PETROGRAPHY, GEOCHEMISTRY AND DIAGENESIS OF CORAL DEPOSITS OF KAVARATTI AND MINICOY ISLANDS, LAKSHADWEEP, INDIA

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by

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CERTIFICATE

This is to certify that the thesis entitled **"Petrography, geochemistry and diagenesis of coral deposits of Kavaratti and Minicoy islands, Lakshadweep, India"** is an authentic record of research work carried out by Mr. N. Anandaraj under my supervision and guidance at the Department of Marine Geology & Geophysics, Cochin University of Science & Technology, under the Faculty of Marine Sciences and no part thereof has been presented for the award of any degree in any university/ Institute.

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CHAPTER 1

INTRODUCTION

1.1 General Introduction

Coral refers to coelenterates secreting a massive calcareous skeleton, particularly of the order Scleractinia (class Anthozoa). Scleractinian corals are divided into two groups: the ahermatypic (non reef building) and the hermatypic (reef building). Structurally these two groups are similar, but the major differences between them lie in the presence of endosymbiotic zooxanthallae in the hermatypic corals, and the extent of their distribution in the seas. The ahermatypic corals are widely distributed at all latitudes, down to several thousand meters depth, whereas the hermatypic corals are stenotypic, limited to warm saline waters, essentially between the tropics of Cancer and Capricon, where minimum water temperatures do not fall below 20°C.

Coral reefs are one of the most ancient ecosystems, dating back to about 225 million years ago. Modern reefs can be as much as 2.5 million years old. Coral reefs thrive mainly in shallow waters, particularly in tropical marine ecosystems and are known for their high rate of biological productivity. The reefs are also sites for rich living and non-living resources.

Coral reefs are generally classified into three main types:

(i) Fringing reefs (shore reefs): develop nearshore where favourable environmental conditions exist such as firm bottom, ideal temperature and salinity and low turbidity (e.g. adjoining the shores of Red Sea).

(ii) Barrier reefs: separated from the shore by a lagoon (e.g. Great Barrier Reef). The width of the lagoon varies considerably along the coasts and with the progressive narrowing of the lagoon, a barrier reef may become fringing.

(iii) Atolls: These are annular reefs that develop at or near the surface of the sea. These can be further sub divided into deep-sea atolls and shelf atolls. Deep sea atolls are isolated with varying sizes (eg. many Indo-Pacific atolls). Shelf atolls are those found on the continental shelf (eg. NW coast of Australia).

The minor types of coral reefs include table reefs, faros, micro atolls, knolls and patch reefs.

Maxwell (1968) has classified the reefs into oceanic and shelf reefs. The oceanic reefs consist of (a) embryonic colony, (b) fringing reef, (c) barrier reef and (d) atolls. The shelf reefs are divided into (1) embryonic colony, (2) platform reef, (3) lagoonal platform, (4) elongated platform reef, (5) wall reef, (6) cuspate reef, (7) prong reef, (8) composite apron reef, (9) open ring reef, (10) open mesh reef, (11) closed ring reef, (12) closed mesh reef, (13) plug reef and (14) resorbed reef.

Although coral reefs cover only a tiny fraction (less than 0.2%) of the ocean bottom, coral reefs capture about half of the Ca added to the ocean every year, fixing it into $CaCO_3$ at very high rates. Coral reefs release CO_2 to the atmosphere due to $CaCO_3$ precipitation. The release of C to the atmosphere in the form of CO_2 from coral reefs is rather very small (less than 100 million tons of C per year) relative to emissions due to fossil fuel combustion (about 5.7 billion tons of C per year). Coral reefs store very little organic carbon and are not very effective "sinks" for CO_2 from the atmosphere.

Coral reefs are among the most endangered ecosystems on earth. Coral reefs in 93 countries (out of 109) have been damaged or destroyed by human activities. This may cause directly or indirectly the death of 5-10% of the world's living reefs, and if continued another 60% could be lost in the next 20-40 years. The most important threats to coral reefs are sedimentation (from poor land use pattern and dredging), eutrophication (over-fertilization and sewage pollution), and overfishing.

Physical damage to coral reefs by tourists would probably be a minor threat if the number of visitors to reefs is restricted to moderate levels. However, large numbers of tourists can cause extensive physical damage. Coral reefs of the major tropical region of the world have been bleached white during the mass bleaching events of the 1980's. Bleaching depresses coral growth rates and in some cases result in mass coral mortality. Bleaching is caused by a number of factors, including siltation, changes in salinity resulting from poor land use pattern, pollution, and slight increase in temperature. Coral reefs may bleach even more extensively if global warming continues unabated.

In India, coral reefs are heavily exploited for coral sand and rock. The extensive collection of ornamental shells, gorgonians, seaweeds, holothuroids and lobsters lead to considerable damage to coral reefs. However, mining of coral and sand are considered to be major problems, particularly in the Gulf of Kutch and as a result some reefs have totally vanished. Apart from anthropogenically caused damages, excess sedimentation to the coral reef areas through fluvial and coastal processes are considered as the greatest threat to the reef areas. Industrial and oil pollution have caused significant damage in the Gulf of Mannar and Palk Bay. Blast fishing and other destructive practices are persistent problems in many areas.

1.2 Coral reefs of the world

The coral reefs of the world cover an estimated area of 6 X 10^5 km^2, equivalent to 0.2% of the world ocean area. Over half of this (54%) lies in the Asiatic Mediterranean and Indian Ocean. Of the remaining, Pacific reefs account for 25%, Atlantic reefs for 6%, Carribbean reefs for 9%, Red Sea reefs for 4% and Persian Gulf reefs for 2% (Smith 1978). Majority of the coral reefs is concentrated along the western part of the three major oceans (Scheer 1984).

1.3 Corals and coral reefs of India

1.3.1 Indian main land

Coral growth along the coast of Indian Peninsula is very limited, most of them are of fringing type and found mainly in Palk Bay and Gulf of Mannar of the Tamil Nadu coast and Gulf of Kutch, Gujarath (Fig. 1.1). There are about 20 small islands and many reefs in the Gulf of Mannar southwest of the Mandapam Peninsula and Rameswaram Island. The scarcity of reefs in the nearshore

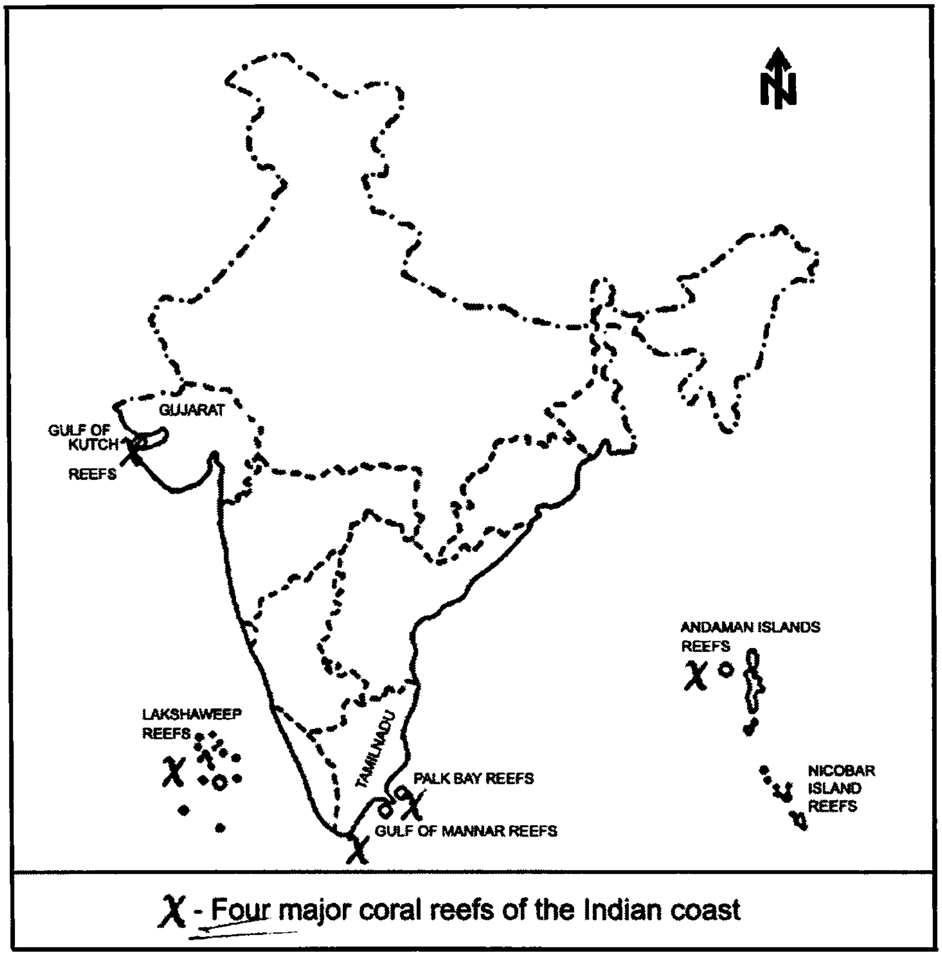

Fig. 1.1 Distributions of coral reefs in India

waters of the Indian coast is principally due to major rivers systems and the sedimentary regime of the continental shelf. About 207 coral species belonging to 55 genera are recorded from the Indian main land reefs.

1.3.2 Indian Island groups

The Andaman and Nicobar Islands in the Eastern Indian Ocean and the Lakshadweep Islands off the southwest coast of India are the Island group of coral reefs. The Andaman and Nicobar groups consist of many hundreds of high islands with extensive fringing reefs. These grow immediately offshore from the mountainous islands and are often several hundred meters wide, extending up to 1000 m in the Nicobars. The Lakshadweep group comprises of 36 islands (most of them are well developed atolls), four large submerged reefs and five big submerged banks. These have the most luxuriant coral growth in India. The Lakshadweep belongs to oceanic group of reef as per the classification of Maxwell (1968).

1.4 Study area

Two islands namely, Minicoy and Kavaratti are selected from Lakshadweep Archipelago for the present study (Fig. 1.2). As the two islands are located hundreds of kilometers apart it is expected to have differences in their mineralogy, geochemistry and their origin. Therefore, Kavaratti (as a representative for the northern block) and Minicoy are selected. Further, a considerable literature is available for Kavaratti while Minicoy is rarely studied. The name Lakshadweep is derived from the two Sanskrit words namely laksha

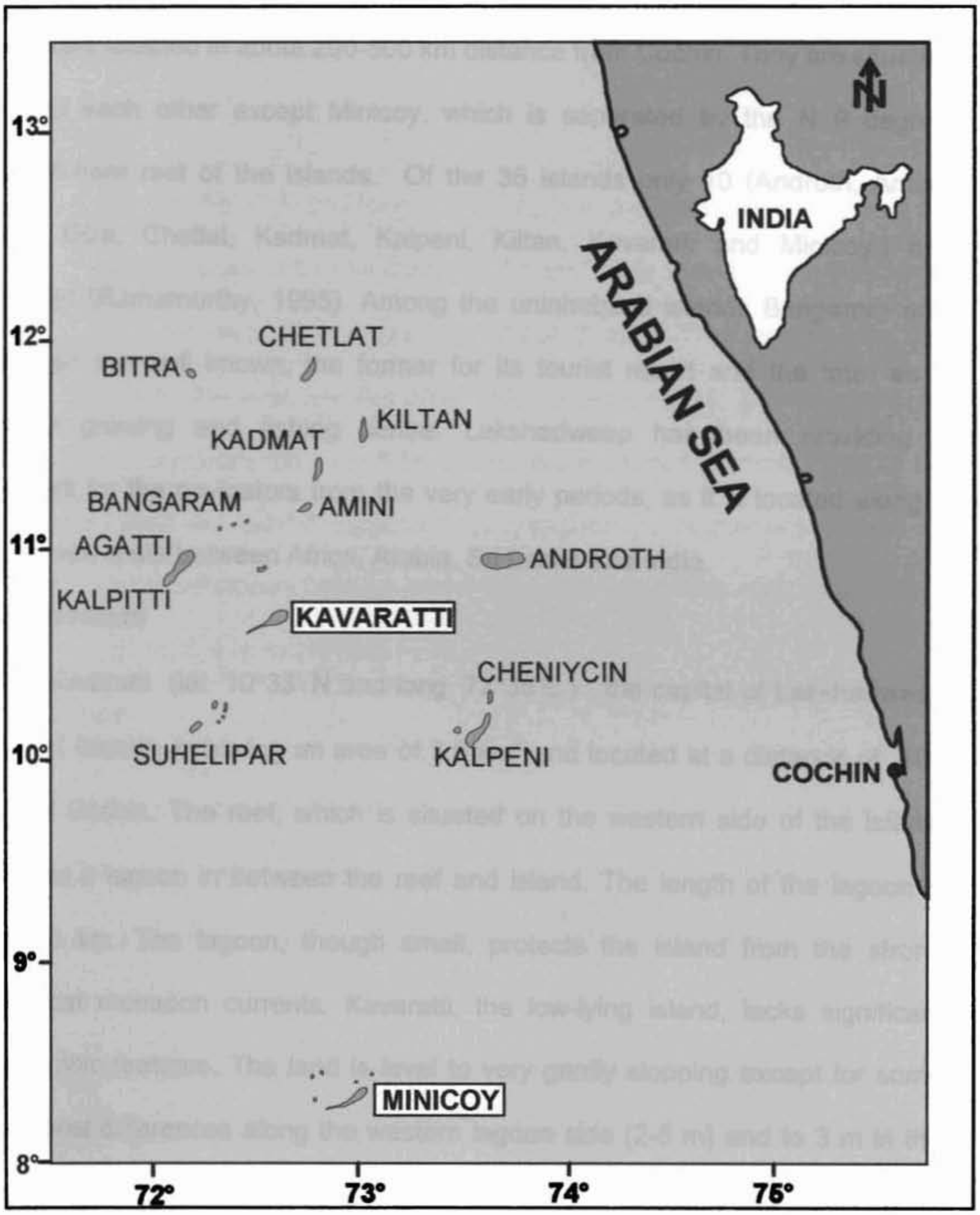

Fig. 1.2 Location of Kavaratti and Minicoy Islands, Lakshadweep

(means hundred thousand) and dweep (means the isles). The synonymous name of Lakshadweep is Laccadive. Lakshadweep islands cover an area of just 32 km^2 (08°00' N to 12°30' N lat. and 71°00' E to 74°00' E long.) (Fig.1.2). These islands are situated in about 200-500 km distance from Cochin. They are situated close to each other except Minicoy, which is separated by the N 9 degree channel from rest of the islands. Of the 36 islands only 10 (Androth, Amini, Agatti, Bitra, Chetlat, Kadmat, Kalpeni, Kiltan, Kavaratti and Minicoy.) are inhabited (Ramamurthy, 1995). Among the uninhabited islands Bangaram and Suhelipar are well known, the former for its tourist resort and the later as a coconut growing and fishing centre. Lakshadweep has been providing a landmark for the navigators from the very early periods, as it is located along a direct trade route between Africa, Arabia, Sri Lanka and India.

1.4.1 Kavaratti

Kavaratti (lat. 10°33' N and long. 72°38'E) , the capital of Lakshadweep group of Islands, is having an area of 3.6 km^2 and located at a distance of 404 km off Cochin. The reef, which is situated on the western side of the island, encloses a lagoon in between the reef and island. The length of the lagoon is about 6 km. The lagoon, though small, protects the island from the strong southwest monsoon currents. Kavaratti, the low-lying island, lacks significant geomorphic features. The land is level to very gently slopping except for some elevational differences along the western lagoon side (2-5 m) and to 3 m in the eastern storm side. The island is oriented in a NE-SW direction. The strong wave during the southwest monsoon beat and breaks the coral reefs on the western side of the atoll and the debris are carried eastward by the ocean currents and deposited along the eastern fringe of the atoll. The smoothly formed sandy beach on lagoon side (western) gives an indication of gradual deposition through time by coral sands.

1.4.2 Minicoy

Minicoy (lat. 08°17'N and long. 73°04' E) is at a distance 398 km away off Cochin. The area covered by this island is 4.4 km^2. The island has a very large lagoon on the western side measuring about 6 km^2. The lagoon has two entrances, one in the west and the other in the northern end. This large lagoon protects the island from the fury of the southwest monsoon currents. The 12 km long island does not exhibit significant geomorphologic differences except for micro level relief differences on the north. The elevation of the island from mean sea level is about 3-4 m in the east.

1.4.3 Climate

Lakshadweep has a warm and humid climate. The temperature starts rising from March and reaches its peak in May (29°C). The temperature then starts falling due to the monsoonal effects and reaches the lowest level in August (27°C).

a) Wind: The winds experienced in the Lakshadweep are those of the two monsoons, influenced in the north by the proximity of the Indian coast and affected in the south by the equatorial winds. The northeast monsoon usually set in the Lakshadweep during October- December and continues until the end of

January. During this period a more or less northerly wind prevails together with long calms, but a little or no heavy weather. The southwest monsoon in the Lakshadweep is rather longer, the southwest wind usually becoming definitely set towards the end of May and continuing regularly until September. The maximum wind speed during June is about 36 km/h.

b) Waves and currents: During SW monsoon the direction of wave approach is from SW- W directions whereas in the pre-monsoon (Feb-Mar) the wave approach is from N-NE directions. As a result of the above the littoral currents in Lakshadweep is S to N during SW monsoon period and N to S during NE monsoon and even during the pre-monsoon period. The Kavaratti and Minicoy belong to micro-tidal regime (Davies and Marshall, 1980). Hurricanes are liable to occur in the Arabian Sea during pre and post monsoon months. During pre-monsoon months (April-June) a number of storms or severe storms usually occur due to disturbances in Lakshadweep Sea. In the post monsoon, cyclonic storms usually occur in October- November due to disturbances in Bay of Bengal. According to India meteorological report (1964) nearly 10 storms occurred each in the year 1893, 1926 and 1930. The decade frequency of storms in the Arabian Sea is as follows: 15 during 1891-1910 and 9 during 1951-1960. A hurricane, which occurred in 1847, eliminated 1150 inhabitants out of 1600 from the island of Kalpeni and 2400 people out of the 3000 from Androth.

c) Rainfall: For the entire Lakshadweep islands, rainfall-recording stations are located at Minocy, Amini, Androth and Agatti. Rainfall data available from these islands are considered as representative to the adjoining islands. The average annual rainfall generally decreases from south to north of the Lakshadweep group of islands. At Minicoy the average rainfall is over 250 cm per annum, the greater part of which falls during the first month of the south-west monsoon. On an average, the number of rainy days (days with more than 2.5 mm rain) in a year at Minicoy and Kavaratti are around 90 during the SW monsoon period ie, June to September. In 1964, Minicoy experienced a high shower of 225 mm in a single day. Heavy showers of short duration are frequent in December i.e. during NE monsoon.

