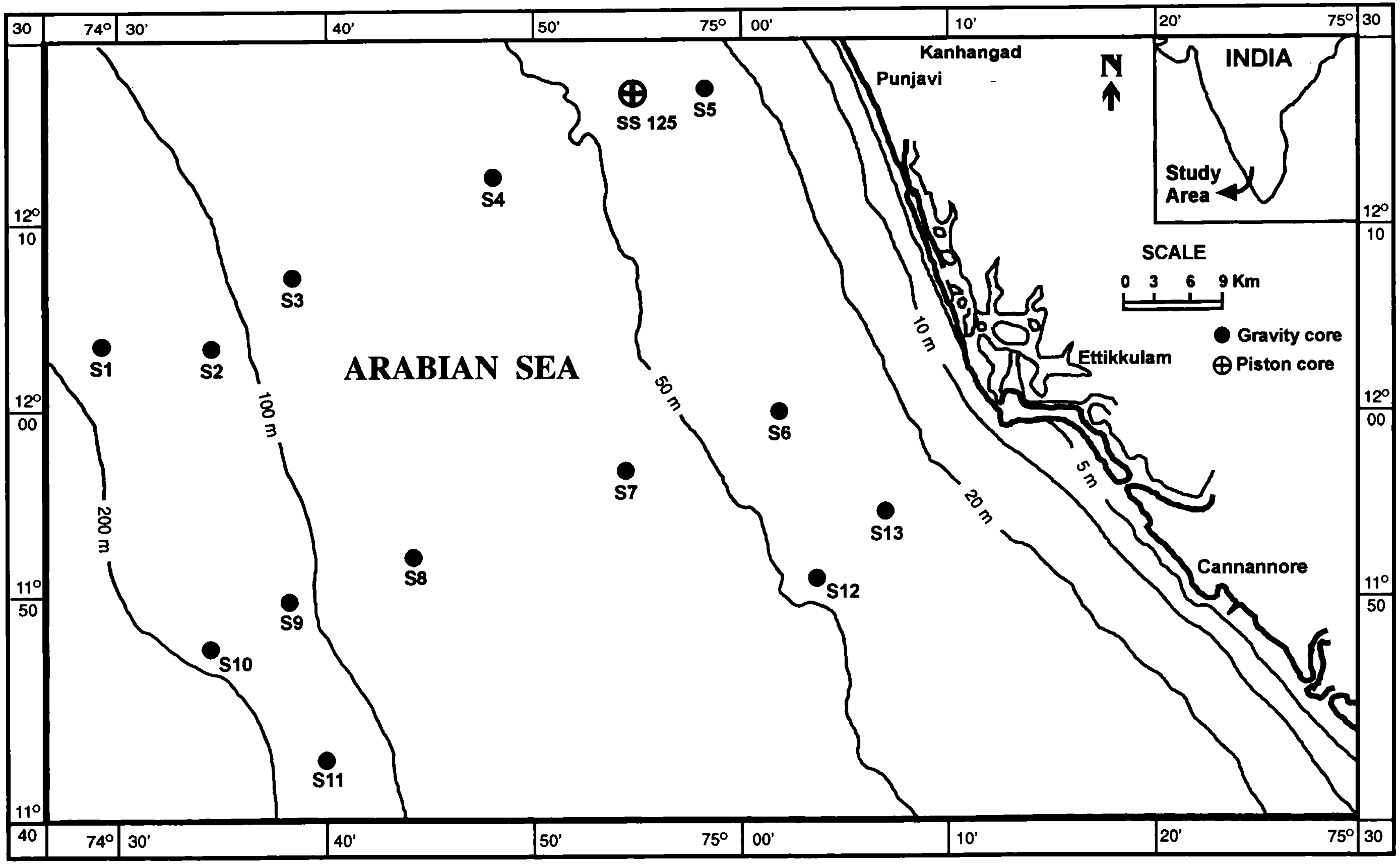

Fig. 2.1. Study area with bathymetry (in meters) and sampling locations

Table. 2.1. Details of sediment cores collected from the shelf off northern Kerala

Core	Distance from shore (Km)	Water Depth (m)	Latitude (N)	Longitude (E)	Core Length (cm)
S1	75	151.0	12°05.02'	74°27.04'	128
S2	64.8	113.5	12°04.45'	74°32.11'	79
S3	55.8	86.0	12°08.38'	74°36.29'	62
S4	32.4	61.4	12°13.16'	74°46.04'	136
S5	14.4	30.2	12°17.27'	74°57.21'	173
S6	18.6	40.0	12°01.17'	75°01.18'	162
S7	40.8	59.0	11°58.11'	74°53.27'	52.5
S8	63.6	79.7	11°53.47'	74°42.09'	49
S9	81	118.1	11°51.02'	74°36.46'	120
S10	93	150.5	11°40.04'	74°32.56'	135
S11	88.2	123.6	11°43.07'	74°38.05'	75
S12	33.6	50.7	11°52.38'	75°01.56'	65.2
S13	22.2	34.5	11°55.41'	75°06.28'	173.2
SS125	18.6	40.0	12°19.48'	74°20.46'	273

All cores were subsampled onboard at 5cm intervals. Core-tops of all the fourteen cores were used for modern distribution pattern studies of foraminifera (planktic and benthic) and pteropods. For vertical pattern studies of microfauna (foraminifera and pteropods) six cores (S1, S6, S7, S8, S10 and SS125) were chosen. A preliminary palynological investigation was also carried out on single core S10 (water depth- 150m). Samples at 10cm regular intervals were selected for the present study. Total 167 samples were analysed for various micropaleontological parameters.

Core sediments comprise of both the biogenic and non-biogenic elements. Biogenic skeletal debris content increases towards outershelf – upper slope with increase in bathymetry. Foraminifera and pteropods are the dominant components of the biogenic skeletal debris in coarse fractions of outershelf core samples. On the other hand, innershelf calcareous assemblages are dominated by benthic foraminifera, remains of bryozoans, pelecypods and gastropods. The minor components include echinoids, sponge spicules and algal fragments.

2.2 LABORATORY INVESTIGATION

Core samples were brought to the Micropaleontology Laboratory of the Department of Marine Geology and Geophysics, Cochin University of Science & Technology and recorded in the sample register. The samples were oven-dried at 50°C temperature and used for all further investigations.

2.2.1 SAMPLE PREPARATION AND ANALYTICAL TECHNIQUES

The present investigation was carried out mainly on the selected calcareous microfaunal groups (foraminifera and pteropods) representing major portion of the biogenic components of the sediments. For separation of calcareous tests from the matrix, the following conventional micropaleontological technique was used.

Samples (20g each) were soaked in 5% hydrogen peroxide for about twelve hours and boiled ~~little~~ gently before wet sieving. After wet sieving over 63 μm screen, samples were dried and again sieved over 100μm and 125μm screens. Care was taken to avoid mechanical damage during sample preparation.

For qualitative and quantitative microfaunal analyses, dried samples (>125μm fraction) were split into subsamples to obtain suitable aliquots consisting sufficient number of specimens of foraminiferal and pteropod populations (>300 specimens of benthic foraminifera and 200-300 specimens of planktic foraminifera and pteropods). Whole sample was analysed in case of rare occurrence of foraminifera and pteropods. All specimens were identified (under a binocular stereozoom microscope WILD MZ8), mounted on microfaunal assemblage slides and counted. Identification of several benthic foraminifera and pteropods were confirmed by the SEM (Scanning Electron Microscope) study. Microfaunal abundance (species wise as well as absolute abundance of foraminifera and pteropods) was estimated for 1g dry sediment >125μm. The relative abundance of individual species is expressed as a percentage of the total population. R-mode cluster analysis was performed on the percentage abundance data of Recent benthic foraminifera.

Palynofossils were analysed for the core S10. The palynomorph recovery from the sediments involves a special physio-chemical method called maceration. Based on the nature of sediments (organic and inorganic components), different maceration techniques are used for the recovery of palynomorphs. Since, most of the samples used in present palynological study are clayey, the following maceration technique was adopted for the palynomorph extraction.

A fixed weight of each sample (20g) was taken in a plastic container and soaked with water. The samples were crushed slowly with a glass rod and treated with concentrated hydrochloric acid to remove the carbonate material. The digested material was then washed with water and kept in hydrofluoric acid for overnight to dissolve the silica content. The acid was removed and the material was sieved through 40μm sieve in order to extract the palynofossils.

Swirling method was used to concentrate the polleniferous material from the macerated residue. This is a simple density separation method in which mineral particles and unwanted organic debris can easily be removed. The macerated residue with 10-15 ml of water was taken in a medium sized watch glass. The watch glass was placed on a flat surface (on table - top). By rotating the watch glass in clockwise direction, the mineral particles and big cuticle pieces were allowed to settle at the bottom and lighter particles including spore and pollen remained suspended on the top. With the help of a dropper, the upper layer of water was transferred to another watch glass and the material was allowed to settle at least for 45 minutes.

For the preparation of slides, few drops of polyvinyl alcohol were added in water free mixture and thoroughly mixed. The mixture was uniformly spread on a cover glass with the help of a glass rod to make a thin and uniform film. The cover glass was oven - dried for about half an hour. Then, it was mounted in Canada balsam on a clean glass slide. The slides were kept in oven at 50 - 60°C for 2-3 days till they got dried. This technique is called double mounting. Four slides were prepared for each sample.

The slides were scanned through a Leitz Dialux-20 microscope for pollen and spores and numbered by using the England Finder. The important palynotaxa were photographed by an Olympus BH-2 microscope with automatic camera attachment.

The palynological study including slide preparation and photography was carried out at the Birbal Sahni Institute of Paleobotany, Lucknow.

2.2.2 STABLE ISOTOPE (OXYGEN AND CARBON) MEASUREMENTS

Stable isotope measurements (both oxygen and carbon) were carried out on a surface dwelling planktic foraminifera *Globigerinoides ruber* (white variety) from every 10 cm intervals throughout the two cores S1 and S10. About 15-20 specimens of clean *G.ruber* from the size fraction >125μm were picked and sent to Leibniz-Labor für Altersbestimmung und Isotopenforschung, Christian-Albrechts Universität, Kiel, Germany. The isotope measurements were carried out on a Finnigam MAT 252 mass spectrometer attached with an automatic CO_2 preparation system. The isotopic composition of the carbonate sample was measured on the CO_2 gas evolved by the treatment of foraminiferal shells with 98% orthophosphoric acid at a constant temperature of 75°C. The standard gas was calibrated against the international carbonate standard Pee Dee Belemnite (PDB). The isotope ratio measurements are given in delta value (δ). The δ-notation represents per mil ‰ deviations from the isotopic standard PDB, prepared from the belemnite *Belemnitella americana* from the Cretaceous Pee Dee Formation of South Carolina. The δ- value is defined as:

$\delta\,^{18}O = \{[(^{18}O/^{16}O_{sample} / (^{18}O/^{16}O)_{standard}] - 1\} \times 1000.$

2.2.3 RADIOCARBON DATING

In addition to stable oxygen isotope stratigraphy, sediment cores S1 and S10 were radiometrically dated by ^{14}C method at the Birbal Sahni Institute of Paleobotany, Lucknow. The radiocarbon age estimation was done for the two stratigraphic intervals of these two cores. Of these four dates, three were on bulk sediments and one on the mollusk shells.

2.2.4 SCANNING ELECTRON MICROSCOPY

Scanning electron microscopic study was carried out on benthic foraminifera and pteropods at the Birbal Sahni Institute of Paleobotany, Lucknow. Surface ultrastructure, ornamentation and other morphological features of several species were studied. Those species unidentifiable under binocular microscope were identified by the scanning electron microscope. Clean and good specimens were hand picked using a binocular microscope and mounted on the sticky surface of the double-sided adhesive tape, over a stub. The stub was coated with gold-palladium (a conductive material) before using for SEM study. Scanning electron micrographs of 56 benthic foraminifera and 11 pteropods species were prepared (Plates 1- 6).

The sedimentological and geochemical data used in the present study were adopted from Haneeshkumar (2001).

Chapter 3

SYSTEMATICS

3.1 FORAMINIFERA

Foraminifera (planktic and benthic), because of their small size, great abundance and readily preserved tests, are most widely used for paleoenvironmental interpretation, biostratigraphy and correlation of marine sediments. Systematic study of foraminifera began with the work of d'Orbigny (1826). The first scientific details on modern foraminifera and their distribution in world oceans was prepared by Brady (1884) based on the collections made by H.M.S.Challenger (187~~2~~3-76). The taxonomy of the foraminifera has gone through several phases of revision since Brady's time (Thalmann, 1932, 1937, 1942 and Barker, 1960). During the last four decades, several references and monographs have appeared which have a significant bearing on the taxonomy of the foraminifera (Leroy, 1964; Saidova, 1975; Zheng, 1988; Hermelin, 1989; Van Marle, 1991; Srinivasan and Sharma, 1969, 1980; Loeblich and Tappan, 1964, 1974, 1981, 19~~87~~8; Kennett and Srinivasan, 1983; Hottinger et al., 1991a,b; Boersma, 1984; Banner and Blow; 1967 and Jones, 1984a,b, 1994).

Our knowledge of shallow water foraminifera with particular reference to the Indian coasts is still limited. The study of foraminifera in Indian waters started with the pioneer work of Chapman (1885), Hofker (1927, 1930) and Stubbings (1939). In 1963, Sastry prepared a bibiliography of the foraminiferal work. Setty (1982) provided a brief historical resume of foraminiferal studies in the Arabian Sea. Recently, Nigam and Khare (1999) provided a comprehensive account of foraminiferal species from the central west coast of India. In the present investigation 18 planktic foraminifera and 59 benthic foraminiferal species were identified. The systematics of planktic foraminifera follows the work of Kennett and Srinivasan (1983) and Hemleben et al. (1989). As the taxonomical concept offered by these workers is well established and widely accepted, planktic foraminifera identified in the present study are not discussed. The species that are recorded are *Globigerina quinqueloba* Natland, *G.bulloides* d'Orbigny, *G. falconensis* Blow, *G. rubescens* Hofker, *Globigerinoides triloba* (Reuss), G. *quadrilobatus*, *G. sacculifer* (Brady), *G.ruber* (d'Orbigny), *Orbulina suturalis* Bronnimann, *O.universa* d'Orbigny, *Globorotalia menardii* (Parker, Jones and Brady), *G. theyeri* Fleisher, *G.ungulata* Bermudez, *Neogloboquadrina dutertrei* (d'Orbigny), *Pulleniatina obliquiloculata* (Parker and Jones), *Globorotaloides hexagona* (Natland), *Globigerinita glutinata* (Egger), *Globigerinella aequilateralis* (Brady) and *Globigerinella calida* (Parker). For the classification and identification of benthic foraminiferal species, the concepts of Cushman (1948), Barker (1960), Loeblich and Tappan (1988) and Jones (1994) and also recent literatures on shallow water foraminifera were followed. The original reference, diagnosis and a brief remark for each of the species are given below. All the important taxa identified are illustrated by scanning electron micrographs in Plates 1 to 4.

PHYLUM	PROTOZOA
ORDER	FORAMINIFERIDA Eichwald, 1830
SUBORDER	TEXTULARIINA Delage and Hérouard, 1896
FAMILY	HORMOSINIDAE HAECKEL,1894
Subfamily	Reophacinae Cushman, 1910

Genus : REOPHAX Montfort, 1808
Species: ***Reophax agglutinatus*** Cushman

Plate,1, Fig.1

Referred by Brady (1884) and Thalmann (1932) to *Reophax scorpiurus* de Montfort, and by Barker (1960) to *Reophax agglutinatus* Cushman. Any relationship with *Reophax scorpiurus* de Montfort was ruled out by Brönnimann and Whittaker (1980).

Test free, elongate, composed of a series of undivided chambers in a straight linear series, outer wall with agglutinated material, firmly cemented with sand grains, mica flakes, sponge spicules and other foraminifera, aperture simple and terminal, some specimens are with short neck.

FAMILY : TEXTULARIIDAE Ehrenberg, 1838,
Subfamily : Textulariinae Ehrenberg, 1838

Genus : TEXTULARIA Defrance, 1824
Species : ***Textularia agglutinans*** d'Orbigny

Plate. 1 Figs. 2, 3

Referred by Brady (1884), Thalmann (1932), Barker (1960), Zheng (1988) and van Marle (1991) to *Textularia*. This species has also been referred by various authors to *Textilina* Norvang 1966 (regarded by Banner and Pereira (1981), Leoblich and Tappan (1988) and Jones (1994) as a junior synonym of *Textularia* Defrance (1824).

Test large, elongate, chambers biserially arranged, wall coarsely agglutinated, thick with grains of varied size and composition, surface roughly finished, aperture interiomarginal.

Species : ***Textularia pseudocarinata*** Cushman
Plate,1 Fig.4

Referred by Brady (1884) to *Textularia carinata* d'Orbigny, by Silvestri (1903) to *Spiroplecta wrightii* and by Charnock and Jones (1990) to Spiroplectammina carinata (d'Orbigny). The genus was originally referred by Kisel'man (1972) as *Spiroplectinella and* by Hofker (1976) as *Spirorutilis.*

Test biserial throughout, wall agglutinated, traversed by canaliculitions that may open as perforations or be closed externally by a thin agglutinated layer, aperture a low arch or slit at the base of the apertural face.

SUBORDER : MILIOLINA Delage and Hérouard, 1896
FAMILY : HAUERINIDAE Schwager, 1876
Subfamily : Hauerininae Schwager, 1876

Genus : QUINQUELOCULINA d'Orbigny, 1826
Species : ***Quinqueloculina agglutinans*** d'Orbigny

Plate.1 Figs.5-7

Referred by Brady (1884) to *Miliolina agglutinans* d'Orbigny, by Thalman (1932) and Barker (1960) to *Dentostomina agglutinans* (d'Orbigny).

Coarsely arenaceous surface and round periphery, test slightly longer than broad, apertural end slightly produced, aperture conspicuous with a tooth.

Species : **Quinqueloculina seminulum** (Linné)
Plate.1 Figs. 8,9

Referred by Brady (1884) to *Miliolina seminulum* Linné, sp., by Thalman (1932) to *Quinqueloculina akneriana* d'Orbigny and by Barker (1960), Haynes (1973) and van Marle (1991) to *Quinqueloculina seminulum* (Linné).

Test oval when viewed laterally, but triangular from the ends, longer than broad, surface smooth, periphery rounded, aperture rounded with a conspicuous tooth.

Species : **Quinqueloculina undulose costata** Terquem

Plate.1 Figs. 10-12

Referred by Terquem (1882) and Rocha and Ubaldo 1964 to *Quinqueloculina undulose costata.*

Test large, stout, surface ornamented with raised lines or costae running obliquely; septal lines distinct; apertural end drawn out into a neck; aperture wide with a simple tooth.

Species : **Quinqueloculina echinata** (d'Orbigny)

Plate.1 Fig. 13

Quinqueloculine chamber arrangement. The surface is ornamented with beautiful spines, aperture end drawn out into a neck.

Subfamily : Miliolinellinae Vella, 1957

Genus : TRILOCULINA d'Orbigny,1826
Species : **Triloculina costata** Brady

Plate.1 Fig. 18

Referred by Brady (1884) as *Triloculina costata*

Test longer than broad, surface ornamented with closely set delicate distinct longitudinal costae; sutures depressed, aperture circular with a tooth.

Species: ***Triloculina echinata*** d'Orbigny

Plate.1 Figs. 19-21

Referred by d'Orbigny (1826) as *Triloculina echinata.*

Test with triloculine chamber arrangement, aperture with bifid tooth. The surface ornamented with beautiful spines.

Species: ***Triloculina laevigata*** d'Orbigny

Plate.1 Fig. 22

Referred by Brady (1884), Bornemann (1855) to *Triloculina laevigata*.

Test ovate in outline, about twice as long as broad, chambers broadly overlap preceding chambers so that only two to three are visible from the exterior, wall imperforate, apertural end slightly prolonged, aperture with bifid tooth.

Species: ***Triloculina oblonga*** (Montagu)

Plate. 1 Figs. 23,24

Referred by Brady (1884) to *Miliolina oblonga* Montagu, sp., by Thalmann (1932) to *Triloculina oblonga* (Montagu) and by Barker (1960) to *Miliolinella oblonga* (Montagu). Brady's species appears almost identical to *Triloculinella obliquinodus* Riccio 1950.

Test elongate with triloculine arrangement. Chambers arranged obliquely with curved angles; sutures distinct, test wall smooth; aperture oval with a simple tooth.

Species: ***Triloculina tricarinata*** d'Orbigny

Plate.1 Fig.25-26

Referred by Brady (1884) to *Miliolina tricarinata* d'Orbigny, sp., and by Thalmann (1932), Barker (1960), Hofker (1976), Whittaker and Hodgkinson (1979), Zheng (1988), Hermelin (1989) and van Marle (1991) to *Triloculina tricarinata* d'Orbigny 1826.

Test slightly longer than broad with three visible chambers; final chamber envelops the preceding one, aperture with a bifid tooth.

Genus : PYRGO Defrance, 1824
Species: ***Pyrgo depressa*** d'Orbigny

Plate.1 Fig.27

Referred by Brady (1884) to *Biloculina*, and by Thalmann (1932), Barker (1960), Hofker (1976), and van Marle (1991) to *Pyrgo*.

Test biloculine, involute, two chambers making the exterior, aperture with a broad bifid tooth.

FAMILY : SPIROLOCULINIDAE Wiesner, 1920

Genus : SPIROLOCULINA d'Orbigny, 1826
Species : ***Spiroloculina communis*** Cushman and Todd

Plate. 1 Figs. 14 - 16

Referred by Brady (1884) to *Spiroloculina impressa* Terquem, by Thalmann (1932) to *Spiroloculina canaliculata* d'Orbigny and by Barker (1960), Haig (1988), Zheng (1988) and van Marle (1991) to *Spiroloculina communis* Cushman and Todd.

Test 1½ to 2 times as long as broad, concave with the central part of the periphery the thickest part, chambers rapidly increasing in size and thickness as added, The peripheral margins of the early chambers persisting as raised ridges in the early part, the chambers tending to be raised above and overlap the previous chambers in the adult stage, chambers extending into a long slender neck at the apertural end.

Species : ***Spiroloculina exima*** Cushman

Plate.1 Fig.17

Referred by Cushman (1922), Rocha and Ubaldo (1964) to *Spiroloculina exima* Cushman.

Test wall smooth and the chambers half coil in length.

Species : ***Spiroloculina* sp.**

Looks like *Spiroloculina exima*. But here the specimens are flat and transparent.

SUBORDER : LAGENINA Delage and Hérouard, 1896
SUPERFAMILY : NODOSARIACEA Ehrenberg, 1838
FAMILY : VAGINULINIDAE Reuss, 1860
Subfamily : Lenticulininae Chapman, Parr and Collins,1930

Genus : LENTICULINA Lamarck, 1804
Species : ***Lenticulina calcar*** (Linné)

Plate.1 Figs.28,29

Referred by Brady (1884) to *Cristellaria*, by Thalmann (1932) and Leroy (1944) to *Robulus*, and by Thalmann (1933~~a~~), Barker (1960), Hofker (1976), and van Marle (1991) to *Lenticulina*. This species has been amended by Thomas (1988).

Test planispiral, bilaterally symmetrical, triangular in side view; wall glassy; aperture radiate. The median slit enlarged in the middle of the apertural face. This species is characterised by the spines projecting out from the peripheral margin of the test.

Species : ***Lenticulina gibba*** (d'Orbigny)

Plate 2 Fig. 1

Referred by Brady (1884) to *Cristellaria* and by Thalmann (1932), Barker (1960) and van Marle (1991) to *Lenticulina.*

Test small, planispirally coiled, involute, chamber size increases gradually, sutures curved, aperture radiate, peripheral keel seen.

Species : ***Lenticulina thalmanni*** (Hessland)

Plate 2 Figs. 2-4

Referred by Brady (1884) to *Cristellaria rotulata* Lamarck, sp. by Thalmann first (1932) to *Lenticulina rotulata* (Lamarck) and later (1933) to *Robulus* n. sp., and by Barker (1960) to *Robulus thalmanni* Hessland. *Robulus* is regarded as a junior synonym of *Lenticulina* . L

Test palnispiral, bilaterally symmetrical, peripheral edge translucent with thick carina, exterior smooth without any ornamentation, aperture situated at the peripheral angle of the last formed chamber radiating with fissures.

Species: ***Lenticulina orbicularia*** (d'Orbigny)

Plate 2 Fig.5

Referred by Brady (1884) to *Cristellaria*, by Thalmann (1932), Leroy (1944a) and Barker (1960) to *Robulus*, and by van Marle (1991) to *Lenticulina.*

Test palnispiral, bilaterally symmetrical, close-coiled compressed test with a prominent keel. Surface smooth. Sutures curved; aperture radiate at peripheral angle, apertural face slightly protruding.

Species: ***Lenticulina* sp.**

Plate.2 Figs. 6-7

Test trochospiral, circular in outline, surface ornamented with granules, aperture ineriomarginal.

FAMILY : LAGENIDAE Reuss, 1862
Subfamily : Lageninae Cushman, 1948

Genus : LAGENA Walker and Jacob, 1798
Species:***Lagena aspera*** Reuss

Plate.2 Figs. 8-10

Referred by Brady (1884), Thalmann (1932), Barker (1960), Hermelin (1989) and van Marle (1991) to *Lagena hispida* Reuss, and by Barker (1960) to *Lagena hispida* var.*crispata* Matthes.

Test globular, extending out into a slender neck at the apertural end, aperture circular with a rim, surface hispid. Bottom of the test produced into a pointed extension. Neck is ornamented with thick circular rim.

Species : ***Lagena hispidula*** Cushman

Plate.2 Fig. 11

Referred by Brady (1884) to *Lagena laevis* Montagu, by Thalmann (1932) to *Lagena laevis* var. *nebulosa* Cushman and by Thalmann (1933), Barker (1960), and Hermelin (1989) to *Lagena hispidula* Cushman.

Test globular with a neck. It has resemblance with *Lagena aspera* but differs from that in having comparatively less hispid surface and the absence of thick rim around neck.

Species: ***Lagena striata*** (d'Orbigny)

Plate.2 Figs. 12-13

Referred by Brady (1884), Thalmann (1932), Barker (1960), Hermelin (1989) and van Marle (1991) to *Lagena striata* (d'Orbigny)

Test oval in shape with a tubular neck, surface of the test provided with parallel costae, the neck is ornamented with a thick rim.

Species: ***Lagena striata*** var. ***strumosa***, Cushman

Plate.2 Figs. 14,15

Referred by Brady (1884) and Thalmann (1932) to *Lagena semistriata* (Williamson) and by Barker (1960) and van Marle (1991) to *Lagena laevis* (Montagu).

It resembles *Lagena striata*. *Lagena striata* is distinguished from *Lagena striata* var. *strumosa* in having fewer and much elevated costae and the absence of the series of rings on the neck.

SUBORDER : ROTALIINA Delage and Hérouard,1896
SUPERFAMILY : NONIONACEA Schultze, 1854
FAMILY : NONIONIDAE Schultze, 1854
Subfamily : Nonioninae Schultze, 1854

Genus : NONION DE Montfort, 1808
Spcies : ***Nonion communis*** (d'Orbigny)

Plate.2 Figs.16,17

Referred by Brady (1884) to *Nonionina scapha* Fichtel and Moll, sp., by Thalmann (1932) to *Nonion scaph-a* (Fichtel and Moll), and by Barker (1960) and van Marle (1991) to *N.scaph-um* (Fichtel and Moll). *Nautilus scapha* Fichtel and Moll 1798 is a primary homonym of *N.scapha* Wulfen 1791. Rögl and

Hansen (1984) regard most records of *scapha* in the sense of Fichtel and Moll as referable to *Nonion commune* (d'Orbigny).

Test planispiral, longer than broad, periphery rounded, sutures distinct, narrow and curved, test wall smooth, umbilicus filled with calcitic substance.

Species : ***Nonion fabum*** (Fichtel and Moll)

Plate.2 Figs. 18-19

Referred by Brady (1884) to *Nonionina boueana* d'Orbigny, by Thalmann (1932) to *Nonion boueanum* (d'Orbigny) and by Barker (1960) to *Nonion cf. asterizans* (Fichtel and Moll).

Test broad, planispiral, chambers numerous, increasing gradually in size as added. Sutures distinct, slightly curved, surface smooth, umbilical region filled with secondary deposited calcite, aperture arched, equatorial interiomarginal slit.

Family : ELPHIDIIDAE Galloway, 1933
Subfamily : Elphidiinae Galloway, 1933

Genus : ELPHIDIUM DE Montfort, 1808
Species : ***Elphidium advenum*** (Cushman)

Plate.2 Figs. 20, 21

Referred by Brady (1884) to *Polystomella subnodosa* Munster, sp., by Thalmann (1932) to *Elphidium adven-um* (Cushman), and by Barker (1960) and van Marle (1991) to *Elphidium adven-a* (Cushman).

Test planispiral, bilaterally symmetrical, involute, chambers numerous with raised sutures. Umbilical region flat, aperture with a row of openings at the base of the apertural face.

Species: ***Elphidium cripsum*** (Linné) crispum

Plate 2 Fig. 22

Referred by Brady (1884) to *Polystomella*, and by Thalmann (1932), Barker (1960) and van Marle (1991) to *Elphidium*. This is the type species by subsequent designation of the genera *Themeon* de Montfort 1808 and *Polystomella* Lamarck 1822.

Test bilaterally symmetrical, comparatively large, raised sutures with well-developed retral processes, aperture consists of a row of pores arranged in a curved line at the base of the apertural face.

Species : ***Elphidium discoidale*** (d'Orbigny)

Plate 2 Figs.23-26

Referred by Cushman (1930) as *Elphidium discoidale* (d'Orbigny)

Test medium size, biconvex, completely involute, broadly rounded periphery, and chambers many, distinct retral processes occurring as only a narrow band. Aperture composed of several small opening at the base of the apertural face.

SUPERFAMILY : BULIMINACEA Jones, 1875
FAMILY : BULIMINIDAE Jones, 1875
Subfamily : Bulimininae Rhumbler, 1895

[illegible]

Genus : BULIMINA d'Orbigny, 1839
Species : ***Bulimina marginata*** d'Orbigny

Plate 3 Figs.1-4

Referred by Brady (1884), Thalmann (1932), Barker (1960), Belford (1966), Haynes (1973) and van Marle (1991) to *Bulimina marginata* d'Orbigny. This is the type species by original designation of the genus *Bulimina* d'Orbigny 1826. Its terminal structure has been well illustrated by Nørvang (1968) and Verhallen (1986).

Test short, tapering towards the initial end, slightly longer than broad, the final convolution conspicuously large. The chambers progressively increase in size as added, chamber margins serrated with short blunt spines, aperture interiomarginal.

SUPERFAMILY : BOLIVINACEA Glaessner, 1937
FAMILY : BOLIVINIDAE Glaessner, 1937
Subfamily : Bolivininae Glaessner, 1937

Genus : BOLIVINA d'Orbigny, 1839
Species: ***Bolivina amygadalaeformis*** Brady

Plate.3 Figs. 5-6

Referred by Brady (1884) and Thalmann (1932) to Bolivina and by Barker (1960) to Loxostomum. Jones (1994) referred this species as *Saidovina amygadalaeformis* (Brady). The generic identity of this species is somewhat questionable.

Test two and a half times longer than broad, compressed, broadest towards the apertural end, periphery acute, biserial, tending to become uniserial towards the apertural end; surface ornamented with numerous delicate longitudinal costae; aperture with a thickened lip. The costae disappear in the last chamber.

Species : ***Bolivina persiensis*** Lutze

Plate.3 Figs.7-9

Test elongate, chambers numerous, somewhat inflatened, sutures not very distinct. This species is distinct from *Bolivina amygadalaeformis* Brady by its test wall ornamented with a series of large irregularly arranged costae and elongate aperture with thick rim opening on the terminal face.

Species: ***Bolivina* sp.**

Plate,3 Fig.10

This form differs from the above two *Bolivina* species by its compressed test and elongate segments increasing in size from initial end, indistinct, depressed, oblique or curved sutures; wall thin and smooth, finely perforate, aperture loop shaped and terminal.

Species : ***Bolivina spathulata*** (Williamson)

Plate,3 Figs. 11-12

Referred by Brady (1884) to *Bolivina dilatata* Reuss, by Thalmann first (1932) to *B. beyrichi* Reuss and later to *B. spathulata* (Williamson), and by Barker (1960) and Van Marle (1991) also to *B.spathulata* (Williamson).

Test elonate, lanceolate, compressed, periphery acute, biserial throughout, chambers broad, surface perforate, aperture terminal.

Species : ***Bolivina ordinaria*** Phleger and Parker

Plate,3 Figs. 13-14

Referred by Phleger and Parker (1951) as *Bolivina ordinaria.*

Test elongate, somewhat compressed, biserial throughout, wall perforate, aperture a narrow loop at the base of the apertural face.

Genus : BRIZALINA O.G.Costa, 1856
Species : ***Brizalina aenariensis*** O.G.Costa

Plate,3 Figs. 18,19

Referred by Brady (1884) to *Bolivina aenariensis* Costa, sp., by Thalmann (1932) to *B. subaenariensis* Cushman and by Barker (1960) to *B. subaenariensis* Cushman var.

Test elongate, lanceolate, compressed, surface perforate with small costae at the early-formed chambers, aperture a basal loop that extends up to the apertural face.

SUPERFAMILY : LOXOSTOMATACEA Loeblich and Tappan, 1962
FAMILY : LOXOSTOMATIDAE Loeblich and Tappan,1962
Subfamily : Loxostominae Saidova, 1981
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Genus : LOXOSTOMUM Ehrenberg, 1854
Species :***Loxostomum limbatum*** (Brady) var.***costulatum*** Cushman

Plate. 3 Figs. 15-17

Referred by Brady (1884) to *Bolivina*, by Thalmann first (1932, 1933) to *Bolivina* and later (1942) to *Loxostomum,* by Barker first (1960) to *Loxostomum* and later (1960, addenda) to *Loxostomoides*, Belford (1966) and van Marle (1991) regarded this species as *Bolivina limbata* Brady 1881.

This species has been established on the basis of the longitudinal costae that are present on the test. The costae are well developed. Sutures distinct, limbate and curved backwards; middle region of the test with sides nearly parallel; segments inflated, aperture terminal and elongate.

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SUPERFAMILY : BULIMINACEA Jones, 1875
FAMILY : REUSSELLIDAE Cushman, 1933
Subfamily : Reussellinae Cushman, 1933

Genus : REUSSELLA Galloway, 1933
Species: ***Reussella spinulosa*** (Reuss)

Plate.3 Figs. 20, 21

Referred by Brady (1884) to *Verneuilina spinulosa* Reuss, by Thalmann (1932) to *Reussia spinulosa* (Reuss), by Thalmann (1933) and Leroy (1944) to

Reussella spinulosa (Reuss), by Barker (1960) to *R.aculeatea* Cushman and by Van Marle (1991) to *R.simplex* (Cushman).

Test elongate compressed, triserial becoming biserial, apertural end truncate and arched, sutures clear and strongly marked, extending externally to form spines. Aperture an arched slit at the base of the apertural face.

Species: ***Reussella simplex*** (Cushman)

?? [illegible] Plate,3 Fig.22

Referred by Cushman (1942) to *Trimosina simplex*.

Reussella simplex differs from *R.spinulosa* by its elongate, triserial test becoming uniserial and granular surface. Aperture arched slit at the base of the apertural face.

FAMILY : TRIMOSINIDAE Saidova, 1981
Subfamily : Tromosininae Saidova, 1981

Genus : TRIMOSINA Cushman, 1927
Species : ***Trimosina milletti*** Cushman

? a or b Plate,3 Figs.23-26

Referred by Millett (1900) to *Mimosina spinulosa* var. *Millett.*

Test pyramidal, triserial and triangular throughout, chambers inflated, a vertical carina at the angles produced laterally into a prominent proximally directed spine on each chamber, sutures depressed, wall perforate, hyaline, aperture a low broad ovate opening parallel to the base of the apertural face bordered by a narrow lip.