1.5 Population

In Kavaratti Island the population is 8677 and the population density is 2410/km^2 (1991 census) whereas in Minicoy, the population is 8320 and the corresponding density is 1890/km^2 (1991census). In both the islands, the thick population is found in and around the areas of higher relief as it sustains a relatively stable freshwater lens. It is this freshwater which acts as prime mover in the diagenesis of carbonate sediments as discussed in chapter 5.

1.6 Geology and Geomorphology

The Lakshadweep group islands form the northern part of the Chagos – Laccadive ridge which is trending in a NS direction over a distance of about 2500 km (Fig. 1.3). The ridge rises from a depth of 2000-2700 m along the eastern front and about 400 m along the western side in the Lakshadweep area (Eremenko and Dutta,1968). The eastern flanks of the ridge is much steeper compared to the western part. Except Minicoy, most of the coral islands are

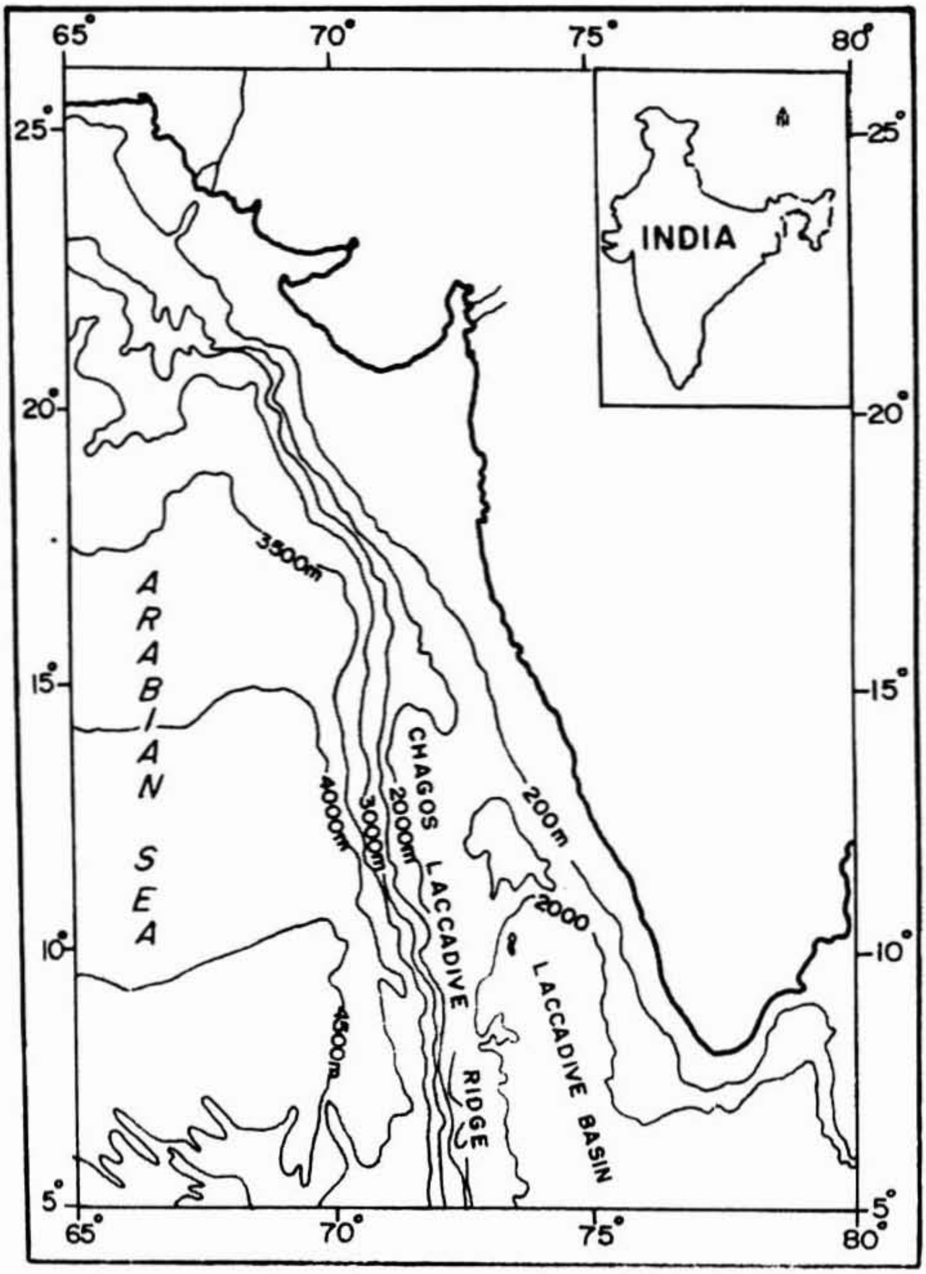

Fig. 1.3 Chagos-Laccadive ridge

concentrated on the north. The N 9° channel separates the Minicoy Island from the rest. The origin of Chagos- Laccadive ridge is a debatable one. According to Eremenko and Dutta, (1968) the ridge is of basaltic origin capped by coral reefs of recent origin. However, Narain et al., (1968) opined that the ridge forms the transition between the oceanic crust in the west and continental crust towards the east. More recently Zutshi et al., (1995) have indicated that the Lakshadweep islands form part of a highly splintered continental mass impregnated with large quantities of oceanic basalt.

There are several theories for the formation of coral reefs of the Lakshadweep islands. One of the theories of the origin of the coral islands of Lakshadweep is that submarine ridge has provided a stable platform over which the corals could grow. The upward growth of coral has kept pace with the relative sea level changes resulting in thick sequence of reef or atoll and the associated sediments in the lagoon and island proper. The lagoons, the beaches and the island proper are covered by nearly 1-5 m thick layer of either calcareous sand or pebbles and gravels (Muraleedharan and Kumar, 1995). Cemented layers are reported to have occurred sporadically within the islands either at the surface or at variable depths (Nair, 1982; Mallik, 1985). In Kavaratti a 10-20 cm thick cemented layer occurs 0.5 m above the water table while in Chetlat island the cemented layer occurs at the surface itself over a larger area. The cementation is due to percolation of fresh water and the dynamics of fresh water is controlled by the variation in permeability.

Most of the islands are more or less elongated and oriented in a NS direction with a lagoon on the western side and a steeper rocky shore on the eastern side. Androth is an exception which is aligned in a East-West direction and has no lagoon. The lagoon is separated by coral reefs, the width vary from 0.5 to 1.5 km. Srivastava et al., (1978) has proposed a three stage model of reef development for the Lakshadweep islands. The reefs of Chetlat and Kiltan and possibly Androth are in an advanced stage of development while Kalpeni, Kavaratti , Agatti and Kadmath are in an intermediate stage. The uninhabited island Suheli is in a primary stage. The occurrence of wave cut platforms and several submarine terraces from the eastern shelf region of the island have been reported by Siddique (1975).

1.7 Accessibility

The Lakshadweep Islands can be visited for scientific purpose only after getting prior permission from the island authorities. The Lakshadweep administration has put strict rules for outsiders in view of less accommodation facilities, very small size of the islands and the scarcity of fresh water. The most frequent mode of transport to Lakshadweep islands is by ships, which are being operated from the ports of Kochi, Beypore and Mangalore. Inter-island transporting system is available among the tourist centres and inhabited islands. Agatti airport links Lakshadweep islands with the mainland.

1.8 Review of Literature

Experimental studies on corals have started in 1910 (Goreau, 1961). Silliman (1953) has studied the chemical composition of corals. Chave (1954) has studied the biogeochemistry of Mg in Medreporarain and Alcypnarian corals and other calcareous marine organisms. Thompson and Livingston (1970) have carried out Ca, Sr and U concentrations and various trace elements of the modern hermatypic and ahermatypic corals. Amiel et.al., (1973 a & b) have carried out studies on the distribution and nature of incorporation of Sr, Mg, Na, K and U in modern aragonitic corals. Weber (1973) has conducted an extensive study on several well-characterized corals from seventeen localities to understand the incorporation of Sr in corals. Weber (1974) has also carried out a detailed study on different varieties of corals to find out the relationship between Mg content and water temperature, water depth, genetic factors and the rate of Mg removal from seawater by corals in reef environment. St. John (1974) has estimated the amount of Cu, Fe, Zn, Co, Cd, Pb and Ni for 265 varieties of corals from the reef of Capricorn group. He has also reported the relationship between trace elements in corals and oceanographic parameters. Goreau (1977b) has discussed in detail the physiological and environmental regulation of trace metals and stable isotopes of corals.

Yamanouchi (1980, 1982,1984, 1988, 1993 and 1998) and Yamanouchi and Hasegawa (1988) have studied the distribution of sandy sediments around coral reefs and beaches of the coral islands of Japan. Alexanderson (1978), Brand and Veizer (1980) and Al-Asam and Veizer (1986) have studied the diagenetic stabilization of aragonite and low-Mg calcite. The petrogenesis of Cenozoic temperate water calcarenites of Southern Australia has been carried out by James and Bone (1989). The diagenesis of carbonate sediments from deep sea and coral islands has been studied by several workers (Bathrust, 1975; Land and Moore, 1980; Macintyre, 1977, 1984 & 1988; Marshall 1983a & 1983b; James and Choquettee, 1983). The geochemistry of the modern carbonate of the Australian region has been investigated extensively by Rao (1981a, 1981c, 1986, 1989, 1990a, 1990b & 1992). Gischler and Lomando (1999) and Kench (1997), have studied the composition of unconsolidated, shallow-marine carbonates. Chevillon (1996) has studied the depositional patterns, pathways and the zonation of reefal and lagoonal sediments. The importance of *Halimeda* bioherms has been undertaken by Roberts et al. (1988). Furukawa et al. (1997) have investigated compositional studies and early diagenesis of sediments. Grossman and Fletcher (1998), Calhoun and Fletcher (1996), Fletcher and Jones (1996), Athens and Ward (1991) have conducted several studies on various aspects of carbonate sand and their age in Pacific localities. Holocene sea levels and shoreline evolution, sedimentation histories have been studied by Roy (1991), Harris et al. (1990) and James et al. (1994). Davies and Marshall (1985) have studied the accumulation of Halimeda bioherms. Harney et. al (1999) have studied the age and composition of Kailua beach, Hawaii.

The Lakshadweep archipelago is of considerable scientific interest, but unfortunately not many studies have been made earlier. The first detailed study on the islands has been conducted by Gardiner (1903-1906) and he published his book "Fauna and Geography of Maldive and Laccadive Archipelago" in two volumes. His study is more linked to the fauna and flora of the atolls. Only in recent years much work has been done on many aspects. Sankaranarayanan

(1973) has studied the chemical parameters such as salinity, pH, total alkalinity, dissolved oxygen, inorganic phosphate, total phosphorous, chlorophyll and particulate organic carbon of the lagoon and the sea around Kavaratti. Naquvi and Reddy (1979) have studied the variation of Ca in the waters of Lakshadweep. According to Pillai (1977) seventy species of hermatypic corals representing 26 genera are found in the Lakshadweep region. Siddique and Mallik (1973) have conducted detailed bathymetric surveys and sediment sampling and indicated that Lakshadweep atolls are marked by shallow lagoons with depths ranging from 1-16 m. The bathymetric surveys conducted by Siddique (1975) reveals the presence of three submerged terraces (10-15 m, 21-36 m and 43-47 m) off the islands of Kadmat and Bangaram. Subsequent study by Nair and Quasim (1978) also reveals the existence of coral banks in several regions of Lakshadweep. The study of Chauhan (1986) and Chauhan and Chaubey (1990) also brought to light the presence of three terraces at depths of 45 m, 69 m and 82 m off the islands of Lakshadweep. The morphology and sediment characteristics of northern part of Trans- Lakshadweep ridge has been studied by Kalluraya et al., (1989). Vinithkumar et al., (1999) and Ramanujam and Mukesh (1999) have studied the geochemistry of coral reef sediments of the Mannar Islands off the Tamil Nadu coast.

The textural characteristics of the carbonate sands of beach and lagoonal environments of the Agatti atoll have been investigated by Hardas (1987). Sanil kumar et al., (1986), Adiga (1989) and Prakash and Suchindan (1994) have investigated the topographic variation, sediment characteristics and beach erosion of the Lakshadweep coral islands. Mallik, (1979, 1981 and 1985) conducted a series of investigations on the sedimentological and biological aspects as well as on the effect of coral sand mining on Kavaratti and Kalpeni atolls. The grain size variation in the Kavaratti lagoon sediments has been studied by Mallik (1976). Siddique (1980) has studied the age of the storm beaches of certain islands of the Lakshadweep by radiocarbon methods. Based on the mineralogical and sedimentological aspects of the surficial sediments and with the support of radio carbon dates, Siddique (1980) opined that there have been stormier conditions in the Arabian sea around 3000-5000 years ago. Mascarenhas et.al., (1980) studied the distribution of Sr and Mg in corals from reef to the island of the Minicoy.

1.9 Objectives of the present study:

1. To study the textural characteristics of the beach and inland sediments of Kavaratti and Minicoy islands
2. To investigate the mineralogical constituents of coral deposits using X-ray diffraction studies.
3. To estimate the concentration of selected major and trace elements (Na, K, Ca, Mg, Sr, Fe, Mn, Cu, Co, Ni, Cr, and Zn) of the carbonate sediments so as to decipher the geochemical characteristics of the coral deposits and
4. To study the diagenetic changes of the coral deposits

Chapter 2

MATERIALS AND METHODS

2.1. Introduction

This chapter deals with the various techniques and procedures adopted in sample collection, processing and analysis of the data collected for this work. The methodology involves three parts, viz : (a) field survey and sampling, (b) laboratory investigation and (c) data processing and interpretation. Various procedures employed in the work are briefly given below.

2.2. Field survey and sampling

Field survey and sampling were done systematically from the beach and within the islands. Beach profiles (7 from Kavaratti and 8 from Minicoy) were carried out on the lagoon side of the islands in the month of April 1998 and April 1999. Since the storm side beach is mainly composed of pebbles, cobbles and boulders no beach profiles were carried out the storm side. Beach profile study help us to understand the variations in beach morphology, the erosional and depositional patterns of the beach (i.e., volume change of the beach sediments) and direction of sediment transport. Different beach profile methodologies are adopted depending on the objective of the study. In the cross-shore direction, generally the elevation of the beach is measured at every 5m interval. But at places where a sharp change in the beach slope is observed, the elevation changes can be recorded at smaller cross-shore intervals less than 5m.

In order to unravel the grain size variations along and across the beach of the islands 14 stations were selected from the Kavaratti island and 18 stations in Minicoy. At each station 2 samples namely foreshore and backshore were collected. Since the storm side mainly consists of pebbles, cobbles, boulders and coral rock pieces and therefore only at selected localities sediments were collected in foreshore and backshore (Plates 2.1, 2.2, 2.3, 2.4, 2.5, 2.6 & 2.7). For a comparative study of the sediment characteristics of beach with that of the adjoining lagoon, 10 bottom samples (5 from each lagoon) were collected from the lagoon area of Kavaratti and Minicoy. In addition, beach profiles were taken to understand the erosion/ depositional history of the islands.

In order to assess the variability in sedimentation pattern, mineralogy, geochemistry and the diagenesis within the islands, sediment samples were collected at close intervals from 18 dug wells and 12 pits respectively from Kavaratti and Minicoy islands (Figs. 2.1 & 2.2). Due to environmental restriction (Plates 2.8 & 2.9) imposed by Government of India, the samples have been collected from the available dug wells and pits. Thus within the islands 81 samples from Kavaratti and 83 from Minicoy were collected. The depth of the dug wells and pits varies from 175 to 490 cm in Kavaratti (Plates 2.10 & 2.11), 35 to 110 cm in Minicoy (Plate 2.12) respectively. Since hard basement rock is encountered at a shallow depth in the Minicoy, sampling was possible only to a depth of around 110 cm. Four live coral samples (2 from each island) from the reef area of Kavaratti and Minicoy (Figs. 2.1 & 2.2) were collected in order to compare the mineralogy of the samples with that of the inland sediment samples.