SUPERFAMILY : FURSENKOINACEA Loeblich and
Tappan, 1961
FAMILY: Fursenkoinidae Loeblich and Tappan, 1961

Genus : FURSENKOINA Loeblich and Tappan, 1961
Species : ***Fursenkoina complanata*** (~~e~~gger 1893)

Plate 4 Figs. 1,2 E

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Referred by Brady (1884) and Thalmann (1932, 1933) to Virgulina schreibersiana Czjzek, by Barker (1960) to V.davisi Chapman and Parr and by Van Marle (1991) to Fursenkoina schreibersiana (Czjzek).

Test narrow, elongate, biserial throughout, although plane of biseriality twists about the test axis, suture oblique, aperture narrow, elongate,extending up the face of the final chamber.

a or b

SUPERFAMILY : TURRILINACEA Cushman, 1927
FAMILY : UVIGERINIDAE Haeckel, 1894
Subfamily : Uvigerininae, Haeckel, 1894

Genus : UVIGERINA d'Orbigny 1826
Species: ***Uvigerina auberiana*** d'Orbigny

Plate 4 Figs.3-~~6~~ 5

Referred by Brady (1884) to *Uvigerina asperula* Czjzek and *U.asperula* var. *auberiana* d'Orbigny and by Thalmann (1932) and Barker (1960) to *U.asperula* (Czjzek).

Test generally small, chambers are triserially arranged in the early stage then becomes biserial. Chambers large and globular, wall finely perforate, aperture short, tubular with a slight neck.

Species: ***Uvigerina peregrina*** Cushman

Plate.4 Figs. 6-8

Referred by Brady (1884) to *Uvigerina* sp., intermediate specimens connecting *Uvigerina pygmaea* d'Orbigny with *U.aculeate* d'Orbigny, by Thalmann (1932) tentatively to *U.mediterranea* Hofker and *U.peregrina* var. *parvula* Cushman, by Barker (1960) to *U.bradyana* Fornasini, and by Hermelin (1989) to *U.peregrina* Cushman.

Test elongate, rounded in section, triserial, wall perforate, surface with longitudinal platy costae, aperture terminal, produced on a neck and bordered with a phialine lip.

Genus : SIPHOUVIGERINA PARR, 1950
Species : ***Siphouvigerina interrupta*** (Brady 1879)

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Plate.4 Fig. 9

Referred by Brady (1884) and Thalmann (1932) to *Uvigerina*, by Barker (1960) to *Neouvigerina* and by Belford (1966) to *Siphouvigerina*.

Early chambers triserial and closely apprised, becoming irregularly loosely biserial. Chambers globular and surface finely hispid, aperture terminal and rounded on a thin and elongate neck.

a or b

Species: ***Siphouvigerina porrecta*** (Brady 1879)

Plate.4 Figs.10-12

Referred by Brady (1884), Thalmann (1932), and van Marle (1991) to *Uvigerina*, and by Barker (1960) to *Neouvigerina*. *Neouvigerina* Hofker 1951 is a junior synonym of *Siphouvigerina* Parr 1950. o

This species is characterised by the projecting angular chambers having serrated edges. Test elongate, irregular in shape, many chambered, early chambers arranged compactly and later ones alternating irregularly, test wall with serrated longitudinal costae, apertural end produced to a tubular neck with a lip.

SUPERFAMILY : BULIMINACEA Jones, 1875
Subfamily : Angulogerininae Galloway, 1933

? not in bibl

Genus : TRIFARINA Cushman, 1923
Species : ***Trifarina aff. angulosa*** (Williamson)

or 1922 check

Plate 4 Figs.13,14

Referred by Brady (1884) to *Uvigerina*, and by Thalmann (1932) and Barker (1960) to *Angulogerina*. The genus *Angulogerina* Cushman is regarded by Jones (1994) as a junior synonym of *Trifarina* Cushman.

Test elongate, sharply triangular in section, angles sharp, wall perforate, and aperture terminal, rounded. It resembles closely with *Trifarina angulosa* but differs by its comparatively shorter and broadest test. Aperture terminal at the end of a short neck.

Species: ***Trifarina carinata*** (Cushman)

Plate 4 Figs.15,16

Referred by Brady (1884) to *Uvigerina angulosa* (Williamson) and by Thalmann (1932) and Barker (1960) to *Angulogerina carinata* var. *bradyana* Cushman and *A.carinata* Cushman.

Test elongate, slightly tapering towards either ends; chambers twisted, sutures distinct, surface ornamented with costae, aperture terminal with a lip at the end of a neck.

SUPERFAMILY : CERATOBULIMIBACEA Cushman, 1927
SUBORDER : ROBERTININA Loeblich and Tappan, 1984
FAMILY : CERATOBULIMINIDAE Cushman, 1927
Subfamily : Ceratobuliminae Cushman, 1927

Genus : LAMARCKINA Berthelin 1881
Species : ***Lamarckina scabra*** (Brady)

Plate.4 Fig.17

Referred by Brady (1884) to *Pulvinulina oblonga var. scabra*, and by Thalmann (1932), Barker (1960), and Belford (1966) to *Lamarckina scabra* (Brady). The generic identity of this species is questionable.

Test unequally biconvex, trochospiral, coiling dextral, chambers enlarging rapidly in size as added, wall hispid and ornamented with small spines.

SUBORDER : ROTALIINA Delage and Hérouard, 1896
SUPERFAMILY : ROTALIACEA Ehrenberg, 1839
FAMILY : ROTALIIDAE Ehrenberg, 1839
Subfamily : Ammoniinae Saidova, 1981 ref.?

Genus : Ammonia Brünnich, 1771
Species : ***Ammonia beccarii*** (Linné)

Plate.4 Figs.23,24

Referred by Brady (1884) and Thalmann (1932) to *Rotalia beccarii* (Linné), by Billman et al. (1980) and Jones (1994) to *Challengerella bradyi*.

Test biconvex, low trochospiral, sutures curved, depressed on umbilical side, umbilical surface with irregular granules along suture and over umbilical region, aperture interiomarginal.

Species : ***Ammonia tepida*** (Cushman)

Referred by Cushman (1926) to *Rotalia beccarii* (Linnaeus) *var. tepida*, Antony (1968) to *Discorbis rosacea* (d'Orbigny), Seibold (1971) to

2

Discorbis tepida (Cushman). Test trochospiral, biconvex, sutures distinct, umbilical surface smooth and aperture interiomarginal.

FAMILY : ROTALIIDAE Ehrenberg, 1839
Subfamily : Ammoniinae Saidova, 1981

Not referred

Genus : ROTALIDIUM Asano, 1936
Species: ***Rotalidium annectens*** (Parker and Jones)

Plate 4 Figs. 18-20

Referred by Parker and Jones (1865) to *Rotalia beccarii* (Linnaeus) *var. annectens*, Huang (1964) to *Ammonia annectens* (Parker and Jones), Muller-Merz (1980) to *Cavorotalia annectens* (Parker and Jones).

Test large biconvex with round periphery, three convolutions present, segments numerous. All the whorls are visible from spiral side. Septal plane arranged obliquely. Spiral side smooth, umbilical side plug split by anatomising fissures into numerous tubercles and pillars that crowd central portion of test.

Subfamily : Rotaliinae Ehrenberg, 1839

Genus : ASTEROROTALIA Lamarck, 1804
Species: ***Asterorotalia dentate*** (Parker and Jones)

Plate 4 Figs. 21,22

? ref

Referred by de Fe'russac (1827) to Calcarina stellata and by Jones (1994) to Pararotalia stellata (de Fe'russac)

Test free, trochospiral, biconvex with many slender spines radiating from the test, septa with intraseptal passages opening as a series of pores or fissures in and along sutures of umbilical side, surface smooth, aperture a low interiomarginal extra umbilical – umbilical arch.

SUPERFAMILY : DISCORBACEA Ehrenberg, 1838
FAMILY : Bagginidae Cushman, 1927
Subfamily : Bagginninae Cushman, 1927

Genus: CANCRIS DE Montfort, 1808
Species : ***Cancris auriculus*** (Fichtel and Moll)

Plate 4 Figs. 25,26

Referred by Brady (1884) to *Pulvinulina oblonga* Williamson, by Thalmann (1932) to *Cancris auriculus* (Fichtel and Moll) and Barker (1960) to *C. oblongus* (Williamson)?

Test trochoid, compressed; chambers few, rapidly enlarging; last chamber highly inflattened and the inner end of it forms a flap which extends to the umbilical area, aperture narrow, on the inner border of the ventral side of the last formed chamber.

Species : ***Cancris indicus*** (Cushman)

Referred by Brady (1884) to *Pulvinulina hauerii* d'Orbigny, sp. by Thalmann (1932) to *Baggina* (?) *indica* (Cushman), by Barker (1960) to *Cancris indicus* (Cushman) and by Belford (1966), Van Marle (1991) and Jones (1994) to *Bagiina indica* (Cushman).

It is distinct from auriculus in the convexity in the test.

SUPERFAMILY : ASTERIGERINACEA d'Orbigny, 1839
FAMILY : AMPHISTEGINIDAE Cushman, 1927 a o
Subfamily : Amphisteginnae Chapman and Parr, 1936

Genus : AMPHISTEGINA d'Orbigny, 1826
Species : ***Amphestegina lessonii*** d'Orbigny

Plate 4 Figs. 27,28

Referred by Thalmann (1932) to *Amphistegina radiata* (Fichtel and Moll), by Barker (1960) to *Amphistegina gibbosa* d'Orbigny, by Larsen (1976) to *A.lessonii* d'Orbigny and by Jones (1994) to *Amphestegina lessonii sensu* Parker, Jones and Brady.

Test low trochospiral, lenticular and unequally biconvex, periphery angular, finely perforate, aperture interiomarginal slit on the umbilical side.

6

SUPERFAMILY : PLANORBULINACEA Schwager, 187~~7~~
FAMILY : CIBICIDIDAE Cushman 1927
Subfamily : CIBICIDINAE Cushman 1927

Genus: CIBICIDES de Montfort 1808
Species : ***Cibicides refulgens*** de Montfort 1808

Plate.4. Fig.29

Referred by Brady (1884) to *Truncaqtulina*, and by Thalmann (1932) and Barker (1960), and Van Marle (1991) to *Cibicides*.

Dorsal side of the test flat, periphery round and slightly lobulate, aperture a low interiomarginal equatorial opening that extends a short distance into the umbilical side but continuous along the spiral sutures on the spiral side.

6

SUPERFAMILY : ROBERTINACEA Reuss, 18~~5~~0
FAMILY : ROBERTINIDAE Reuss, 18~~5~~0 6
Subfamily: ALLIATININAE McGowran, 1966 — year ?

? Ref

Genus : Geminospira Makiyama and Nakagawa, 1941 —
Species : ***Geminospira brayi Bermu'dez*** 1952 — ? Ref

Plate.4 Figs. 30-32

Referred by Brady (1884) to Bulimina convoluta Williamson, also by Thalmann first (1932) to Bulimina convoluta Williamson, later (1933) to Cancris convolutes (Williamson) and later Belford (1966) to Geminospira bradyi Bermudez.

Test elogate, chambers highest on the dorsal margin, a series of secondary chamberlets on the ventral margin alternating in position with the primary chambers and extending back towards the proloculus, aperture an interiomarginal slit.

SUPERFAMILY : CHILOSTOMELLACEA Brady, 1881
FAMILY: Gavelinellidae Hofker, 1956 } year ?
Subfamily : Gavelinellinae Hofker, 1956

Genus : Hanzawaia Asano, 1944
Species : ***Hanzawaia mexicana*** Lankford

Plate, 4. Figs. 33-35

Referred by Asano (1944) to Hanzawaia nipponica Asano. italics

Test trochospiral, planoconvex, convex side involute with clear central umbilical boss, periphery subangular, aperture interiomarginal.

3.2 PTEROPODS

Pteropods are marine gastropods adapted to pelagic life. The fin-shaped wings enable these animals to swim actively in the upper most 500m of the water column, migrating diagonally diurnally from great depths (during day time) to shallow positions (at night) (Herman, ~~1978~~ or 1971a ?). Pteropods are widely distributed and abundant in all oceans, although most species seem to prefer the circumglobal tropical and subtropical regions. Distribution of pteropods is limited by various physical and chemical parameters, such as temperature, salinity, food, oxygen content, and water depth (Herman, 1978 or Herman and Rosenberg, 19). The fossil record of shelled pteropods extends back to the Cretaceous, but the phylogenic relationships among pteropods all still under discussion. Most likely, pteropods evolved from littoral gastropods through the lightening, reduction or even loss of the shell. The foot was transformed into two fin shaped wings, which were uniquely adapted to enable the animals to swim (Bé and Gilmer, 1977; Herman, 1978). F.martens M gave the first reference about shelled microgastropods in

1676. George Cuvier established the order of pteropoda within the mollusca. De Blainvelle (1624) was the first to recognise that pteropods were gastropods related to opisthobranchia.

The classification of the pteropods has gone through several astages of development since Pelseneer's (1888) creation of two suborder: Thecosomata and Gymnosomata. Meisenheimer (1905, 1906) divided the Thecosomata into Euthecosomata and Pseudothecosomata. Further refinements at the family and subfamily levels have been introduced by Tesch (1913, 1948), Van der Spoel (1967, 1972), Rampal (1973), Bé and Gilmer (1977) and Van der Spoel and Boltovskoy (1981). In the present study, the most commonly used and widely accepted systematic classification by Bé and Gilmer (1977) and Van der Spoel and Boltovskoy (1981) was followed. In the present investigation, 14 species belonging to 6 genera were identified.. The important species are illustrated by Scanning Electron photomicrographs (Plate, 5 and 6).

PHYLUM : MOLLUSCA
CLASS : GASTROPODA
SUBCLASS : OPISTHOBRANCHIA
ORDER : THECOSOMATA de Blainville, 1824
SUBORDER : EUTHECOSOMATA Meisenheimer, 1905
FAMILY : LIMACINIDAE GRAY 1847

Genus : LIMACINA Bosc, 1817
Species : ***Limacina inflata*** (d'Orbigny)
Plate. 6 Figs. 9,10

Test spirally left coiled, shell apex depressed by subsequent expanding whorls, inner whorls do not project beyond a level. Umbilicus very deep and distinct, so that inner whorls are visible in interior view. Aperture more or less heart- shaped. Surface of the shell minutely pitted.

Limacina inflata is a mesopelagic (migratory) pteropod and widely distributed in the tropical and subtropical regions of all oceans (Bé and Gilmer (1977, Almogi-Labin et al., 1991 and Singh and Rajarama, 1997). It is abundant in the western Indian Ocean, Arabian Sea, off the coasts of India, and in the South Equatorial Current between Madagascar and the Timor Sea (Sakthivel, 1973; Singh and Rajarama, 1997; Singh et al., 2001). Its occurrence is not so frequent in the Bay of Bengal and the North Equatorial Current, possibly because of the relatively low salinities in these regions (Sakthivel, 1973). *Limacina inflata* exhibits distinct seasonal fluctuation in abundance (Wormelle, 1962 and Moore, 1949). In the Indian Ocean, it is more abundant during the southwest monsoon than during the northeast monsoon (Sakthivel, 1973; Singh and Rajarama, 1997 and Singh, 1998). The abundance of *L.inflata* in deep sea has been suggested to be associated with the oxygen minimum zone (Almogi-Labin et al, 1998).

Species : ***Limacina trochiformis*** (d'Orbigny)
Plate. 6 Fig. 11

Test low spired, height equals the maximum diameter, surface smooth with little ornamentation. Umbilicus constricted and aperture oval or elliptical.

Limacina trochiformis is an epipelagic (non-migratory) warm water species, whose peak abundance occurs in tropical regions especially in the Florida current, Gulf Stream, Somali Current, the southeastern Arabian Sea, Bay of Bengal and the eastern tropical Pacific (Pelseneer, 1888a,b; Tesch, 1904; Meisenheimer, 1905; Wormelle, 1962; Chen and Be, 1964; Myers, 1968; McGowan, 1968; Sakthivel, 1969). *L.trochiformis* is widespread and is the third most abundant species of *Limacina* in the Indian Ocean. Singh

only 188

(1998) and Singh et al. (2002) recorded abundant occurrence of L.trochiformis in eastern Arabian Sea marginal sediments. This species is characteristic of highly productive areas such as upwelling regions.

Species : ***Limacina bulimoides*** (d'Orbigny)

Test medium sized, elongated, high spired, trochospiral, umbilicus closed to very marrow, columella arched and aperture elliptical. *L. bulimoides* is a mesopelagic (migratory), subtropical pteropod.

It is generally less abundant in the tropical waters and boundary currents (Bé and Gilmer (1977). Sakthivel (1969) reported this species from the tropical Indian Ocean between 10°S to 12°S latitude.

FAMILY : CAVOLINIIDAE FISCHER, 1883
Genus : CRESEIS Rang, 1828
Species : ***Creseis acicula*** (Rang)
Plate 5 Fig.7

Test very much elongated, needle-like, quite straight or very nearly so with circular aperture. It shows a characteristic pencil like shape and smooth test.

Creseis acicula is a warm-water, cosmopolitan epipelagic (non-migratory) species. This species is abundant in the tropical and subtropical regions with the exception of the central water masses (Meisenheimer, 1905, and van der Spoel, 1967). Its occurrence is observed in South Atlantic and Central Indian Ocean (McGowan, 1960; Sakthivel, 1969). A common occurrence of *C.acicula* is recorded in the active current systems and areas bordering water masses (McGowan, 1960; Sakthivel, 1969 and Singh et al., 1998). This species is regarded as the most euryhaline, eurythermal pteropod species (Rottman, 1980)

Species : ***Creseis virgula conica*** (Rang)

Plate. 5 Figs. 6,9,10

Test always curved dorsally, sometimes very sharply so that the hind part forms an angle of about 100 degrees with the anterior portion, shell cross-section expanding more rapidly, curved or straight.

It is a warm tropical species occurring frequently in Bermuda waters (Chen and Be, 1964) and in the Mediterranean Sea (Menzies, 1958). It is present in the Arabian Sea (Singh, 1998; Singh and Rajarama, 1997).

Species : ***Creseis virgula virgula*** (Rang)

Plate, 5 Fig. 8

Test strongly flexed dorsally to an angle about 40° to 50°, transverse diameter increasing rapidly in the beginning and gradually in the adult stage, aperture rounded. It shows the characteristic curvature along the length of the test.

C.virgula virgula, a typical tropical eurythermic, epipelagic (non-migratory) species with a temperature range from 15°C to 27.5°C (Chen and Be, 1964; Rottman, 1980 and Bé and Gilmer, 1977). Common occurrence is noticed off the Somali coast, Bay of Bengal, Gulf of Oman (Sakthivel, 1969; Bhattacharjee 1997); Arabian Sea (Stubbins, 1938; Singh et al., 1998) and off Great Barrier Reef (Russell and Colman, 1935).

Species: ***Creseis chierchiae*** (Boas)

Plate, 6 Fig. 1-3

Test elongated, conical and gradually increasing in size. More than 2/3 of the test length is covered by finer transverse striations. The striations are nearly equidistant from each other. Aperture circular. *C.chierchiae* differs from *C.acicula* by the absence of transverse striations in later.

C.chierchiae occurs in low salinity waters of Gulf of Thailand and South China Sea. It is found in abundance in the Gulf of Panama near Florida and the western continental shelf of India by (Rottman, 1976; Singh and Rajarama, 1997; Singh, 1998; Singh et al., 2001).

Genus : CLIO Linne, 1767

Species : ***Clio pyramidata*** Linne

Test triangular and conical, diameter of the test increasing uniformly. Thin and depressed peripheral ring on dorsal side of the test. *Clio pyramidata* does not have the concave margins on its lateral sides, which are characteristic of *convexa*. Protoconch is medium to small in size with constricted area between the two protruded peripheral rings. The area between the peripheral rings is covered with vertical striations.

It is a erythermic, mesopelagic (migratory), subtropical to transitional species with wide latitudinal distribution. In Indian Ocean it commonly occurs between 20°S - 10°N. It is also found in north of Madagascar, near the east coast of Africa and southwest coast of India (Sakthivel, 1973 and Singh et al., 1998).

Species : ***Clio convexa*** (Boas)
Plate, 5 Fig.5

Test triangular elongated, posterior side slightly curved ventrally, very little ornamentation. Protoconch small in size with a blunt cusp.

It is a sub-tropical to transitional species with wide latitudinal distribution. This species is restricted to the Indo-Pacific region (Bé and Gilmmer, 1977). It is also reported from eastern and western Pacific Ocean (van der Spoel, 1967). It is also found abundantly in the eastern Arabian Sea (Singh,1998).

Genus : DICARIA Gray, 1850
Species : ***Diacria trispinosa*** (de Blainville)
Plate, 6 Fig. 7

Test biconvex, faint concentric growth lines are present on the both sides of the test, dorsal side less convex than the ventral side. Prominent three longitudinal ridges on the dorsal side of the test and two lateral spines.

It is a eurythermic warm-water species. It also occurs in a good number in subtropical seas. Fair occurrence of this species is reported from Caribbean Sea, Mediterranean Sea (Chen, 1971 and Meinseheimer, 1905), Arabian Sea, Bay of Bengal and Pacific Archipelago (Tesch, 1946; Sakthivel, 1969; Singh, 1998; Bhattacharjee, 1997, 2000 and Singh et al., 2001).

Species: ***Diacria quadridentata*** (de Blainville)
Plate,6 Figs. 4-6 ,8

Test biconvex, ventral side more convex than the dorsal side, wall ornamented, five longitudinal ridges on the dorsal side, distinct marginal striations on the apertural face.

Diacaria quadridentata is a warm water cosmopolitan species which has a rather patchy but widespread distribution. It is more stenothermic and has a narrower latitudinal distribution range than *Dicaria trispinosa*. It is found particularly in the equatorial Indian Ocean. High abundance is reported in equatorial boundary currents in Pacific and Indian Oceans (Tesch, 1948; Sakthivel, 1969).

Genus : CAVOLINIA Abildgard, 1761
Species : ***Cavolinia longirostris*** (de Blainville)
Plate,5 Figs. 1-3

Test inflated, well ornamented, prominent ridges on the dorsal side and distinct growth lines on the apertural face of the ventral side.

It is a warm water, cosmopolitan species. It shows patchy distribution in the tropical ocean (Be and Gilmer, 1977). It is common in tropical Indian Ocean (Sakthivel, 1969) and in good numbers in Arabian Sea (Stubblings, 1938 and Singh et al., 1998), Gulf of Elat (Van der Spoel, 1971)).

Species : ***Cavolinia gibbosa*** (Rang)
Plate.5 Fig.4

The ventral part of the test is bent into a sharp angle, projecting forward in profile view. White test with a brown or red stripe along the side slits, but very often-quite hyaline.

Cavolinia gibbosa is a warm water species with a patchy but widespread distribution in the sub-tropical regions. In the South Pacific, Indian Ocean and Atlantic Ocean, *Cavolinia gibbosa* occurrences are predominantly in the sub-tropical belts, while it is conspicuously rare in the equatorial regions (Meisenheimer 1905; Tesch, 1946, 1948; Sakthivel, 1969; Singh, 1998 and; Singh et al., 1998).

Genus : HYALOCYLIS Fol, 1875
Species: ***Hyalocylis striata*** (Rang)

Test transparent to white but very delicate in nature. Conical, slightly curved dorsally, faintly ornamented by numerous growth increments.

Hyalocylix striata is a typical epipelagic tropical species. It is common in Caribbean Sea, equatorial Atlantic (Chen and Be, 1964 and Boltovskoy, 1971). Good occurrence is also noticed in the western Indian Ocean, Arabian Sea and north equatorial current in Indian Ocean (Sakthivel, 1969; Singh et al.1998 and Bhattacharjee, 2000).

3.3 PALYNOMORHS

Palynostratigaphical investigations of Quaternary sediments offer a good database for the reconstruction of past vegetation and understanding the climatic changes during the recent past. Palynology- the study of spores and pollen helps to decipher the past climate by its characteristic pollen. Unlike animals, plants are unable to move away from inhospitable condition and thus depict the paleoenvironmemtal nature of deposition in a particular time. A preliminary study was carried out on core S10 samples. The prime objectives to analyse the palynological contents was to record nature of the assemblage and its richness in sediments. The recovered spores and pollens were as far as possible compared with photographs of living forms.The examined samples are poor in spore-pollen assemblage. The assemblage consists mainly of angiospermic pollen, pteridophytic spores, phytoplankton, microthyriaceous ascostomata and fungal spores. Liliaceous pollens are most abundant. All the spore and pollen types are illustrated by photographs (Plate, 7).

***Tetraporina* type**

Plate,7 Figs 1,2

Algal spore with 1-3 pore like opening at the corner, rhomboidal spore coat laevigate, irregularly folded. In *Teraporina* there are normally 4 pores but in the present specimens no distinct spore was observed.

Phytolankton type-1

Plate.7 Fig.3

Algal cyst funnel shaped with a long tail like flagellum at one end (53X9μm without tail), pylome apical, circular in shape, cyst body psilate

Phytoplankton type-2

Plate,7 Fig. 4-6

Cysts subcircular, 49-58μm, covered with translucent hairy processes, hairs 10-22μm long, closely placed forming a hallow around the main body.

Phytoplankton type-3

Plate,7 Figs. 7-9

Cysts subcircular, 58X56μm without processes. Processes strongly built, 8-12μm long and 4-6μm broad, hallowed, tubular, serrated at tip. Pylome not observed.

Fungi

***Notothyrites* sp.**

Plate,7 Fig.10

Ascostromata subcircular, 7OX60µm, pore at the center distinct, sub circular, margin of pore few layered thick, dark, in rest part hyphae radially arranged, parallel to each other, transverse septa indistinct.

Inaperturate spore

Plate,7 Figs. 11,12

Spores subcircular-circular, 35-47µm, spore coat less than 2µm thick, irregularly folded, no aperture could be seen.

Monoporate sopre:

Plate,7 Fig.13

Spore originally subcircular, 71X65µm, folded. Monoporate, pore distinct without any thickening, spore coat upto 2µm thick, pislate

Multicellular type:

Plate,7 Figs. 14,15

Spores multicellular, elliptical, individual cell broader than long, 5-10µm celled. Monoporate, pore distinct in some specimens only.

Spores of Pteridaceae:

(i) Verrucose type:

Plate. 7 Fig.16

Sopre subcircular, 53X28µm , trilete well developed extending upto two third radius. Exine less than 2µm thick, verrucose, verrucae not very closely placed, 2-3µm high, inter-verrucose exine laevigate.

(ii) Laevigate type:

Plate.7 Fig.17

Spores triangular, zonate, zona uniformly broad. Trilete, rays extending upto twothird radius, exine laevigate.

Pollen of Liliaceae

(i) **Reticulate type:**

Plate. 7 Figs. 18-29

Pollen grains oval - elliptical bilaterally symmetrical 50-74 X 24-36µm, monosulcate, sulcus boat shaped, distinct, extending from one end to other. Exine upto 2µm thick, sexine thicker than nexine, exine reticulate, size of meshes more or less same throughout, lumina squarish to subcircular. Some of the pollen grains are ruptured into two halves giving the indication that the aperture may be zonisulcate.

(i) **Spinose type:**

Plate.7 Figs. 30,31

Pollen grain oval, 57X28µm, monosulcate, sulcus long, distinct, extending one end to other along the longer axis. Exine less than 2µm thick, sexine thicker than nexine, spinose, spines 2-3cm long, swollen at base, pointed at tip, spines sparsely placed, interspinal exine laevigate. The monosulcate,, spinose pollens are found in the group Haloriceac of the family Liliacae.

Note:

The pollen record of core S10 is characterised by the abundance of liliaceous pollen. In contrast to other record from the eastern Arabian Sea (Van

Campo, 19~~86~~), mangrove pollens represented by the family Rhizophoraceae are conspicuously absent in the examined core samples. The pteridophytic spores are also rarely encountered. Van Campo (19~~86~~91) has recorded dominance of the pollen Chenopodiaceae, Poaceae and Cyperaceae. All these pollen types are not at all found in the present bore hole samples. A preliminary palynological record of core S10 indicates high relative abundance of pollen in samples from upper 45cm representing Holocene period. Samples from the lower part of the core (from 50cm downwards) have low abundance of pollen indicating arid condition during the glacial period. However, absence of chenopodiaceous and poaceous pollen characterising arid conditions (Van Campo, 19~~86~~91; Prell and Van Campo, 1986) in the assemblage could not be rationally approved.

Chapter 4

DISTRIBUTION OF FORAMINIFERA AND PTEROPODS IN SURFACE SEDIMENTS

The biotic components of the marine sediments have been immensively used for reconstructing paleoecology and paleoceanography. Any biological proxy used in recording changes is defined by a better understanding of various environmental and ecological factors controlling its distribution pattern in modern conditions. In recent years, there has been a growing interest among the micropaleontologists to study distribution pattern of various microfaunal groups (living and dead) using water samples and sea surface sediments in order to have thorough knowledge on the relationship between their distribution and environmental conditions. As a result, many new biological proxies were established and few were refined. Previous studies reveal that there are several proxies that can be effectively used only to the restricted geographic locations. Therefore, it has become essential to study modern distribution pattern of different microfaunal groups in different marine regimes on local and regional scales. In this context, marine sediments off the western Indian coast have received special attention of micropaleontologists and biologists since last two decades. Many of these investigations were focused on the distribution pattern of foraminifera in the near-shore and innershelf regions. Further, less attention has been paid to study other significant microfaunal groups than foraminifera such as pteropods.

In the present investigation, an attempt has been made to record modern distribution pattern of two important microfaunal groups (foraminifera and pteropods) constituting major portions of the biogenic components in sediments off southwest coast of India. Top samples of fourteen cores recovered systematically transect wise at closely spaced bathymetry across the shelf were used for the pattern study. Foraminiferal and pteropod assemblages were analysed both qualitatively and quantitatively. However, emphasis was given on the detailed investigations of benthic foraminiferal and pteropod assemblages. Planktic component of foraminiferal assemblages was examined only for estimating absolute abundance and recording benthic/planktic ratio.

4.1 SEDIMENT CHARACTERISTICS OF SURFICIAL SEDIMENTS

Textural characteristics of the surficial sediments across the shelf are presented in Figures 4.1 and 4.2. Based on the textural attributes, major sedimentary units were identified on the shelf viz. innershelf (<50m isobath), mid-shelf (50 - 115m isobath) and the outershelf (>115m isobath). The innershelf region is dominated by clayey-silt (clay 27- 61%, silt 37 -72 % and sand <1%). In the mid-shelf, wide expanse of sharply contrasting sediment composition rich in sand is noticed (sand 77 - 96%, silt 2 - 3 % and clay 5 - 18%). The steeper outershelf is abundant in clay with both silty clay and sand-silt-clay textural grades distributed over it (clay 39 - 62 %, silt 21 - 44% and sand 16 - 20%). Though the sediments in the mid-shelf are surmised as transgressive and still-stand Holocene sand sheet, it contains around 8 – 18 % mud (except shallow part) attributing to the modern process of sedimentation. Moreover, the deposits

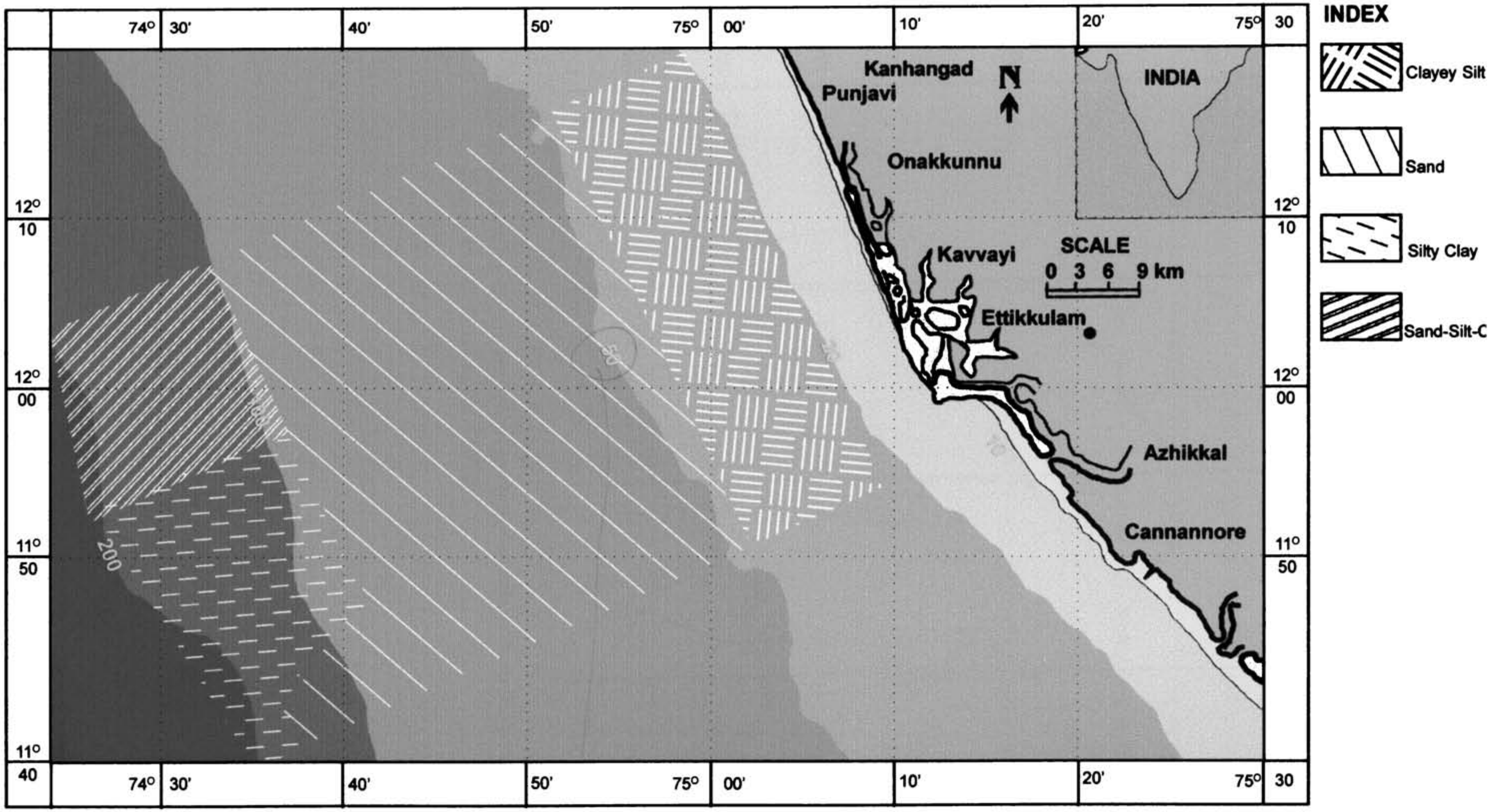

Fig. 4.1. Sediment distribution pattern in the study area

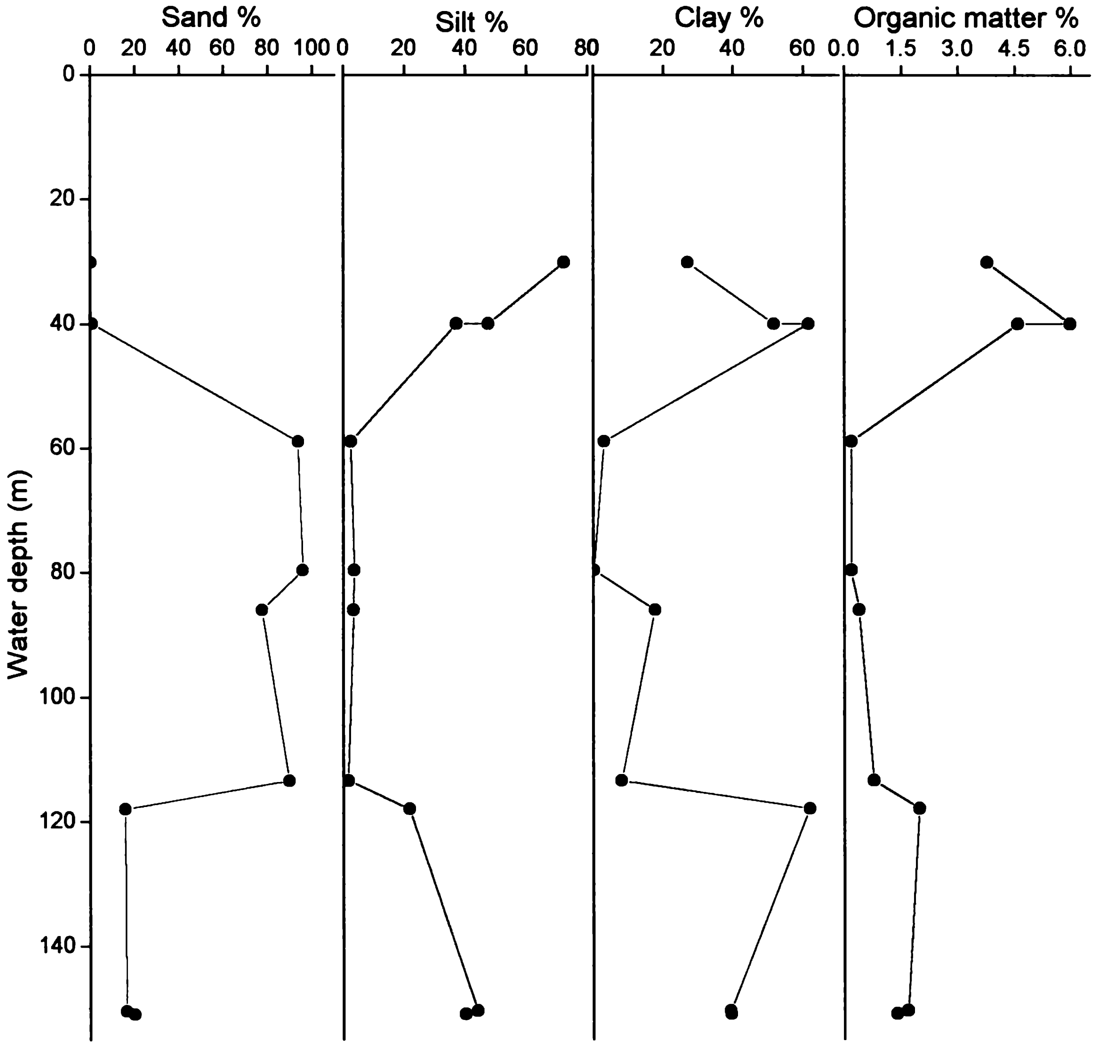

Fig. 4.2. Textural attributes and organic matter variation in surficial sediments across the shelf off north Kerala.