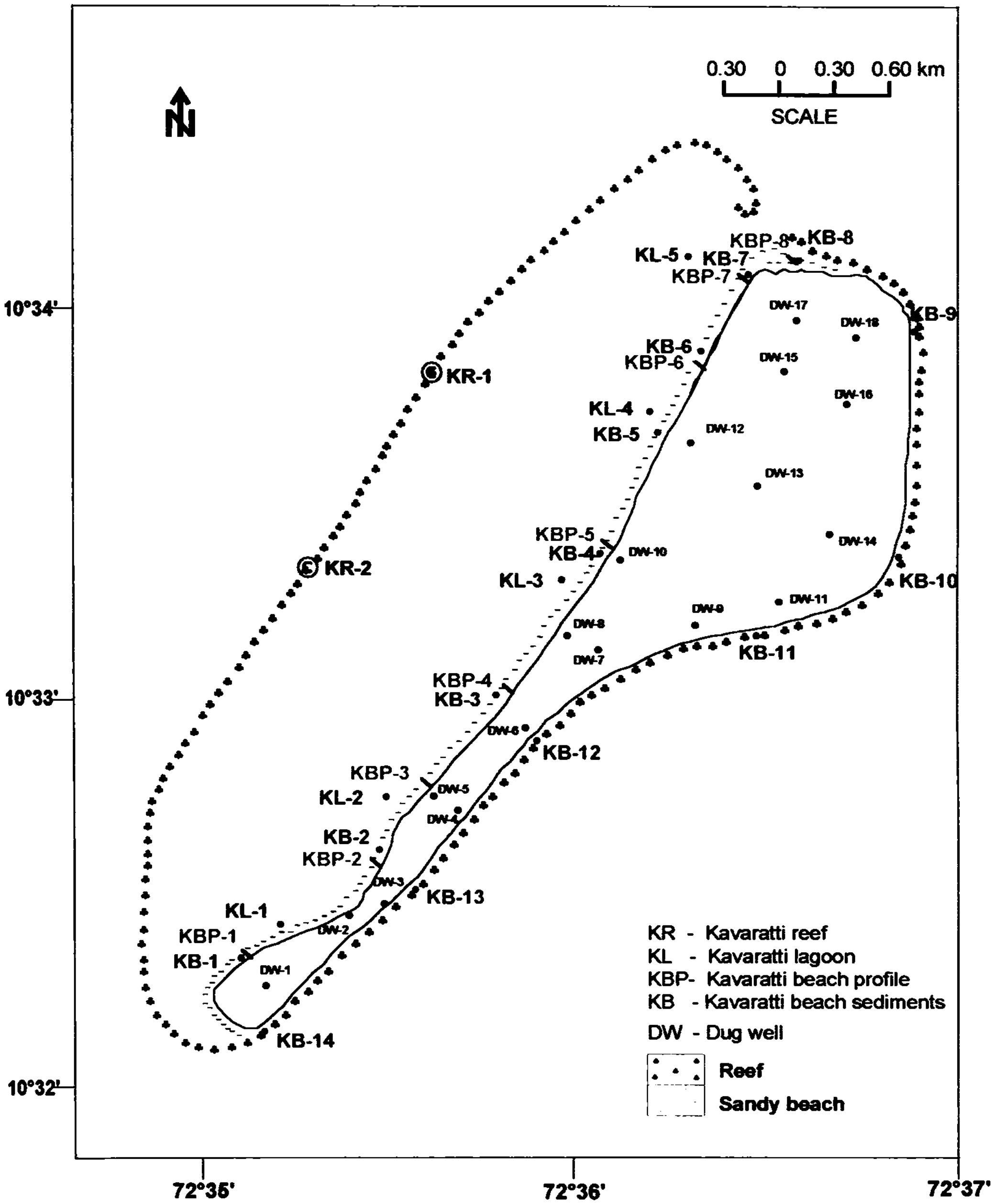

Fig.2.1 Beach profile and sampling stations in Kavaratti Island

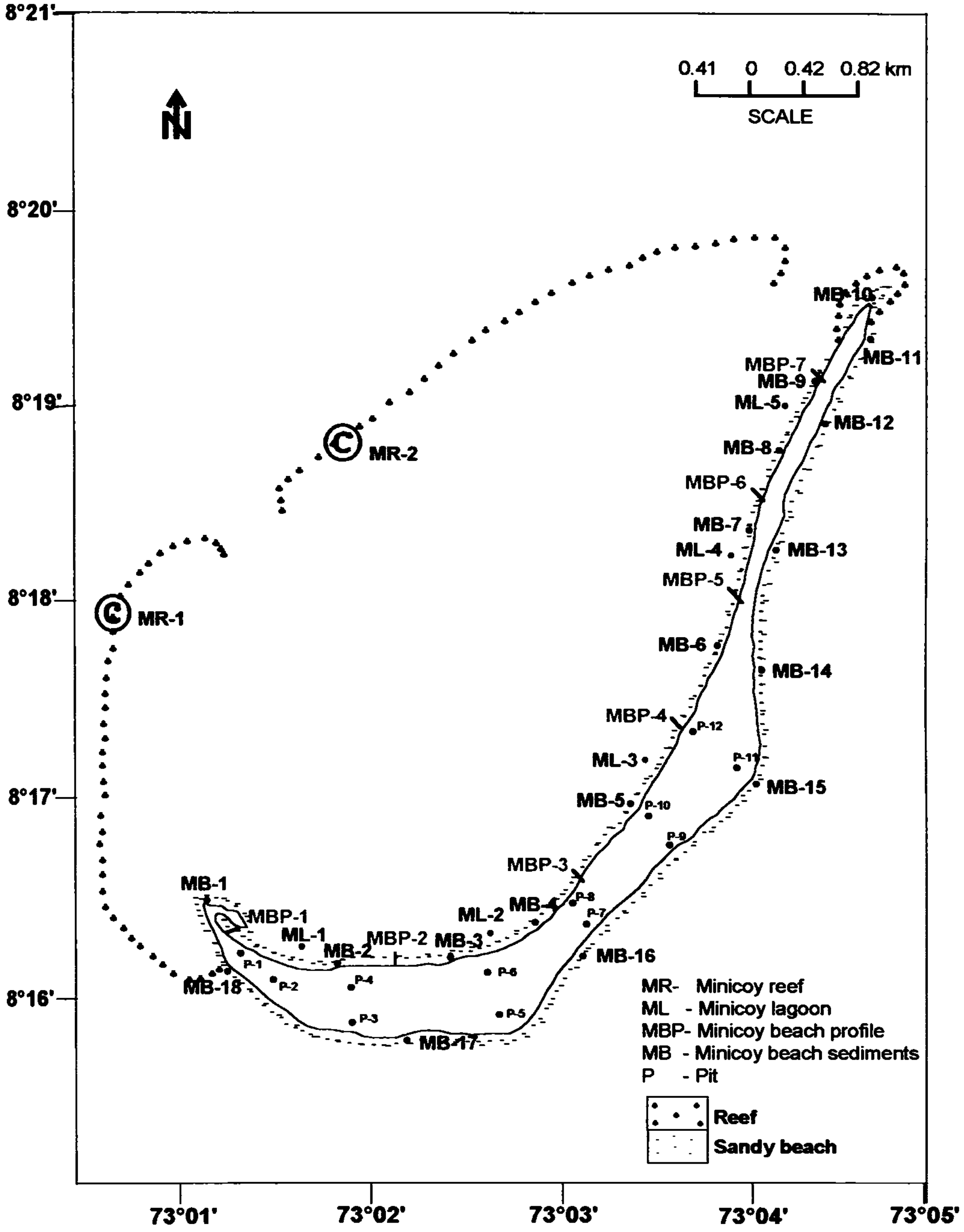

Fig.2.2 Beach profile and sampling stations in Minicoy Island

Plate 2.1. A pebble beach of the storm side of the Kavaratti island.

Plate 2.2. An emerged conglomerate platform of the storm side beach of the Kavaratti. The reef flat with coral rubble, exposed during low tide is also shown.

Plate 2.3. An exposed reef flat at low tide of the storm side beach iof Minicoy.

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Plate 2.11. A view of the dug well showing layers of pebbles and sand.

Plate 2.12. A shallow pit of Minicoy consisting of medium and fine sand.

Plate 2.13. A storm side beach of Minicoy being protected by tetrapods.

Plate 2.14. A close view of the beach protection measures along the storm side beach of Kavaratti.

Plate 2.15. A gentle southern lagoon beach of Minicoy island.

Plate 2.16. A view of the beach protection along the lagoon side of Minicoy. Stabilization of the back shore beach by artificial concrete blocks is also seen.

2.3. Laboratory investigation

2.3.1 Sample preparation

Since wet chemical methods were essential and followed for the analysis, it is essential to bring the sediment and rock sample into solution. So, the samples were processed and were brought to solution by the procedures elaborated below:

2.3.2 Sample processing

Representative known quantity of sediment samples were dried in a hot air oven at 60^0C. The samples were then homogenised, coned and quartered, and a 'quartered-fraction' was taken for final processing and each sample crushed by hardened steel mortar. The sample powder was thoroughly homogenised. About 5-10 g of it was ground to 230-mesh size by the help of agate mortar. Care was taken to keep the contamination at the minimum level.

2.3.3 Sample dissolution

0.5 gm of powdered sample was treated with hydrochloric acid at room temperature until reaction ceased. Hydrochloric acid was added to the samples very slowly so that it would not affect the weight of sample. When carbonate material was dissolved the sample solution was transferred to a clean 100 ml volumetric flask. The unclear portion was centrifuged at 4500 RPM with distilled water to separate from the clear portion. The supernatant liquid was added to the 100 ml volumetric flask, which contained the sample solution. The residue was weighed and the weight of the residue was subtracted from total weight (0.5 gm) of the sample. The final volume was made up to 100 ml. Blanks were prepared in the same way as added for sample preparation. The samples and blanks were stored in 100 ml clean (unused) plastic bottles for measurements thereafter. All the glasswares, polythene and teflonwares used in the present work were cleaned with dilute hydrochloric acid, followed by repeated cleaning with distilled water.

2.3.4 Chemical analysis

The digested samples were used for elemental analysis following various techniques.

Determination of Na and K

The primary stock solutions of Na and K were prepared by dissolving 2.542 g of NaCl and 1.907 g of KCl respectively in distilled water and made upto 1000 ml. Intermediate stock solutions of Na and K were prepared by diluting 10 ml of the above stock solutions to 100 ml with distilled water. By proper dilution of intermediate solution with distilled water different standards were prepared for Na and K. The different standards of Na and K solution are aspirated to the flame photometer, fitted with suitable filters, under carefully controlled conditions and the photometer readings are noted down. A standard calibration curve was drawn for Na and K by plotting the concentration of the standard Na and K solution respectively on the x-axes against their corresponding photometer reading on the y-axes.

A 5 ml of "B-solution" was diluted with distilled water and made up to 100 ml. Further, by proper dilution of the above samples they were also aspirated to the flame photometer and the corresponding photometer reading for Na and K was noted and plotted in the standard calibration curve. The concentration of the elements determined from the graph and computed for the whole sample. To check the accuracy of the analysis the solution of in-house rock standards was also run along with the sample solution and the analytical results are compared with the standard published values.

Ca and Mg

Ca and Mg in the sample were determined titrimetrically with standard EDTA solution (APHA, 1981). Murexide was used as indicator. Colour changes from pink to purple at the end point.

Sr, Fe, Mn, Cu, Co, Zn, Ni, and Cr

These metals were analysed using atomic absorption spectrophotometer (Perkin Elmer Model 2380).

Precision and accuracy

The precision and accuracy of the heavy metal estimation were checked against two USGS standard rock samples. All the metal values were in agreement with the published values of Rentala and Loring (1975) and Flanagan (1976).

2.3.5 Sediment organic carbon

Sediment organic carbon was determined by wet oxidation method of El Wakeel and Riley (1957). Organic matter was oxidized by a known quantity of chromic acid and the amount of chromic acid used was then determined by back titration with standard ferrous ammonium sulphate solution. Diphenylamine was used as an indicator.

2.3.6 Texture

The bulk sediments were washed, dried and subjected to coning and quartering and a representative portion (about 100 gm) was subjected to dry sieving. Each sample was sieved for 15 minutes on a mechanical Ro-Tap sieve shaker using standard set of ASTM sieves at half phi (½ ϕ) intervals. The fractions left over in each sieve were weighed and cumulative weight percentages were calculated. The cumulative weight percentages of the above analyses were plotted against phi units on a probability chart. The cumulative frequency curve is drawn and the phi values of 1, 5,16, 25, 50, 75, 84 and 95 were recorded. The grain size parameters such as mean size; standard deviation, skewness and kurtosis were calculated following Folk and Ward (1957).

$$\text{Mean size} = \frac{P_{16} + P_{50} + P_{84}}{3}$$

$$\text{Standard Deviation} = \frac{(P_{84} - P_{16})}{4} + \frac{(P_{95} - P_5)}{6.6}$$

$$\text{Skewness} = \frac{(P_{84} + P_{16} - 2P_{50})}{2(P_{84} - P_{16})} + \frac{(P_{95} + P_5 - 2P_{50})}{2\,(P_{95} - P_5)}$$

$$\text{Kurtosis} = \frac{(P_{95} - P_5)}{2.44(P_{75} - P_{25})}$$

Separation of the microfossils

A preliminary micropaleontological investigation was also carried out for DW-6 (Kavaratti) and P-4 (Minicoy). For separation of calcareous tests from the matrix, the following conventional micropaleontological technique was used.

The sediment was soaked with hydrogen peroxide (50%) for overnight in order to clean the microfauna from the matrix. After wet sieving over 200 mesh the samples were dried and the residue thus obtained was collected in small plastic bottles and numbered properly. Care was taken to avoid mechanical damage during sample preparation.

The residues of calcareous microfauna (such as bryozoa, foraminifera, coral fragments etc), mineral grains and fine sediments were examined under the stereozoom binocular microscope (Wild MZ8). All benthic foraminifera were identified (Leoblich and Tappan, 1988) and mounted on microfaunal assemblage slides and counted. The identification was confirmed by the SEM study.

2.3.7 Mineralogy

X-ray powder diffraction is commonly employed to study modern and ancient carbonate sediments, limestones and dolomites. XRD analysis can yield information on the chemical composition of carbonate minerals. It is also used to determine the percentage of the various $CaCO_3$ minerals. When monochromatic X-rays irradiate crystalline materials, a pattern of diffraction curves which gives sufficient information to determine both the dimensions of unit cell of the crystal lattice and the atomic arrangement within the cell. Standard X-ray diffraction techniques make use of the Bragg's equation to obtain a measure of the atomic structure of a substance. The Bragg's law states that

$$n\lambda = 2d \sin \theta$$

where λ, is the wave length of the incident radiation, d is the atomic lattice spacing measured in angstroms (Å), θ is the angle between an incident monochromatic X-ray beam and the chosen atomic plane and n is an integer.

Powdered samples of less than 63 micron size were analysed with X-ray diffractometer using nickel filtered copper K-α radiation. They were scanned from 20- 35 ° 2θ at 1.2° 2θ/ minute. Instrumental settings are 20 mA, 40 KV, time constant 5, receiving slit 0.2 and automatic divergent slit and were maintained for all the samples. The diffractograms were obtained and the peaks of the minerals were identified using standard JCPDF (Joint Commission of Powder Diffraction Files) cards.

In order to know the surface and vertical variation of the mineralogical constituents of the coral deposits, 30 representative samples (18 from 5 dug wells of Kavaratti and 12 samples from 4 pits of Minicoy) were analysed. For proper evaluation of the complete mineralogical variation with depth, 8 samples have been selected with in DW-13 of Kavaratti Island. In addition to the samples collected from the islands, 4 live corals (2 from each islands) were undertaken for X-ray studies. The XRD results reveal that aragonite, high-Mg calcite and low-Mg calcite are the carbonate minerals present in the samples.

2.3.8 Radio carbon dating

The coral rocks were dated at the Birbal Sahni Institute of Paleo Botany, Lucknow following Agrawal et al (1971). The samples were powdered and washed in distilled water. It was then treated with dilute HCl to remove carbonate fraction. The carbon in the organic matter of the sediment was converted into benzene. Radiocarbon activity of the benzene was measured by liquid scintillating counter " QUANTULUS". The dates presented here are based on the radiocarbon half-life value of 5730 yrs.

2.3.9 Thin sections

For the preparation of thin sections, the rock is broken into small sized chips. One of the broad sides of the chip was ground to make flat and smooth and was mounted on a glass slide using Canada balsam. Then the other side was subjected to grinding till the section acquired a thickness of around 0.03 mm.

2.3.10 Scanning Electron Microscopic (SEM) studies

SEM has become an essential tool in the micromorphological investigation of the minerals and their alteration features. Such studies are important to delineate the environment of weathering, transportation and the subsequent alteration (Krinsely and Doomkamp, 1973).

Coral samples were fixed over the SEM stubs using a double sided stick tape. A thin layer of conducting silver paint was applied to the bottom of the sample for better conduction. The specimen was coated with gold palladium alloy in a vacuum evaporator. The sample was then scanned using stereoscan.

Chapter – 3

TEXTURE

3.1 Introduction

Granulometric studies of unconsolidated sediments have proved their usefulness in the study of the mechanism of transport and deposition of sediments. The grains size analysis of clastic sediments is very important in many ways which are as follows: (a) the grain size is a basic descriptive measure of the sediment, (b) the grain size distributions are generally characteristic of sediments deposited in certain environments (c) the grain size distribution may yield information about the physical mechanisms acted on the sediments during deposition and (d) the grain size are related to other properties such as permeability, mineralogy, geochemistry etc. There have been repeated attempts to use grain size parameters to differentiate environment of deposition (Folk and Ward, 1957; Passega, 1957, 1964, 1977; Mason and Folk, 1958; Friedman, 1961, 1962 & 1967; Folk, 1966; Visher, 1969;Hails and Hoyt, 1969; Moiola et al., 1974; Stapor and Tanner, 1975; Nordstorm, 1977). Further, the characteristic of grain size distribution of sediments are related to the source materials, processes of weathering, abrasion and corrosion of the grains and sorting processes during transport and deposition (Mishra, 1969; Patro et al., 1989; Williams et al., 1978; Forstner and Wittmann, 1983; Seralathan, 1979, 1984; Samsuddin, 1990; Padmalal and Seralathan, 1991, Padmalal, 1992; Joseph et al., 1997; Majundar and Ganapathy, 1998; Rajamanickam and Gujar, 1985 & 1997; Rajaguru et al., 1995).

Several studies on the size distribution of clastic sediments have revealed the existence of statistical relationships between the different size parameters such as mean size, sorting (standard deviation), skewness and kurtosis (Folk and Ward, 1957; Visher, 1969). The relationship between mean size and sorting is particularly well established and many studies have shown that the best sorted sediments are generally those with mean size in the fine sand grade (Pettijohn, 1957; Griffiths, 1967; Allen, 1970). Based on the log normal distribution of grain size, Visher (1969) has identified three types of populations such as rolling, saltation and suspension, which indicate distinct modes of transportational and depositional processes.

Textural parameters of carbonate sands are evaluated for understanding the dynamics of various sedimentary processes responsible for the deposition of modern carbonate sands of reefal origin (Folk and Robbles, 1964; Force, 1969; Lewis, 1969; Mallik, 1976, 1979, 1981& 1985; Sanil Kumar et al., 1986; Hardas, 1987; Nelson et al, 1982 & 1988; Adiga, 1989; James et.al., 1992 & 1994; Rao and Amini, 1995). In the present study an attempt has been made to understand the relationship between grain size distribution and energy conditions which are responsible for the deposition of carbonate sands of Kavaratti and Minicoy Islands.

3.2 Results:

3.2.1 Kavaratti Island:

The beach profile variation along the lagoon side beach of the Kavaratti Island is presented in Fig. 3.1. The textural parameters of the sediments of lagoon, beach and the island are presented in Table 3.1 while the content of different classes of sediments is given in Table 3.2. The distribution of different class of sediments of the lagoon and the beaches (lagoon and storm side) are shown in Figs. 3.2, 3.3 and 3.5 respectively. The alongshore variation of phi mean size and standard deviation values for the lagoon beach is charted in Fig. 3.4. The Fig 3.6 exhibits the inter-relationship between the different textural parameters of the beach sediments. The variation of different class of sediments in the dug wells of the northern and central part of the island is presented in Fig. 3.8 while the variation in the lithology of the southern part of the Kavaratti island is shown in Fig. 3.7.

Kavaratti-Beach Profile: The lagoon beach is oriented more or less in a NE-SW direction. No beach profiles were made in the southern tip of the island and at chicken neck area as the beach materials are cobbles and boulders. The rest of the beach sections, where beach profiles have been done, show a remarkable variation from south to north. The slope of the beach in the southern and south-central part is very steep whereas in the north-central and northern part of the beach, the beach slope is becoming gentle to flat (Fig. 3.1). The beach width in the south is about 20-25 m whereas in the northern end the width is 30 m

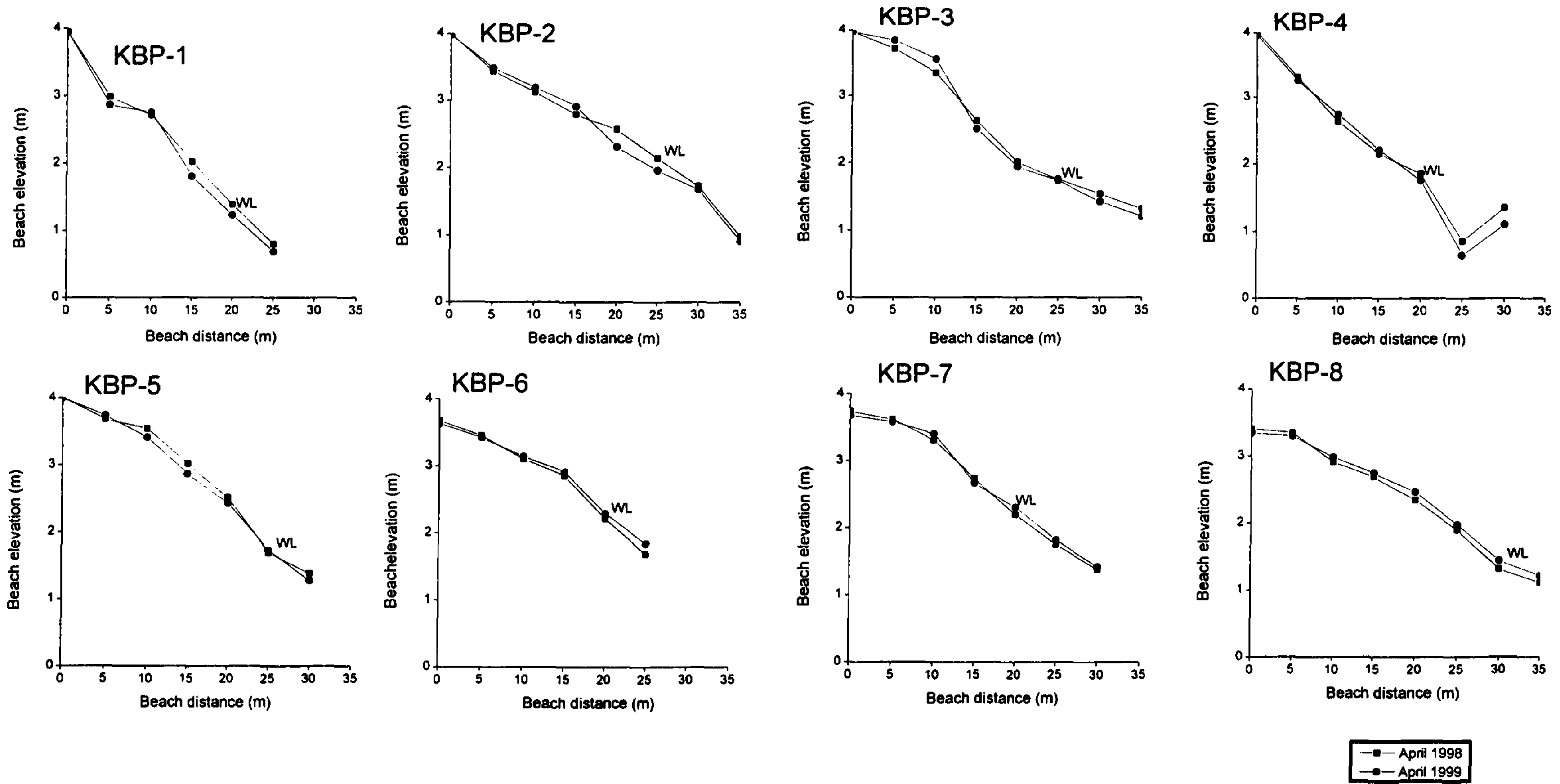


Fig.3.1 Beach profiles of the lagoon side of the Kavaratti Island

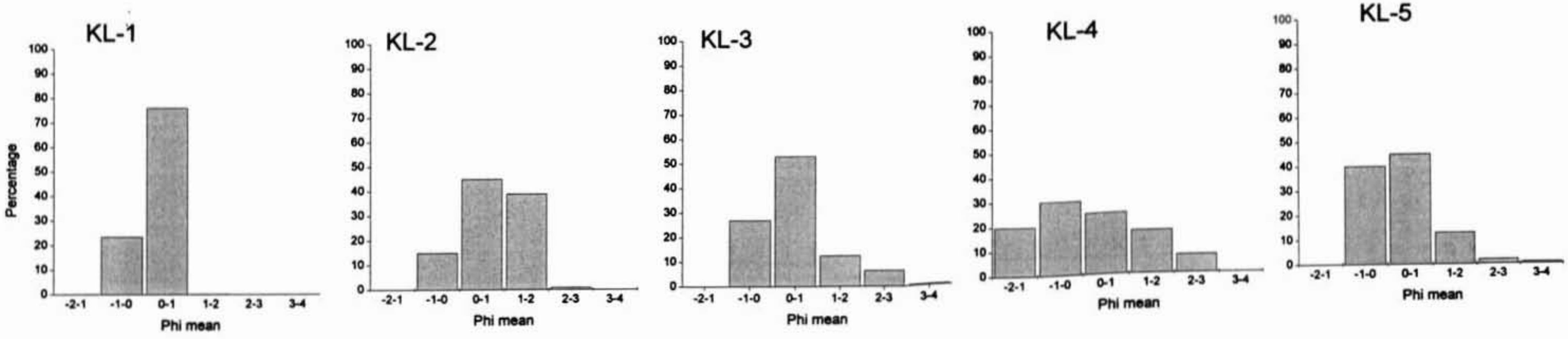


Fig. 3.2 Variation of different size classes of the lagoon sediments of Kavaratti

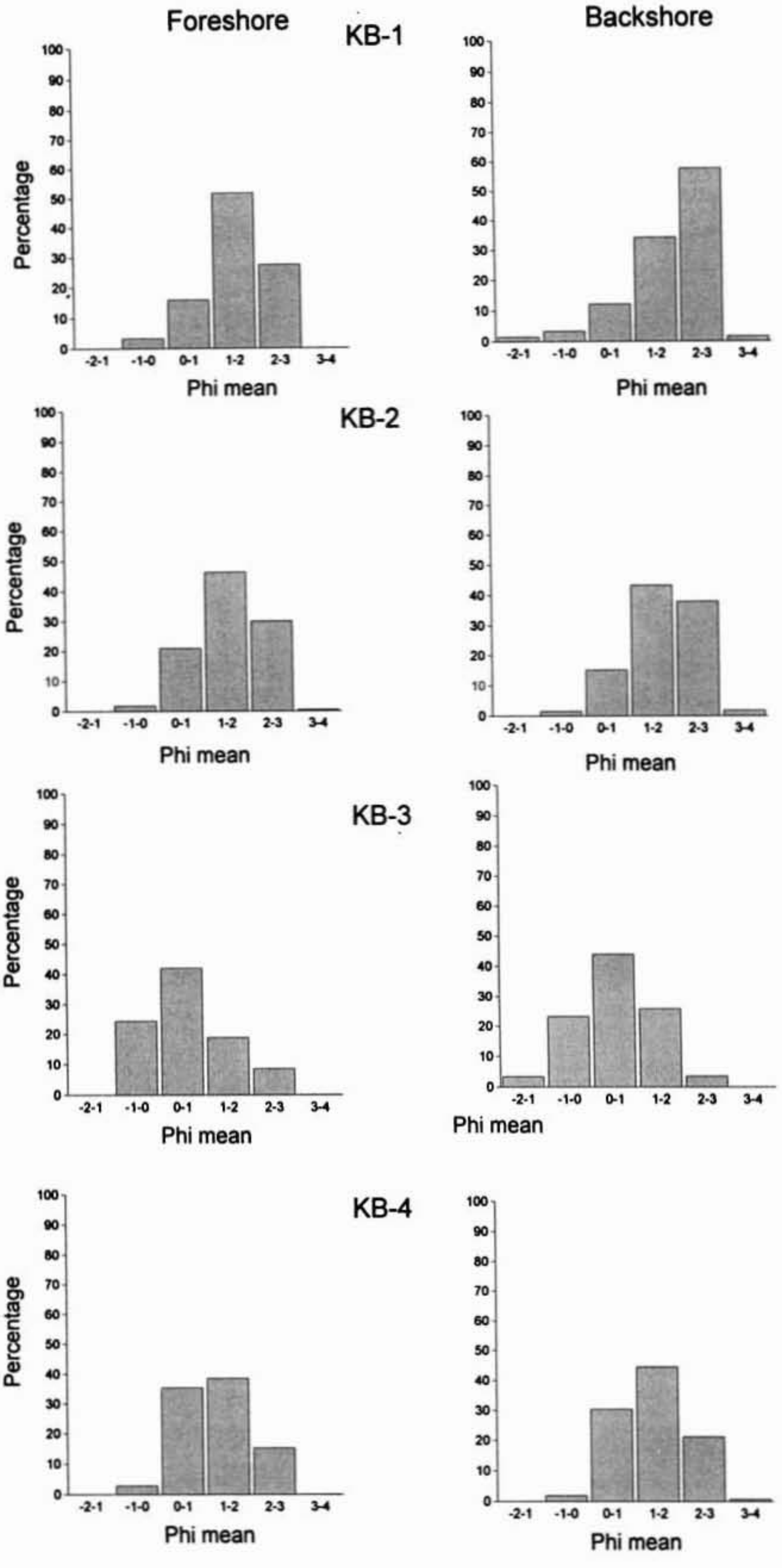
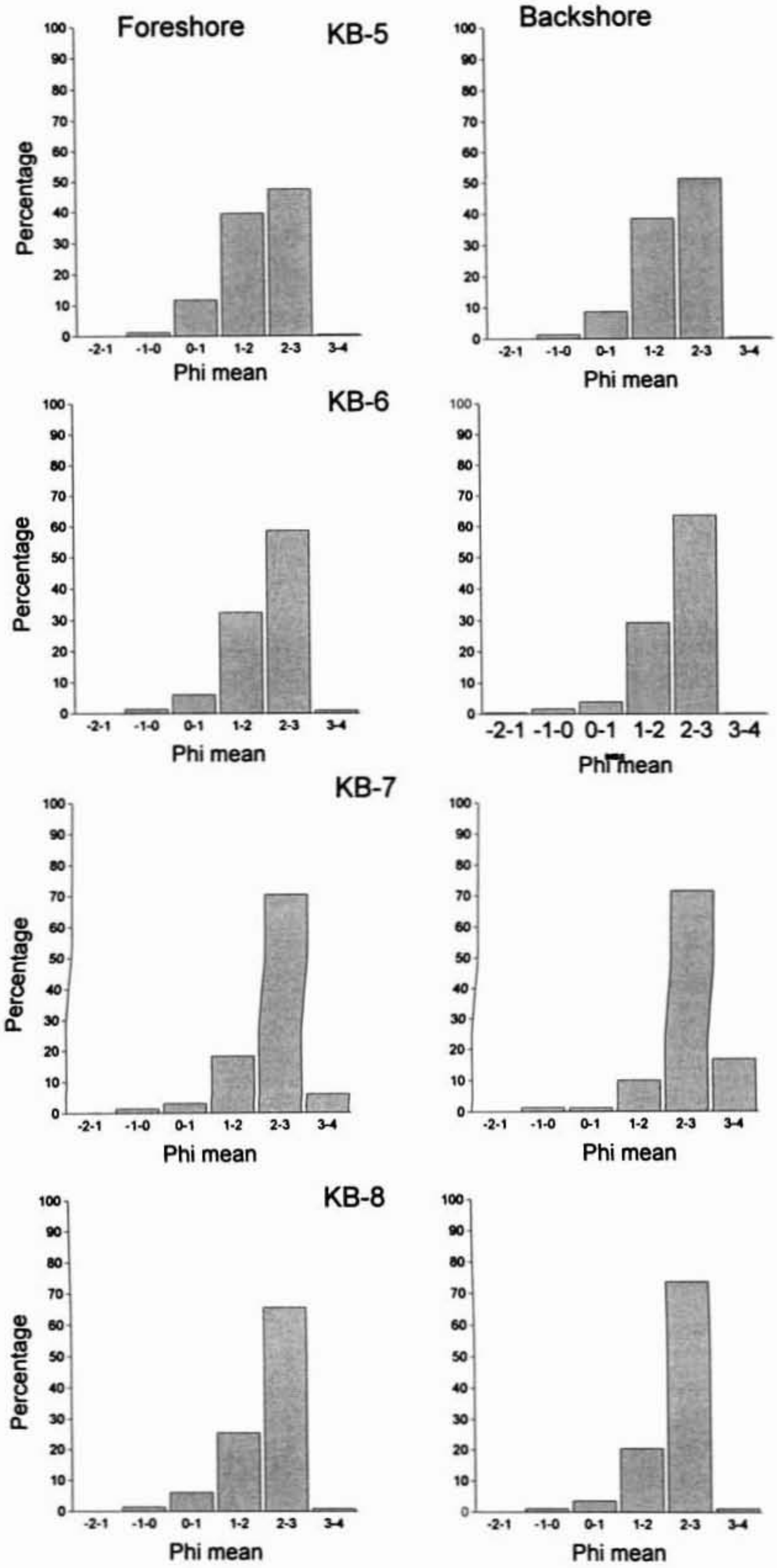


Fig. 3.3 Distribution of different size classes of sediments along the lagoon side beach of the Kavaratti Island.



(Fig. 3.3 continued)

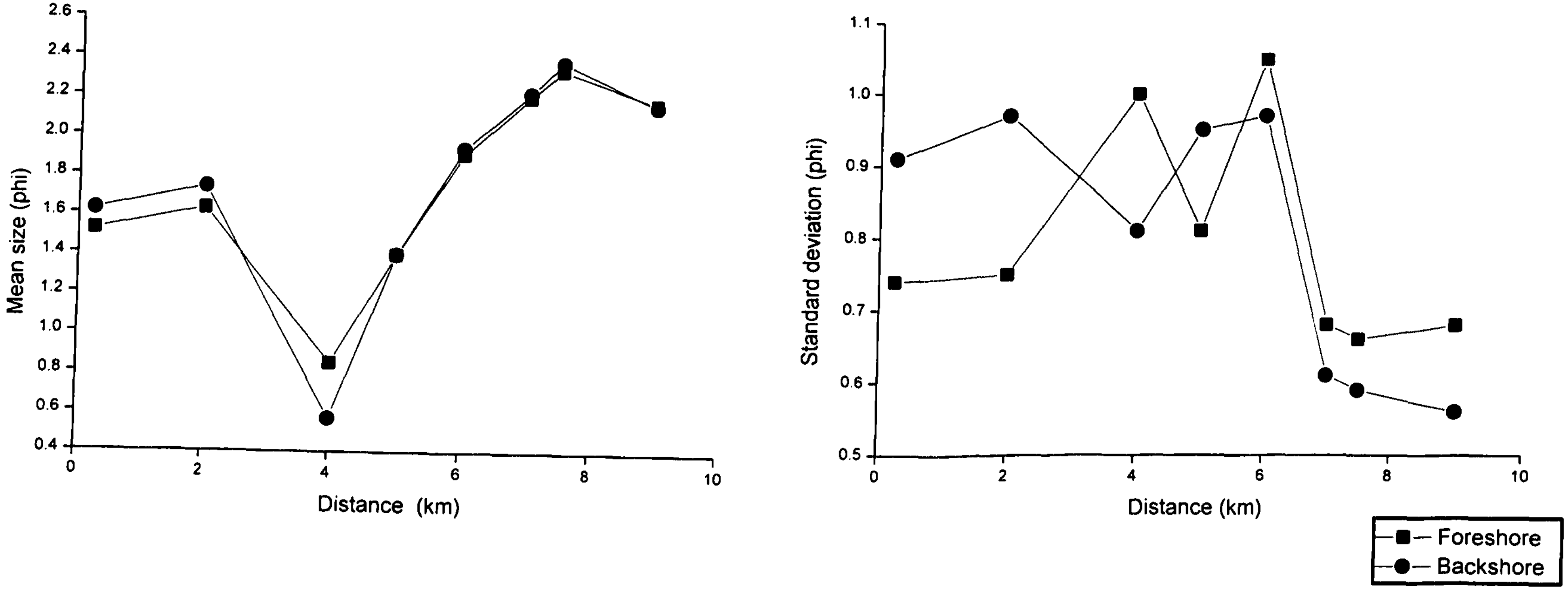


Fig. 3.4. Longshore variation of textural parameters of the sediments of the lagoon beach of Kavaratti Island