Keep scale uniform at least for first 3

in mid-shelf region are below the effective depth of wave erosion (Singh et al., 1998).

Modern physical and biological processes are the primary controlling factors on the diametric composition of organic matter (OM) in the surficial sediments. Sediment samples from the innershelf region are rich in OM (4 - 6%), whereas, mid-shelf sediments contain only <1% organic matter (Fig.4.2). Organic matter in the outershelf sediments has been estimated as 1.5 - 2% (Fig.4.2).

S

4. 2 BENTHIC FORAMINIFERAL ASSEMBLAGE

Qualitative analysis of benthic foraminiferal assemblages in the surficial sediment samples from the study area (across the shelf off north Kerala) enabled to record total fifty-five species (Table 4.1). Samples from shallow water (innershelf) yielded less than twelve species. A general increase in simple species diversity is recorded corresponding to increase in bathymetry with its maximum (40 species) in the sample from the outershelf (Fig.4.3). The absolute abundance of benthic foraminifera estimated in 1g of dry sediment (> 125 μm) varies between 460 and 16750. Within the innershelf and outershelf domains, a general increase in absolute abundance corresponding to increase in bathymetry is noticed with the exception of one sample from 50.7m W.D, showing minimum occurrence of benthic foraminiferal individuals. The mid-shelf is characterised broadly by low occurrence of benthic foraminifera without much variation with changing water depth. Maximum concentration of benthic foraminifera in the study area is recorded from the outershelf. The record of numerical foraminiferal

Table.4.1. A checklist of recorded benthic foraminifera in the surficial sediments of the continental shelf of north Kerala.

1. *Ammonia beccarii* (Linné)
2. *Ampestegina lessonii* d'Orbigny
3. *Ammonia tepida* (Cushman)
4. *Asterorotalia dentate* (Parker and Jones)
5. *Bolivina amygdalaeformis* Brady
6. *Bolivina oersiensis* Lutze
7. *Bolivina spathulata* (Williamson)
8. *Bolivina* sp.
9. *Bulimina marginata* d'Orbigny
10. *Cancris auriculus* (Fichtel and Moll)
11. *Cancris indicus* (Cushman)
12. *Cibicides refulgens* de Montfort
13. *Elphidium advenum* (Cushman)
14. *Elphidium cripsum* (Linné) Crispum
15. *Elphidium discoidale* (d'Orbigny)
16. *Hanzawaia mexicana* Lankford
17. *Lagena aspera* Reuss
18. *Lagena hispidula* Cushman
19. *Lagena striata* (d'Orbigny)
20. *Lagena striata* var. *strumosa*, Cushman
21. *Lamarckina scabra* (Brady)
22. *Lenticulina calcar* (Linné)
23. *Lenticulina gibba* (d'Orbigny)
24. *Lenticulina orbicularia* (d'Orbigny)
25. *Lenticulina* sp.
26. *Lenticulina thalmanni* (Hessland)
27. *Loxostomum limbatum* (Brady) var. *costulatum* Cushman
28. *Nonion commune* (d'Orbigny) is
29. *Nonion fabum* (Fichtel and Moll)
30. *Pyrgo depressa* d'Orbigny
31. *Quinqueloculina agglutinans* d'Orbigny
32. *Quinqueloculina echinata (d'Orbigny)*
33. *Quinqueloculina seminulum* (Linné)
34. *Quinqueloculina undulose costata* Terquem
35. *Reophax agglutinatus* Cushman
36. *Reussella simplex* (Cushman)
37. *Reussella spinulosa* (Reuss)
38. *Rotalidium annectens* (Parker and Jones)
39. *Siphouvigerina interrupta*(Brady)
40. *Siphouvigerina porrecta* (Brady)
41. *Spiroloculina communis* Cushman and Todd
42. *Spiroloculina exima* Cushman
43. *Spiroloculina* sp.
44. *Textularia agglutinans* d'Orbigny
45. *Textularia pseudocarinata* (Cushman)
46. *Trifarina aff. angulosa* (Williamson)
47. *Trifarina carinata* (Cushman)
48. *Triloculina costata* Brady
49. *Triloculina echinata* d'Orbigny
50. *Triloculina laevigata* d'Orbigny
51. *Triloculina oblonga* (Montagu)
52. *Triloculina tricarinata* d'Orbigny
53. *Trimosina milletti* Cushman
54. *Uvigerina auberiana* d'Orbigny
55. *Uvigerina peregrina* Cushman

Not recorded here →
Bolivina ordinaria
Brizalina aenariensis
Fursenkoina complanata
Geminospira brayi

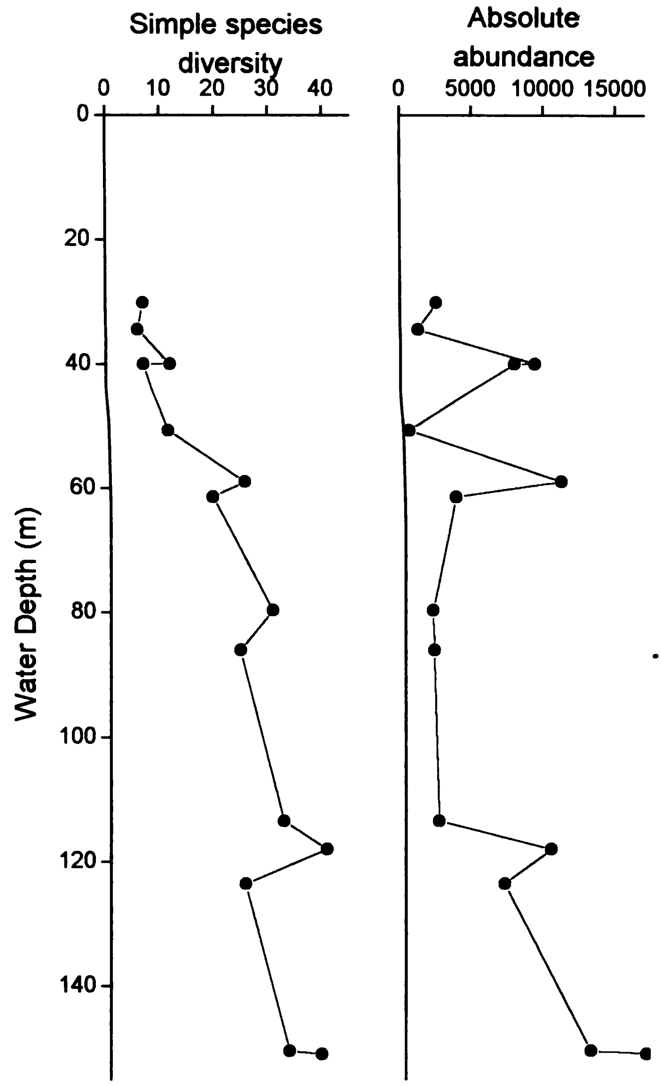

Fig.4.3. Simple species diversity and absolute abundance of benthic foraminifera in surficial sediments (in 1g of dry sediment).

abundance suggests that the richness of benthic population in surficial sediments is probably controlled by the nature of substrate in association with the nutrient content in sediments, bathymetric and other hydrographic conditions. Low occurrence of benthic foraminifera in mid-shelf appears to be attributed to sand substrate having low in-situ organic matter. On the other hand, muddy substrate (clayey and silty) with higher organic matter is favoured by the foraminifera. Similar observation on the relationship between substrate and benthic foraminifera was made previously by Boltoskoy and Wright (1976) and Setty and Nigam (1982). It is intriguing to note a bathymetric control on the variation of total number of benthic species (simple species diversity) in foraminiferal population from shallower to the deeper conditions across the shelf (Fig.4.3). This observation suggests that the diversity change in foraminiferal population is probably not dependent on the nature of substrate. The bottom water properties such as dissolved oxygen, salinity and temperature may be the probable factors controlling benthic foraminiferal diversity.

4. 3 BENTHIC FORAMINIFERAL BIOFACIES

R-mode cluster analysis was performed on the percentage abundance of 30 significant species in benthic foraminiferal population, which enabled to identify three distinct assemblages characterising different biofacies on the shelf off north Kerala (Table 4.2).

(i) Assemblage I – Outershelf (>115m W.D): Benthic foraminiferal assemblage from 115 to 150m W.D. is characterised by the dominance of agglutinated foraminifera such as *Reophax agglutinatus*, Table.4.2. Summary of benthic foraminiferal assemblages recognised across the shelf off north Kerala

Code	Assemblage	Water Depth (m)	Benthic Simple Species Diversity	Characteristic benthic foraminifera
I	Outershelf	>115m	25-40	*Reophax ag~~gl~~utina~~ns~~, Quinqueloculina agglutinans, Textularia agglutinans, Uvigerina peregrina*
II	Mid-shelf	115-50m	11-32	*Hanzawaia mexicana, Lenticulina calcar, Triloculina tricarinata, Triloculina laevigata, Quinqueloculina seminulum*
III	Innershelf	<50m	6-12	*Ammonia beccarii, Ammonia tepida, Rotalidium annectens, Asterorotalia dentate, Elphidium discoidale*

natus

Quinqueloculina agglutinans and *Textularia agglutinans*. Another distinct feature of this assemblage is the presence of *Uvigerina peregrina*, which is totally absent in shallow water (inner- and mid-shelf) assemblages. Benthic foraminiferal population in outershelf regime is distinguished by high simple diversity varying between 25 and 40.

(ii) Assemblage II – Mid-shelf (115 - 50m W.D): In surficial sediments between 50 to 115m isobath, the foraminiferal population is distinguished by the dominance of *Hanzawaia mexicana* and *Lenticulina calcar* accompanied by miliolids (*Triloculina tricarinata*, *T. laevigata*, *Quinqueloculina seminulum* and *Spiroloculina* sp.). The significant occurrence of other species mainly in shallower part of the mid-shelf (*Bolivina persiensis*, *Bulimina marginata*, *Rotalidium annectens*, *Ammonia beccarii*, *A. tepida*, *Cibicides refulgens*, and *Elphidium discoidale*) suggests that this assemblage can be subdivided. Total number of benthic foraminifera in mid-shelf assemblages varies between 11 and 32.

(iii) Assemblage III – Innershelf (<50m W.D.): The characteristic of the innershelf benthic foraminiferal assemblage is the abundance occurrence of *Ammonia beccarii* s.l. (*Rotalidium annectens*, *Ammonia beccarii*, A. *tepida and Asterorotalia dentate*) and *Elphidium discoidale*. Low benthic foraminiferal simple diversity (6-12) in foraminiferal population is another distinct feature of these assemblages from the shallow regions.

4. 4 BATHYMETRIC DISTRIBUTION PATTERN OF IMPORTANT BENTHIC FORAMINIFERA

Modern benthic foraminiferal assemblages recorded from the study area comprise mainly of elphidiids, rotaliids, cibicidids, nonionids, bolivinids, miliolids, uvigerinids, lagenids and agglutinated taxa (Reophax *agglutinatus*, *Textularia agglutinans* and *Quinqueloculina agglutinans*) (Table 4.3). Surficial distribution pattern of significant foraminifera of these faunal groups are briefly discussed below.

ROTALIIDS AND ELPHIDIIDS: Rotaliid population is represented primarily by *Rotalidium annectens*, *Ammonia beccarii*, *A. tepida* and *Asterorotalia dentate* (Fig.4.4). Maximum occurrence of each of these species is noted in the innershelf samples (<50m W.D.). In general, *R.annectens* dominates the rotaliid population. Murray (1991) considered *annectens*, *beccarii*, *tepida* and *dentate* together as *Ammonia beccarii* s.l. In mid-shelf to the outershelf samples, rotaliids are not so significant in foraminiferal population. It is noticeable that muddy sediments of innershelf are rich in organic matter (4 - 6%). The present observation indicates a positive correlation between *Ammonia beccarii* s.l. abundance and the organic matter, which is in good agreement with the view of Setty and Nigam (1982). *Ammonia* - *Asterorotalia* association has been considered as one of the major contributors of the foraminiferal assemblages from the shore to 55m W.D. (Murray, 1991). Abundance of *Ammonia* in foraminiferal assemblage indicates hyposaline condition (Setty, 19~~8~~74). Walton

X In fig 4.4 R annectens % occurrence [illegible]

Table.4.3. A checklist of common benthic foraminiferal species in surficial sediments

The Rotaliids and Elphidiids (epifauna and infauna)
Rotalidium annectens
Ammonia beccarii
Ammonia tepida
Asterorotalia dentate
Elphidium discoidale

The Cibicidids (mainly epifauna)
Cibicidis refulgens

The Nonionids (mainly infauna)
Nonion fabum
Nonion communis

The Bolivinds and Uvigerinids (mainly infauna)
Bolivina persiensis
Bolivina amygadalaeformis
Bolivina sp.
Bulimina marginata
Uvigerina peregrina

The Miliolids (mainly epifauna)
Quinqueloculina seminulum
Spiroloculina cummunis
Spiroloculina sp.
Triloculina tricarinata
Triloculina laevigata

The Lagenids (mainly infauna)
Lagena aspera
Lagena hispidula
Lagena striata
Lagena straita var. *strumosa*

The agglutinated forms (mainly epifauna)
Reophax agglutinatus
Textularia agglutinans
Quinqueloculina agglutinans

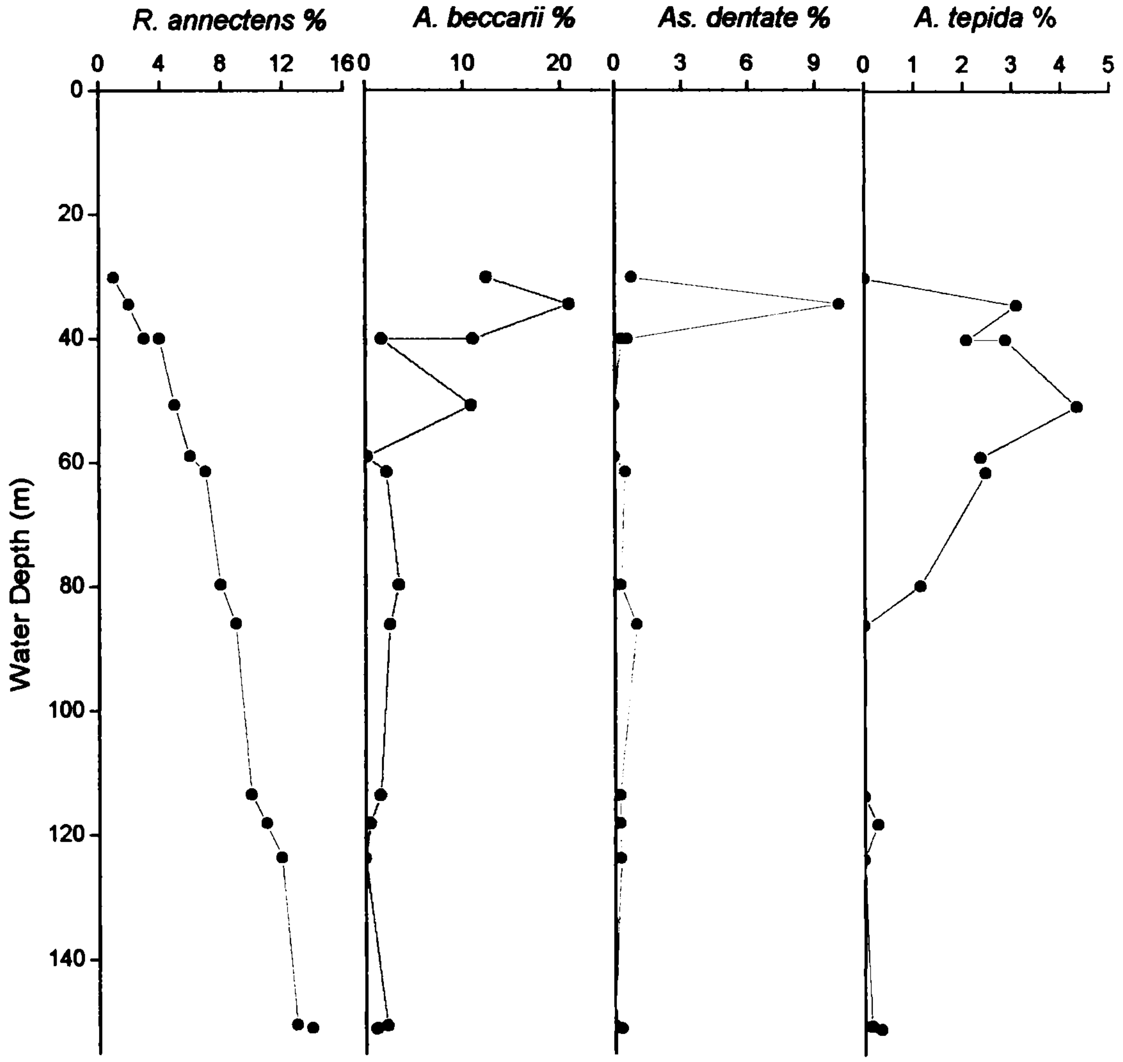

Fig.4.4. Percentage frequency of ***Rotalidium annectens***, ***Ammonia beccarii***, ***Asterorotalia dentate*** and ***Ammonia tepida*** in surficial sdiments.

Scale must be same for comparison

(1964) suggested environment with periodic hyposalinity variation as favourable condition for this fauna. The maximum occurrence of *Ammonia beccarii* s.l. in the shallow samples appears to be attributed to the high nutrient in the sediment as well as variable hydrographic condition (mainly salinity) associated with the fluvial discharge during monsoon seasons.

Another important contributor of rotaliid population is the genus *Elphidium*. *Elphidium* is considered as indicator of brackish-hyposaline condition (Murray, 1991). In the study area *Elphidium discoidale*, a non-keeled infaunal taxon dominates the elphidiid population. This species occurs with its maximum abundance in the innershelf (Fig.4.5). It is conspicuously absent in the mid-shelf and appears again in the outershelf samples. As both the innershelf and outershelf sediments are characterised by clayey and silty-clay textures respectively, abundance of *discoidale* appears to be associated with the substrate. A preference for non-keeled *Elphidium* to the muddy-sand substrate has been observed previously by Nigam (1987) and Murray (1991).

NONIONIDS: This group is represented mainly by *Nonion fabum* and *Nonion communis*. Both the ~~taxa~~ species show their maximum concentration in the innershelf region (Fig.4.5). Across the shelf, both the species show a general decreasing trend in their abundance with increase in water depth (Fig.4.5). The genus *Nonion* is known to occur in wide range of environmental conditions from hyposaline to normal marine environment (Murray, 1991). The highest concentration of *Nonion* in the innershelf region having predominance of muddy

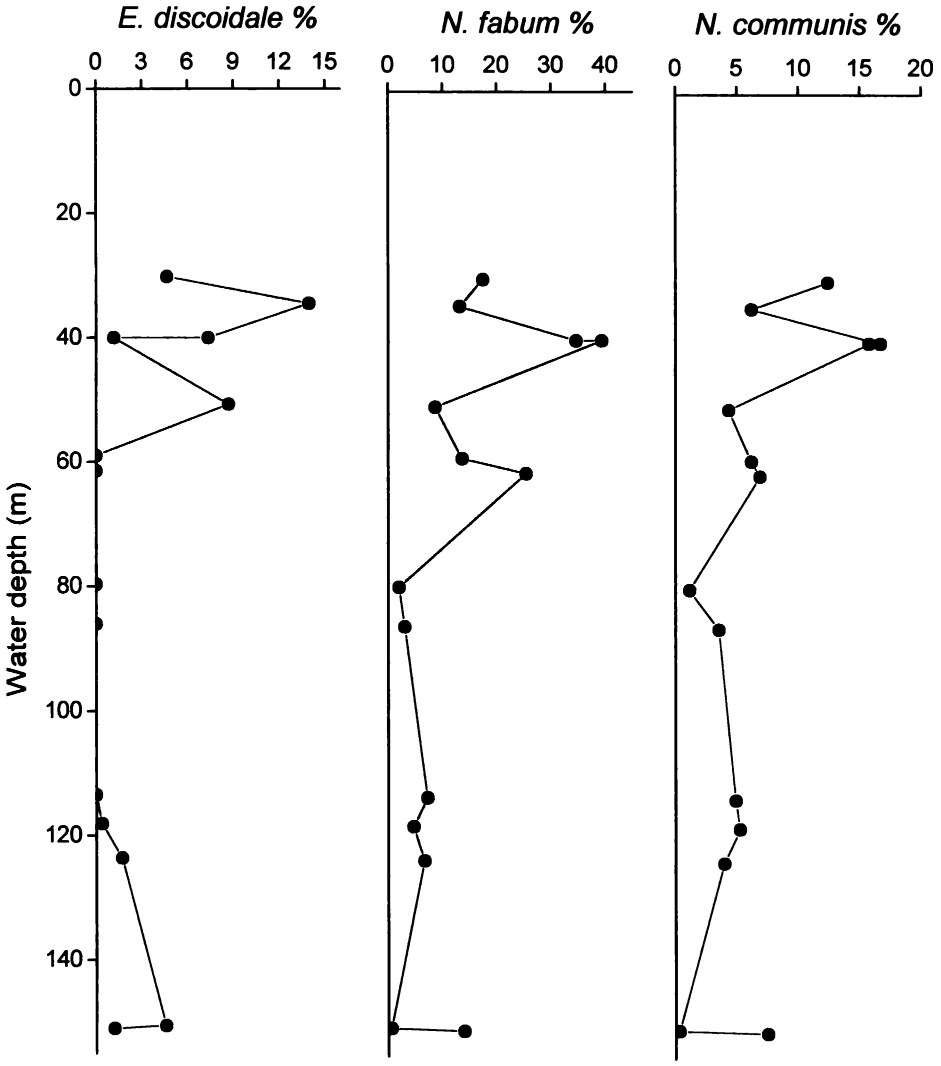

Fig.4.5. Percentage frequency of *Elphidium discoidale*, *Nonion fabum* and *Nonion cummunis* in surficial sediments.

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sediments containing high organic matter suggests its relationship with the nature of substrate. Nigam (1987) and Murray (1991) also observed a muddy or silty substrate preference for the genus *Nonion*.

BOLIVINIDS AND UVIGERINIDS: *Bolivinid* group in foraminiferal assemblages from the study area is constituted by the genera *Bolivina*, *Bulimina* and *Reussella*. *Bolivina persiensis* predominates the *Bolivina* population. This species shows its maximum concentration (11-13%) in the shallower part of the mid-shelf (60-70m W.D.) (Fig.4.6). The innershelf and deeper part of the mid-shelf are conspicuously devoid of *Bolivina*. In the outershelf samples, relative abundance of *Bolivina* spp. varies between 4.5 and 1 percent from shallower to the deeper conditions. According to Murray (1991) the genus *Bolivina* is associated with the muddy substrate. Nigam (1987) reported a prominent occurrence of *Bolivina* in association with *Nonion* in coarse substrate with low organic carbon content from the innershelf regime of the central west coast of India. Its absence in innershelf clayey sediments of the study area probably suggests that this genus does not prefer fine substrate and an environmental condition with seasonal salinity fluctuations. *Bulimina marginata* is the second most significant species of the *Bolivinid* population. Similar to the *Bolivina persiensis*, this species occurs with its maximum abundance in shallow mid-shelf region (~9 %) (Fig.4.6). A rare occurrence of *Bulimina marginata* is recorded from the innershelf and deep mid-shelf areas. Further, it shows an increase in abundance in the outershelf (~6%). A similarity in bathymetric distribution pattern of *Bolivina* and *Bulimina* suggests a close associationship between them as far as their ecological preferences are

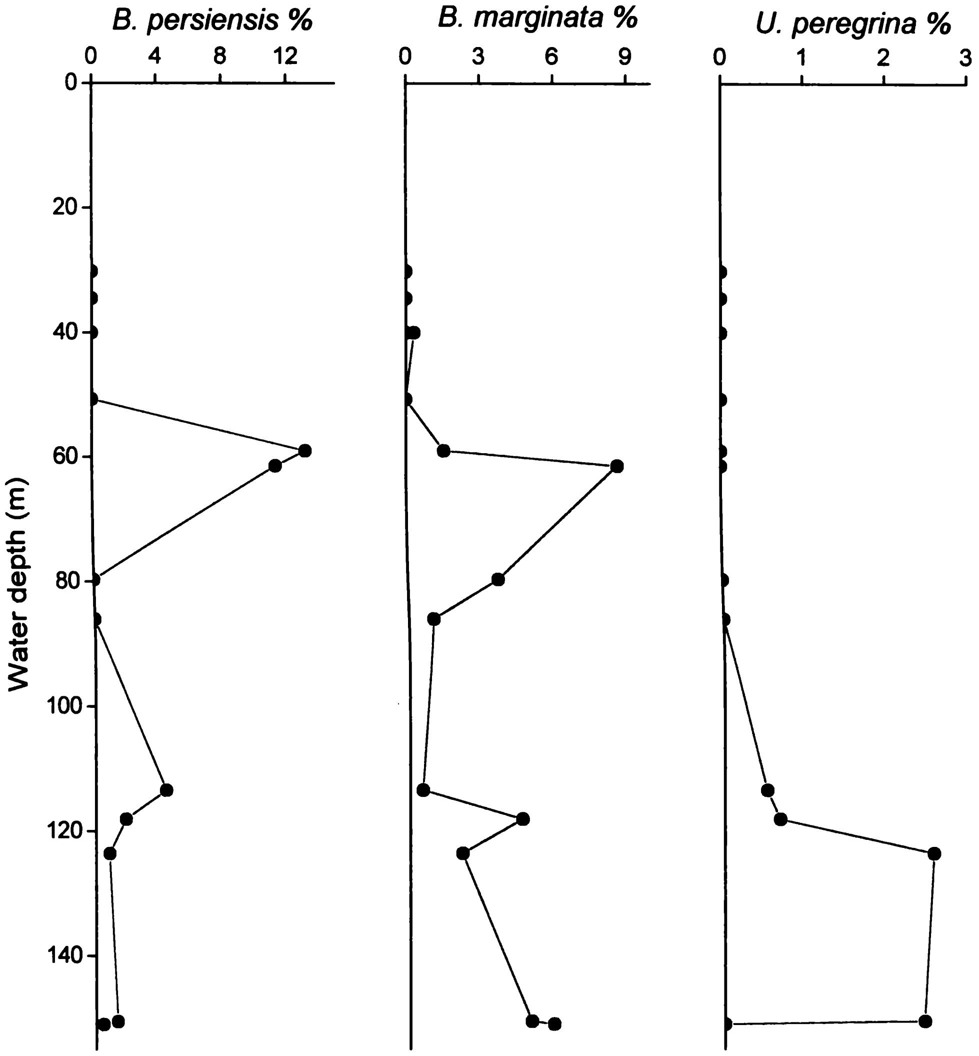

Fig.4.6. Percentage frequency of *Bolivina persiensis, Bulimina marginata* and *Uvigerina peregrina* in surficial sediments

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concerned. Both *Bulimina* and *Bolivina* together may be considered as characteristic association of shallow mid-shelf condition in the study area. A significant occurrence of *Bulimina* in association with *Nonionella* has been recorded from the deeper part of the innershelf of the central west coast of India (Nigam, 1987). According to Murray (1991), *Bulimina* prefers muddy sand substrate.

UVIGERINIDS: *Uvigerina peregrina* is an important taxon of the uvigerinid population. *Uvigerina* is a genus that is known to prefer muddy substrate and marine environment (Murray 1991). In the study area, this species is present only in the outershelf samples. It is noticeable that the outershelf sediments are relatively richer in fine (clay-silt) sediments with higher organic matter. Its absence in the innershelf region probably suggests its preference ~~with~~ for muddy substrate and normal marine condition but not the hyposaline condition.

MILIOLIDS: Miliolid population in foraminiferal assemblage is mainly constituted by the genera *Quinqueloculina*, *Triloculina*, and *Spiroloculina*. The main contributor of *Quinqueloculina* population is the species *Quinqueloculina seminulum*. Genus *Spiroloculina* is represented by *Spiroloculina cummunis, Spiroloculina sp.*, and *S.exima* and *T. tricarinata* and *T. laevigata* are the main constituents of the genus *Triloculina* (Fig.4.7). Noticeably, innershelf sediments are devoid of the miliolid fauna. The maximum concentration of miliolids is recorded from the mid-shelf region characterised by a coarse, sandy substrate with low organic matter. Foraminiferal assemblages from the outershelf region also consist these miliolid taxa but comparatively very low than of the mid-shelf.

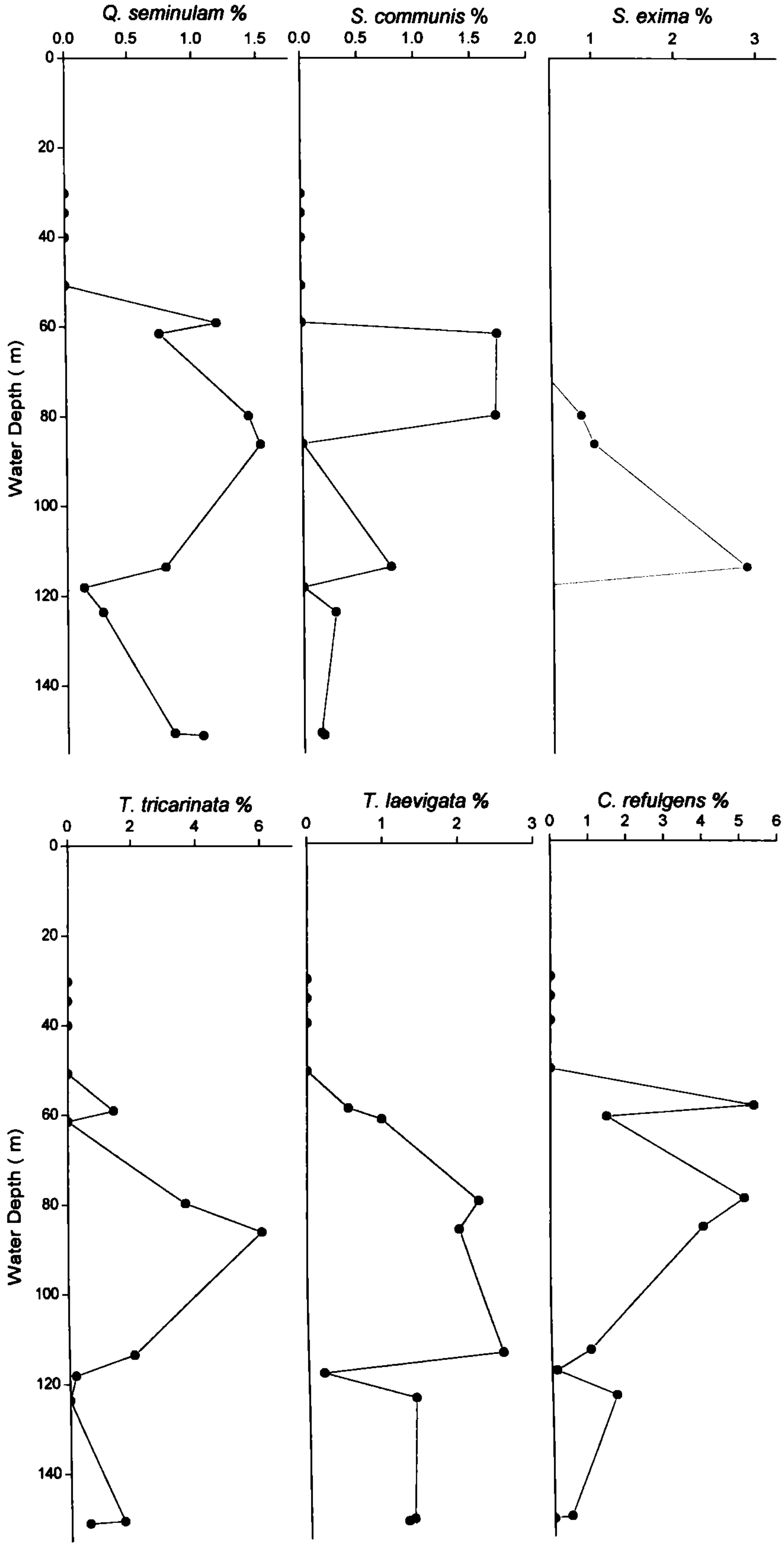

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Fig.4.7. Percentage frequency of *Quinqueloculina seminulum*, *Spiroloculina communis*, *Spiroloculina exima*, *Triloculina tricarinata*, *Triloculina laevigata* and *Cibicides refulgens* in surficial sediments.

The pattern of relative abundance of these taxa shows a similar trend across the shelf (Fig.4.7). Genera *Quinqueloculina*, *Triloculina* and *Spiroloculina* are epifaunal forms, free or clinging in marine hypersaline environment (Murray 1991). Present observation also suggests that these miliolid fauna prefers coarse substrate with low organic matter and high salinity.