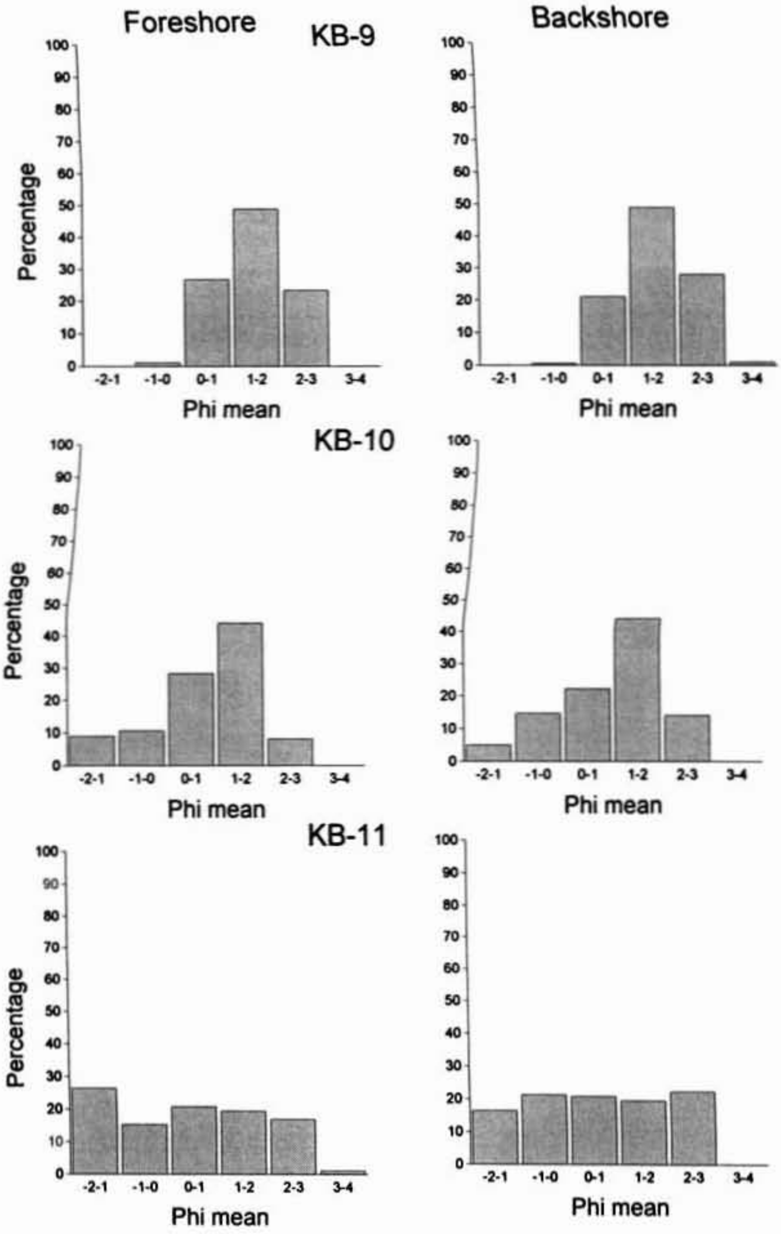
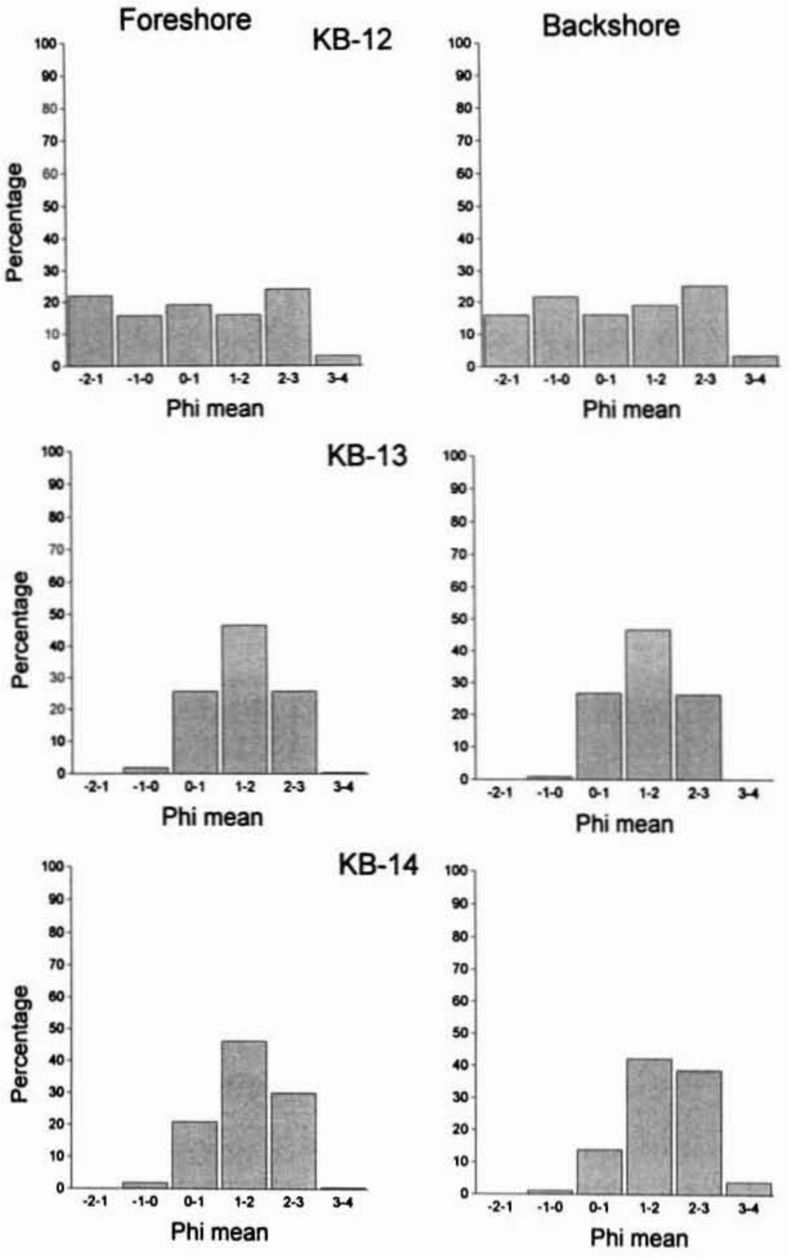


Fig. 3.5 Variation of different size classes of sediments along the storm side beach of the Kavaratti Island.



(Fig. 3.5 continued)

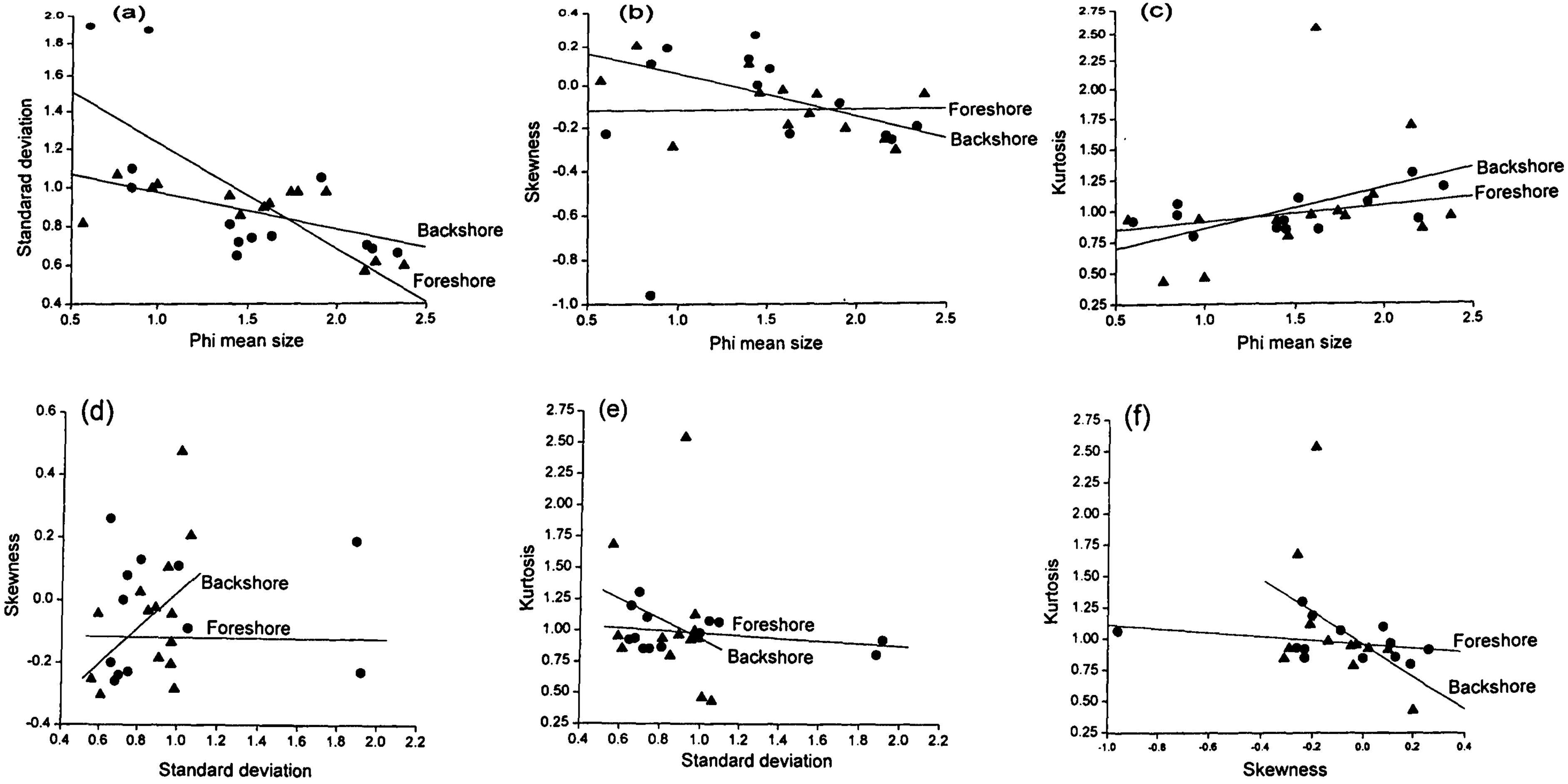


Fig. 3.6 Interrelationship of different textural parameters of the beach sediments of the Kavaratti Island.

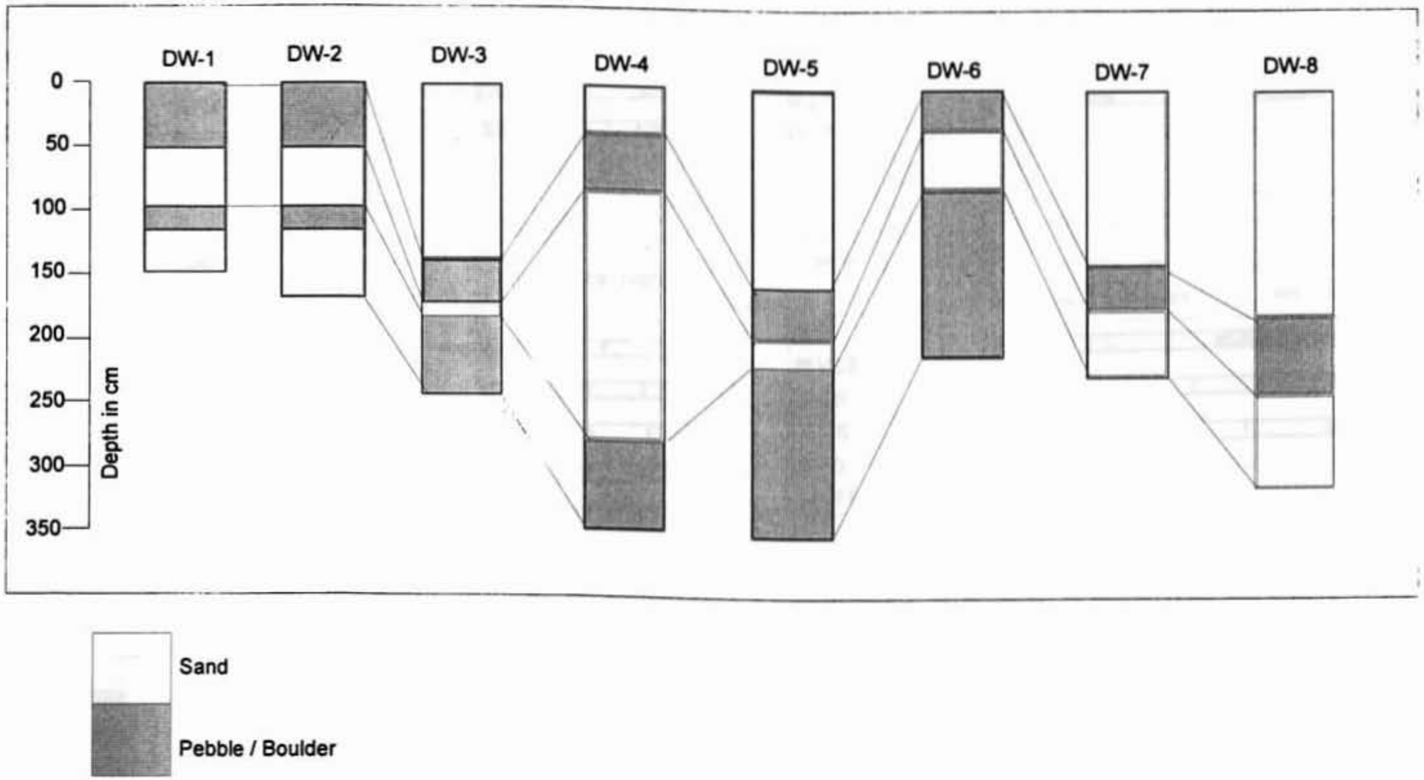


Fig. 3.7 Litho column from dug wells inthe southern part of Kavaratti island.

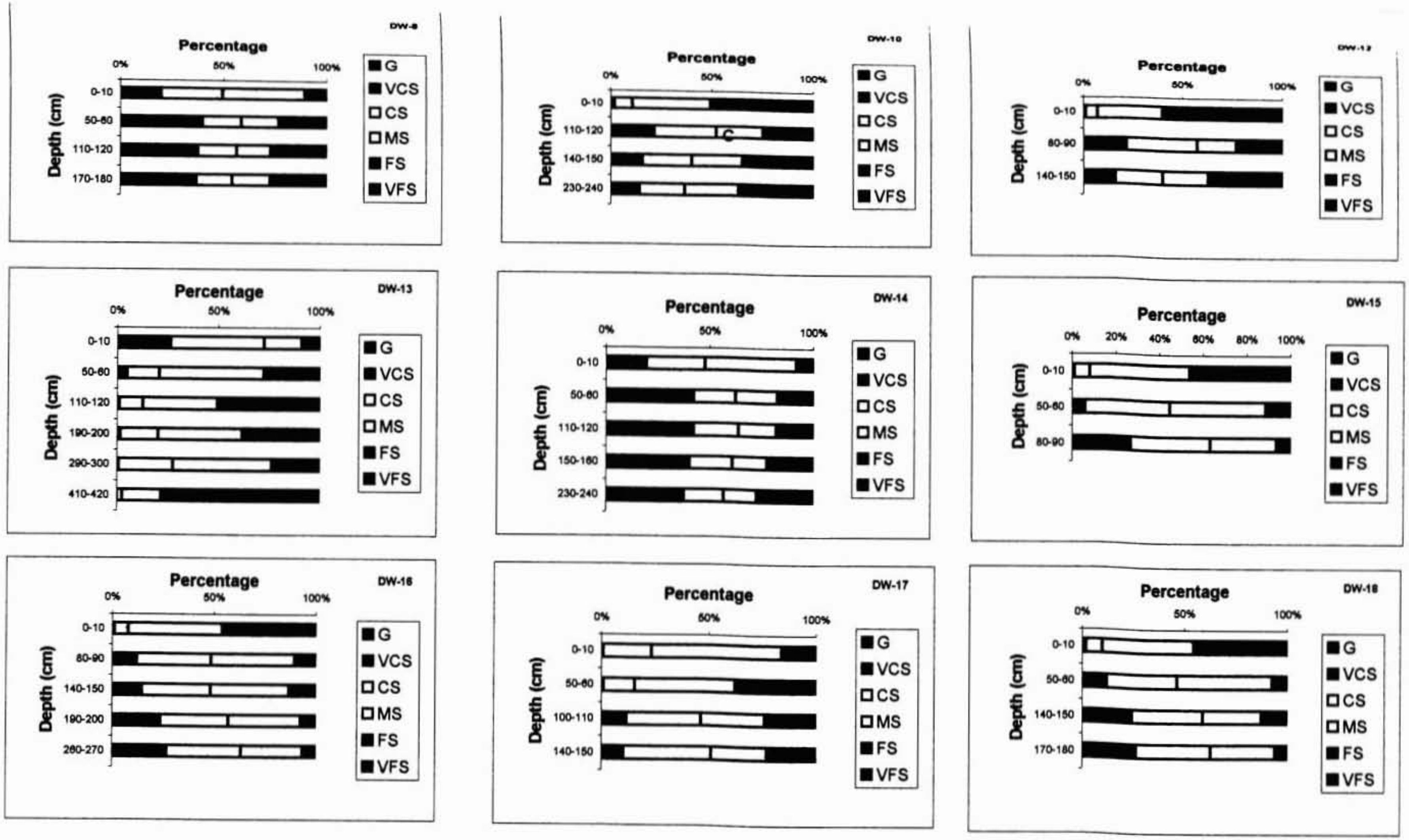


Fig. 3.8 Vertical distribution of different class of sediments of the Kavaratti Island.

Table 3.1 Grain size parameters of the sediments of the Kavaratti Island

Kavaratti Island

Sa.No	Mz	SD	Sk	KG
Lagoon				
KL-1	-0.08	0.87	-0.57	1.24
KL-2	0.68	0.91	-0.02	1.04
KL-3	0.43	1.01	0.25	1.08
KL-4	0.32	1.76	-0.14	0.98
KL-5	0.46	1.18	0.03	0.96
Beach				
Lagoon side - Foreshore				
KB-1	1.52	0.74	0.08	1.10
KB-2	1.63	0.75	-0.23	0.85
KB-3	0.85	1.00	0.11	0.97
KB-4	1.40	0.81	0.13	0.86
KB-5	1.91	1.05	-0.09	1.07
KB-6	2.20	0.68	-0.26	0.93
KB-7	2.34	0.66	-0.20	1.19
KB-8	2.17	0.68	-0.24	1.30
Lagoon side- Backshore				
KB-1	1.62	0.91	-0.19	2.54
KB-2	1.74	0.97	-0.14	0.99
KB-3	0.57	0.81	0.02	0.93
KB-4	1.40	0.95	0.1	0.92
KB-5	1.94	0.97	-0.21	1.12
KB-6	2.22	0.61	-0.31	0.85
KB-7	2.38	0.59	-0.05	0.95
KB-8	2.16	0.56	-0.26	1.68
Strom side- Foreshore				
KB-9	1.44	0.66	0.26	0.92
KB-10	0.85	1.10	-0.96	1.06
KB-11	0.60	1.92	-0.23	0.92
KB-12	0.94	1.89	0.19	0.80
KB-13	1.45	0.72	0.00	0.85
KB-14	1.63	0.75	-0.23	0.85
Storm side- Backshore				
KB-9	1.59	0.89	-0.03	0.96
KB-10	0.97	0.99	-0.29	0.93
KB-11	1.00	1.01	0.47	0.46
KB-12	0.77	1.06	0.20	0.43
KB-13	1.46	0.85	-0.04	0.79
KB-14	1.78	0.97	-0.05	0.95

Sa.No	Mz	SD	Sk	KG
Island proper				
DW-9				
0-10	0.81	1.11	-0.94	1.02
50-60	0.63	1.91	-0.19	0.89
110-120	0.91	1.82	0.14	0.76
170-180	0.87	1.81	0.11	0.78
DW-10				
0-10	1.90	0.66	-0.15	1.39
110-120	1.11	1.59	-0.09	1.12
140-150	1.61	1.11	-0.07	0.91
230-240	1.57	1.41	-0.03	0.93
DW-12				
0-10	2.00	0.63	-0.16	1.43
80-90	1.16	1.65	-0.12	1.14
140-150	1.63	1.30	-0.09	0.92
DW-13				
0-10	0.63	0.87	0.22	1.00
50-60	1.51	0.91	-0.13	1.02
110-120	1.87	0.95	-0.28	1.18
190-200	1.84	0.93	-0.21	1.01
290-300	1.43	0.85	0.06	0.80
410-420	2.47	1.11	-0.27	1.05
DW-14				
0-10	1.93	0.51	-0.39	0.54
50-60	1.97	0.02	-0.28	0.83
110-120	1.91	0.01	-0.26	0.79
150-160	1.89	0.03	-0.29	0.81
230-240	1.80	0.70	0.33	1.15
DW-15				
0-10	1.94	0.55	0.08	0.82
50-60	1.13	0.78	0.07	0.93
80-90	0.81	1.40	0.26	1.27
DW-16				
0-10	0.85	1.10	-0.96	1.06
80-90	0.60	1.92	-0.23	0.92
190-200	0.81	1.87	0.12	0.88
260-270	0.94	1.89	0.19	0.80
DW-17				
0-10	1.51	0.69	0.13	1.16
50-60	1.62	0.72	0.31	1.01
100-110	1.58	0.70	0.28	1.10
140-150	1.11	0.98	0.22	1.24
DW-18				
0-10	0.81	1.18	-0.91	1.03
50-60	0.59	1.87	-0.21	0.96
140-150	0.91	1.81	0.14	0.84
170-180	0.89	1.78	0.11	0.81

Table. 3.2 Frequency distributions of different class of sediments of the Kavaratti Island

Sa.No	G	VCS	CS	MS	FS	VFS
Lagoon						
KL-1	0.0	23.5	76.0	0.3	0.1	0.0
KL-2	0.0	15.0	45.0	39.0	1.0	0.0
KL-3	0.0	27.0	53.0	12.5	6.5	0.5
KL-4	20.0	30.0	25.0	17.5	7.3	0.2
KL-5	0.0	40.0	45.0	13.0	1.9	0.1
Beach						
Lagoon side- Foreshore						
KB-1	0.0	3.3	15.9	51.7	27.4	0.0
KB-2	0.0	1.8	20.9	46.2	29.9	0.5
KB-3	0.0	24.3	41.9	18.9	8.5	0.2
KB-4	0.0	2.7	35.3	38.5	15.2	0.1
KB-5	0.0	1.2	11.7	39.4	47.2	0.4
KB-6	0.0	1.4	6.1	32.4	58.7	1.0
KB-7	0.0	1.4	3.1	18.2	70.6	5.9
KB-8	0.0	1.4	6.1	25.4	65.6	0.9
Lagoon side- Backshore						
KB-1	1.5	3.4	12.1	34.0	57.6	1.6
KB-2	0.0	1.5	15.2	43.2	37.9	1.8
KB-3	3.4	23.3	43.9	25.8	3.5	0.0
KB-4	0.0	1.9	30.3	44.4	21.1	0.7
KB-5	0.0	1.3	8.7	38.4	51.2	0.4
KB-6	0.4	1.6	3.9	29.3	63.6	0.3
KB-7	0.0	1.3	1.2	9.9	71.6	16.7
KB-8	0.0	1.1	3.5	20.4	73.5	1.1
Storm side- Foreshore						
KB-9	0.0	1.1	26.7	48.8	23.3	0.0
KB-10	9.0	10.6	28.2	44.0	8.2	0.0
KB-11	26.4	15.3	20.7	19.5	17.0	1.1
KB-12	21.9	15.6	19.1	15.9	23.9	3.0
KB-13	0.0	1.8	25.6	46.5	25.6	0.4
KB-14	0.0	1.8	20.9	46.2	29.9	0.5
Storm side- Backshore						
KB-9	0.0	0.6	21.0	48.8	27.9	1.0
KB-10	5.0	14.6	22.2	44.0	14.1	0.0
KB-11	16.4	21.3	20.7	19.5	22.2	0.0
KB-12	15.9	21.6	16.0	18.9	24.9	3.1
KB-13	0.0	0.9	26.6	46.5	26.0	0.0
KB-14	0.0	1.1	13.9	42.2	38.6	3.9

Sa.No	G	VCS	CS	MS	FS	VFS
Island proper						
DW-9						
0-10	8.4	11.6	29.5	40.0	10.4	0.0
50-60	20.2	19.8	18.7	18.4	20.4	2.5
110-120	18.4	19.5	18.7	16.4	24.3	2.7
170-180	16.8	20.4	17.4	18.4	25.3	2.0
DW-10						
0-10	0.0	2.1	8.7	38.6	48.4	2.2
110-120	10.4	11.3	30.6	23.1	24.3	0.3
140-150	5.6	10.3	24.3	25.1	31.6	3.1
230-240	4.6	9.8	22.4	26.4	32.4	4.4
DW-12						
0-10	0.0	1.1	6.1	32.2	58.6	1.0
80-90	11.9	10.0	35.8	19.8	21.3	1.7
140-150	6.9	9.3	23.6	23.1	34.4	2.6
DW-13						
0-10	0.2	26.3	45.9	18.8	8.5	0.2
50-60	1.8	3.3	15.8	51.7	27.4	0.0
110-120	0.0	1.2	11.7	36.7	49.9	0.4
190-200	0.0	1.8	18.7	41.4	31.5	6.6
290-300	0.0	1.1	26.7	48.8	23.3	0.0
410-420	0.0	0.2	2.6	19.1	57.3	20.2
DW-14						
0-10	9.0	10.6	28.2	44.0	8.2	0.0
50-60	26.4	16.7	20.7	20.5	17.0	0.4
110-120	23.8	18.6	21.7	18.2	17.3	0.4
150-160	23.2	17.4	20.5	16.9	21.4	0.6
230-240	22.0	15.6	19.1	15.9	23.9	3.0
DW-15						
0-10	0	1.09	6.93	45.91	44.81	1.02
50-60	0	5.89	38.5	43.36	10.6	0.54
80-90	16	10.8	36.3	30.28	5.59	0.59
DW-16						
0-10	0.1	1.1	6.9	45.9	44.8	1.0
80-90	7.0	5.8	38.5	43.4	10.7	0.1
190-200	12.4	11.4	33.4	35.6	6.8	0.4
260-270	16.0	10.8	36.3	30.3	5.5	0.6
DW-17						
0-10	0.0	0.9	22.5	60.6	14.0	1.9
50-60	0.0	1.2	14.5	46.8	35.0	2.5
100-110	0.0	11.8	34.8	29.7	22.8	0.9
140-150	0.5	10.0	40.9	25.8	20.9	1.8
DW-18						
0-10	0	2.01	7.8	44.9	43.6	1.69
50-60	6.8	5.3	34.5	46.3	6.8	0.3
140-150	14.6	9.8	34.7	28.4	11.4	1.1
170-180	15.4	11.1	36.4	31.4	5.2	0.5

(Fig.3.1). Beach profiles of the 1998 and 1999 measurements show a marginal deposition in the northern part of the lagoon beach (at KBP-6, KBP-7 & KBP-8) and a little erosion on the south (at KBP-1 & KBP-2).

Kavaratti-Lagoon Sediment: The textural parameters of the lagoon sediments are presented in Tables 3.1 and 3.2. Only at KL-1 very coarse and coarse sands are observed while in other stations the sediment class vary considerably. Towards north of the lagoon the proportion of medium and fine sand populations increases (Fig. 3.2). Only at KL-1 very coarse and coarse sands are observed while in other stations the presence of all class of sand populations as well as considerable amount of granule are observed. The phi mean size of the lagoon sediments varies from –0.08 to 0.66 ϕ (Table 3.1). The sediments are moderately to poorly sorted (0.87 to 1.76 ϕ), fine skewed to very coarse skewed (0.25 to –0.57) and mesokurtic to leptokurtic (0.96 to 1.24).

Kavaratti - Beach sediments: The grain size parameters of the lagoon and storm side beach sediments show significant variations (Table 3.1). The sediments of the lagoon side beach are generally sandy in nature except at the southern end (Fig. 3.3). On the other hand, in the storm side sandy beaches are formed only at isolated pockets whereas in other places pebbles, conglomerates and coral rocks are very common.

a) Kavaratti - Lagoon side beach: The histogram (Fig. 3.3), which presents the distribution of different class of sediments and their variations from south to north, shows that medium and fine sands are so predominant in the southern two stations and are getting reduced with concomitant increase in coarse and very coarse sand percentages up to the central beach (KB-3). From the central part of the island onwards once again the content of medium and fine sands increase towards north and finally in the northern beaches fine sand predominates i.e. around 70% (Table 3.2).

The beach sediments of lagoon side show the phi mean size ranging from 0.85 to 2.34 ϕ in foreshore and 0.57 to 2.38 ϕ in the backshore respectively (Table 3.1). From the central part of the beach, the phi mean size increases both towards north and south (Fig. 3.4) Comparatively the northern part of the beach sediments are having high phi mean size than the southern part which means that fine sands are predominant on the north. The terminal samples of the island are slightly coarser than the adjoining samples (Fig.3.4).

The alongshore variation of phi mean size of the lagoon beach (Fig.3.4) does not show any significant variations between the foreshore and backshore beaches except in the southern two stations. In these two stations the foreshore sediments are slightly coarser than the backshore. The longshore variation of the standard deviation values (Fig. 3.4) show that there is a steady increase in standard deviation values from south to the central region of the beach, which means that the sorting becoming poorer up to the central region of the beach but on the northern end of the beach the sediments are comparatively better sorted than the rest of the beach.

The sorting values of the beach sediments show a narrow range. The sediments of the foreshore (0.66 to 1.05 ϕ) and backshore (0.56 to 0.97 ϕ) are moderately well sorted to moderately sorted. But most of the samples of the foreshore and backshore are poorly sorted. Although the sediments range from fine-skewed to coarse-skewed in the foreshore (0.13 to –0.26), most of the samples are coarse-skewed. In the case of backshore region the sediments are fine-skewed to very coarse skewed (0.1 to –0.31) of which the coarse-skewed sediments predominate. Sediments range from being platykurtic to leptokurtic (0.85 to 1.30) in the foreshore, while in the backshore it ranges from platykurtosis to very leptokurtosis (0.85 to 2.54).

b) Kavaratti - Storm side beach: The storm beach is also known as an open coast. In the northern part of the storm side beach (KB-9) medium sand predominates both in foreshore and backshore region (Fig. 3.5) over fine and coarse sand populations. In KB-10, the granule and very coarse sand constitute a significant population of the sediment distribution. However, in the central part of the beach (KB-11 & KB-12) the distribution of granule and different sand grades are more or less uniform both in foreshore and backshore. The sand distributions in the southern two stations are similar to the pattern of sand distribution on the northern extremity of the storm side beach. The storm side beach sediments of the Kavaratti Island have the phi mean size from 0.6 to 1.63 ϕ in the foreshore and 0.77 to 1.78 ϕ in the backshore. On the southern and northern end of the storm side beach high phi mean size values are observed. The sediments of the foreshore beach are moderately well sorted to poorly sorted (0.66 to 1.92 ϕ) while the sediments of the backshore are moderately sorted to poorly sorted (0.85 to 1.06 ϕ). The foreshore beach sediments are fine-skewed to very coarse-skewed (0.26 to –0. 96) whereas the backshore very fine-skewed to coarse-skewed sediments (0.47 to –0. 29) are found. In the foreshore region the sediments are platykurtic to mesokurtic (0.8 to 1.06) whereas in the backshore the sediments range from very platykurtic to mesokurtic (0.43 to 0.96).

Kavaratti-Scatter plots of Beach sediments: From the phi mean size vs. standard deviation diagram (Fig.3.6 a), it is evident that most sediments show sorting values ranging from 0.6 to 1.2 ϕ. Only a few sediments of the foreshore, having phi mean size values between 0.5 and 1 ϕ, show sorting values close to 2 ϕ. Most of the sediments are moderately well sorted to moderately sorted. Moderately well sorted sediments are seen in the size range between 2 and 2.5 ϕ. Nearly 2/3 of sediments have a narrow size range between 1.25 and 2.2 ϕ. The Fig. 3.6a further shows that with an increase of phi mean size, the standard deviation values decrease attesting that better sorted sediments are confined to fine mode. The scatter plot of phi mean size vs. skewness (Fig 3.6b) does not show any trend for the backshore sediments while the foreshore sediments reveal a negative trend which means that coarser sediments are positively skewed (Fig.3.6b and Table 3.1) Majority of the sediments shows a close range in skewness values i.e., between -0.3 and 0.2 though the phi mean size varies widely from 0.5 to 2.5 ϕ. The phi mean size vs. kurtosis plot shows that majority of the sediments has a very narrow range of kurtosis (Fig. 3.6c); falling between 0.75 and 1.25 in spite of a wide range of phi mean size. The plot (Fig. 3.6c) shows a slight positive correlation between phi mean size and kurtosis indicating that with the increase of phi mean size, kurtosis values shift from platy to meso and then to leptokurtosis.

The standard deviation vs. skewness plot indicates that the foreshore sediments do not reveal any trend whereas the backshore sediments show a positive correlation (Fig. 3.6d). It is clear that although the standard deviation values show a narrow range the skewness of the sediments vary widely. Standard deviation vs. kurtosis plot (Fig.3.6e) shows a negative trend for the foreshore. In general sorting of the sediments improves when the kurtosis values change from platy to mesokurtosis and then to leptokurtosis. The extreme kurtosis value observed in the backshore is due to the presence of dominant fine mode. The plot of skewness vs. kurtosis (Fig. 3.6f) does not indicate any significant trend for the foreshore sediments whereas the backshore sediments indicate that as the skewness changes from negative to positive the kurtosis values change from leptokurtosis to platykurtosis.

Kavaratti-Sediments of the island proper: Dug well samples collected from different part of the Kavaratti island (Fig. 3.8) show a drastic change in sediment characteristics from north to south. For proper presentation of the results and discussion the island is divided into three sections namely the northern, central and southern. The sediments of the northern part of the island (DW-15, DW-16, DW-17 and DW-18) show considerable differences compared to the central part (DW-9, DW-10, DW-12, DW-13 and DW-14). The sediment of the northern part of the island consists mainly of coarse, medium and fine sands. Coarse sand and granule are restricted to the deeper parts of the dug wells. Also the wells showing appreciable granule content are from the storm side of the island (DW-16 and DW-18). The general tendency in the dug wells of the northern part of the island is that medium and fine sand populations decrease with increase of depth whereas coarse and very coarse sands and granule increase towards bottom of the dug wells.

The sediments of the central section of the island show the presence of appreciable granule percentage in addition to the other class of sands. The central part of the island samples show no clear variation in the sediment class with depth. DW-14 shows the presence of considerable granules (26.4 %). In this well the content of coarse sand and fine sand increases with depth while the medium sand percentage is getting decreased with depth. DW-13 shows that the content of fine and medium sands increase upto 120 cm. DW-9 and DW-14, which have been collected from the storm side of the island show close similarity to the one collected at the central (DW-12) and lagoon side (DW-10) of the island.

Dug wells of the southern side of the island show more of pebbles, cobbles and boulders. Among the eight dug wells, in the southern part, three are located closer to lagoon side (DW-2, DW-5 and DW- 8) whereas DW-1, DW-3, DW-4 and DW-6 are closer to storm side. The location of DW-7 is more or less at the centre of the island. In DW-1, DW-2 and DW-6 sandy sediments are absent at the surficial level. DW-3, DW-5, DW-7 and DW-8 show considerable thickness of sand content at the top (Fig. 3.7) followed by a more or less uniform thickness of a pebble bed ranging from 30-50 cm. Below the top pebble bed a varying thickness of coarse to very coarse sand unit is found in all the dug wells. The thickness of sand unit is very large in DW-4. However, the sand layer is so thin in DW-1, DW-2, DW-3 and DW-5. Except DW-7 and DW-8, the bottom is represented once again by another pebble bed in the remaining dug wells.

3.2.2 Minicoy Island:

The beach profile variation of the Minicoy lagoon beach is presented in Fig. 3.9. The textural parameter of the island is given in Table 3.3 while the variations of different class of sediments are presented in Table 3.4. The textural variation of different class of sediments of the Minicoy lagoon is shown in Fig. 3.10 while that of the lagoon beach in Fig. 3.11 and storm side beach in Fig. 3.13. The alongshore variation of phi mean size and standard deviation values of the Minicoy lagoon beach sediments are presented in Fig. 3.12. The interrelationship between the different textural parameters of the Minicoy beach sediments is presented in the scatter diagrams (Fig. 3.14). The variation of different class of island proper sediments is presented in Fig. 3.15.