AGGLUTINATED FORAMINIFERA: The agglutinated benthic foraminiferal population is mainly constituted by *Textularia agglutinans, Quinqueloculina agglutinans and Reophax agglutinatus* (in decreasing order of their abundance) (Fig.4.8). These agglutinated forms are absent in the samples from the innershelf region. Mid-shelf samples consist of a few individuals of these taxa. The maximum concentration of these agglutinated taxa is recorded from the outershelf region (25 % to 36%).

1.1

Although, a lot of work has been done on the ecological significance of agglutinated faunas, but still it remains a matter of debate. It is interesting to record here that the outershelf sea bottom/sediment samples with >125m W.D. lie under deficient bottom water (Table.2.1.)) Dissolved oxygen in bottom water becomes anaerobic: 0-0.1 ml $l^{-1}O_2$ in deeper areas with >100m W.D.). An increase in organic matter in the fine-grained sediments (silt and clay) can be attributed to the anaerobic condition or/ and high productivity. The increased organic matter in oxygen deficient water may produce corrosive pore-water in muddy sediments. Under this condition, organic-cemented agglutinated foraminifera will occur (Murray, 1991). As no dissolution is noticed on the

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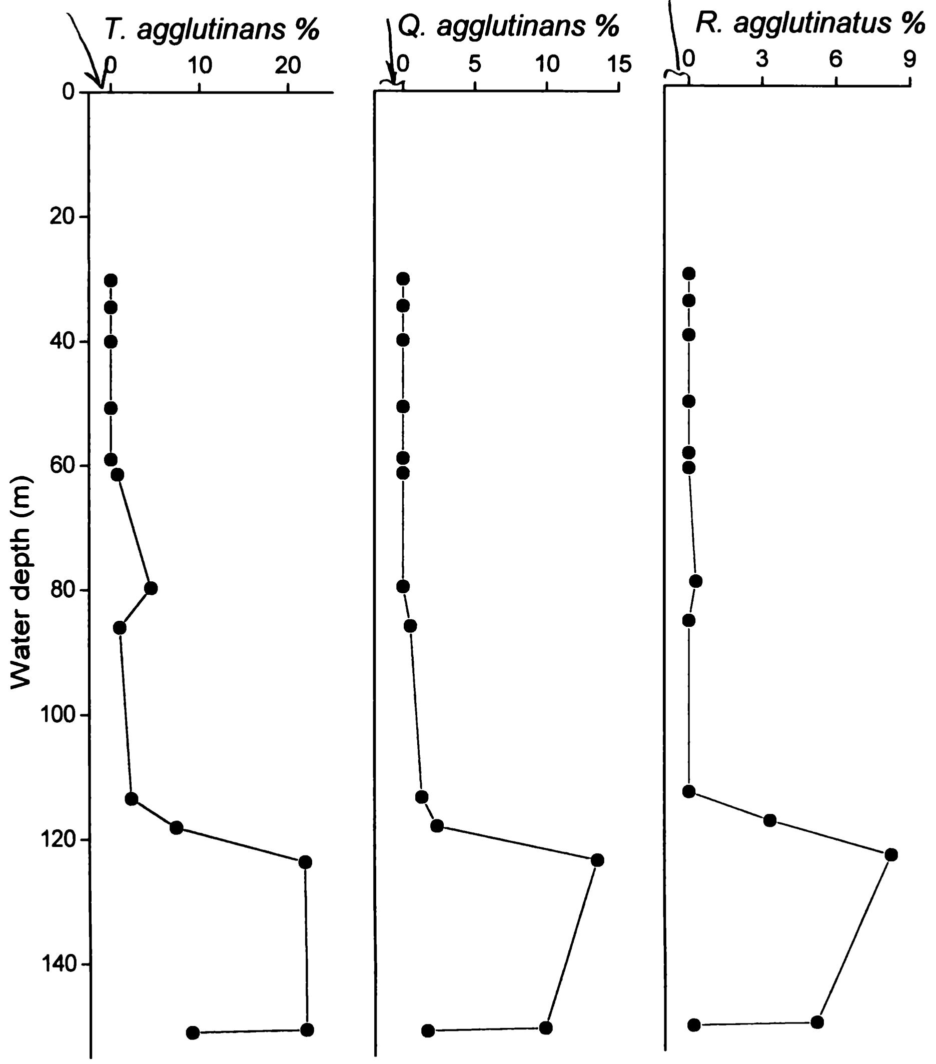

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Fig.4.8. Percentage frequency of *Textularia agglutinans, Quinqueloculina agglutinans* and *Reophax agglutinatus* in surficial sediments.

calcareous test recovered from these samples, considering agglutinated fauna, as indicative of such condition should be further tested.

CIBICIDID: Cibicidid population is represented by single species - *Cibicides refulgens*. This species is absent in the innershelf sediments. Its maximum occurrence (~5%) is recorded from the shallower part of the mid-shelf (Fig.4.7). A general decrease in its relative abundance is recorded with increase in bathymetry, across the mid- outershelf. It has similar pattern of bathymetric distribution like miliolids. *Cibicides* is sessile, epifaunal genus, preferring a hard substrate in marine environment (Murray, 1991).

4 .5 PTEROPOD ASSEMBLAGE S

Previous studies on the modern pteropods of the Arabian Sea, the Red Sea and the Mediterranean Sea suggest that their distribution is controlled by the hydrographic, oceanographic and climatic conditions (Herman and Rosenberg, 1969; Herman, 1971; and Weikert, 1982, 1987; Auras-Schudnagies et al., 1989; Singh and Rajarama, 1997). Therefore, pteropods can also be a proxy for paleoclimatic and paleoceanographic interpretations. The potentiality of pteropods in deciphering past changes is limited to the Quaternary sedimentary records from the tropical shallow and marginal seas where they are well preserved. In the shelf sediments of southwest coast of India, pteropods constitute one of the main carbonate components. In the present investigation, pteropod assemblages were analysed qualitatively as well as quantitatively in core-top samples from the shelf off north Kerala in order to record the distribution pattern of various species with changing water depth.

The pteropod assemblages in the surficial sediments are characterised by low diversity. In all, fourteen species were identified (Chapter 3). The assemblage comprises of both the epipelagic and mesopelagic taxa. Except *Limacina inflata*, *L. bulimoides* and *Clio convexa* (mesoplelagic - migrators), other recorded species are regarded as epipelagic non-migrator (Almogi-Labin et al. 1991).

4. 6 BATHYMETRIC DISTRIBUTION PATTERN OF IMPORTANT PTEROPODS

Based on the pattern of bathymetric distribution of pteropod species, three distinct assemblages can be recognised: Assemblage 1 (characteristic of innershelf) comprises of single species *C.acicula*; Assemblage 2 (characteristic of mid-shelf) mainly composed of *L.inflata*, *C.chierchiae*, *C.virgula* and *L.trochiformis* (in decreasing order of abundance) and Assemblage 3 (characteristic of outershelf) mainly composed of *L.inflata*, *L.trochiformis*, *C.virgula*, and *C.chierchiae* (in decreasing order of abundance). Other species encountered do not show significant variation in their abundance with change in the bathymetry.

From 40 to 150m depths, a decreasing trend in relative abundance of *Creseis* (*acicula*, *chierchiae* and *virgula*) and increasing trend in *L.inflata* is recorded (Fig.4.9). *L.trochiformis* does not show any definite trend with changing water depth. This observation suggests that *Creseis* spp. (*acicula*, *chierchiae* and *virgula*) and *L.inflata* are highly sensitive to change in bathymetric condition. Hence, the distribution pattern of *Creseis* spp. (epipelagic) and *L.inflata* (mesopelagic) recorded in the surficial sediments of the study area is water depth

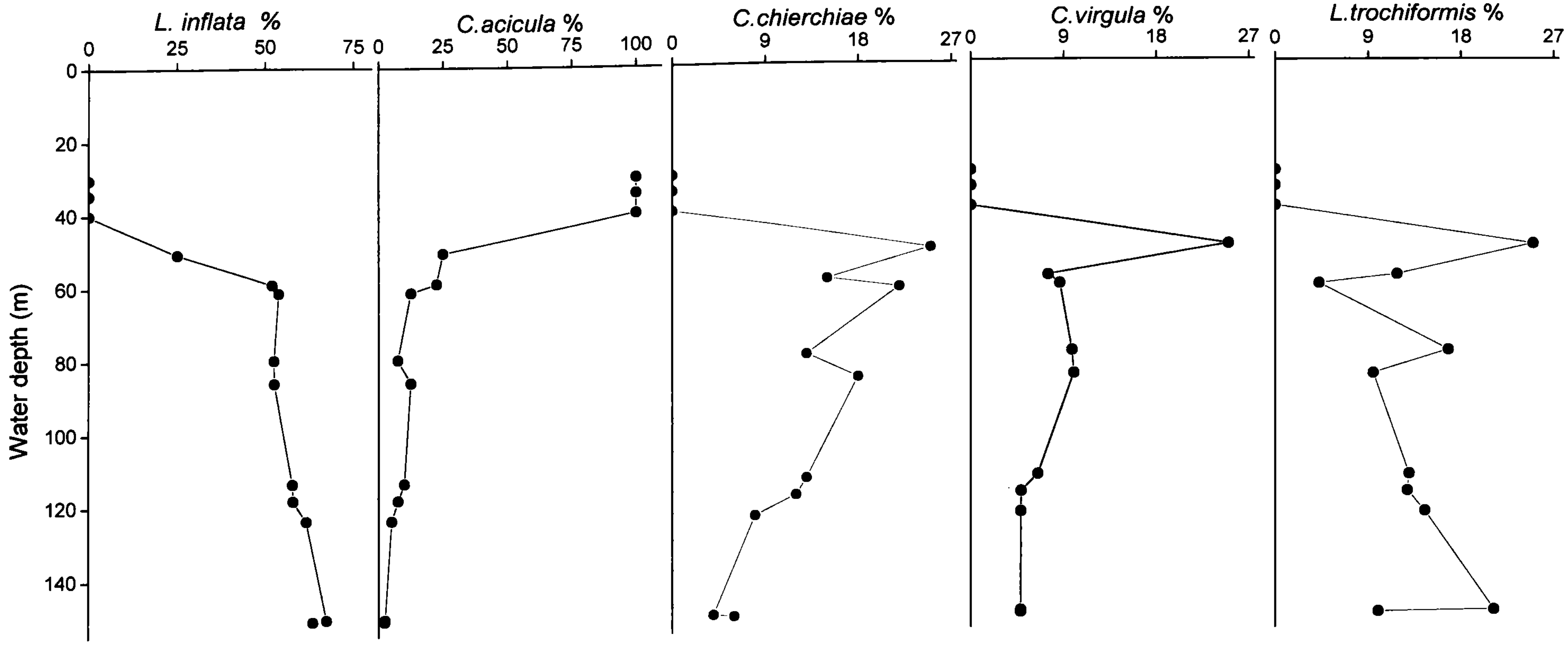

Fig.4.9. Percentage frequency of *Limacina inflata, Limacina trochiformis, Creseis acicula, Creseis chierchiae and Creseis virgula* in surficial sediments.

dependent. Therefore, they can be considered as potential bathymetric indicators, useful for inferring the paleobathymetry from the core sections. Considering previous observation on 'similarity in living and surface sediment assemblages' from elsewhere (Weikert, 1982, 1987; Almogi-Labin, 1984) is also valid to the present study area, it is presumed that bathymetric distribution of pteropods in the surficial sediments reflects its living counterpart. Moreover, relatively larger size of pteropod tests helps in their deposition close to the natural habitat (Herman and Rosenberg, 1969).

4.7 *LIMACINA INFLATA* AND *CRESEIS* SPP. AS DEPTH INDICATOR

The idea of 'pteropods as bathymetric indicator' was suggested by Herman and Rosenberg (1969) based on their preliminary study on the recent sediments of northwestern continental shelf of India. But the efficacy of pteropods in paleobathymetric reconstruction had not been validated until recently. Singh et al. (2001) observed a well-defined relationship between the *L.inflata* and *Creseis* spp. abundance and water depth for the region. An attempt was made to document the relationship between quantitative variation in modern depth sensitive pteropods (*L.inflata* and *Creseis* spp.) and water depth (Fig.4.10). For this purpose, *L.inflata*/ *Creseis* spp. ratio vs known water depth was plotted and polynomial curve fitting of second order was performed on the data set (Fig.4.11). This model shows a definite correlation between the changes of abundance ratio of *L.inflata*/ *Creseis* spp. to the bathymetric variation. Thus, the modern data on depth-species relationship derived here can be employed to the fossil record with confidence.

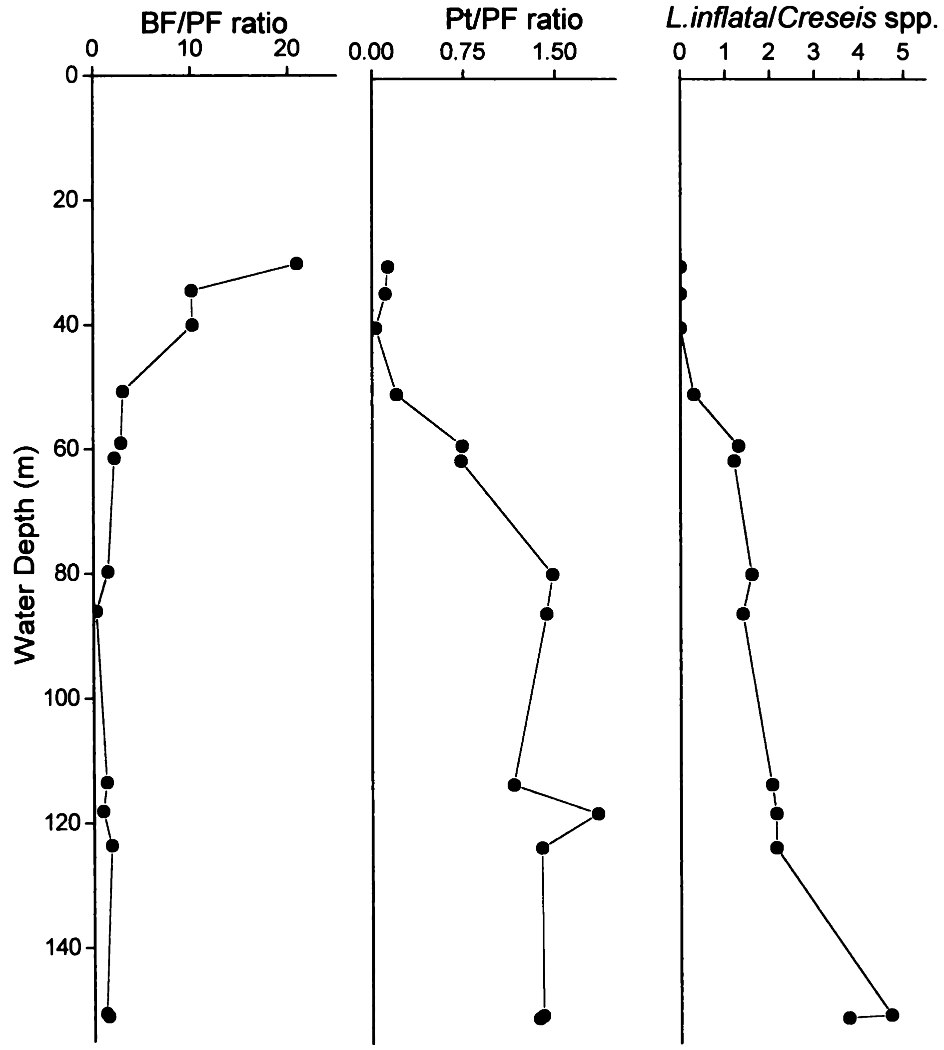

Fig.4.10. Bathymetric distribution of benthic/planktic foraminifera (BF/PF), pteropods/planktic foraminifera (Pt/PF)and *L.inflata/Creseis* spp. (in 1g of dry sediment).

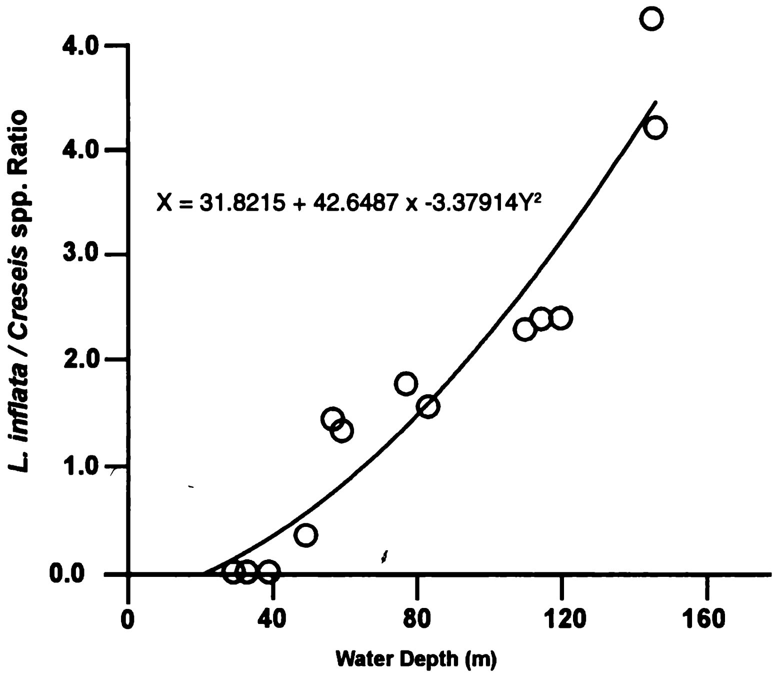

Fig. 4.11. Proposed model showing relationship between *Limacina inflata / Creseis* spp. ratio and water depth

4.8 BENTHIC / PLANKTIC FORAMINIFERA (BF/PF) AND PTEROPODS / PLANKTIC FORAMINIFERA (Pt/PF) RATIO

Distribution pattern of absolute abundance of foraminifera in the surficial sediments of the study area reveals an increase in planktic percentage with bathymetry. This observation is documented in terms of benthic/planktic foraminifera (BF/PF) abundance ratio (Fig.4.10). The study suggests a depth control on the variation of benthic/planktic foraminifera (BF/PF) ratio. However, the response of BF/PF abundance ratio to changing water depth is higher between 30m and 80m as evident by gradual decrease in ratio from 21.0 to 1.5. No prominent variation in BF/PF ratio is noticed in sample coming from deeper water than 80m. Abundance ratio of two major pelagic components (pteropods and planktic foraminifera) of the assemblages is also found to be depth controlled (Fig.4.10). Depth-distribution curves of Pt/PF (pteropods/planktic foraminifera) and BF/PF ratios show opposite trend with an abundance increase in former with distance from the shore. Hence, BF/PF and Pt/PF ratios can also be considered as proxies for paleobathymetric determinations.

The potentiality of BF/PF ratio in paleo-depth estimation has already been established by previous workers (Bandy, 1956; Stehli and Creath, 1964; Kafescioglu, 1975; Murray, 1976; Aoshima, 1978; Van Marle, 1998; Nigam and Henriques, 1992). However, the present data reveal that the response of benthic/planktic foraminifera abundance ratio to changing water depth was more sensitive at <80m water depths. Previous studies carried out on the modern pteropods (aragonitic) and planktic foraminifera (calcitic) in deep sea sediments of the Atlantic Ocean, the Mediterranean Sea and the Red Sea suggest Pt/PF as a proxy for the degree of aragonite Vs calcite preservation (Berner, 1977; Almogi-Labin et al., 1986). Therefore, the applicability of BF/PF and Pt/PF ratios in paleodepth estimation appears to be largely limited to shelf regimes.

Chapter 5

CHRONOSTRATIGRAPHY

Quaternary marine sedimentation of continental shelves was controlled mostly by changes in sea level, climatic fluctuations, sediment supply and rate of subsidence. The combined effects of regional tectonics and eustasy determine the accommodation potential for the sediments and the distribution of facies within the genetically related packages. The rate of relative rise and fall in sea level determines the formation of type of sequence. Rising of sea level results in transgression or landward migration of the shoreline. On the other hand, seaward migration of shoreline or regression is a result of sea level fall. The varieties of substrate that have existed on the shelf at different Quaternary sea levels furnish backgrounds against which different types of coastal development can be evaluated. Stratigraphy is the integrated effect of topographic change through time in depositional environments. Stratigraphic sequences therefore become a partial record of evolution (Vail et al., 1977). For better reconstruction of Quaternary environments, a precise chronological framework is important. The main objective of stratigraphy is to place a succession of events in chronological order for precise correlation. It is customary to identify and employ multiple stratigraphic criteria in order to maximise precision. The most readily available method for stratigraphic subdivisions of sediment core sections is through biostratigraphy i.e., the biologic events, integrated with radiochronology, oxygen isotope record and magnetostratigraphy. The depositional sequence (lithostratigraphy) of the sections also helps in positioning of stratigraphic boundaries within a sequence-stratigraphic framework. The subsurface sedimentary sequences from the continental shelves associated primarily with the transgressive/regressive sea level cycles, are dated through their paleontologic and physical/stratigraphic relationships in order to have chronostratigraphic scheme for the area under investigation. Depositional sequences are first identified in lithostratigraphic sections and tied to a time-scale through their biostratigraphic relationship and radiochronology to establish their accurate chronostratigraphy.

In the present study an integrated approach has been adopted to make subdivisions of the examined core sections employing stable oxygen isotope, microfaunal and lithological criteria combined with the radiocarbon dates.

5.1 STABLE OXYGEN ISOTOPE STRATIGRAPHY

Oxygen isotope variation depicting global climatic events is increasingly used for establishing chronostratigraphic framework and correlation. Core S1 (W.D. 151m) and S10 (W.D. 150.5m) were chosen for oxygen isotope study as only these two among all the examined cores provide complete record of the last glacial and Holocene changes.

The oxygen isotope composition of surface water planktic foraminifera *G.ruber* was measured from every 10cm interval of cores S1 and S10 (Figs. 5.1 & 5.2). Downcore variation in the oxygen isotope composition reflects primarily variation in the ice volume and global climate. The changes in local factors, such as evaporation-precipitation pattern and continental runoff also affect the isotopic

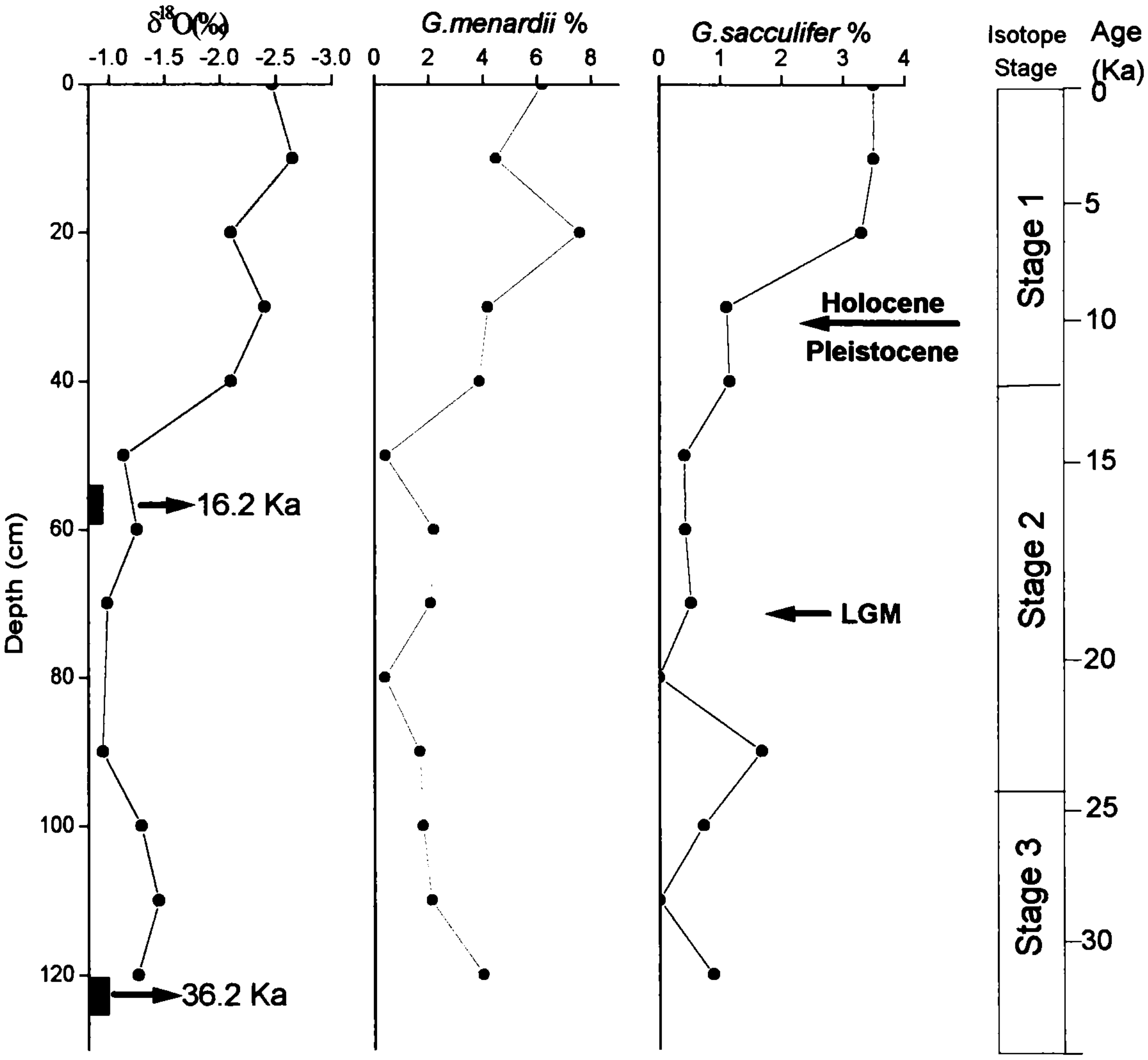

Fig. 5.1. Stable Oxygen isotopic composition of *Globigerinoides ruber*, percentage frequency of *Globorotalia menardii*, *Globigerinoides sacculifer* plotted against depth in core S1. Isotope stage boundaries and estimated ages are given to the right. The last glacial maximum (LGM) and Holocene / Pleistocene boundary are indicated.

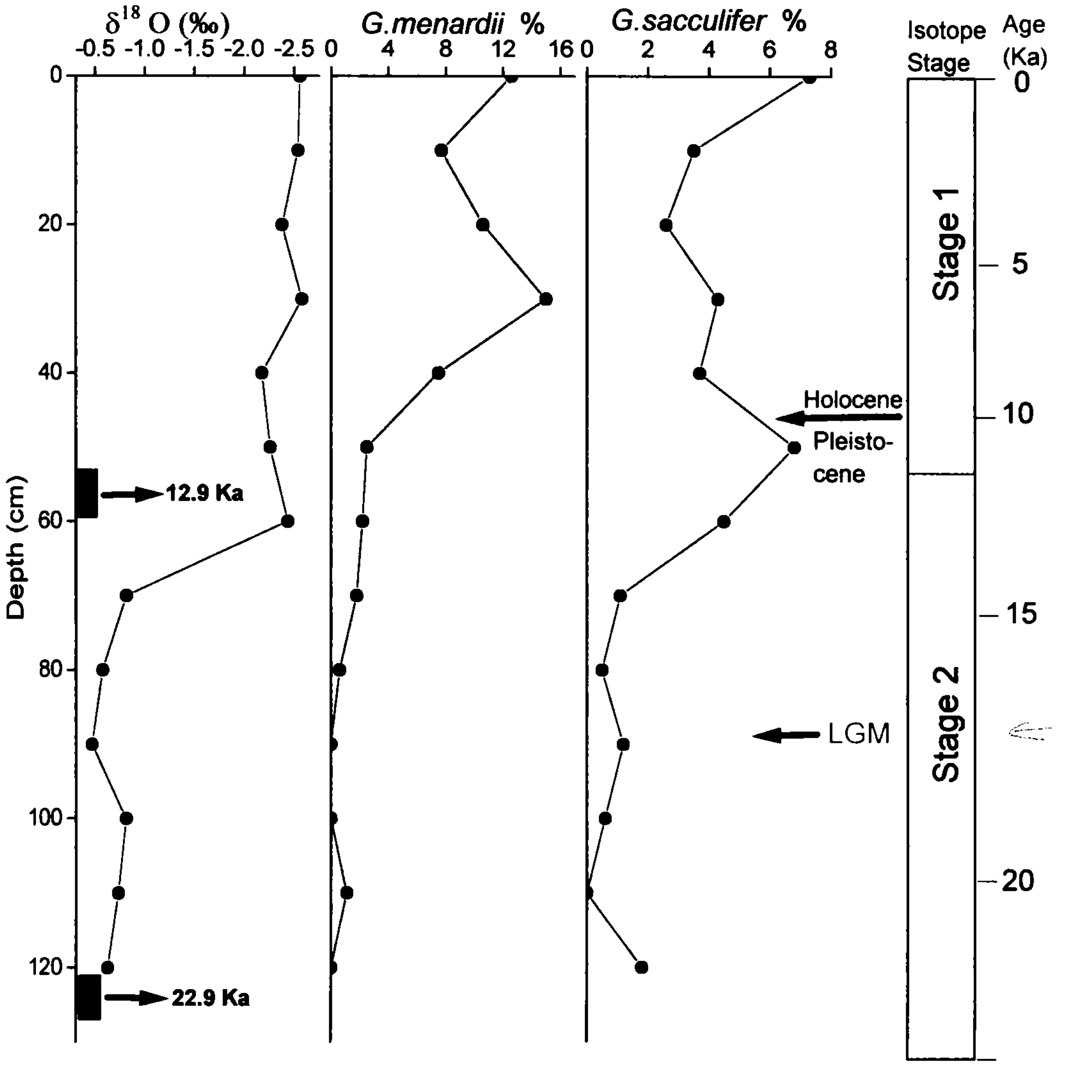

Fig.5.2. Stable Oxygen isotope composition of *Globigerinoides ruber*,percentage frequency of *Globorotalia menardii*, *Globigerinoides sacculifer* plotted *against depth in core S10. Isotope Stage boundaries and estimated ages* are given to the right. The last glacial maximum (LGM) and Holocene / Pleistocene boundary are indicated.

composition particularly of surface water planktic foraminifera. The sites of the cores S1 and S10 are 78 Km and 74 Km away respectively, from the coast and the area under investigation receives relatively less fresh water from the land as no major continental runoff to the sea. Therefore, salinity variation of surface water due to seasonal fresh water discharge is limited to the innershelf areas. Moreover, the isotope records of the examined cores for the glacial - Holocene period show good correspondence with the data presented by Duplessy (1982) for locations in close proximity to the core sites. The Holocene period is marked by the $\delta^{18}O$ mean value as -2.34 ‰ in core S1 and –2.42 ‰ in core S10. The general trends of both the records are similar except a slightly high glacial $\delta^{18}O$ mean value in core S1.

Isotope stratigraphy for these two core sections was established by correlating $\delta^{18}O$ records (*G.ruber*) with the time scale of Martinson et al. (1987). The oxygen isotope records reflect that core S1 goes upto interglacial Stage 3 and core S10 spans complete last glacial (Stage 2) and Holocene periods. In core S1, Stage 1/ Stage 2 (12 Ka) boundary is marked at 40cm core depth and Stage 2/ Stage 3 (24 Ka) boundary is demarcated at 92cm. Stage 1 / Stage2 boundary in core S10 is delineated at 52cm core depth. The Last Glacial Maximum (LGM: ~ 18 Ka) was identified by the youngest $\delta^{18}O$ maximum in the isotope records. The LGM in core S1 lies at 70cm core depth and in core S10 at 90cm. → The [illegible]

5.2 RADIOCHRONOLOGY

The isotope stage boundaries and position of Last Glacial Maximum demarcated in cores S1 and S10 using stable oxygen data were confirmed by the radiocarbon dates obtained from two depth intervals of each core. In core S1 ^{14}C dates for 55cm to 60cm and 120 to 130 cm depth intervals were measured as 16.2 Ka and 36.2 Ka respectively. Radiocarbon ages for 50 to 60cm and 120 to 130cm depth intervals in core S10 were estimated as 12.9 Ka and 22.9 Ka respectively (Figs. 5.1 & 5.2).

5.3 BIOSTRATIGRAPHIC SUBDIVISIONS

Biostratigraphic subdivisions of the Quaternary marine sedimentary records are made primarily from certain planktic foraminiferal criteria such as evolutionary appearances, extinctions, acmes and changes in coiling patterns (Ericson et al., 1954; Frerichs, 1968; Ericson and Wollin, 1968; Berggren et al., 1980; Srinivasan and Singh, 1991 and Singh and Srinivasan, 1993). These criteria are applicable to the long Quaternary records of deep-sea sediments rich in planktic foraminifera. In shallow marine sequences, it becomes difficult in making biostratigraphic subdivisions using planktic foraminifera due to their less frequent occurrence or even absence in the sediments. Therefore, it is necessitated to recognise other microfaunal criteria, which can be useful in stratigraphic divisions of shallow marine sections. As the sedimentary records of the shelves are manifestation of various sea level cycles (transgression, regression and still-stand) and associated changing environmental conditions, bathymetry of the core site should be kept into consideration while analysing the downcore variation in the microfaunal assemblages. Sediments recovered from different water depths are characterised by distinct assemblages. At a particular site, variations in microfaunal assemblages along the core can be a response of changes in bathymetry together with the environmental condition occurred during the glacial-interglacial period. Therefore, the late Pleistocene and Holocene microfaunal association across the shelf shows significant differences in space and time. Hence, even on a local scale the microfaunal criteria applicable for the particular depositional regime (eg. outershelf) may not hold true for other regimes. Quantitative microfaunal records (foraminifera and pteropods) of the examined cores recovered systematically transect wise across the shelf provided an excellent opportunity to document faunal successions which can be applicable in stratigraphic subdivisions of late Pleistocene – Holocene sections from outershelf, mid-shelf and innershelf regimes.

(i) CORES S1 AND S10 (OUTERSHELF REGIME)

These cores from the outershelf comprise of foraminifera (both planktic and benthic) and pteropods as major biotic components of the sediments. Planktic foraminiferal records of cores S1 and S10 do not consist datum marker species commonly used in the late Quaternary biostratigraphy except *Globorotalia menardii*. In both the cores, *G.menardii*, a typical warm water species shows a significant change in its relative abundance from glacial to the Holocene period (Figs. 5.1 & 5.2). Downcore variation in planktic foraminiferal assemblages indicates proliferation in *G.menardii* at the beginning of the Holocene (Figs.5.1 & 5.2.). *G.sacculifer*, another tropical taxon follows almost the similar pattern as of *G.menardii*. Therefore, proliferation of *G.menardii* and *G.sacculifer* can be considered as important microfaunal event to mark the Holocene/Pleistocene boundary (~ 10 Ka).

Data on down-core variation in absolute abundance of planktic foraminifera, benthic foraminifera and pteropods (recorded in terms of Pt/PF and BF/PF ratios) reveal a noticeable change from glacial to interglacial interval (Fig. 6.10). A significant increase in Pt/PF ratio and corresponding decrease in BF/PF ratio is recorded during intervals of interglacial period. Distribution pattern of modern foraminifera and pteropods documented in the study area suggests Pt/PF minimum and BF/PF maximum as indicative of shallowest condition (see Chapter.4). Therefore minimum occurrence of Pt/PF and corresponding maximum in BF/PF in outershelf sequence can be considered as a marker of the Last Glacial Maximum (LGM), when sea level stood its lowest from the PMSL (Present Mean Sea Level).