Minicoy - Beach Profile: The Minicoy Island lagoon beach is also oriented more or less in a NE-SW direction. The beach slope is gentle in the south and slightly steep in the north Beach profiles (Fig. 3.9) show no major changes between 1998 and 1999 measurements. The southern and northern beach sections

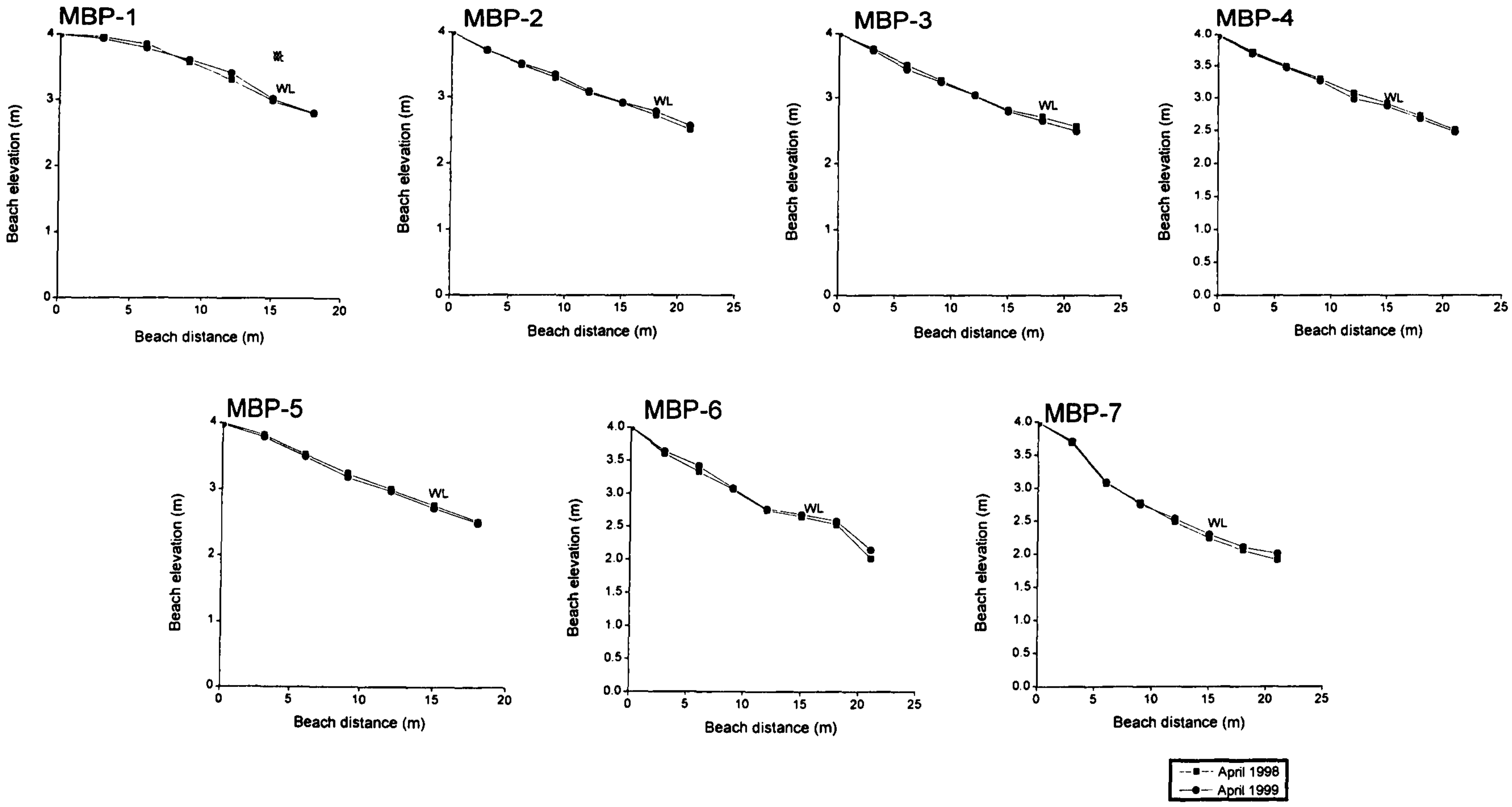


Fig. 3.9 Beach profiles of the lagoon side of the Minicoy Island

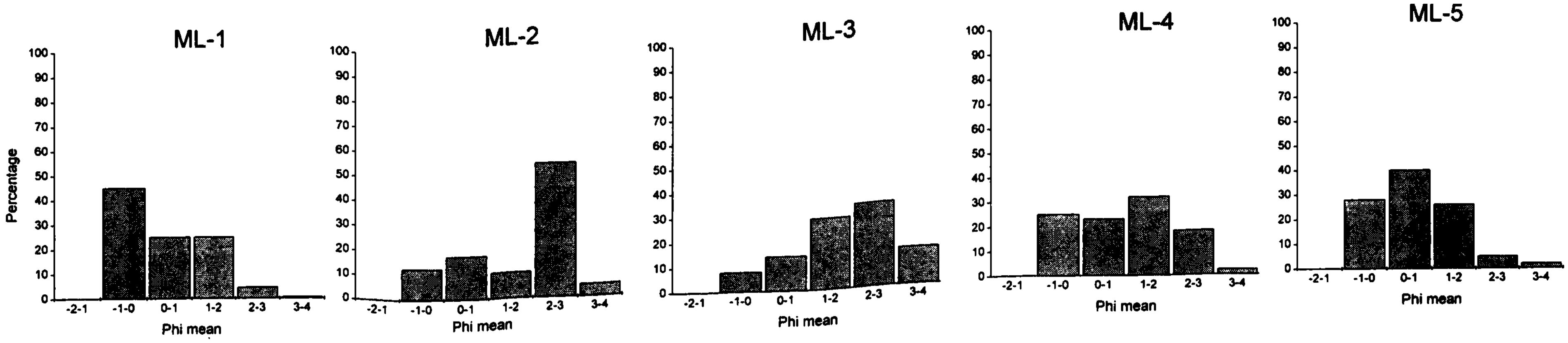


Fig. 3.10 Variation of different size classes in lagoon sediments of the Minicoy

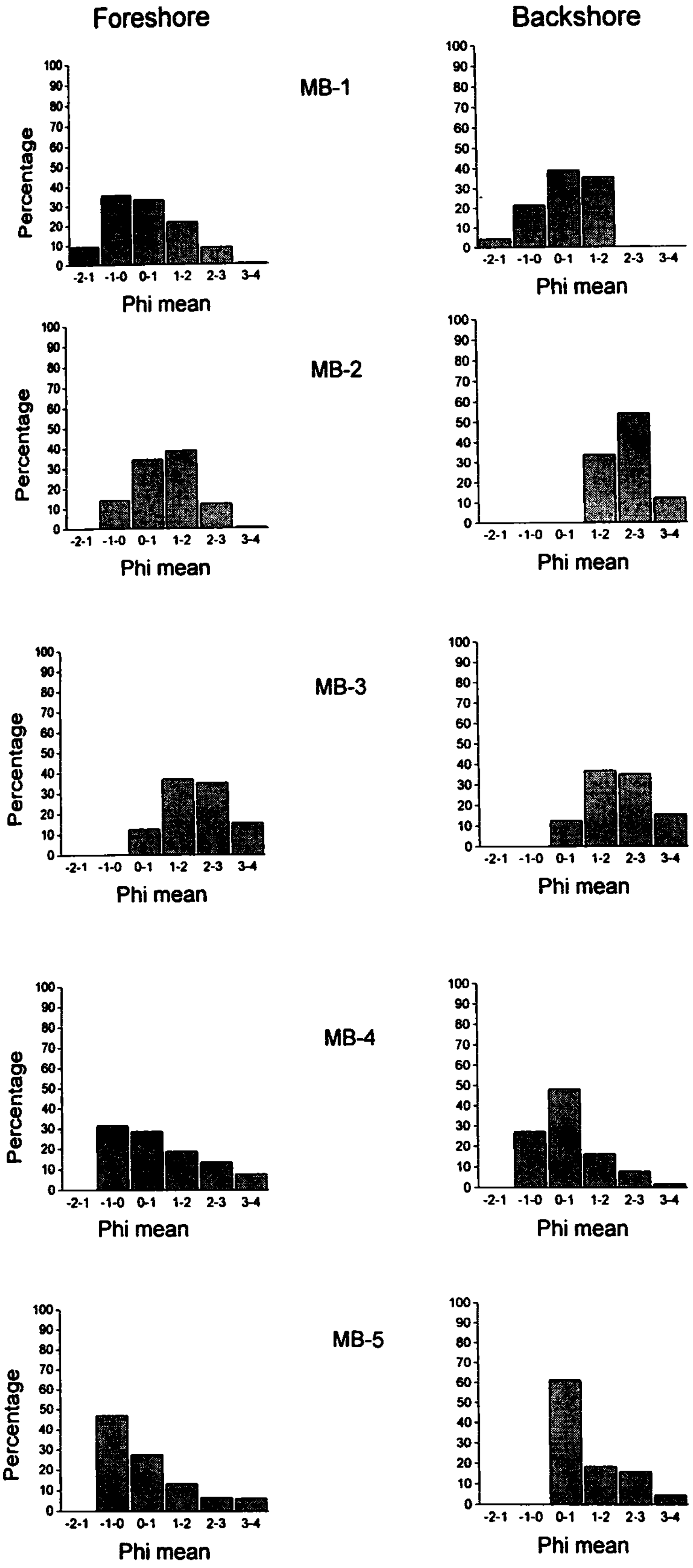
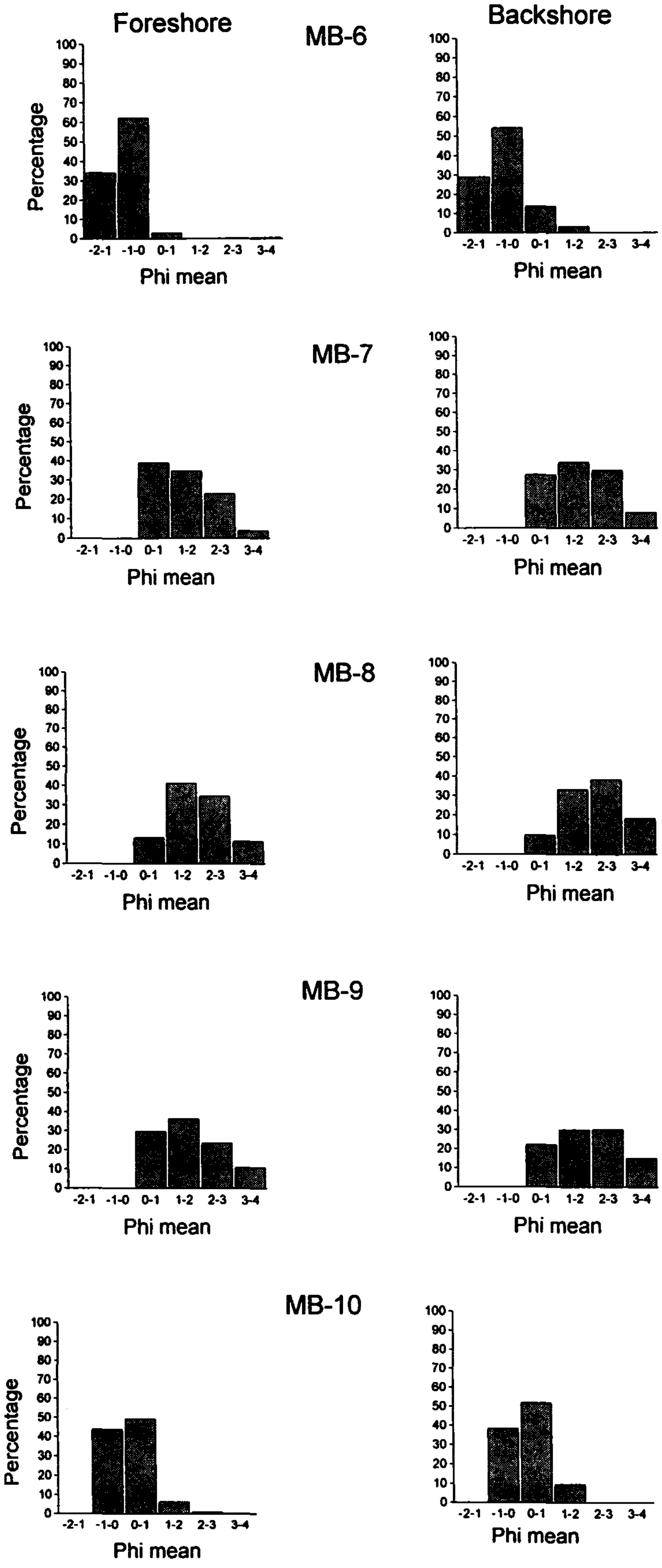


Fig.3.11 Variations of different size classes of lagoon side beach sediments of Minicoy Island



(Fig. 3.11 continued)

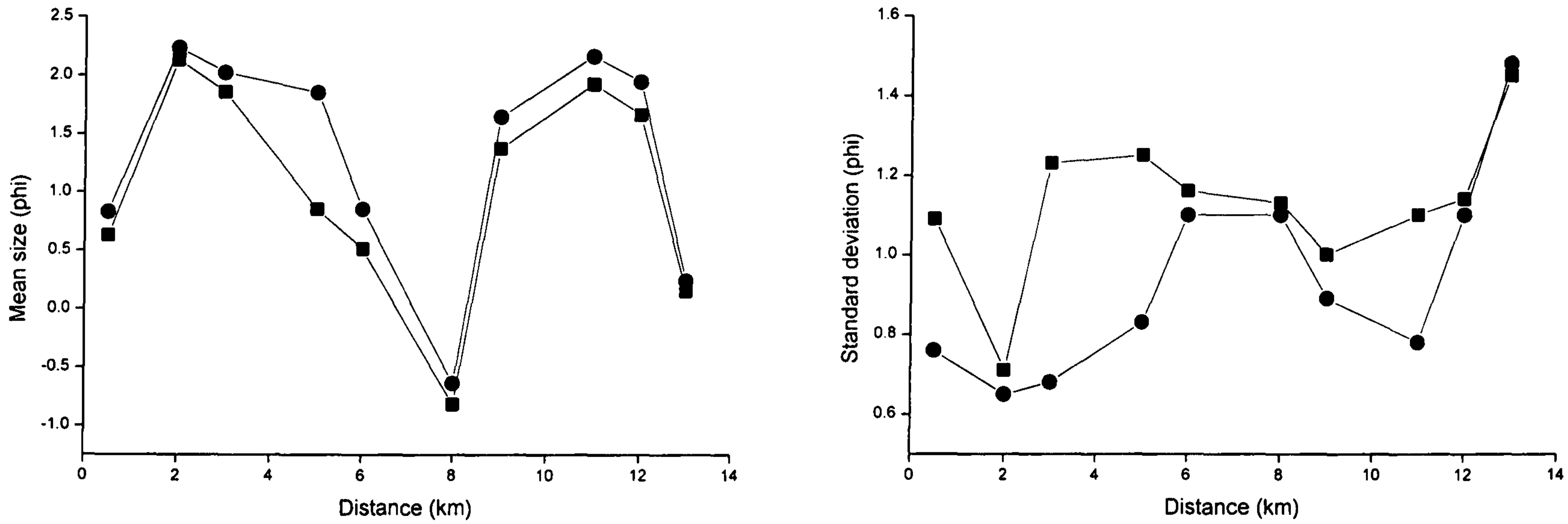


Fig. 3.12 Longshore variation of textural parameters in the lagoon beach of Minicoy Island