(ii) CORES S7 AND S8 (MID-SHELF REGIME)

The mid-shelf regime of the study area is sand- rich in contrast to the outer- and innershelf. Because of the nature of the sediments dominated by sand, gravity corer could not penetrate deep and only short length cores were recovered. Although, sand dominates all along the core, bottom portion of the cores is relatively high in clay and silt contents. Benthic foraminiferal record shows presence of two distinct units representing different biofacies with its boundary between 40cm and 50cm depth. The characteristic difference in these two units is recorded in absolute abundance of benthic foraminifera and relative abundance of *H. mexicana*. A high abundance of total benthic foraminifera and high percentage of *H. mexicana*, with their gradual downward decrease distinguish the upper unit of cores S7 and S8 (Fig.5.3). Lower unit is characterised by low abundance of benthic foraminifera and minimum occurrence of *H. mexicana* (Fig.5.3). The two biofacies identified in these mid-shelf cores may represent two different stratigraphic intervals. These units could not be kept in time frame because of non-availability of radiocarbon age.

(iii) CORE SS125 AND S6 (INNER-SHELF)

Cores SS125 and S6 come from the innershelf region. The faunal assemblages of these cores are distinct from the outershelf. Foraminiferal assemblages of the core samples mainly comprise of benthic populations. Planktic foraminifera and pteropods are rarely present in these core samples, therefore having no value in stratigraphic divisions. An attempt has been made to identify foraminiferal criteria, which can be useful for stratigraphic subdivisions of innershelf sequences by analysing benthic assemblages (Figs. 5.4). Quantitative benthic foraminiferal data of core SS125 reflect two distinct assemblages characterising two biofacies upper one upto 170cm core depth and lower one from 170cm to the core bottom. From core-top upto 170cm, microfaunal assemblages are distinguished by a general high abundance of benthic foraminifera, with further increase at certain interval upto >5000 specimens (per gram of dry sediment). The genus *Nonion* dominates the assemblage (approximately 80% of the total benthic foraminiferal population) (Fig.5.4). The lower part of the core from 180cm to 270cm depth is characterised by a low

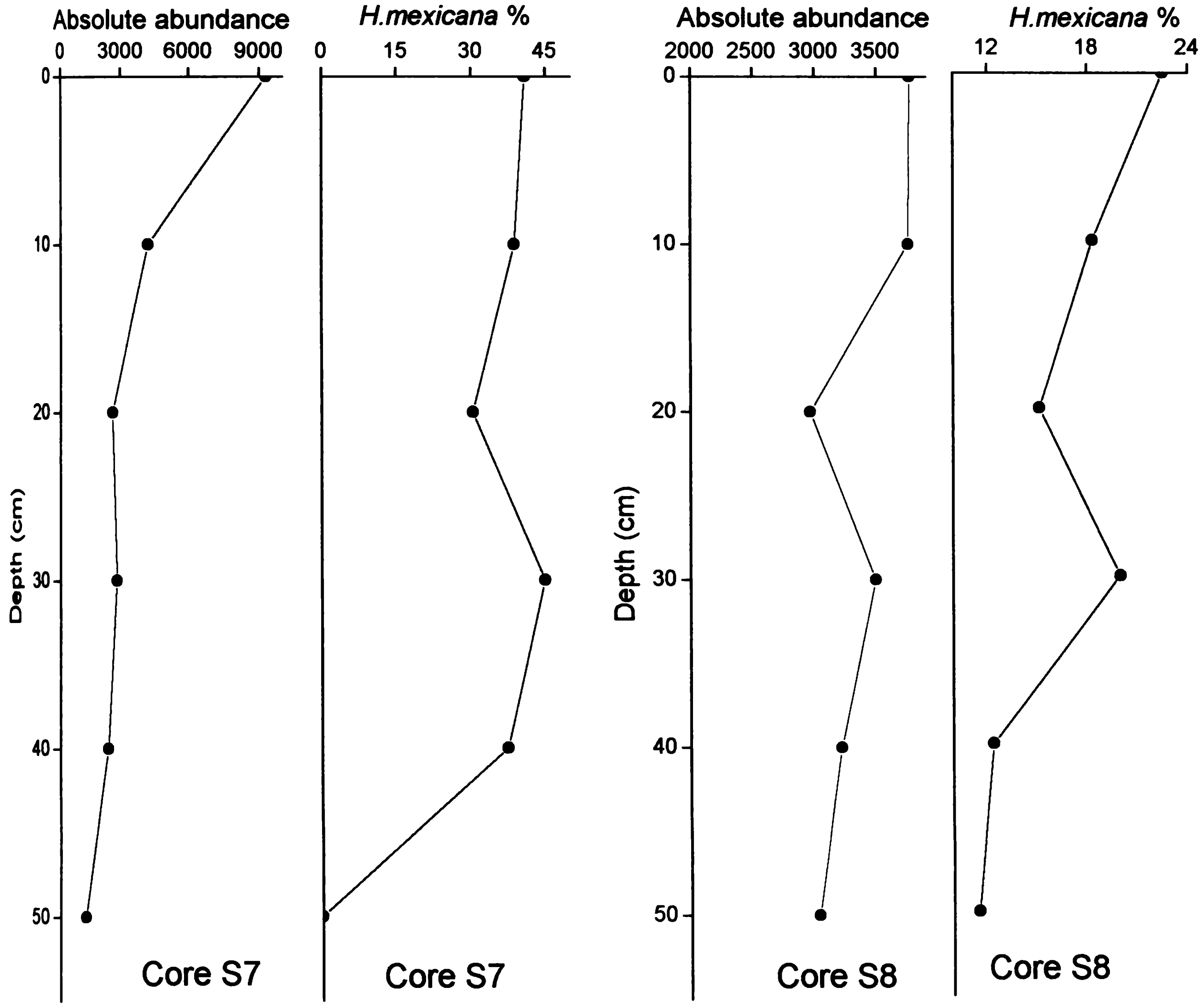

Fig.5.3. Absolute abundance and percentage frequency of *Hanzawaia mexicana* in cores S7 and S8

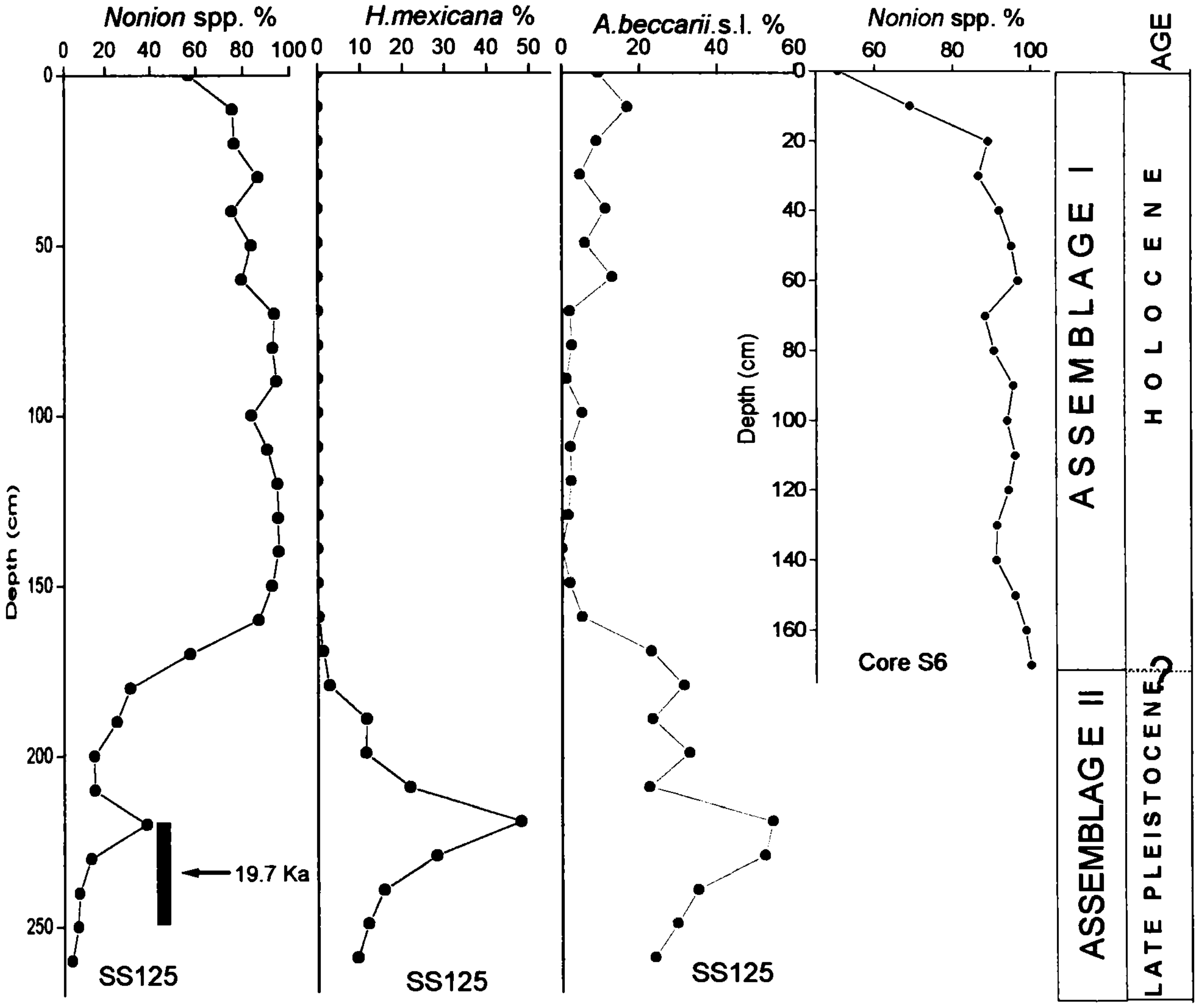

Fig. 5.4. Perentage frequency of . *Nonion* spp.,*Hanzawaia mexicana* and *Ammonia beccarii*.s.l. in core SS125 and *Nonion* spp. in core S6. Inferred biofacies (based on the distinct benthic foraminiferal assemblages) and stratigraphic ages are given to the right.

abundance of foraminifera. Relative abundance of *Nonion* population in lower unit is decreased considerably to 20%, and substituted by *Hanzawaia mexicana* and *Ammonia becarii* s.l. (Fig.5.4). By comparing the faunal record of core with the modern benthic foraminiferal data, it can be inferred that lower stratigraphic unit represents regressive period of the sea level during the late Pleistocene and upper unit represents the Holocene period when sea level started rising and reached to the present level. A radiocarbon age of 19.7 Ka was estimated for sediments 225–250cm interval (Fig.5.4). The present study reveals that the quantitative abundance of *Nonion*, *Hanzawaia* and *Ammonia* in foraminiferal assemblages could be taken into consideration for demarcating the Holocene and the last glacial intervals in innershelf sedimentary records. Benthic foraminiferal record of core S6 indicates that the entire core (162 cm length) is stratigraphically equivalent to the upper unit of core SS125.

5.4 LITHOSTRATIGRAPHIC SUBDIVISIONS

A lithostratigraphy of a marine section is established based on the variation in sediment facies in time. The spatial dimension of a lithounit is dependant on the extent and rate of sea level transgression/regression took place during a particular period. Throughout the geological column, lithostratigaphic boundaries are time parallel, and are therefore regarded as equivalent status to chronostratigraphic units in stratigraphic subdivisions and subsequent correlation. The sequential geometry of the sedimentary facies along the core is identified based on the textural characteristics.

An attempt has been made to establish lithostartigraphy in the examined core sections: S1, S10 (outershelf), S7, S8 (mid-shelf) and SS125 (innershelf), using Haneeshkumar's (2001) data on granulometric characteristics (Figs. 5.5 to 5.9).

(i) CORES S1 AND S10 (OUTERSHELF REGIME)

In both the cores S1 and S10, downcore sediment distribution patterns are characterised by clayey silt, silt clay and silt (Figs. 5.5 & 5.6). Two major sedimentary units representing different facies are seen in core S1 with its boundary at 75 cm core depth. The top unit of the core is composed of sediments with considerable amount of sand content and lower one by its clayey nature. The bottom unit (from 75cm downward) is predominant with siltyclay. The silt and clay content ranges from 23.58 to 86.56 % and 0.81 to 64.91% respectively. Core S10 depicts three distinct units. The top 40cm of the core is composed of 15% sand. The middle unit extending from 40 to 100cm is rich in silt content (upto 80%) but show substantial decrease in clay (~20%). The sand contents in core samples ranges between 0.47 and 16.75 %. The silt and clay content varies from 41.7 to 79.25 % and 19.99 to 50.45 % respectively.

what about
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(ii) CORES S7 AND S8 (MID-SHELF REGIME)

In these two cores taken from the mid shelf, sand fraction outweighs other textural classes silt and clay (Figs 5.7 & 5.8). Sand content along the core varies between 85.96 to 99.5 % in S7 and between 80.18 to 95.76 % in core S8. Silt and clay are present only as minor constituents. Bottom part of the cores has

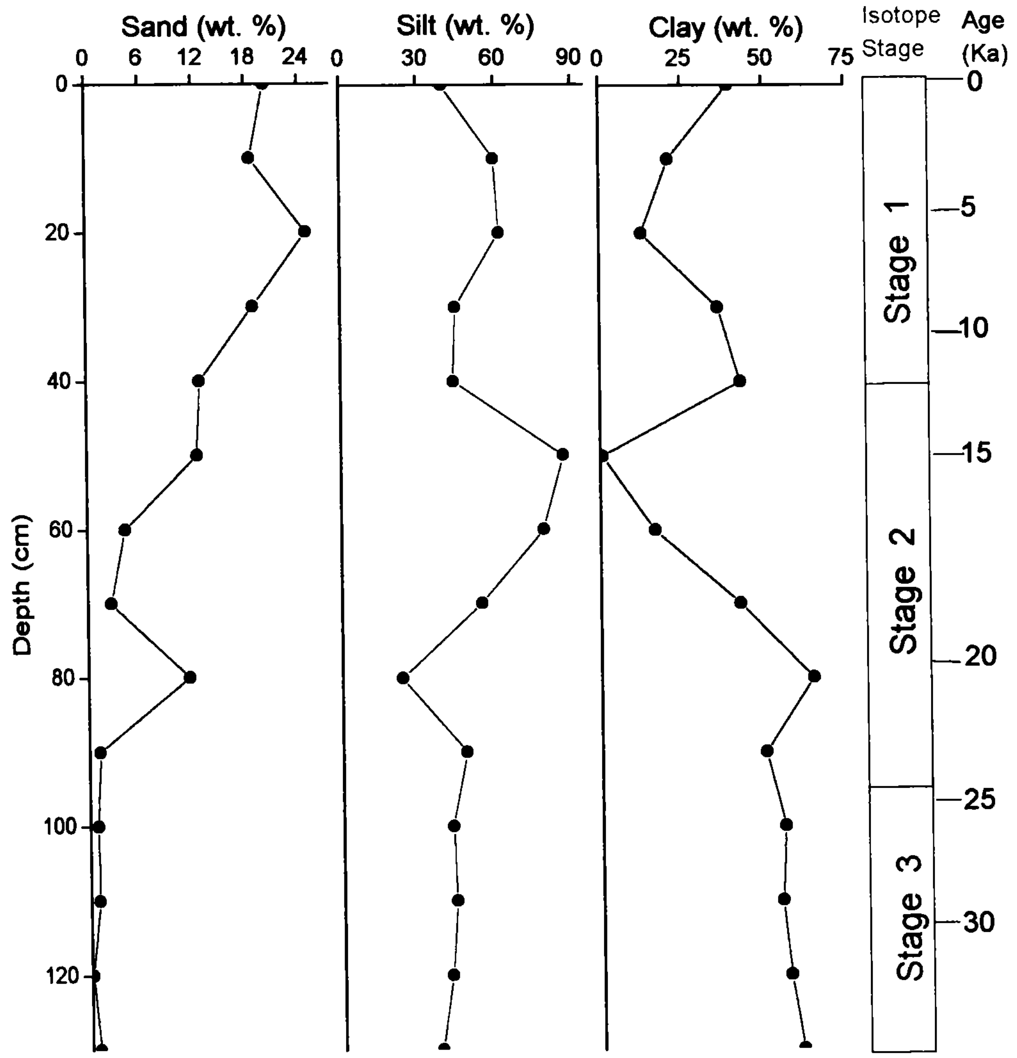

Fig.5.5. Weight percentage of sand, silt and clay in core S1. Estimated ages are given to the right

Scale

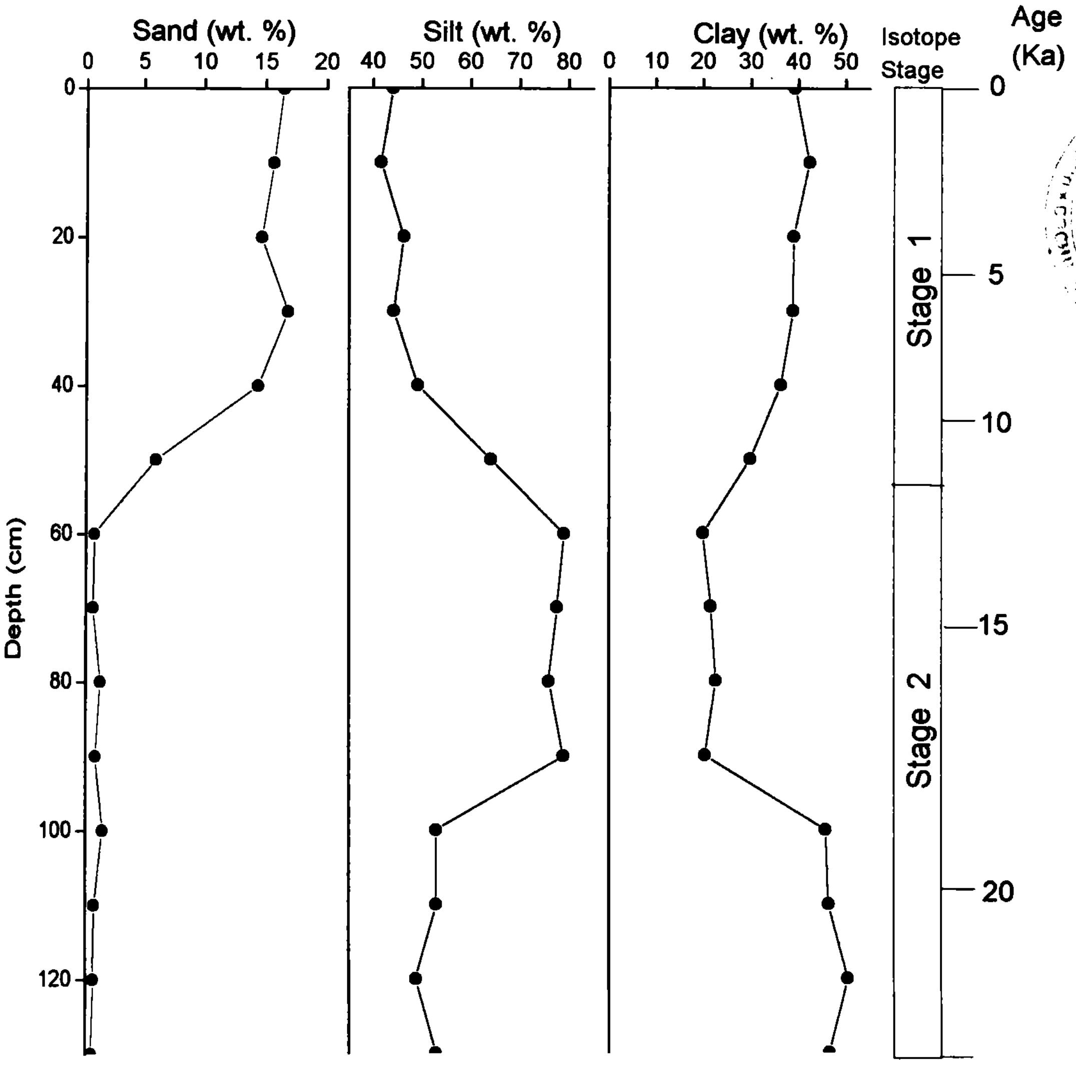

Fig.5.6. Weight percentage of sand, silt and clay in core S10. Estimated ages are given to the right.

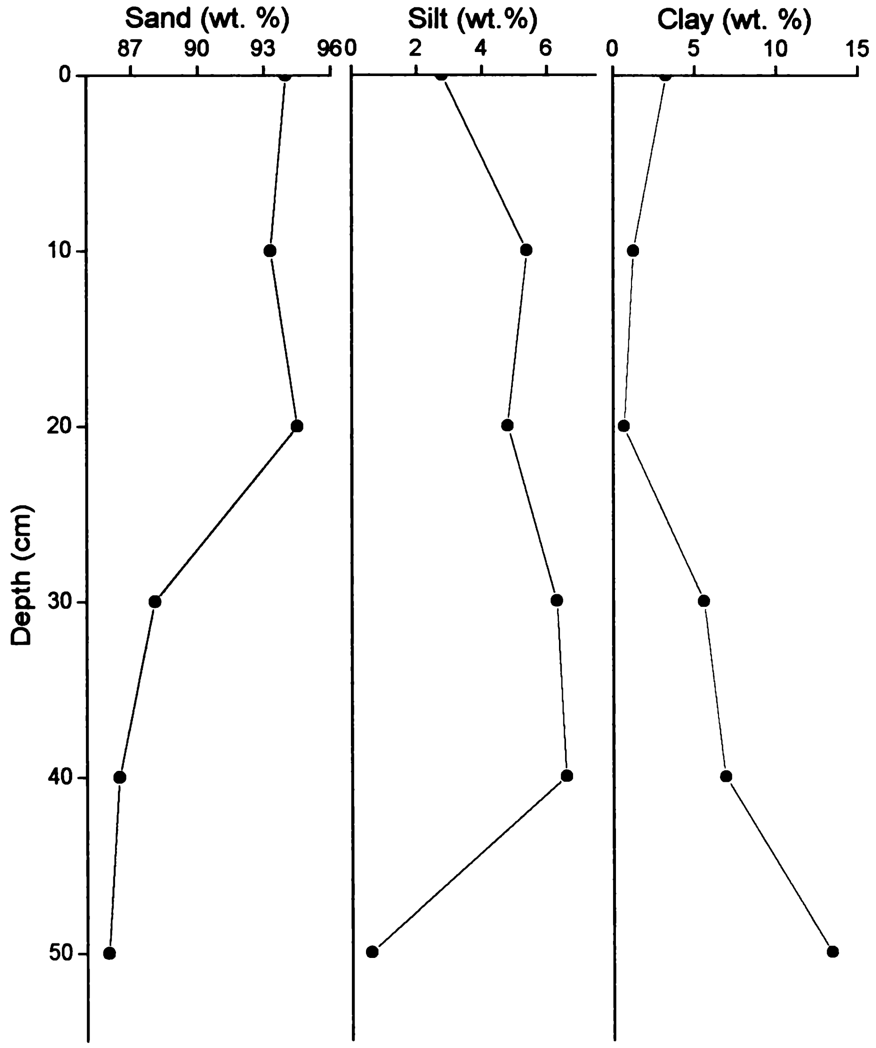

Fig. 5.7. Weight percentage of sand, silt and clay in core S7

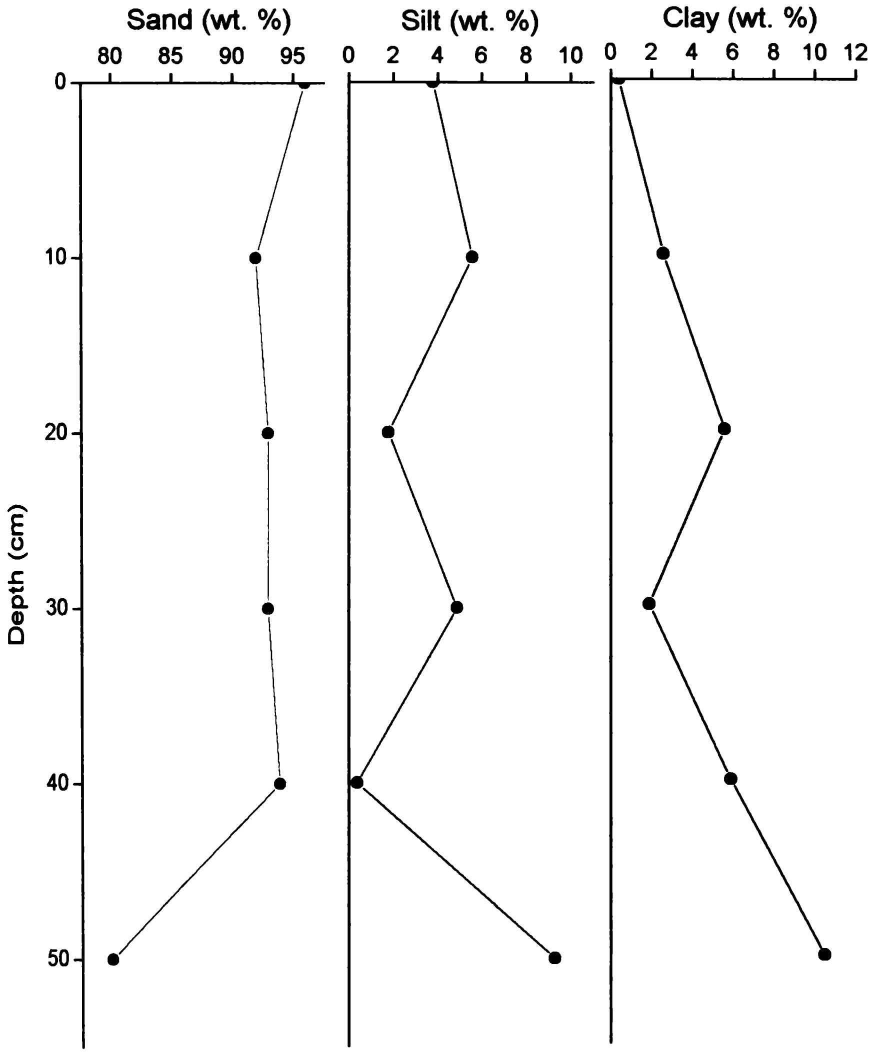

Fig.5.8.Weight percentage of sand, silt and clay in core S8

addition of mud content at the expense of sand revealing a manifestation of change in sediment facies beneath.

(ii) CORE SS125 (INNERSHELF REGIME)

273cm long SS125 core shows two major lithounits reflecting distinct differences in their textural characteristics, with the boundary at 170 cm (Fig.5.9). The upper unit is characterised by insignificant quantity of sand and the lower is remarkably sand rich. Clay is the dominant component (~60%) followed by silt (~ 40%) in the upper unit. In the lower unit, silt and clay together constitute only 20%, whereas sand increases upto >80%. The silt and clay in the core ranges from 2.97 to 50.11 % and 7.98 to 64.57 % respectively.

The present study enabled to establish a precise chronostratigraphic framework for two best cores S1 and S10 representing a complete record of the last glacial and Holocene periods by integrating isotope stratigraphy, radiochronology, biostratigraphy and lithostratigraphy. There are excellent chronological and stratigraphic correlations between these two core sections, coming from the outershelf regime off north Kerala. The study provides an excellent opportunity to recognise specific planktic foraminiferal species, which can be of potential use in stratigraphic subdivisions of shallow marine cores especially from the outershelf areas. Benthic foraminifera are found to be more applicable than planktic foraminifera and pteropods for stratigraphic divisions in core sections from mid-shelf and innershelf regions. The study reveals a good stratigraphic correlation among various lithounits and microfaunal biofacies recognised in cores. However, it is warranted to have radiochronology of the

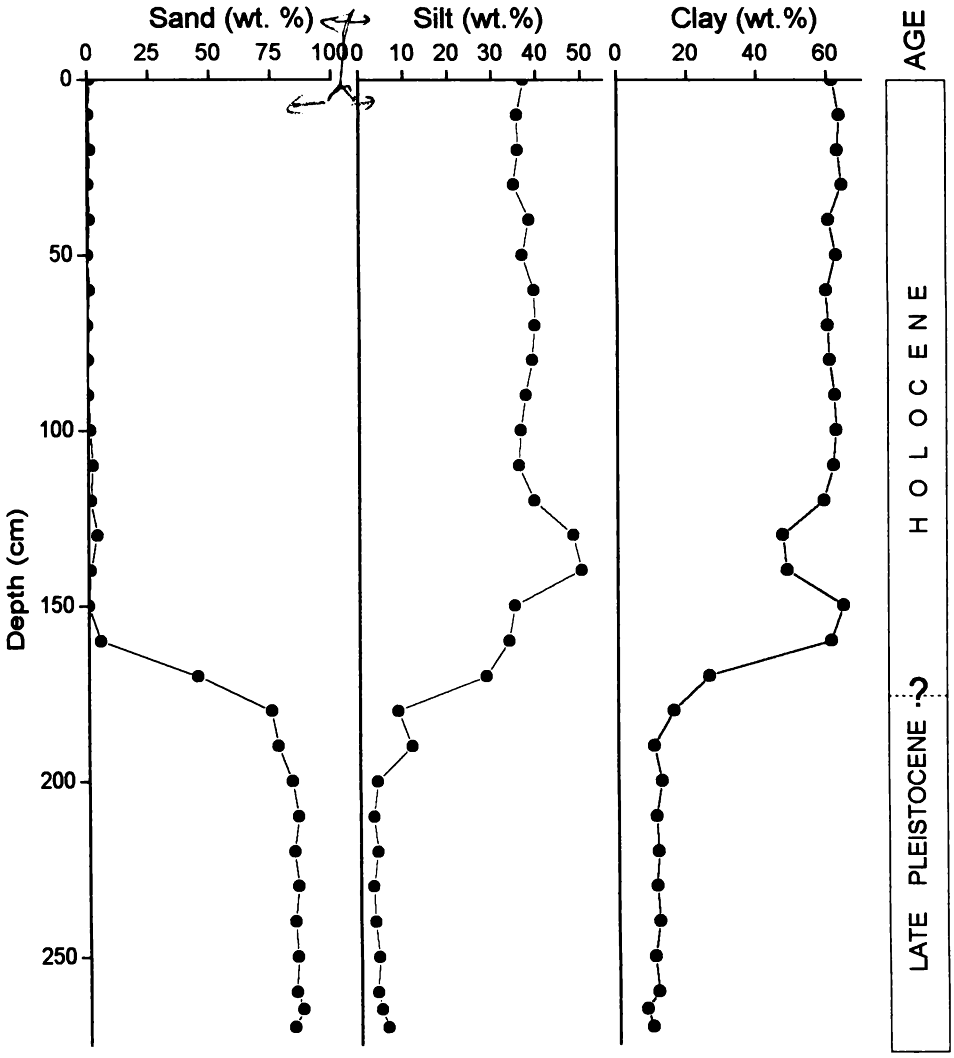

Fig.5.9.Weight percentage of sand, silt and clay in core SS125. Stratigraphic ages are given to the right.

examined inner- and mid-shelf cores S6, S7, S8 and SS125 for obtaining a precise chronostratigraphy and to validate the proposed stratigraphically important microfaunal parameters in correlation.

Chapter 6

LATE QUATERNARY FORAMINIFERAL AND PTEROPOD RECORDS

The microfaunal composition in marine sediments has been known to change with environmental conditions. Any fluctuation in the past environment is reflected by the variation in microfaunal assemblages. Foraminifera are frequently used in deciphering past changes. Pteropods are also found to be a potential tool for paleoceanographic reconstruction in certain areas. The late Quaternary sequence of the continental shelf of northern Kerala offers an exceptional opportunity to investigate both the foraminiferal and pteropod records and their paleoenvironmental significance.

6.1 DOWNCORE VARIATION IN BENTHIC FORAMINIFERAL ASSEMBLAGES

A detailed study has been carried out on the late Quaternary benthic foraminifera, as they represent the dominant constituents of foraminiferal population. For vertical pattern study, three cores were chosen, one each from the outershelf (S10), the mid-shelf (S7) and the innershelf (SS125) regimes. Benthic foraminiferal records of the examined core sections reflect variations in absolute abundance, diversity and relative abundance of important genera and species. Downcore variations of these changes are discussed for each section examined:

(I) CORE S10

Benthic foraminiferal record of core S10 indicates a gradual decrease in absolute abundance from core-top downward upto 40cm (from 12000 specimens/g to 6000 specimens/g). The middle of the core from 50 to 100cm (~10 to 19 Ka BP) is characterised by higher benthic foraminiferal abundance varying between 9000-13000 individuals/g (Fig.6.1). From 110cm core depth downwards, total abundance decreases to its minimum (5000/g).

The richness of species in benthic foraminiferal population is expressed in total number of species i.e. simple species diversity. Maximum species diversity is recorded in sample from 90cm depth representing Last Glacial Maximum (18 Ka BP). Core samples of Pre-LGM period show low number of species in benthic foraminiferal population. After showing decreasing trend between 18 and 14 Ka BP, species diversity increases again during 14 to 12 Ka BP (Fig.6.1). Total number of species in benthic foraminiferal population fluctuates between 30 and 35 during the Holocene.

Benthic foraminiferal assemblages comprise of both the infaunal and epifaunal taxa. Infaunas are those taxa, which are living within the sediments, and epifaunal taxa are those living on or above the sediment surface. The availability of nutrient in sediments and nature of substrate are considered to be important factors for fluctuations in relative abundance of these two groups in benthic population. Quantitative data of core S10 reflect significant variations in epifaunal and infaunal groups at certain stratigraphic intervals (Fig.6.1). An increase in relative abundance of infaunal benthic foraminifera and corresponding decrease in epifaunal taxa is recorded during ~18 to 14 Ka BP and at around 5 Ka BP. High abundance of infauna during these intervals

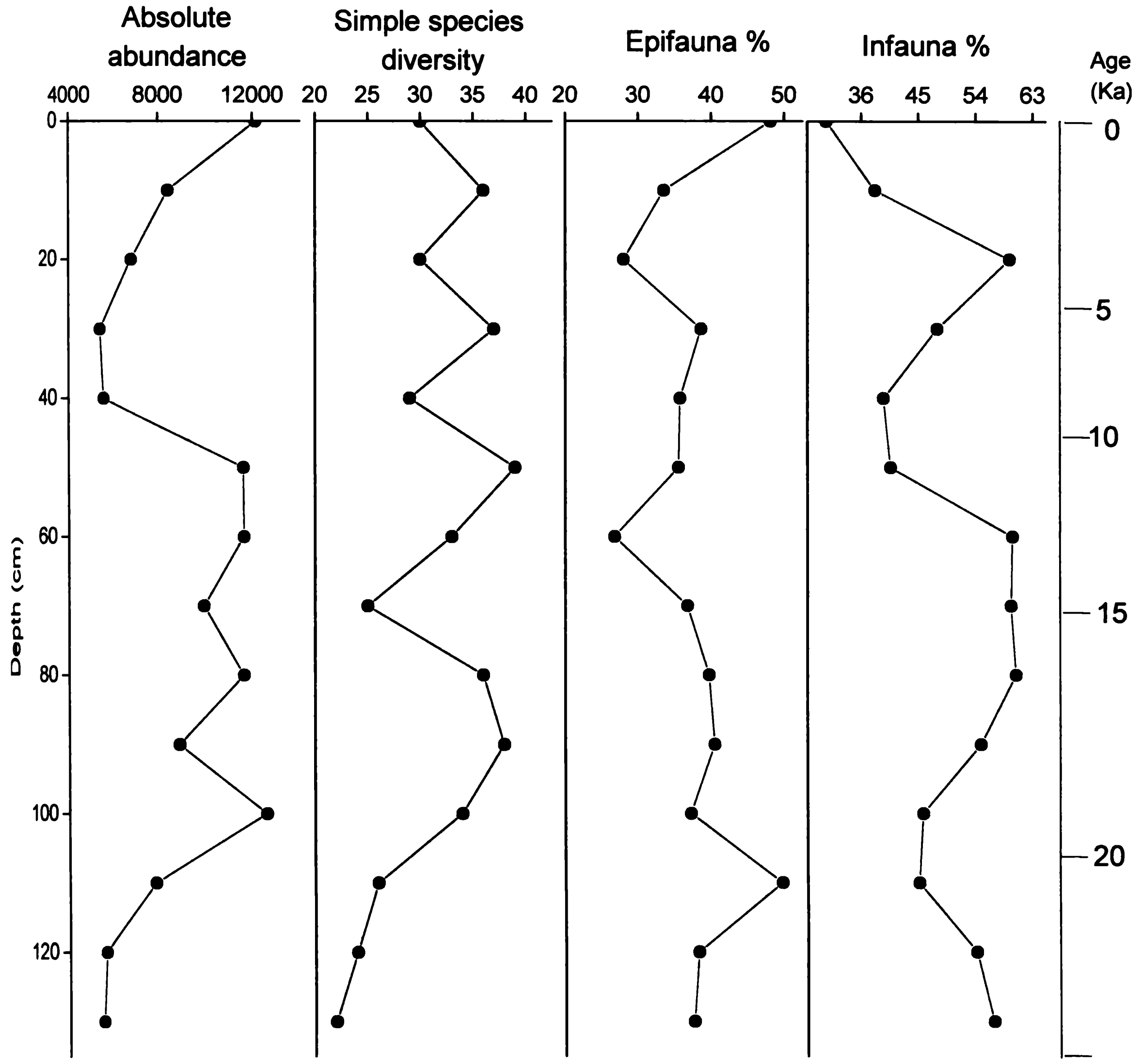

Fig.6.1. Absolute abundance, species diversity (benthic foraminifera) and percentage frequency of epifauna and infauna in core S10. Estimated ages are given to the right side

probably reflects eutrophic conditions attributed to the increased supply of nutrients to the sediments (Altenbach and Sarnthein, 1989 and Li et al, 1996). On the other hand, low occurrence of infaunal taxa and corresponding increase in epifaunal population may be resulted due to deficiency of nutrients in the sediments during oligotrophic conditions and scarcity of muddy substrate. Based on the planktic foraminiferal record of the same core, Singh (1998) has suggested an intensified upwelling during ~18 to 15 Ka BP. A stronger upwelling might have resulted enhanced productivity and subsequently enrichment of nutrient in sediments.

Benthic foraminiferal population in core S10 is mainly constituted by *Ammonia beccarii* s.l. (*Ammonia beccarii, Rotalidium annectens*, *Asterorotalia dentate*, and *Ammonia tepida*), *Textularia agglutinans*, *Bolivina persiensis*, *Bulimina marginata*, *Hanzawaia mexicana*, miliolids (*Quinqueloculina agglutinans, Q. seminulum, Q. undulosa costae, Spiroloculina communis, S. exima, Triloculina echinata, T. oblonga, T. laveigata, T. costate, T. tricarinata*), nonionids (*Nonion fabum* and *N. cummunis*) and *Reophax agglutinatus*. The fluctuation in relative abundances of these benthic foraminifera can be linked with the changes in various factors such as ecological conditions (bathymetry, temperature, salinity etc), nature of the substrate and nutrient content. In the present study an attempt has been made to record the variation pattern in the dominant constituents of benthic foraminiferal assemblages and to infer probable reasons of the faunal changes.

Ammonia beccarii s.l. shows prominent fluctuations in its relative abundance along the core. The percentage frequency of *Ammonia beccarii* s.l. is higher during ~23 to 14 Ka BP and it decreases from glacial to interglacial period (Fig.6.2). The Holocene samples consist relatively lower abundance of *Ammonia beccarii* s.l.. Studies on modern benthic foraminiferal distribution suggest that *Ammonia beccarii* association prefers muddy shelf sediments richer in organic matter (Setty and Nigam, 1982 and Murray, 1991). The component species of *Ammonia beccarii* s.l. are reported to occur in waters of wide salinity range (~ 18 to 33 ‰). The important factors controlling downcore variation appear to be nutrient content in the sediment, nature of substrate and bathymetric condition. Sea level variation along the southwest coast of India during the last glacial – Holocene resulted changes in bathymetric condition, migration of coast (seaward and landward) and sediment characteristics. Fine muddy sediments enriched in organic carbon, of the lower portion of the core characterising innershelf condition prevailed during the last glacial period (when sea level was conspicuously low) might have been favourable for *Ammonia beccarii.*s.l.. Sea level rise and simultaneous increase in bathymetry at the core site and deposition of coarse sediments, during post – LGM and Holocene periods would have caused a reduction in abundance of *Ammonia beccarii* s.l.

Bulimina marginata and *Bolivina persiensis*, important infaunal taxa of benthic foraminiferal population show identical pattern of downcore variations in their abundances (Fig.6.2). It is intriguing to note that relative abundance of *B. marginata* increases from 18 to 14 Ka BP. Since 14 Ka BP, its percentage

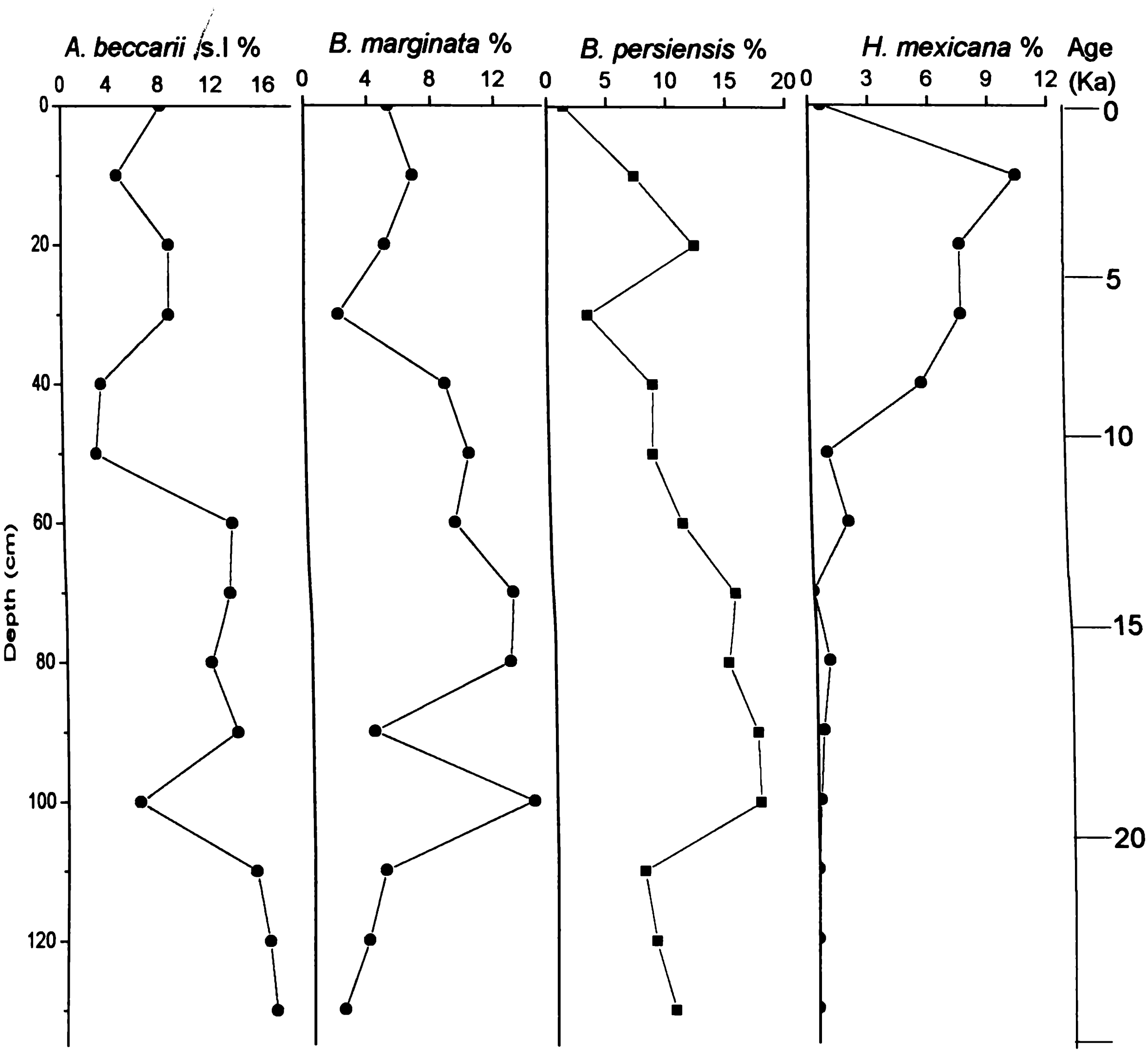

Fig.6.2. Percentage frequency of *Ammonia beccarii* s.l, *Bulimina marginata*, *Bolivina persiensis* and *Hanzawaia mexicana* in core S10. Estimated ages are given to right side.

abundance decreases gradually with minor fluctuations during the Holocene. Both *B. marginata* and *B. persiensis* are considered to occur frequently in eutrophic conditions (Murray, 1991 and Hermelin and Shimmield, 1995). An intensified upwelling and consequently eutrophication during ~18 to 14 Ka BP was suggested by Singh (1998).

Hanzawaia mexicana shows its significant occurrence (5 to 10 %) in Holocene samples with the exception in core-top (Fig.6.2). This taxon is almost absent or rarely present in samples from 60 to 130 cm core depths. *H. mexicana* is a characteristic mid-shelf species preferring sandy substrate (Murray, 1973, 1991). Its rare and sporadic occurrence in silty-clay sediments of the last Glacial interval and significant presence in sandy Holocene samples suggest nature of substrate a major factor controlling distribution pattern of *H. mexicana*.

Miliolid population in core S10 is mainly composed of *Quinqueloculina agglutinans*, *Q. seminulum*, Triloculina *tricarinata*, *T. laevigata* and *Spiroloculina communis* (Fig.6.3). The miliolids constitute approximately 20 to 25% of benthic foraminiferal assemblages from the lower part of the core representing 21 to 14 Ka BP. *Q. agglutinans* is the most dominant contributor to the miliolid population in the core. The pattern of variation in relative abundances of total miliolids and Q.*agglutinans* approximately parallels to one another (Fig.6.3). The maximum abundance of miliolids is recorded during the last glacial period. Distribution record of modern benthic foraminifera from the study area reveals that miliolid taxa occur abundantly in mid-shelf sandy sediments with low organic matter.

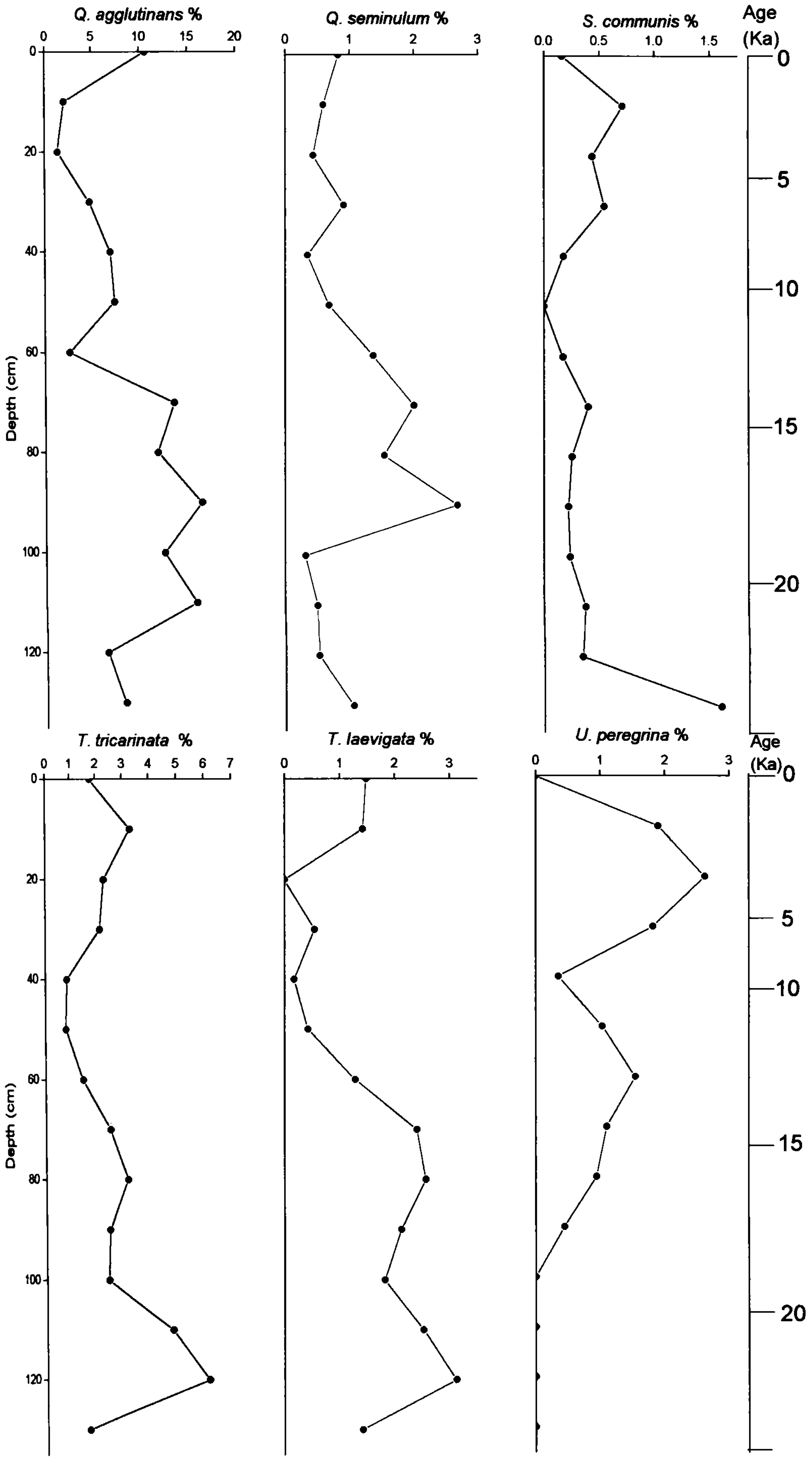

Fig.6.3. Percentage frequency of *Quinqueloculina agglutinans*, *Q. seminulum*, *Spiroloculina communis*, *Triloculina laevigata*, T. *tricarinata* and *Uvigerina peregrina* in core S10. Estimated ages are given to right side

High abundance of miliolids in fine sediments of glacial period and decreased percentage frequency in coarser Holocene sediments suggest that variable ecological conditions (bathymetry, salinity etc) in addition to the nature of substrate, are also important factors responsible for fluctuations in miliolid population. Miliolids are known to prefer hypersaline environment (Murray, 1991). Increase in water salinity (associated with low precipitation and high evaporation) would have caused an increase in abundance of miliolids during the glacial period.

Although, *Uvigerina peregrina* is not the dominant taxon of benthic foraminiferal assemblages of core S10, downcore variation in its abundance indicates change in environmental condition. This taxon occurs in outershelf and deep waters preferring muddy substrate (Murray, 1991). A gradual increase in relative abundance of *U. peregrina* is recorded from ~18 to 14 Ka BP. An increase in abundance of *U. peregrina* is recorded in the early Holocene from ~8 to 5 Ka BP. During the late Holocene period, its abundance decreases gradually since 5 Ka BP. Singh (1998) has recorded high abundance of *G. bulloides* (an indicator of upwelling and nutrient rich water) from this core during ~18 to 15 Ka BP. Present observation suggests a relationship between *U. peregrina* abundance and upwelling associated productivity. Hermelin and Shimmield (1995) have documented an enhancement of *U. peregrina* abundance in the Quaternary western Arabian Sea foraminiferal record during high productivity conditions. Additionally, changes in bathymetric condition, thermocline, and intensity of oxygen deficient zone during the glacial to Holocene periods may be other probable factors influencing abundance of *U. peregrina*.

(ii) CORE S7

Core S7 (0.5m long) was recovered from the sand dominated inner part of the mid-shelf. The core is entirely sand dominated without any significant variation in lithology and organic matter content in sediments (Haneeshkumar, 2001). Microfaunal data of core S7 reflects low absolute benthic foraminiferal abundance between 30 to 50cm depth. A gradual increase in absolute abundance is recorded from 30cm depth to core-top (Fig.6.4). Species diversity curve of benthic foraminifera does not show any particular pattern (Fig.6.4). Relative abundance of infauna in benthic foraminiferal population decreases from the core-top downwards to its minimum from 30 to 40cm depth and increases again in bottom-most sample at 50 cm (Fig.6.4). The epifaunal taxa show a trend in downcore variation, opposite to the infauna. The important benthic foraminifera indicating prominent change in their relative abundances along the core are: *H. mexicana, Nonion* spp., *Ammonia beccarii* s.l. and miliolids (Fig.6.5). Other genera such as *Cancris* spp. and *Bolivina* spp. also depict some variation in their abundances (Fig.6.6), but not so conspicuous. Benthic foraminiferal assemblages from the upper 40cm of the core are characterised by high abundance of *H. mexicana*, *Nonion* spp. and corresponding low occurrence of *Ammonia beccarii* s.l. and miliolids. Bottom- most sample consists a low occurrence of *H. mexicana*, *Nonion* spp. and increased abundance of *Ammonia beccarii* s.l., miliolids and significant presence of agglutinated taxa. Based on the

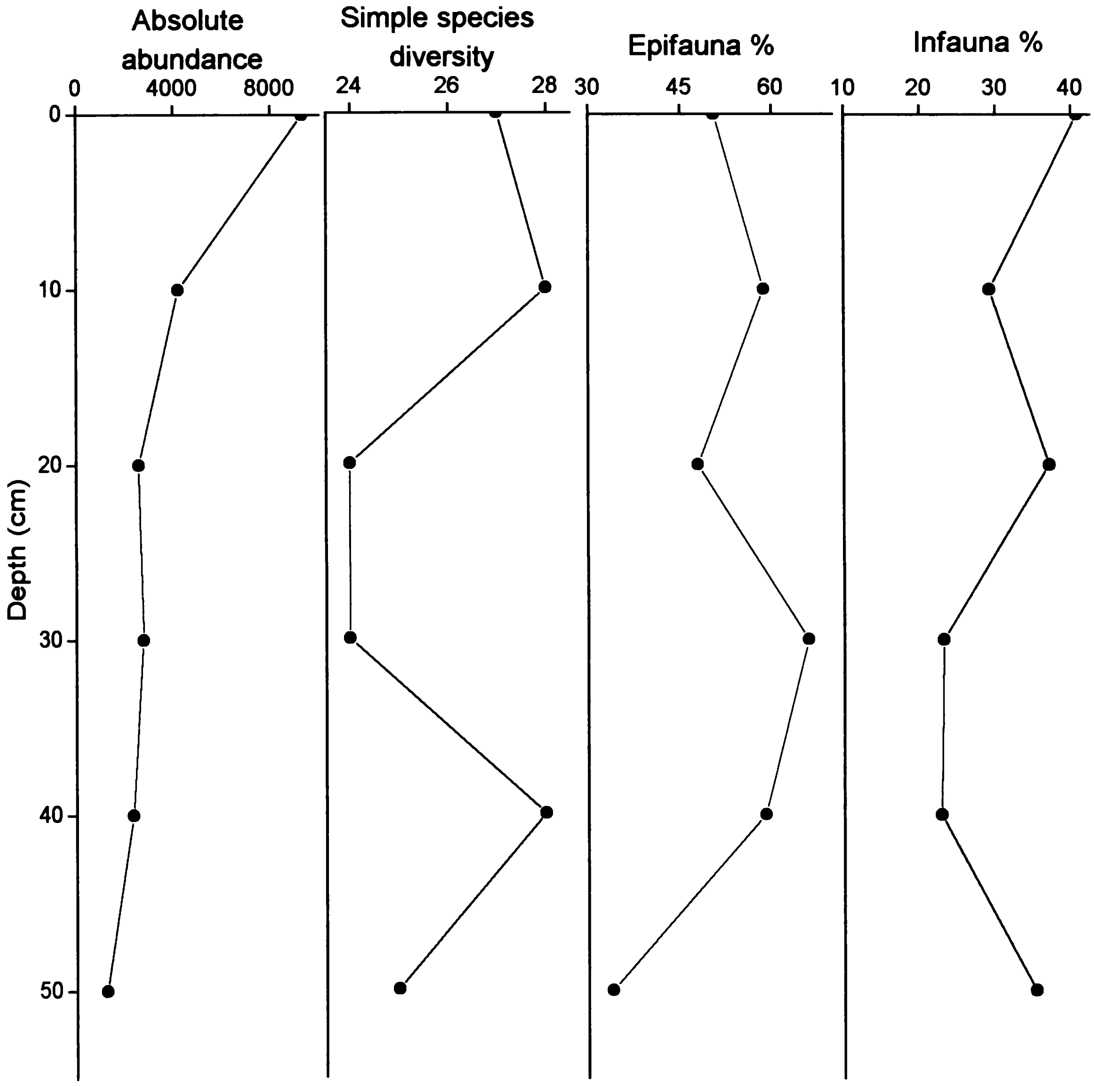

Fig.6.4. Absolute abundance, species diversity (benthic foraminifera) and percentage frequency of epifauna and infauna in core S7

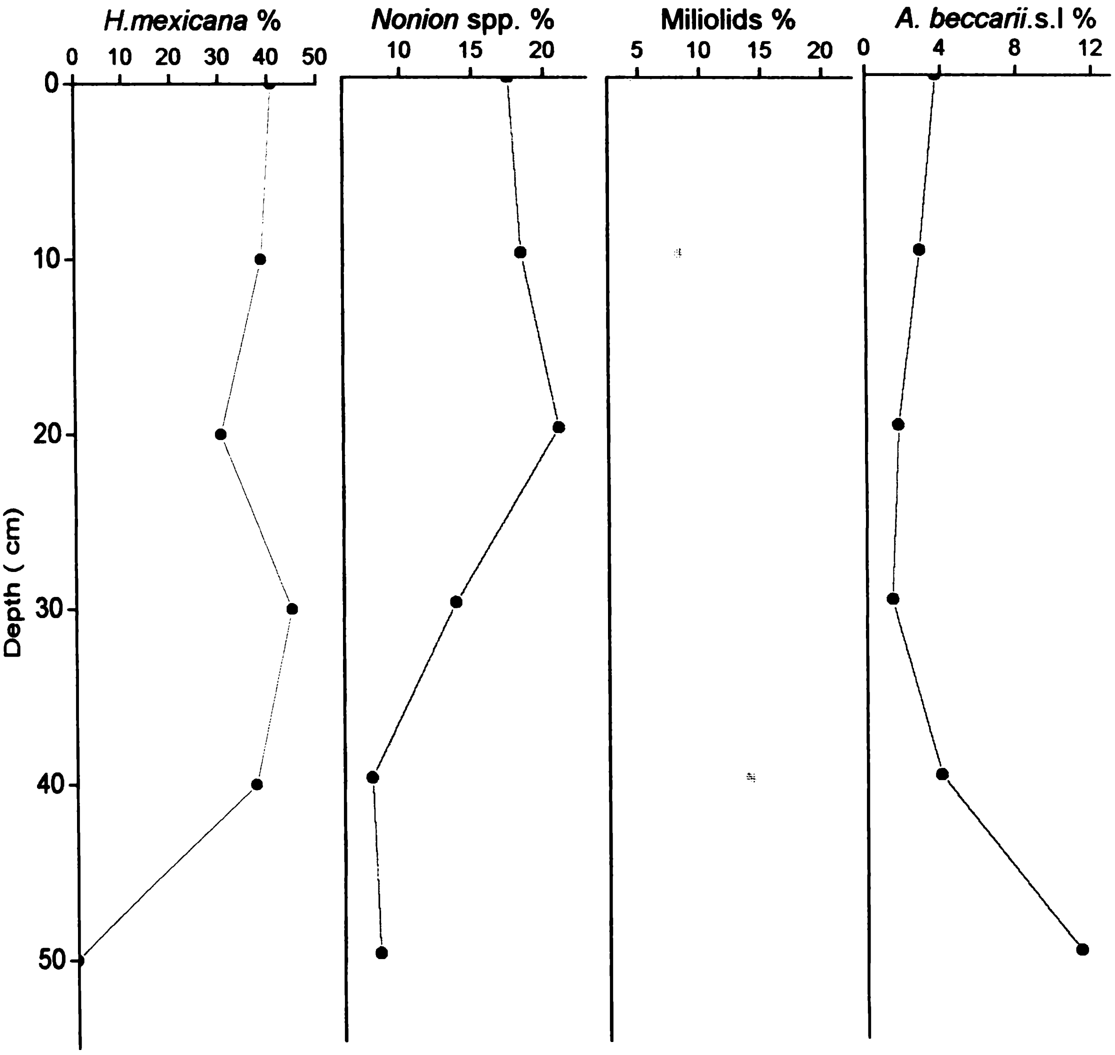

Fig.6.5. Percentage frequency of *Hanzawaia mexicana*, *Nonion* spp., total miliolids and *Ammonia beccarii* s.l. in core S7

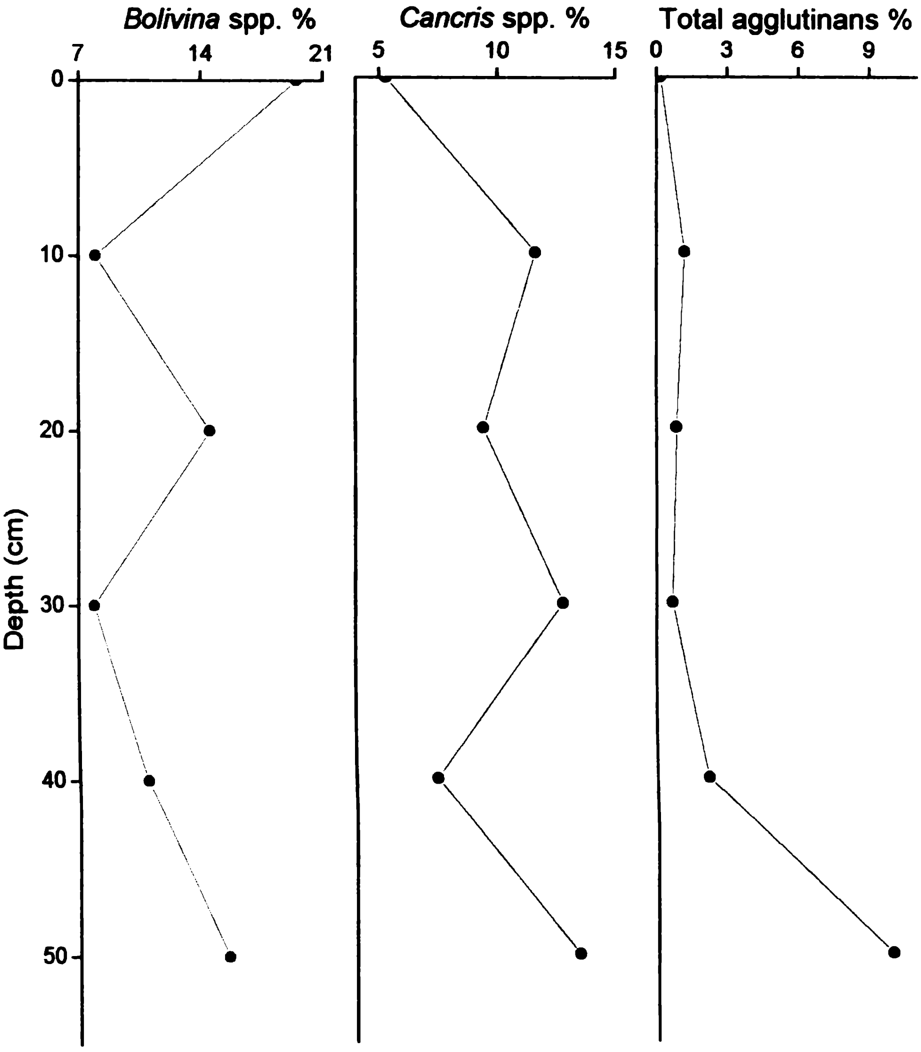

Fig.6.6. Percentage frequency of *Bolivina* spp., *Cancris* spp. and total agglutinans in core S7

distinct faunal change recorded in the core, two biofacies characterising upper 40cm sedimentary column and other core-bottom (50 cm) can be inferred.

Downcore variation in textural attributes in the sedimentary record is inconspicuous, thus no significant change in nature of substrate along the core. Two foraminiferal biofacies recognised in the core appear to be associated with the change in ecologic condition primarily the bathymetry. The limited data set based on only a few samples precludes inferring a clear-cut relationship between change in environmental conditions and variation in assemblages. A gradual increase in absolute abundance of benthic foraminifera from bottom most sample to the core-top may be associated with the changes in bathymetry at the core site influencing the benthic foraminiferal population. Bathymetric distribution pattern of modern benthic foraminifera across the shelf suggests a positive correlation between total abundance of benthic foraminifera and water depth. As no conspicuous changes in content of organic matter and substrate along the core are noticed (Haneeshkumar, 2001), these factors do not appear to be significant for benthic foraminiferal variation.

(iii) CORE SS125

Cores SS125 comes from the mud dominated innershelf zone. The core site lies on 40m isobath. Core SS125 comprises of two distinct lithounits: upper 170cm muddy sediments and lower 170-270cm sandy. The dominant constituents of benthic foraminiferal assemblage showing variation in their abundances along the core are: *Nonion* spp., *Ammonia beccarii* s.l., *H. mexicana*, *Cancris* spp. (*auriculus* and *indicus*) and *Elphidium* spp. (*crispum* and *discoidale*) (Figs.6.8 & 6.9). A significant faunal variation is also observed in absolute abundance and species diversity of benthic foraminiferal population (Fig.6.7). Benthic foraminiferal assemblages of the two lithologic core units are distinct in their composition. Lower stratigraphic unit (sandy) is characterised by low absolute abundance, high simple species diversity and increased occurrence of *H. mexicana*, *Ammonia beccarii* s.l., *Cancris* spp. and *Elphidium* spp. Species diversity of benthic foraminiferal population in upper stratigraphic unit is relatively lower (Fig.6.7). In general, absolute abundance is higher in the upper part of the core with fluctuations at certain core depths (Fig.6.7). Infaunal genus *Nonion* (*cummunis* and *fabum*) dominates foraminiferal assemblages of upper stratigraphic (muddy) unit (Fig.6.7). On the other hand, epifaunal taxa preferring sandy substrate show a significant increase in abundance upto 30 – 40% in lower stratigraphic unit (Fig.6.7). Significant presence of textulariids in sandy sediments of lower unit is another characteristic feature of foraminiferal assemblages. Abundance of *Ammonia beccarii* s.l. is indicative of estuarine and nearshore environment and *Elphidium* occurs in brackish water, marshy and lagoonal to innershelf condition (Nigam, 1987; Murray, 1991 and Nigam and Chaturvedi, 2000).

The estuarine - lagoonal and near-shore epifaunal benthic foraminiferal population of lower stratigraphic unit 180 to 270cm is gradually replaced by the typical infaunal nonionids preferring muddy substrate and innershelf condition. The radiocarbon age estimated for 225 to 250cm core depth as 19.7 Ka indicates sand dominated lower stratigraphic unit representing glacial period, when sea

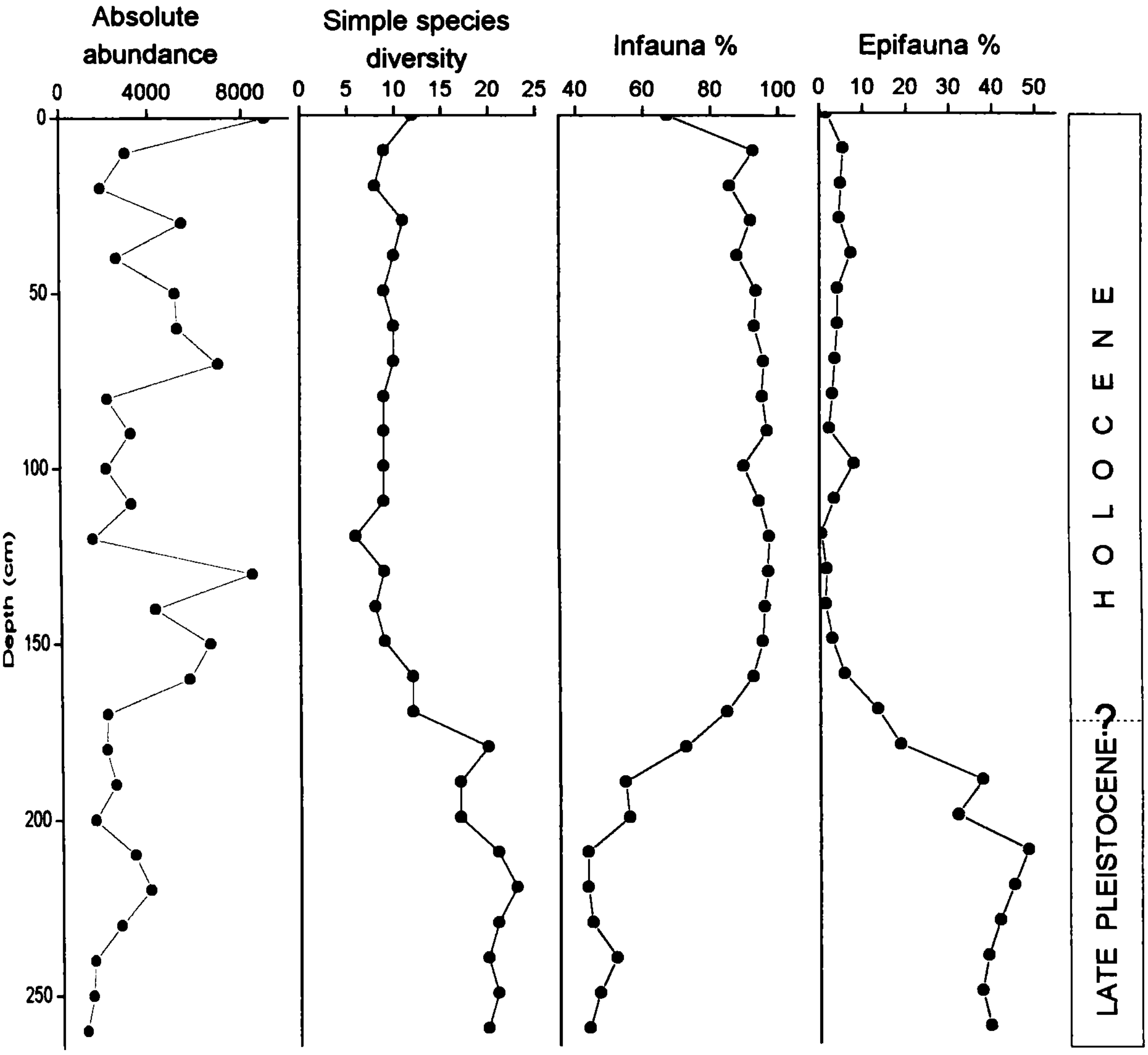

Fig.6.7. Absolute abundance, species diversity (benthic foraminifera) and percenatge frequency of infauna and epifauna in core SS125

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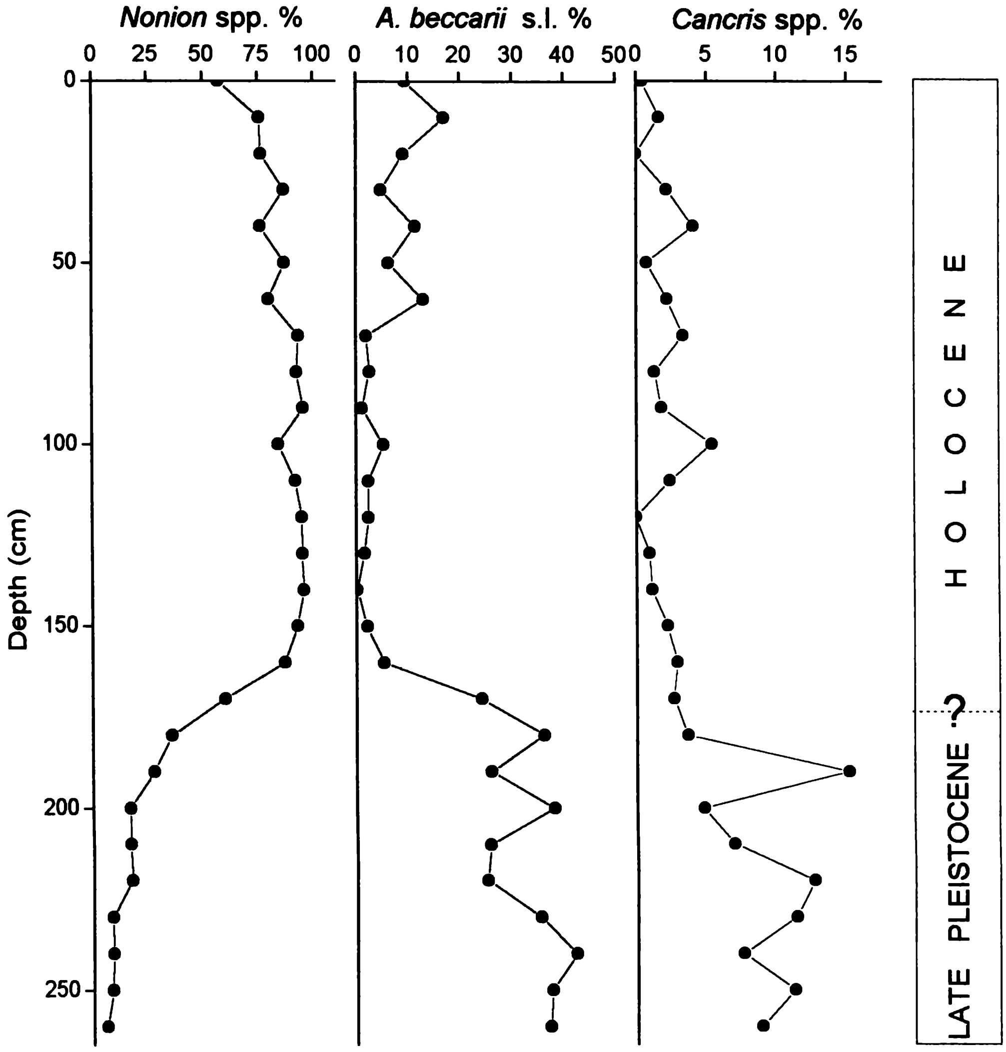

Fig.6.8. Percenatge frequency of *Nonion* spp., *Ammonia beccarii*.s.l. and *Cancris* spp. in core SS125

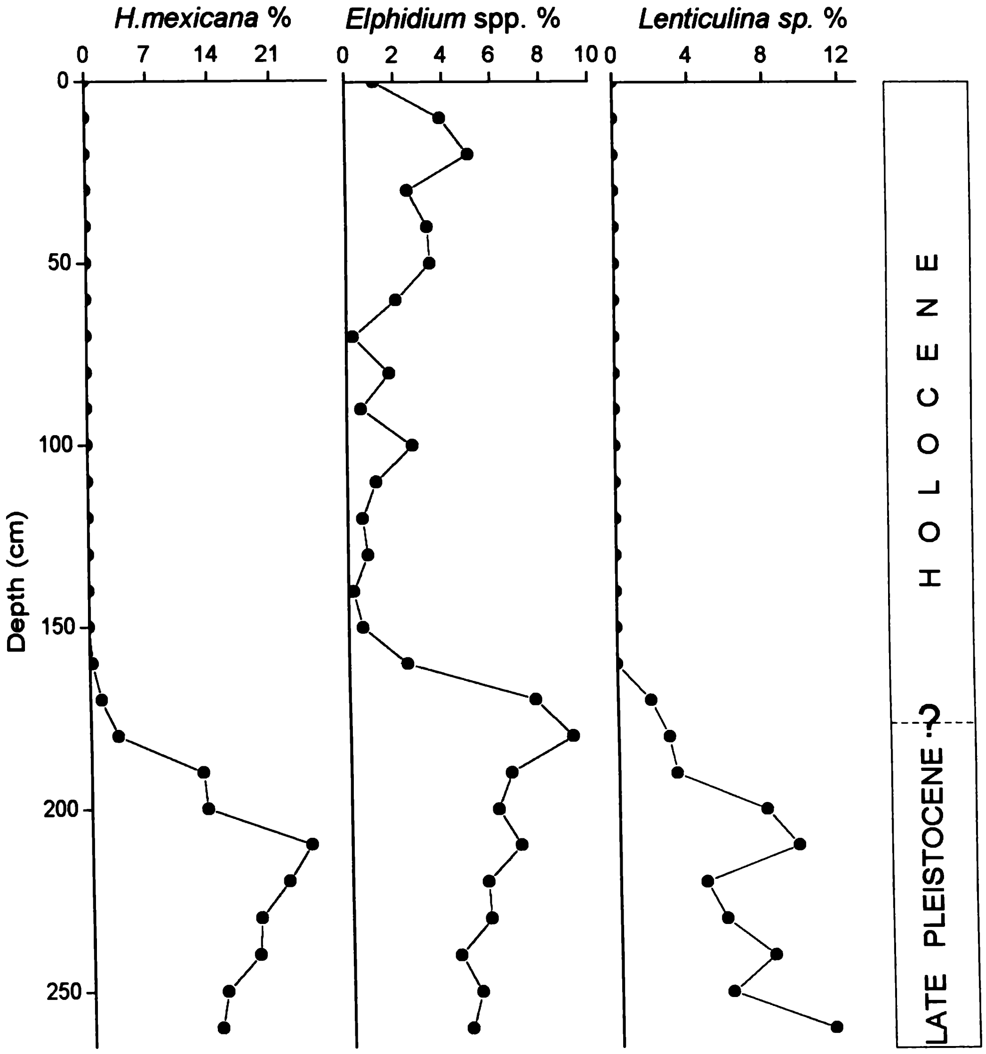

Fig.6.9. Percentage frequency of *Hanzawaia mexicana*, *Elphidium* spp. and *Lenticulina* sp. in core SS125

level was considerably lowered. A gradual rise in sea level during post – LGM and Holocene period might have led a change in environmental condition from lagoonal-marshy to innershelf and deposition of fine sediments preferred by nonionids.

Gathering information on former sea level or in other words paleo-water depths on local scale is gaining importance now a days because knowledge on paleobathymetric changes of the area provides better assessment of the past sea and tectonism. The continental shelves are potential areas for paleodepth level fluctuations and controlling factors involved such as global climatic change determination because sedimentation here is primarily controlled by sea level variations (transgression and regression) occurred in the past. Paleobathymetry of an area can be deciphered by analysing remains of faunal assemblages and lithological and sedimentological characters of shallow marine core sections. The biological indicators of paleo-water depth are established by assessing sensitivity of biota to modern bathymetric conditions (Peterson, 1986). The present investigation on depth distribution pattern of modern foraminifera and pteropods using core-top samples enabled to identify several biological proxies that are useful in paleobathymetric reconstruction (Chapter.4). Present study reveals that certain pteropod species are highly depth sensitive. Study further suggests bathymetric control on the abundance ratios of benthic/planktic foraminifera (BF/PF) and pteropods/planktic foraminifera (Pt/PF).

An attempt has been made to extract information on bathymetric conditions associated with the sea level variations in this region during the late Quaternary, based on the downcore distribution pattern of these biological proxies. For this exercise, two cores S1 and S10 representing complete record of last glacial and Holocene period were studied. Moreover, these two are the only suitable cores for reconstructing complete history of bathymetric changes occurred during the late Quaternary, as they were recovered from 150 m deep water below Present Mean Sea Level (PMSL). Other available cores (<130m water depth) from the study area are too shallow to document bathymetric change in the last glacial period.

6.2 DOWNCORE VARIATION IN ABSOLUTE ABUNDANCE OF PLANKTIC, BENTHIC FORAMINIFERA AND PTEROPODS

Numerical abundances of total benthic and planktic foraminifera and pteropods were recorded in all the examined samples of cores S1 and S10, and they are expressed in terms of abundance ratios of BF/PF (benthic/planktic foraminifera) and Pt/PF (pteropods/planktic foraminifera). Records of BF/PF and Pt/PF ratios were plotted against core depths calibrated with the integrated chronostratigraphy (Fig.6.10). Pattern of downcore variation in BF/PF ratio in both the cores S1 and S10 indicates its maximum value (>5.0) during the Last Glacial Maximum (LGM). BF/PF ratio decreases significantly (<4.0) after 15 Ka BP. Since 7 Ka BP no major variation is recorded. Foraminiferal assemblage of pre-LGM interval is relatively richer in planktic population as reflected by low BF/PF ratio varying between 2.0 and 4.0. The variation pattern of Pt/PF (pteropods/planktic foraminifera) abundance ratio is opposite to the BF/PF ratio.

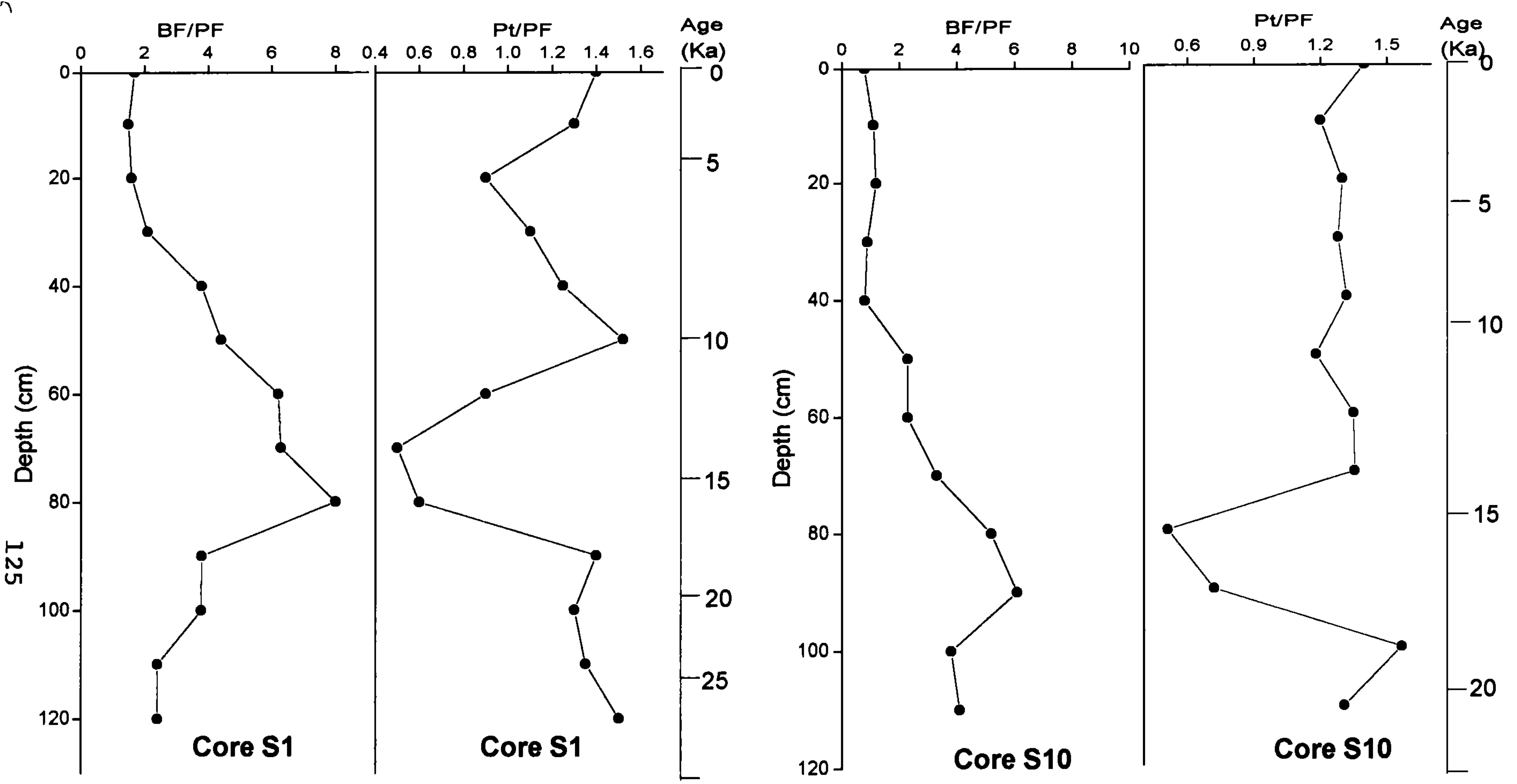

Fig. 6.10. Distribution of benthic/planktic foraminifera (BF/PF) and pteropods/planktic foraminifera (Pt/PF) ratios in cores S1 and S10. Estimated ages are given on right side.

A minimum in Pt/PF ratio (<0.8) is recorded during the LGM. An increase in Pt/PF ratio and corresponding decrease in BF/PF ratio is documented during the post - LGM and pre- LGM periods. BF/PF and Pt/PF ratios recorded in the surficial sediments across the shelf indicate higher value of former and lower value of later in shallower conditions. On the other hand, lower BF/PF ratio and higher Pt/PF ratio indicate deeper condition (Singh et al., 1998). Previous workers have recognised the applicability of planktic percentage in foraminiferal population in paleobathymetric reconstruction (Bandy, 1956; Stehli and Creath, 1964; Wright, 1977; Aoshima, 1978; Van Marle, 1988 and Nigam and Henriques, 1992).

6.3 DOWNCORE VARIATION IN DEPTH SENSITIVE PTEROPODS

Bathymetric distribution of modern pteropods in the study area suggests that certain pteropod species: viz: *Limacina inflata, Creseis acicula, C. virgula* and *C. chierchiae* are highly depth sensitive. The limited depth range of these pteropod species with high sensitivity to the variations in water depth makes them good indicators of past bathymetric conditions. Thus, the modern pteropod data on depth – species relationship can be employed to fossil record with confidence. A model on the relationship between abundance ratio of *L. inflata*/*Creseis* spp. and water depth has been proposed (Singh et al., 2001) (Fig. 4.11, Chapter.4). The proposed model provides data on the modern distribution – depth relationship of these bathometers, which can be used for inferring the paleobathymetry of the study area.

The downcore variations of the bathymetric indicators (*L. inflata/ Creseis* spp.) in cores S1 and S10 were studied in order to reconstruct the late Quaternary history of paleo-water depth variation and therefore sea level fluctuations in the study area (Fig.6.11). *L. inflata/Creseis* spp. numerical abundance ratio broadly follows the pattern of $\delta^{18}O$ record (Figs.5.1 & 5.2). The glacial period is characterised by lower value of *L .inflata/Creseis* spp. ratio and the interglacial by higher value. The lowest value occurs during the LGM (0.3 to 0.5). *L. inflata/ Creseis* spp. ratio in core S1 ranges from 2.1 to 2.8 between 36 and 25 Ka BP. From 24 Ka BP, it decreases to its minimum during the LGM. Between 15 and 10 Ka BP, a drastic increase in the value (~3.0) was recorded. From 10 to 5 Ka BP, *L. inflata/Creseis* ratio increase is low but gradual. Since 5 Ka BP, no distinct change in the assemblage is noticed. A gradual increase in *L. inflata* abundance in the assemblages reflects increase in water depth. On the other hand, dominance of *Creseis* spp. (*acicula, virgula* and *chierchiae*) in the assemblage is indicative of shallow water condition. A change in environmental condition resulted due to sea level variation linked with the global climatic cycles is also reflected by the variation in faunal assemblages in terms of other parameters such as BF/PF and Pt/PF and also by the textural characteristics of the sediments (Figs. 6.10, 5.5 & 5.6).

6.4 RECONSTRUCTION OF LATE QUATERNARY SEA - LEVEL CHANGES

Our knowledge on sea level variations during the late Quaternary along the western continental margin of India is still in its infancy. A few efforts have been made to reconstruct Holocene sea-level fluctuations, particularly in northern part

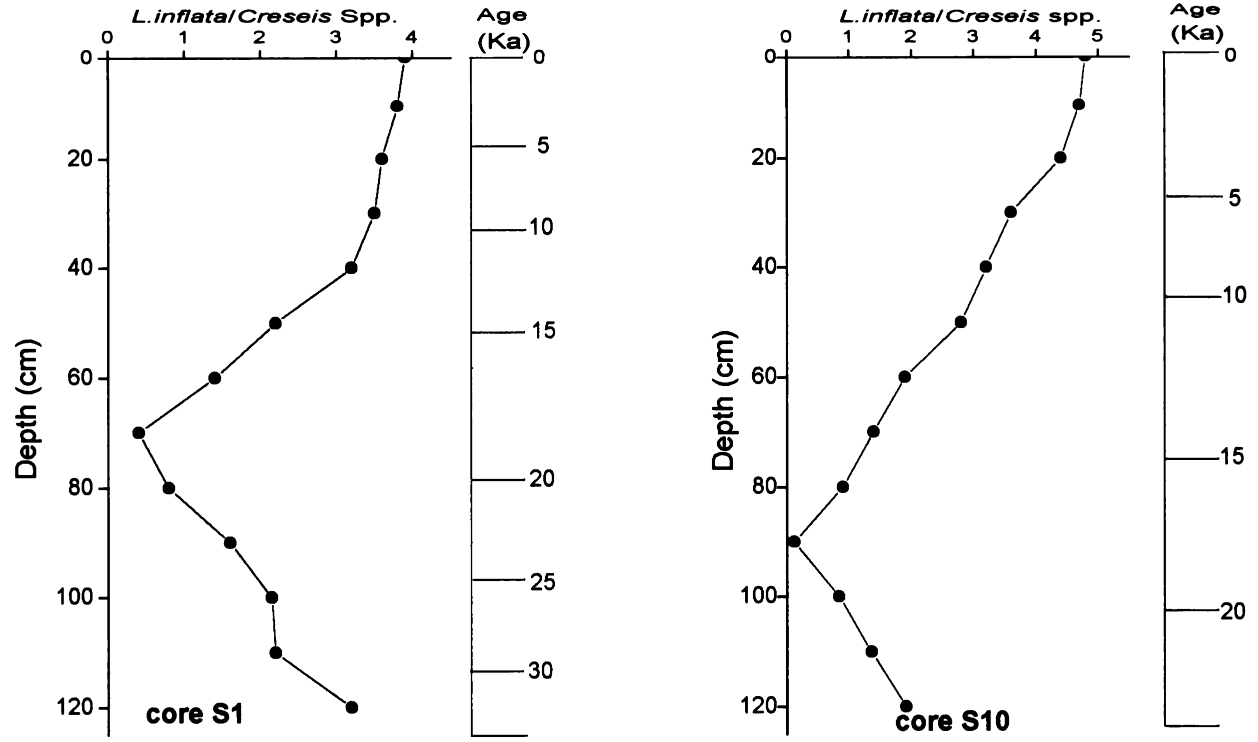

Fig.6.11. Distribution of *L.inflata/Creseis* spp. ratio in cores S1 and S10. Estimated ages are given to right side

of the western continental shelf, using ooids and benthic foraminifera. Kale and Rajaguru (1985), Nigam et al. (1992) and Hashimi et al. (1995) proposed sea level curves for the west coast of India. In the present study, bathymetric changes (therefore sea level changes) along the southwest coast of India during the last 36 Ka BP were inferred from two marine core sections (core S1 and S10) off northern Kerala by using proposed model (Chapter.4, Fig.4.11) on *L. inflata/ Creseis* spp. abundance – depth relationship. The paleo-depth estimate for each sample of the cores S1 and S10 was derived from the *L. inflata/ Creseis* spp. value using the equation ($X= 31.8215 + 42.6487x - 3.37914\ Y^2$). Based on the paleobathymetric records obtained from cores S1 and S10, sea level curves were drawn (Fig.6.12). Sea level curves for both the core sites situated closely reflect compliant consistency in terms of changing pattern (amount, timing and rate) in paleo-water depth. This study offers first time sea level data along the western continental shelf of India for the period prior to the LGM.

The present result was also compared with the records of glacio-eustatic sea level changes (Fairbridge, 1977; Duplessy, 1982; Chappell and Shackleton, 1986 and Fairbanks, 1989). The sea level curve at core site S1 reveals that the sea was below 25m than PMSL around 36 Ka BP (Fig.6.12). A gradual lowering with slow rate occurred from 36 to 25 Ka BP. The sea level at 30 Ka BP stood around 40m below PMSL and corroborating the observation made by Chappell and Shackleton (1986). The rate of sea level lowering increased from 22 Ka BP. After reaching its maximum lowering during the LGM (-100m ± 5m), sea level started rising. The global picture of sea level fluctuation derived from the

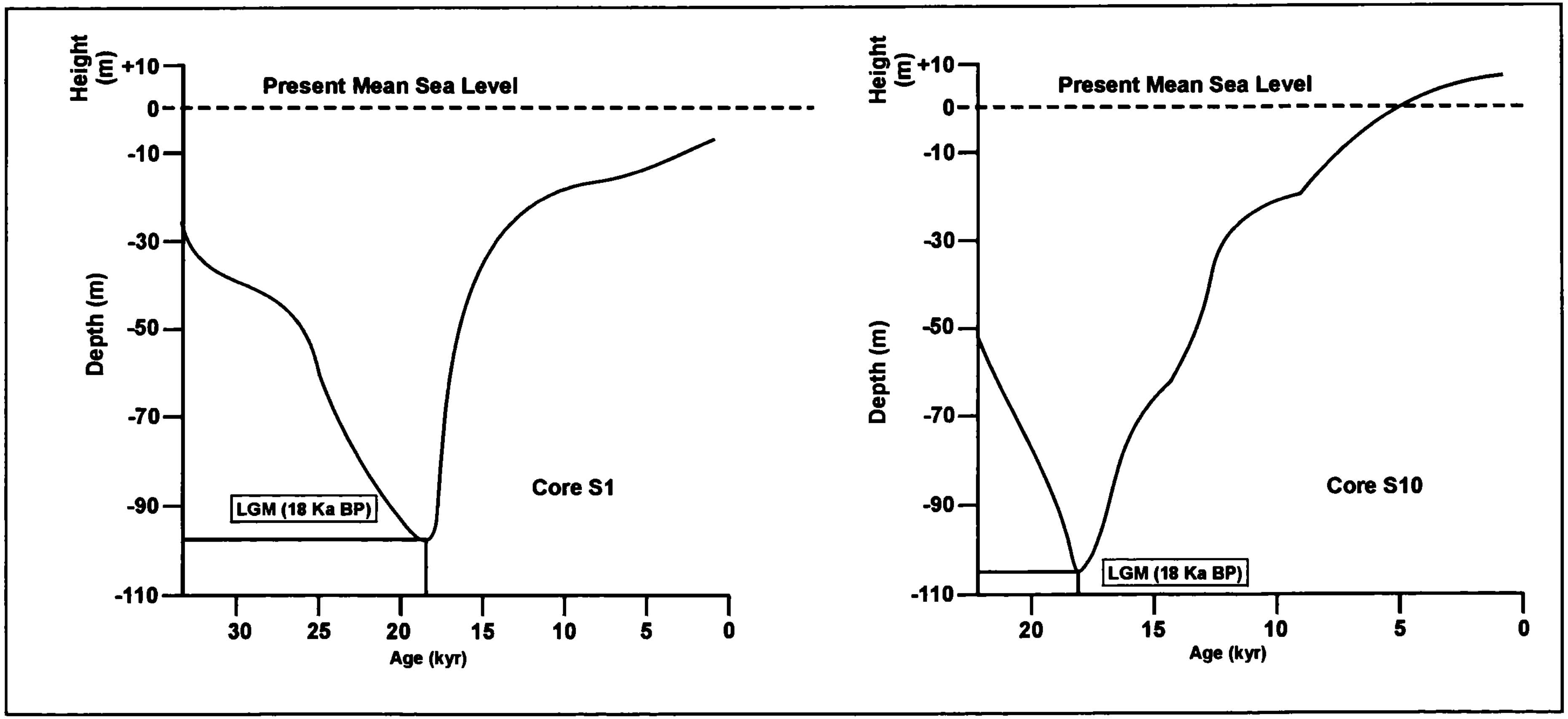

Fig. 6.12. Late Quaternary sea level curves for the southwestern continental margin based on the inferred bathymetry from cores S1 and S10 [PMSL : Present Mean Sea Level (depth sounding)]

behaviour of west Antarctic sheet suggests a gradual shrinkage after 18 Ka (LGM) resulting sea level rise (Clark and Lingle, 1979). The estimate of sea level during LGM derived here is a little different to the estimate 121 ± 5m by Fairbanks (1989). Between 15 and 10 Ka BP, the rate of sea level rise was maximum as evident by the nature of sea level curves with steep gradient during this period. The sea level continued rising after 10 Ka BP but relatively with the reduced rate. The level of the sea was 20 ± 5 m below the present sea level at 10 Ka BP. Since 5 Ka BP, the sea level rise has been very slow. A rapid sea level rise between 14 and 7 Ka BP appears to be attributed to high glacial melt water discharge during this period as suggested previously by Fairbanks (1989). Fairbridge (1977) documented minor phases of still stands or reversals in overall rising trend during the early Holocene. A minor phase with reduced rate in sea level rise observed between 12 and 10 Ka BP from core S10 curve can be linked with the mid-glacial pause with little ice volume loss as suggested by the French two-step deglaciation model (Ruddiman, 1987). This event could not be detected in core S1, probably due to the constraints of non-availability of finer time resolution data on sea level fluctuations.

The general trend of sea level changes for the last 36,000 years deciphered here has similarity to many records in the world and also with the Holocene sea-level curve proposed by Hashimi et al. (1995). A minor difference between present sea level data and other regional and global records could have occurred due to other factors. Precision in paleo-water depth estimation using *L.inflata*/*Cresis* spp. records in core sections may be influenced by factors other than bathymetry, such as glacial/ interglacial fluctuation in ecology, hydrography, sediment dilution, $CaCO_3$ dissolution and fragmentation of pteropod population in sediments. Nevertheless, present study proves pteropods as important biological indicators for reconstructing general trends of sea level from core records along the western continental shelf of India.

Chapter.7

SUMMARY

The sedimentary record of western continental shelf offers an excellent opportunity to investigate the late Quaternary foraminiferal and pteropod assemblages and their response to the past oceanographic changes. In the present work, a detailed micropaleontological investigation of foraminiferal and pteropod records in the late Quaternary sequence from the shelf of northern Kerala was carried out with the specific objectives: (i) to study the distribution pattern of Recent foraminifera and pteropods and to identify new proxies useful for the paleoenvironmental interpretations (ii) to establish a precise chronostratigraphy for the late Quaternary core sections and (iii) to study temporal distribution of the foraminifera and pteropods in order to evaluate their response to the late Quaternary oceanographic and climatic changes occurred along the shelf of northern Kerala. To achieve these scientific objectives, a systematic transect-wise core sampling across the shelf of northern Kerala (covering innershelf, mid-shelf and outershelf regimes) was done and total fourteen cores were recovered. Of these sediment cores, two coming from the outershelf represent complete record of the last glacial and the Holocene. The foraminifera (benthic and planktic) and pteropods were examined both qualitatively and quantitatively. An emphasis was given on the detailed investigation of benthic foraminiferal and pteropod assemblages. In total 59 benthic foraminiferal, 18 planktic foraminiferal and 14 pteropod species were recorded. All the benthic foraminifera and pteropods were briefly discussed with their systematic positions and salient morphological features and illustrated by scanning electron micrographs. A preliminary qualitative palynological study was also carried out on one core section recovered from the outershelf regime, which enabled to record 13 types of pollen and spores. Quantitative data of microfaunal assemblages were generated on split samples (>125µm) consisting >300 specimens of benthic foraminifera and 200-300 individuals of planktic foraminifera and pteropods. Whole sample was analysed in case of a rare occurrence of foraminifera and pteropods. Planktic component of foraminiferal assemblages was used mainly for estimating absolute abundance.

Core-top samples were used for recording spatial distribution pattern of foraminifera and pteropods. The record of numerical foraminiferal abundance suggests that the benthic population richness across the shelf is controlled by the nature of the substrate in association with the nutrient content, bathymetric and other hydrographic parameters. The study reveals a bathymetric control on benthic/planktic (BF/PF) foraminiferal and pteropods/planktic foraminiferal (Pt/PF) abundance ratio. Bathymetric distribution pattern of BF/PF ratio is opposite to the Pt/PF ratio with decreasing trend of former from the shore across the shelf. Quantitative benthic foraminiferal record in the surficial sediments reveals a positive correlation between the diversity and bathymetry. R-mode cluster analysis performed on 30 significant Recent benthic foraminifera, determines three major assemblages, Assemblage I (>115m W.D., outershelf), Assemblage II (115-50m W.D., mid-shelf) and Assemblage III (<50m W.D., innershelf). And these assemblages correspond to three distinct outershelf, mid-shelf and innershelf lithofacies. The three benthic foraminiferal biofacies are in association with the three characteristic pteropod assemblages identified across the shelf of northern Kerala.

An attempt was made to document the relationship of Recent benthic foraminiferal distribution with nature of substrate, nutrient content in sediments, bathymetry and hydrographic condition. Recent benthic foraminiferal assemblages recorded from the study area comprise mainly of rotaliids, elphidiids, nonionids, miliolids, bolivinids cibicids, uvigerininids, lagenids and agglutinated taxa. The present investigation suggets a positive correlation between abundance of rotaliids as well as nonionids and nature of substrate, organic matter. The present observation further reveals that the bolivinids in the study area prefer coarse substrate and avoid an environmental condition with seasonal salinity fluctuations. It is noticed that *U.peregrina* prefers muddy substrate richer in organic matter and normal marine condition. The maximum concentration of miliolids and cibicidids recorded from the mid-shelf region indicates their preference for coarse substrate with low organic matter and relatively high salinity condition. The agglutinated taxa are conspicuously absent in the innershelf samples and showing their maximum concentration in the outershelf region having fine substrate, high organic carbon and normal marine condition.

Bathymetric distribution pattern of pteropods indicates that certain species (*Limacina inflata*, *Creseis acicula*, *C.chierchiae* and *C. virgula*) are highly sensitive to change in water depths. The present observation validates the idea " pteropods as bathymetric indicator" proposed by the previous workers. An attempt has been made to prepare a model on relationship between abundance change of depth sensitive species and variation in present bathymetric condition. The proposed model was applied to decipher the late Quaternary sea level history of this region based on the temporal variation of the depth sensitive pteropods.

A precise chronological framework for the late Quaternary sequence is a prerequisite for the better record of faunal succession and deciphering the past environmental conditions. The chronostratigraphy with high precision of a sediment core section is established by integrating biostratigraphy with lithostratigraphy, radiochronology and oxygen isotope stratigraphy. The conventional planktic foraminiferal criteria are found to be not applicable for biostratigraphic subdivision in shallow marine cores of the continental shelves. Moreover, sedimentary records across the shelf vary in their faunal assemblages in space and time because sedimentation herein is mainly controlled by the sea level transgressive/regressive cycles. Therefore, biostratigraphic markers applicable for one region (eg. outershelf) may not be useful for the other regions across the shelf. In the present work, cores from all the three regimes (outer-, mid- and innershelf) were studied. An attempt has been made to establish integrated bio-litho-radio-chronostratigraphy for the two best suitable cores of the outershelf regime. Both the cores represent complete record of the last glacial and the Holocene period (one represents the last 36,000 years and another 23,000 years). The present study also enabled to recognise the important foraminiferal criteria, which could be useful in biostratigraphic subdivisions in the outershelf, the mid-shelf and the innershelf sedimentary records. *Globorotalia menardii and Globigerinoides sacculifer* (tropical planktic foraminifera) are found to be applicable in demarcating Holocene/Pleistocene boundary in outershelf core sections. The study suggests that the quantitative occurrence of certain benthic foraminifera such as *Hanzawaia mexicana*, *Nonion* spp. can be considered as important criteria for the biostratigraphic division of shallow marine sections (mid- to innershelf).

For vertical pattern study of the late Quaternary foraminiferal and pteropod assemblages, four cores were chosen: two from the outershelf and one each from the mid- and the innershelf regimes. Foraminiferal records in the examined core sections indicate variations in absolute abundance of planktic and benthic components. The major fluctuations in benthic foraminiferal assemblages are reflected in diversity, abundance of epifaunal, infaunal taxa, relative abundance of rotaliids (mainly *Ammonia beccarii* s.l.), miliolids, bolivinids and uvigerinids. Benthic foraminiferal record of the last 23,000 yrs shows an increased abundance of epifaunal taxa (preferring muddy substrate and higher organic carbon) during 18-14 Ka BP and at around 5 Ka BP. High abundance of infauna during these intervals has been suggested to reflect eutrophication and high productivity condition associated with the enhanced upwelling. A general increase in abundance of bolivinids (*B. marginata* and *B .perseinsis*) and uvigerinid (*U. peregrina*) occurring frequently in eutrophic condition is also documented during this interval. The change in bathymetry at the depositional site and the nature of sediments (substrate) resulted due to sea level fluctuations during the late Pleistocene – Holocene period, has been considered as probable reason for the downcore variation in relative abundance of *H. mexicana*, miliolids and *Ammonia beccarii*.s.l. . Additionally, a change in hydrographic condition linked with the last glacial-Holocene climatic variation might have also influenced the benthic foraminiferal assemblages. The benthic foraminiferal record of the innershelf region reflects prominent downcore variation in relative abundance of *Nonion* spp. (infauna), *H.*

mexicana, *Ammonia beccarii* s.l., *Cancris*, *Elphidium* and agglutinate taxa (epifauna). The benthic foraminiferal assemblage in the upper portion of the core is distinct from the lower portion. The lower stratigraphic unit (late Pleistocene) is characterised by the dominance of epifaunal taxa (*H.mexicana*, *Ammonia beccarii* s.l., *Cancris* spp. , *Elphidium* and the agglutinated taxa) in benthic population. The estuarine-lagoonal near-shore epifaunal benthic foraminiferal population was gradually replaced by the typical innershelf infaunal nonionids in the upper stratigraphic unit representing the Holocene period. A gradual rise of sea level during the post LGM period probably resulted in change of depositional environment and consequently in bio-litho facies.

The downcore variation of the depth sensitive pteropods (*Limacina inflata* and *Creseis* spp.) in two cores retrieved from the outertshelf, was investigated in order to reconstruct the late Quaternary bathymetric changes in the study area. The paleo-depth estimate was made based on the record of *L.inflata/Creseis* spp. ratio in the cores using the proposed model on abundance – depth relationship of these bathymetric indicators. The paleobathymetric records obtained from the two cores indicate compliant consistency in terms of changing pattern (amount, timing and rate) in paleo-water depth. Sea level curves for both the core sites were drawn using the paleo-water depth records. The present investigation reveals that the sea was below 25m than Present Mean Sea Level (PMSL) around 36Ka BP. A gradual lowering with slow rate occurred from 36 to 25 Ka BP. The rate of sea level lowering increased from 22 Ka BP. During the last glacial maximum, sea level was approximately 100m below than PMSL. The study indicates that the rate of sea level rise was maximum between 15 and 10 Ka BP. The sea level continued rising after 10 Ka BP but with the reduced rate. The inferred sea level record shows that the sea level rise has been very slow since 5 Ka BP. This study provides first time sea level data along the western continental shelf of India for the period prior to the LGM (Last Glacial Maximum).

PLATE 1

Fig. 1	*Reophax agglutinatus* Cushman	X
Fig. 2	*Textularia agglutinans* d'Orbigny	X
Fig.3	*T.agglutinans* d'Orbingny ;enlarged view of agglutinated surface	X
Fig.4	*Textularia pseudocarinata* Cushman	X
Fig.5	*Quinqueloculina agglutinans* d'Orbigny ; front view	X
Fig.6	*Q.agglutinans* d'Orbigny ; rear view	X
Fig.7	*Q.agglutinans* d'Orbigny ;apertural view	X
Fig.8	*Quinqueloculina seminulum* (Linnè); front view	X
Fig.9	*Q. semimulum* (Linnè); front view	X
Fig.10	*Quinqueloculina undulose costata* Terquem; front view	X
Fig.11	*Q. undulose costata* Terquem; apertutal view	X
Fig.12	*Q. undulose costata* Terquem; enlarged view of costae	X
Fig.13	*Quinqueloculina echinata* d'Orbigny; front view	X
Fig.14	*Spiroloculina communis* Cushman and Todd; rear view	X
Fig.15	*S. communis* Cushman and Todd; front view	X
Fig.16	*S. communis* Cushman and Todd; enlarged front view	X
Fig.17	*Spiroloculina exima* Cushman; rear view	X
Fig.18	*Triroloculina costata* Brady; front view	X
Fig.19	*Triloculina echinata* d'Orbigny ; rear view	X1
Fig.20	*T. echinata* d'Orbigny ; front view	X1
Fig.21	*T. echinata* d'Orbigny ; apertural view	X3
Fig.22	*Triloculina laevigata* d'Orbigny ; front view	X9
Fig.23	*Triloculina oblonga* (Montagu); front view	X1
Fig.24	*T. oblonga* (Montagu); rear view	X1
Fig.25	*Triloculina tricarinata* (d'Orbigny); front view	X1
Fig.26	*T. tricarinata* (d'Orbigny); apertural view	X2
Fig.27	*Pyrgo depressa* d'Orbigny	X1
Fig.28	*Lenticulina calcar*(Linnè)	X1
Fig.29	*L. calcar*(Linnè); apertural view	X1

PLATE

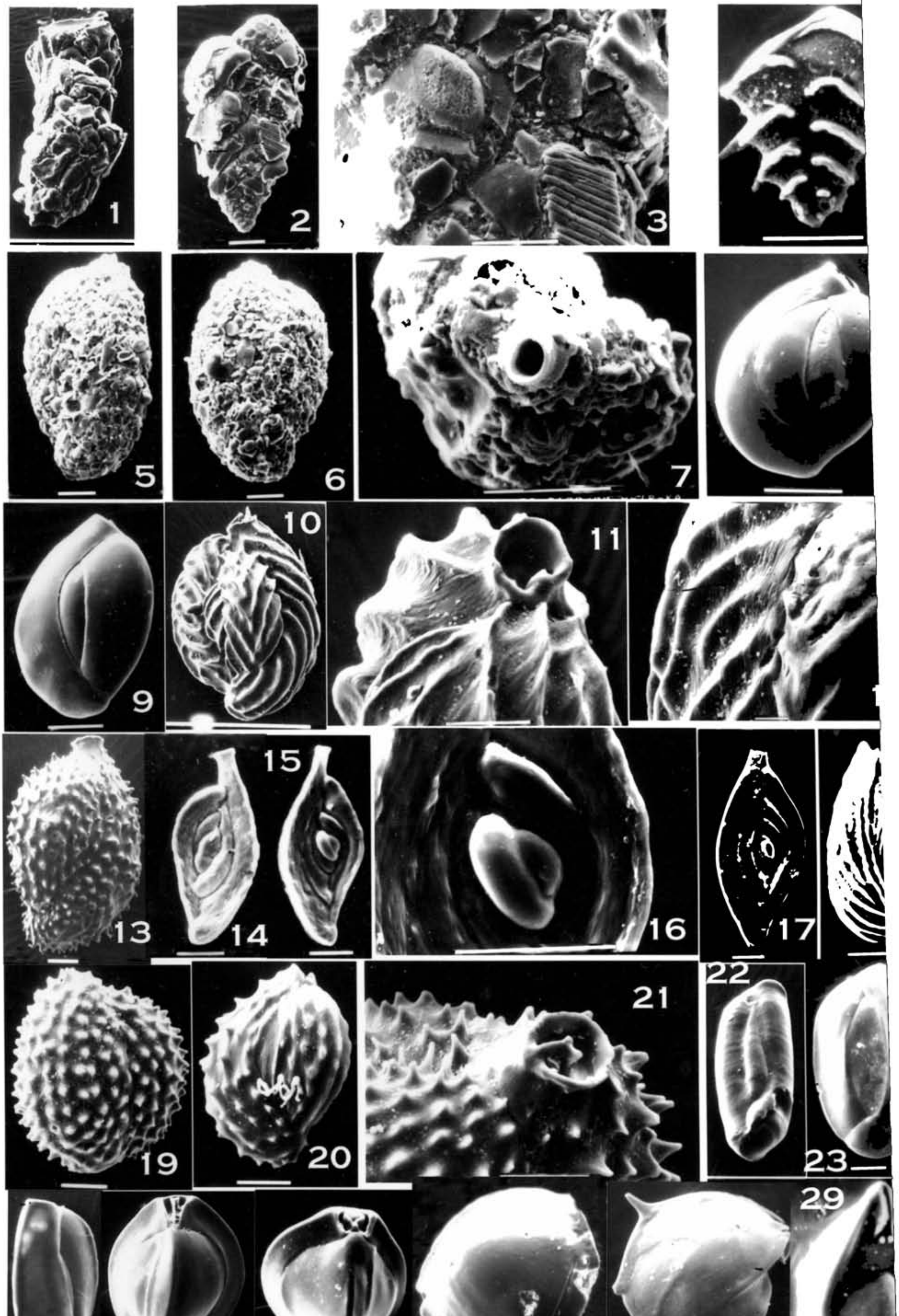

PLATE 2

Fig.1	*Lenticulina gibba*(d'Orbigny)	X170
Fig.2	*Lenticulina thalmanni* (Hessland); dorsal view	X252
Fig.3	*L. thalmanni* (Hessland), ventral view	X194
Fig.4	*L. thalmanni* (Hessland), apertural view	X462
Fig.5	*Lenticulina orbicularia* (d'Orbigny); dorsal view	X252
Fig.6	*Lenticulina sp. ;* dorsal view	X212
Fig.7	*Lenticulina sp. ;* ventral view	X212
Fig.8	*Lagena aspera* (Reuss)	X221
Fig.9	*Lagena aspera* (Reuss); enlarged neck view	X503
Fig.10	*L. aspera* (Reuss); enlarged view bottom portion	X655
Fig.11	*Lagena hispidula* Cushamn	X212
Fig.12	*Lagena striata* (d'Orbigny);	X274
Fig.13	*L. striata* (d'Orbigny); enlarged view of neck	X1420
Fig.14	*Lagena striata var. strumosa* Cushman	X231
Fig.15	*L. striata var. strumosa* Cushman : enlarged view of neck	X549
Fig.16	*Nonion cummunis* (d'Orbigny); Spiral view	X156
Fig.17	*N. cummunis* (d'Orbigny); umbilical view	X221
Fig.18	*Nonion fabum* (Fichtel and Moll); Spiral view	X252
Fig.19	*N.fabum* (Fichtel and Moll); umbilical view	X252
Fig.20	*Elphidium advenum* (Cushamn); umbilical view	X241
Fig.21	*E. advenum* (Cushamn); enlarged view of surface	X549
Fig.22	*Elphidium cripsum* (Linnè); umbilical view crispum	X163
Fig.23	*Elphidium discoidale* (d'Orbigny); spiral view	X221
Fig.24	*E. discoidale* (d'Orbigny); umbilical view	X221
Fig.25	*E. discoidale* (d'Orbigny); apertural view	X503
Fig.26	*E. discoidale* (d'Orbigny); enlarged surface view	X503

PLATE 2

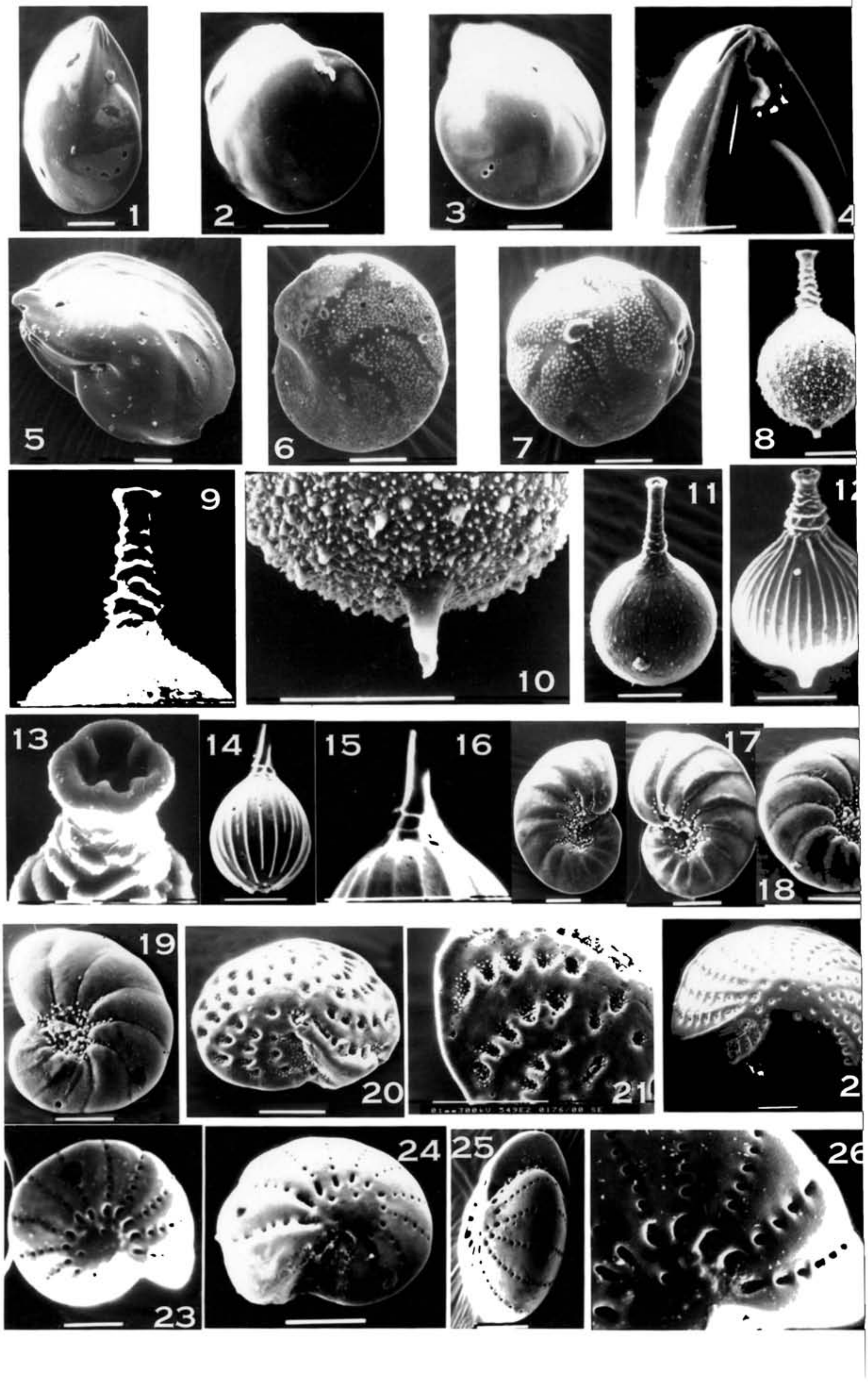

PLATE 3

Fig.1	*Bulimina marginata* d'Orbigny	X212
Fig.2	*B. marginata* d'Orbigny	X212
Fig.3	*B. marginata* d'Orbigny; apertural view	X549
Fig.4	*B. marginata* d'Orbigny; enlarged view of surface ultrastructure	X845
Fig.5	*Bolivina amygadalaeformis* Brady	X150
Fig.6	*B. amygadalaeformis* Brady; enlarged view of surface ultrastructure	X356
Fig.7	*Bolivina persiensis* Lutze	X186
Fig.8	*B. persiensis* Lutze; apertural view	X885
Fig.9	*B. persiensis* Lutze; enlarged view of surface ultrastructure	X745
Fig.10	*Bolivina sp.*	X241
Fig.11	*Bolivina spathulata* (Williamson); dorsal view	X178
Fig.12	*B. spathulata* (Williamson); ventral view	X163
Fig.13	*Bolivina ordinaria* Phleger and Parker; dorsal view	X178
Fig.14	*B. ordinaria* Phleger and Parker; ventral view	X241
Fig.15	*Loxostomum limbatum (*Brady) var. *costulatum* Cushman	X115
Fig.16	*L. limbatum (*Brady) var. *costulatum* Cushman; apertural view	X406
Fig.17	*L. limbatum (*Brady) var. *costulatum* Cushman, surface ultrastructure	X462
Fig.18	*Brizalina aenariensis* O.G.Costa	X186
Fig.19	*B. aenariensis* O.G.Costa; surface ultrastructure	X372
Fig.20	*Reussella spinulosa* (Reuss)	X252
Fig.21	*R. spinulosa* (Reuss); apertural view	X503
Fig.22	*Reussella simplex* (Cushman)	X221
Fig.23	*Trimosina milletti* Cushman; dorsal view	X212
Fig.24	*T. milletti* Cushman; ventral view	X274
Fig.25	*T. milletti* Cushman; ventral view	X263
Fig.26	*T. milletti* Cushman; apertural view	X356

PLATE

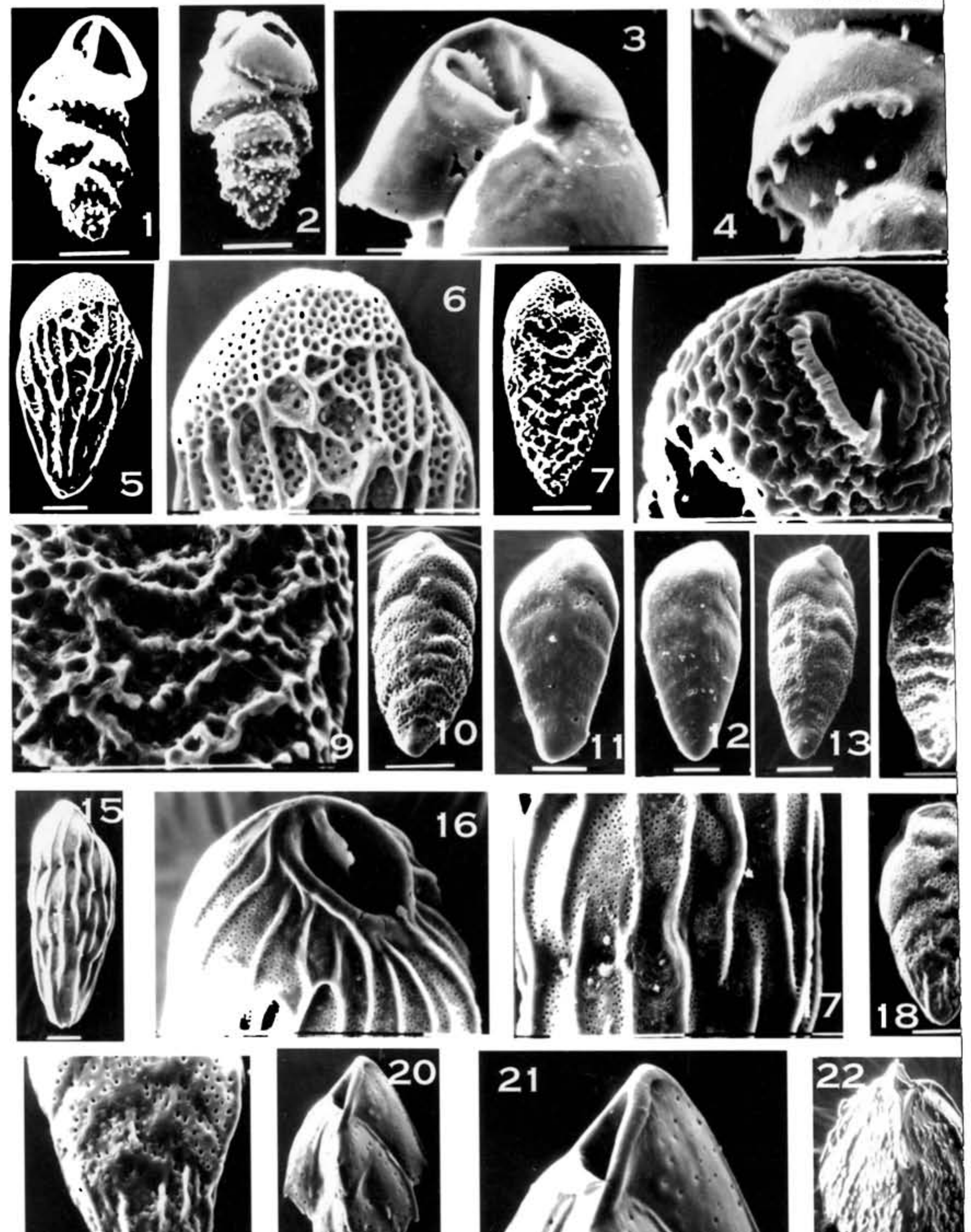

PLATE 4

Fig.1	*Fursenkoina complanata (*Egger*)* ; dorsal view	X163
Fig.2	*F. complanata (*Egger*)* ; ventral view	X221
Fig.3	*Uvigerina auberiana* d'Orbigny	X231
Fig.4	*U. auberiana* d'Orbigny; surface ultrastructure	X655
Fig.5	*U. auberiana* d'Orbigny; apertural view	X885
Fig.6	*Uvigerina peregrina* Cushamn	X120
Fig.7	*U. peregrina* Cushamn; apertural view	X312
Fig.8	*U. peregrina* Cushamn; surface ultrastructure	X312
Fig.9	*Siphouvigerina interrupta* (Brady)	X163
Fig.10	*Siphouvigerina porrecta* (Brady)	X221
Fig.11	S. *porrecta* (Brady), surface ultra structure	X442
Fig.12	*S. porrecta* (Brady), apertural view	X372
Fig.13	*Trifarina aff. anglulosa* (Williamson) , ventral view	X203
Fig.14	*T. aff. anglulosa* (Williamson), dorsal view	X221
Fig.15	*Trifarina carinata* (Cushamn)	X170
Fig.16	*T. carinata* (Cushamn), apertural view	X442
Fig.17	*Lamarckina scabra* (Brady)	X163
Fig.18	*Rotalidium annectens* (Parker and Jones); ventral view	X97
Fig.19	*R. annectens* (Parker and Jones); dorsal view	X97
Fig.20	*R. annectens* (Parker and Jones); apertural view	X212
Fig.21	*Asterorotalia dentate* (Parker and Jones); dorsal view	X57
Fig.22	*A. dentate* (Parker and Jones); ventral view	X57
Fig.23	*Ammonia beccarii* (Linnè); dorsal view	X356
Fig.24	*A. beccarii* (Linnè); ventral view	X312
Fig.25	*Cancris auriculus* (Fichtel and Moll); dorsal view	X221
Fig.26	*C. auriculus* (Fichtel and Moll); ventral view	X221
Fig.27	*Amphestegina lessonii d'Orbigny;* spiral view	X287
Fig.28	*A. lessonii d'Orbigny;* umbilical view	X287
Fig.29	C*ibicides refulgens* de Montfort; spiral view	X221
Fig.30	*Geminospira bradyi* Bermudez	X194
Fig.31	*G. bradyi* Bermudez, apertural view	X680
Fig.32	*G. bradyi* Bermudez, apertural view	X1620
Fig.33	*Hanzawaia mexicana* Lankford, spiral view	X194
Fig.34	*Hanzawaia mexicana* Lankford, umbilical view	X194
Fig.35	*Hanzawaia mexicana* Lankford, apertural view	X194

PLATE

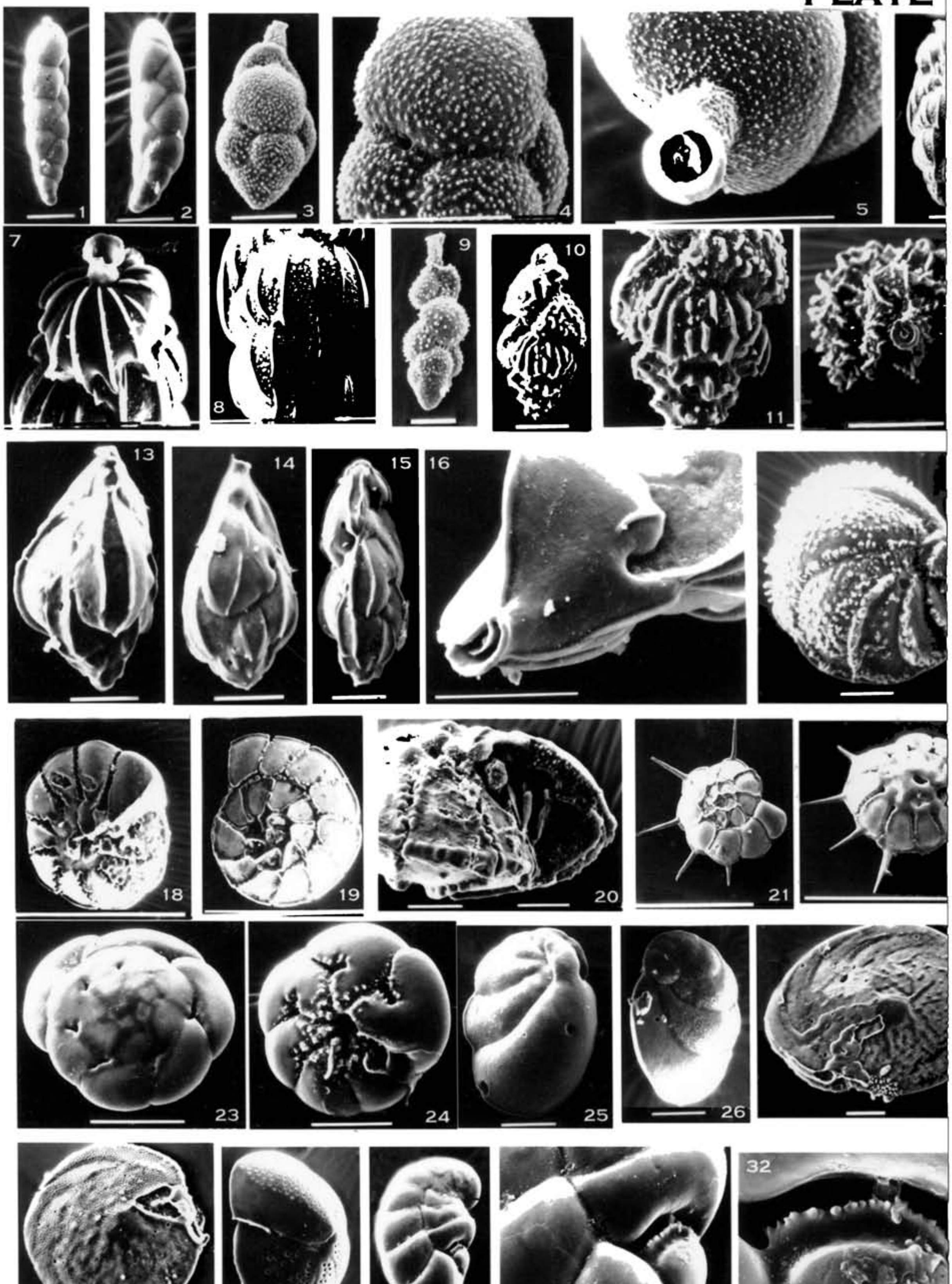
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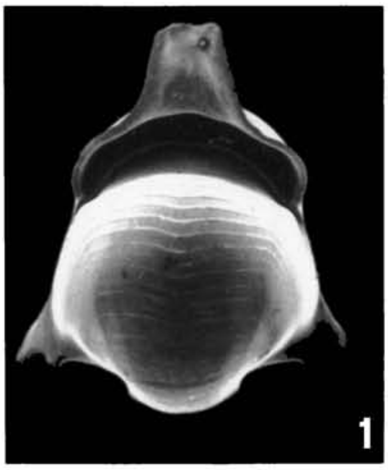
PLATE 5

Fig. 1	*Cavolinia longirostris* (de Blainville)	X100
Fig. 2	*Cavolinia longirostris* (de Blainville)	X420
Fig. 3	*Cavolinia longirostris* (de Blainville)	X173
Fig. 4	*Cavolinia gibbosa* (d'Orbigny)	X184
Fig. 5	*Clio convexa* (Boas)	X102
Fig. 6	*Creseis virgula conica* (Rang)	X102
Fig. 7	*Creseis acicula* (Rang)	X104
Fig. 8	*Creseis virgula virgula* (Rang)	X98
Fig. 9	Creseis virgula conica (Rang)	X110
Fig. 10	Creseis virgula conica (Rang)	X117

PLATE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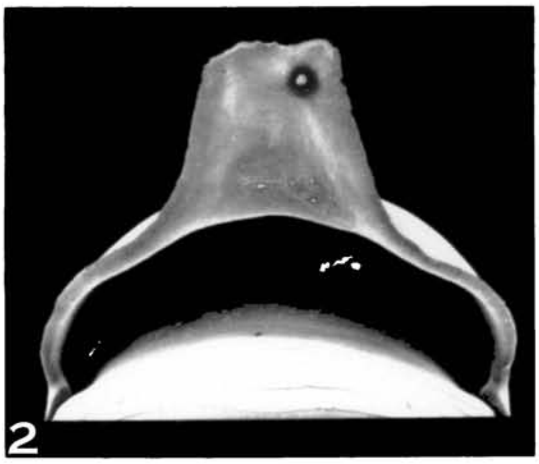
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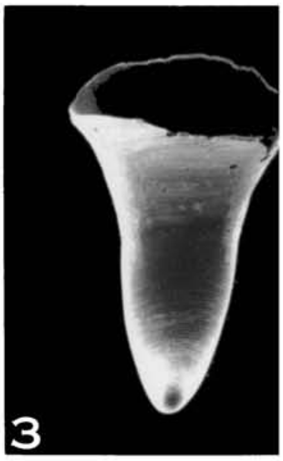
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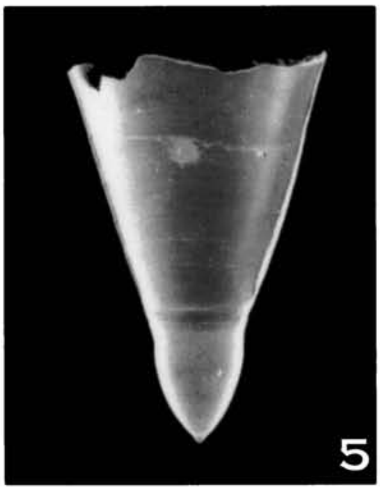
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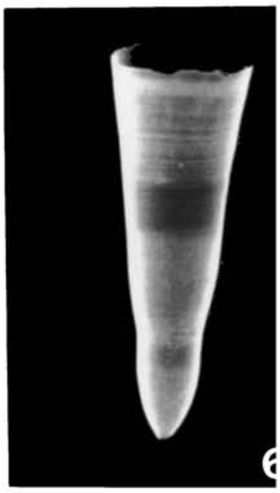
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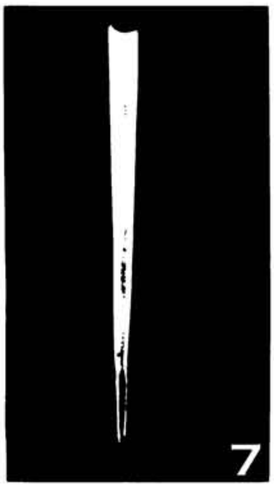
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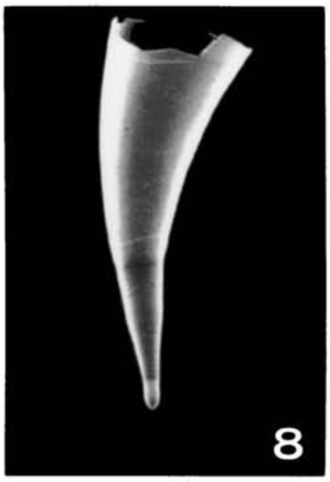
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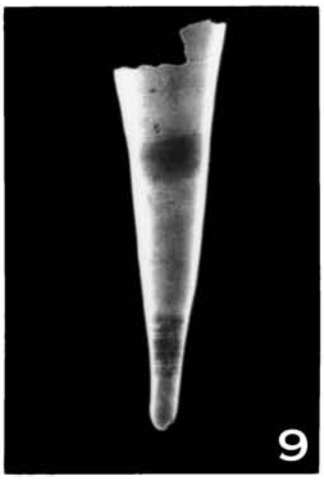
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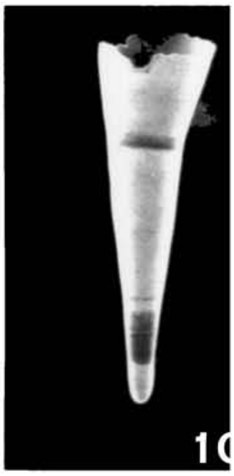
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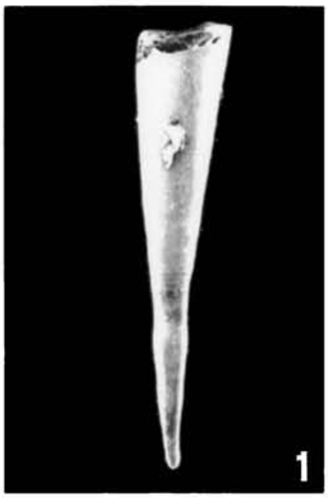
PLATE 6

Fig. 1	*Creseis chierchiae* (Boas)	X105
Fig. 2	*Creseis chierchiae* (Boas)	X210
Fig. 3	*Creseis chierchiae* (Boas)	X107
Fig. 4	*Diacria quadridentata* (de Blainville)	X95
Fig. 5	*Diacria quadridentata* (de Blainville)	X97
Fig. 6	*Diacria quadridentata* de Blainville *(enlarged view of surface)*	X170
Fig. 7	*Diacria trispinosa* (de Blainville)	X124
Fig. 8	*Diacria quadridentata* (de Blainville)	X110
Fig. 9	*Limacina inflata* (d'Orbigny)	X160
Fig. 10	*Limacina inflata* (d'Orbigny)	X175
Fig. 11	*Limacina trochiformis* (d'Orbigny)	X230

PLATE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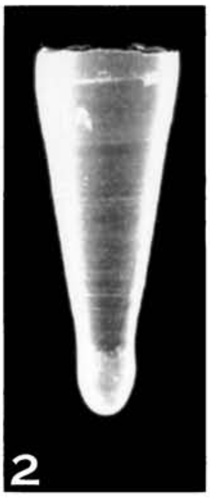
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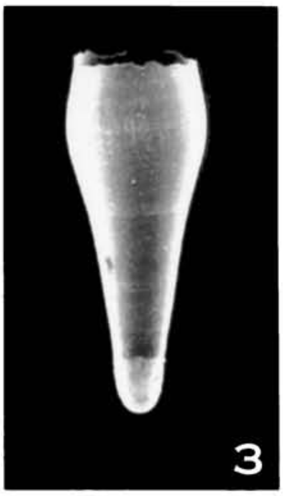
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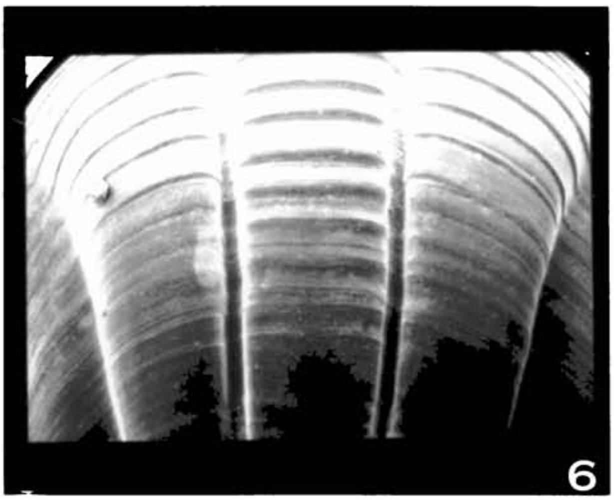
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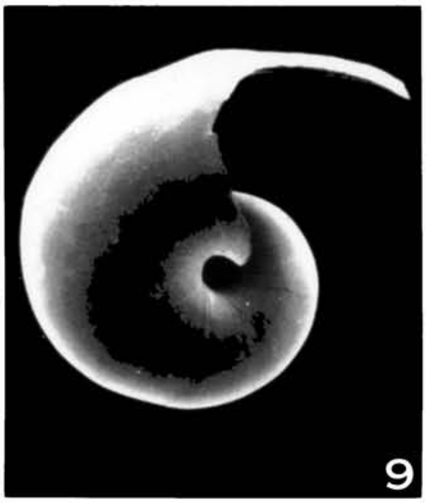
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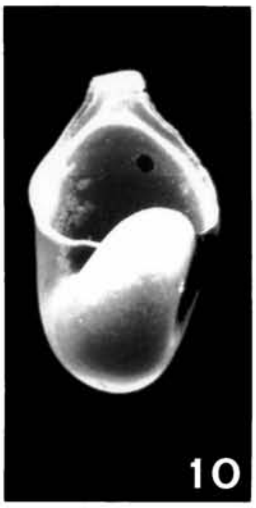
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PLATE 7

Fig.1,2	Tetraporina type	X100
Fig. 3.	Phytoplankton type-1	X100
Fig. 4-6	Phytoplankton type-2	X100
Fig. 7-9	Phytoplankton type-3	X100
Fig. 10	Notothyrites. Sp	X40
Fig. 11,12	Inaperturate spore	X40
Fig. 13	Monoporate spore	X100
Fig. 14, 15	Multicellular type	X100
Fig. 16	Verrucose type	X100
Fig. 17	Laevigate type	X100
Fig. 18-29	Reticulate type	X100
Fig. 30, 31	Spinose type	X100

PLATE 7


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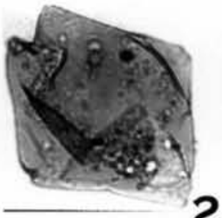
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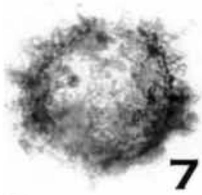
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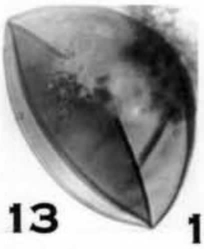
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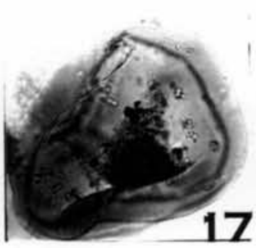
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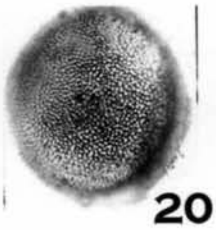
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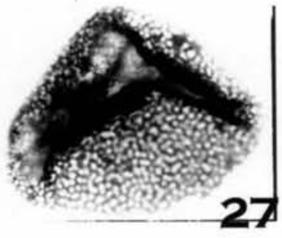
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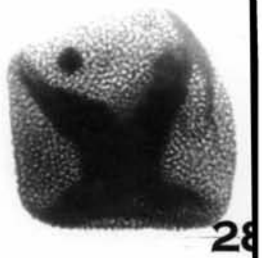
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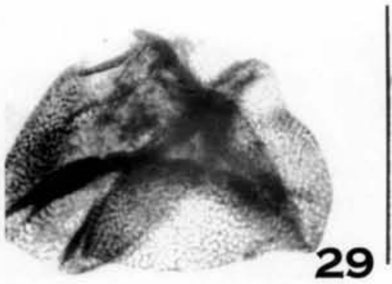
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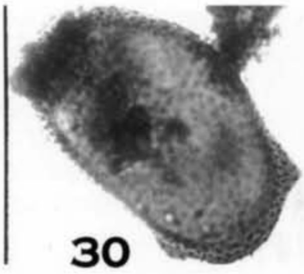
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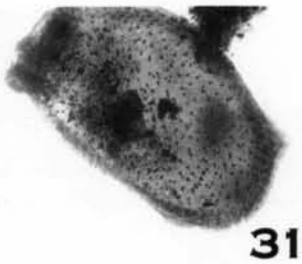
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