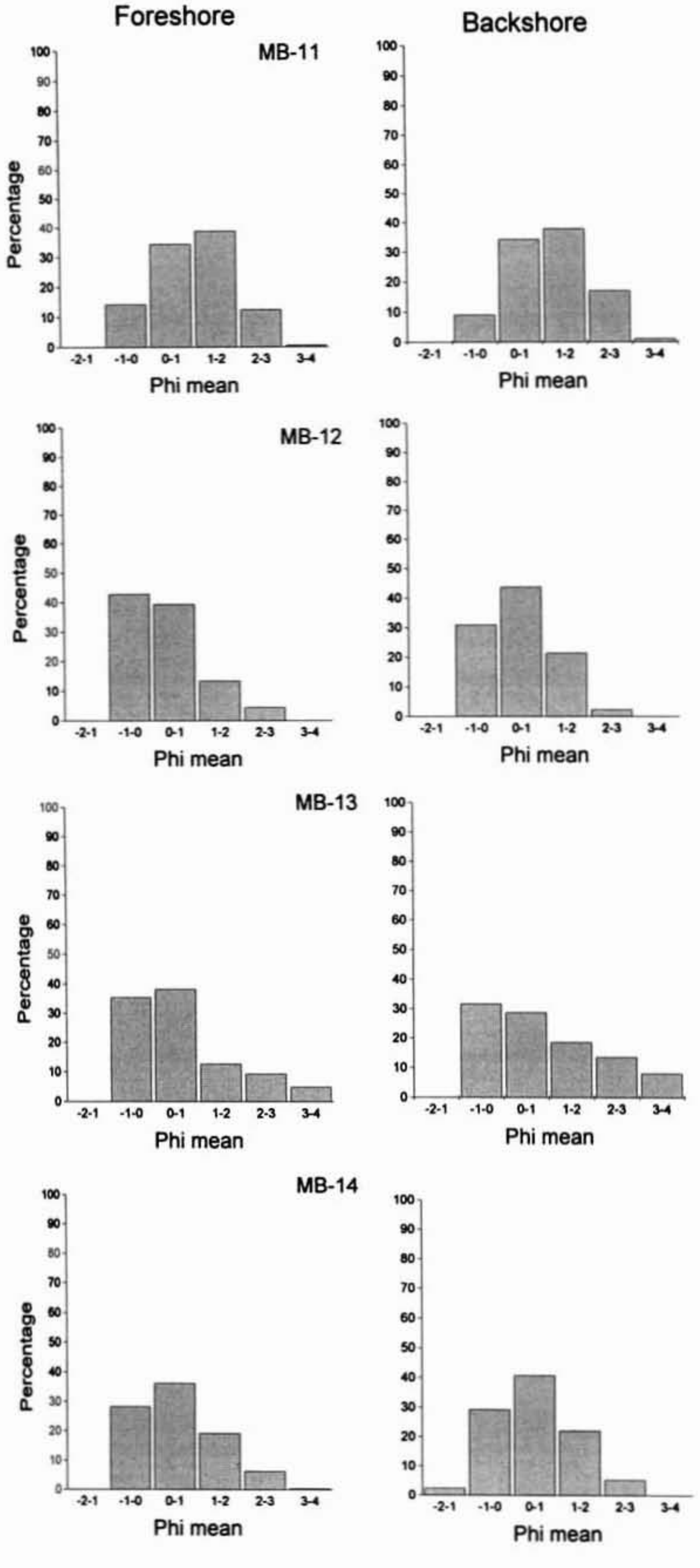
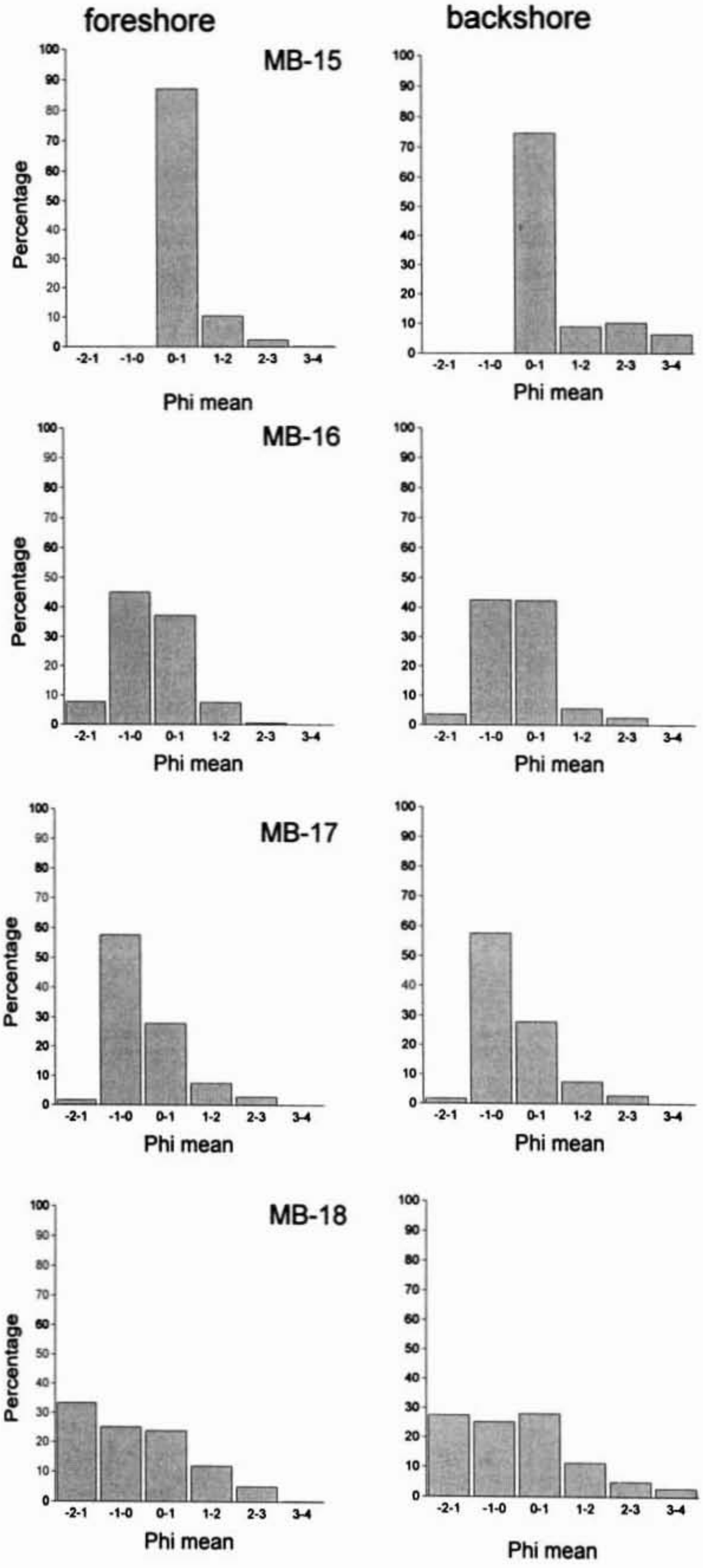


Fig.3.13 Variation of different size classes of sediments along the storm side beach of the Minicoy Island



(Fig.3.13 continued)

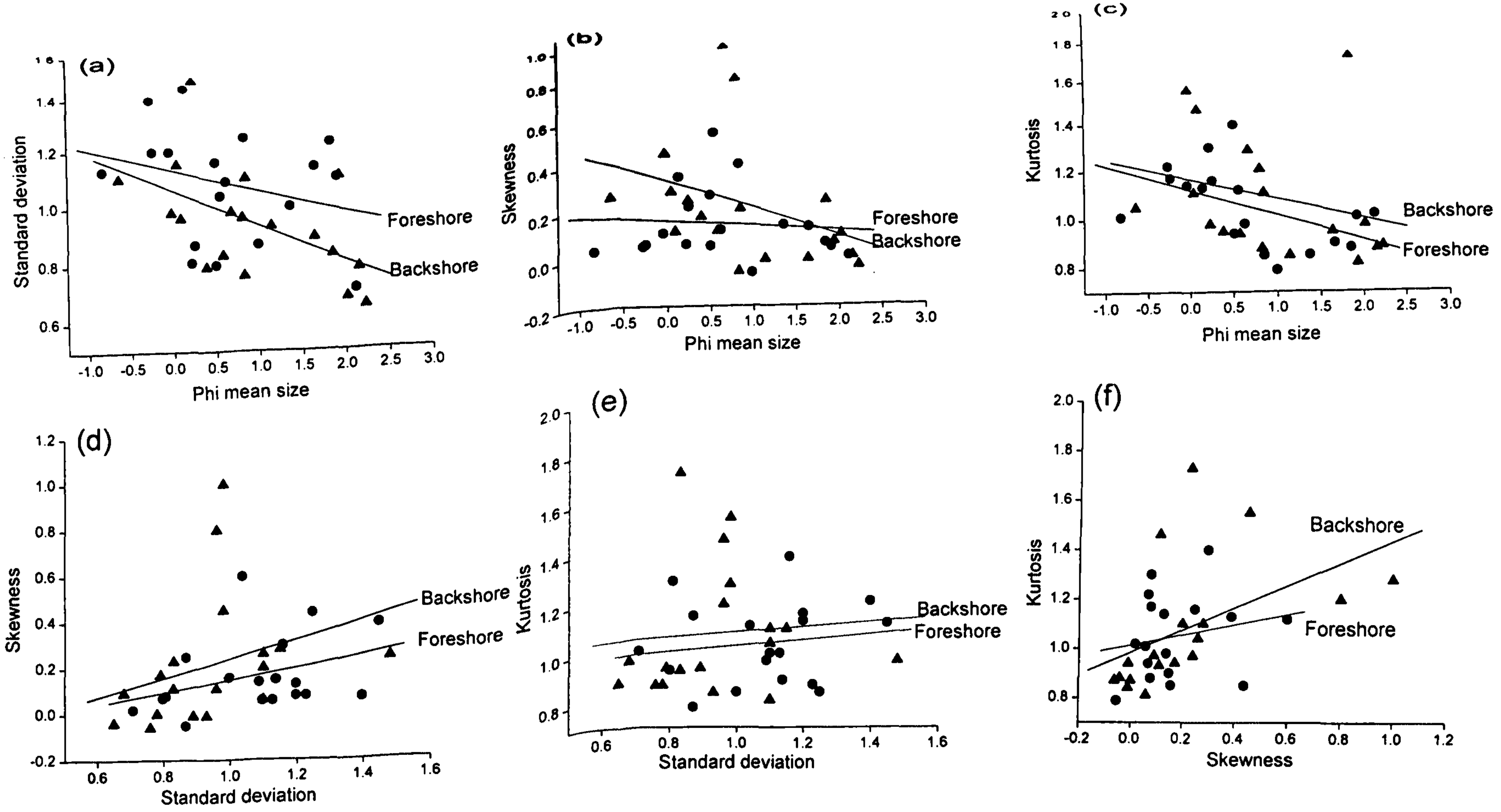


Fig. 3.14 Interrelationship of different textural parameters of the beach sediments of the Minicoy Island.

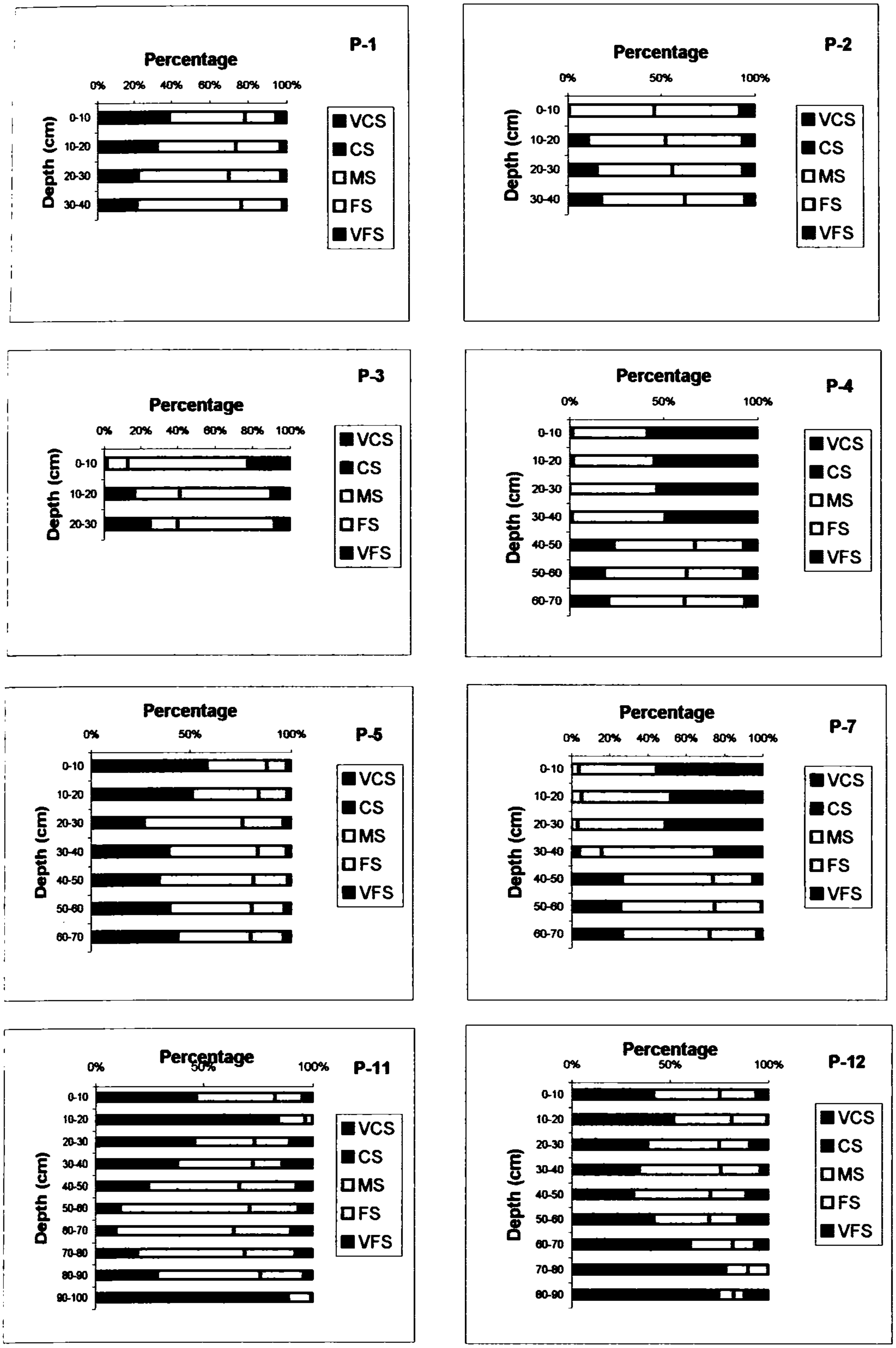


Fig. 3.15 Vertical distribution of different class of sediments of the Minicoy Island

Table 3.3 Grain size parameters of the sediments of the Minicoy Island

Sa.No	Mz	SD	Sk	KG
Lagoon				
ML-1	0.24	1.36	-0.10	0.96
ML-2	1.76	1.21	-0.31	0.91
ML-3	1.83	1.31	-0.14	0.78
ML-4	1.22	1.22	0.03	0.93
ML-5	0.77	1.60	-0.02	0.64
Beach				
Lagoon side- foreshore				
MB-1	0.63	1.09	0.14	0.98
MB-2	2.13	0.71	0.02	1.02
MB-3	1.85	1.23	0.08	0.88
MB-4	0.85	1.25	0.44	0.85
MB-5	0.51	1.16	0.30	1.40
MB-6	-0.82	1.13	0.06	1.01
MB-7	1.37	1.00	0.16	0.85
MB-8	1.92	1.10	0.06	1.01
MB-9	1.66	1.14	0.15	0.90
MB-10	0.15	1.45	0.39	1.13
Lagoon side- Backshore				
MB-1	0.83	0.76	-0.06	0.87
MB-2	2.23	0.65	-0.04	0.88
MB-3	2.02	0.68	0.09	0.97
MB-4	1.85	0.83	0.23	1.73
MB-5	0.85	1.10	0.20	1.10
MB-6	-0.64	1.10	0.26	1.04
MB-7	1.64	0.89	-0.01	0.94
MB-8	2.16	0.78	0.00	0.87
MB-9	1.94	1.10	0.06	0.81
MB-10	0.24	1.48	0.24	0.97
Storm side- foreshore				
MB-11	-0.03	1.20	0.13	1.14
MB-12	-0.23	1.20	0.08	1.17
MB-13	-0.26	1.40	0.07	1.22
MB-14	0.23	0.81	0.08	1.30
MB-15	0.51	0.80	0.07	0.94
MB-16	0.56	1.04	0.60	1.12
MB-17	0.26	0.87	0.25	1.16
MB-18	1.00	0.87	-0.05	0.79
Storm side- Backshore				
MB-11	0.05	1.15	0.28	1.10
MB-12	-0.02	0.98	0.45	1.55
MB-13	0.09	0.96	0.11	1.46
MB-14	0.68	0.98	1.00	1.28
MB-15	0.58	0.83	0.11	0.93
MB-16	0.81	0.96	0.80	1.20
MB-17	0.39	0.79	0.17	0.94
MB-18	1.14	0.93	-0.01	0.84
Island proper				
P-1				
0-10	1.21	0.84	0.09	0.84
10-20	1.44	0.80	0.11	0.87
20-30	1.58	0.78	0.13	0.89
30-40	1.61	0.76	0.14	0.93

Sa.No	Mz	SD	Sk	KG
P-2				
0-10	2.02	0.67	0.04	0.93
10-20	1.89	0.74	-0.06	0.88
20-30	1.86	0.80	0.00	0.83
30-40	1.72	0.75	0.07	0.90
P-3				
0-10	2.01	0.64	0.01	0.91
10-20	1.87	0.72	-0.02	0.84
20-30	1.83	0.76	-0.01	0.79
P-4				
0-10	3.00	0.55	-0.03	0.91
10-20	3.06	0.63	-0.15	0.76
20-30	3.04	0.58	-0.26	0.79
30-40	2.97	0.60	0.00	0.81
40-50	1.65	0.83	0.24	0.88
50-60	1.71	0.81	0.21	0.91
60-70	1.73	0.83	0.13	0.93
P-5				
0-10	0.99	0.75	0.34	1.00
10-20	1.10	0.77	0.32	1.05
20-30	1.40	0.72	0.24	0.94
30-40	1.27	0.64	0.33	1.50
40-50	1.36	0.67	0.24	0.92
50-60	1.33	0.78	0.35	1.66
60-70	1.23	0.82	0.22	0.94
P-7				
0-10	2.80	0.52	-0.01	0.94
10-20	2.94	0.61	-0.10	0.77
20-30	2.70	0.61	-0.11	0.81
30-40	2.81	0.59	0.01	0.79
40-50	1.71	0.89	0.21	0.84
50-60	1.69	0.86	0.19	0.94
60-70	1.73	0.86	0.11	0.91
P-11				
0-10	1.26	0.71	0.51	1.11
10-20	1.19	0.74	0.56	1.09
20-30	1.10	0.78	0.61	1.04
30-40	1.40	0.79	0.59	1.11
40-50	1.68	0.81	0.28	0.98
50-60	1.71	0.84	0.24	1.01
60-70	1.79	0.76	0.25	0.99
70-80	1.64	0.79	0.12	1.02
80-90	1.24	0.97	-0.14	1.38
90-100	0.06	0.77	0.06	0.81
P-12				
0-10	1.21	0.79	0.51	1.09
10-20	1.14	0.74	0.52	1.21
20-30	1.54	0.82	0.61	1.02
30-40	1.61	0.74	0.26	0.98
40-50	1.58	0.79	0.21	0.94
50-60	1.68	0.81	0.24	1.10
60-70	1.74	0.74	0.21	0.95
70-80	1.61	0.74	0.14	1.12
80-90	1.21	0.98	-0.01	1.21
90-100	0.50	0.71	0.02	0.84

Table 3.4 Frequency distributions of different class of sediments of the Minicoy Island.

No	G	VCS	CS	MS	FS	VFS
goon						
-1	0.0	45.0	25.0	25.0	4.5	0.5
-2	0.0	12.5	17.5	10.5	54.5	5.0
-3	0.0	8.0	14.0	29.0	34.0	15.0
-4	0.0	25.0	23.0	32.0	18.0	2.0
-5	0.0	28.0	40.0	26.0	4.9	1.9
ach						
goon side- foreshore						
6-1	9.3	35.4	32.9	21.6	8.7	0.6
6-2	0.0	14.2	34.3	38.7	12.4	0.6
6-3	0.0	0.0	12.5	36.9	35.1	15.5
6-4	0.0	31.5	28.6	18.7	13.4	7.6
6-5	0.0	46.9	27.4	13.1	6.5	6.1
6-6	34.2	62.2	2.8	0.0	0.3	0.6
6-7	0.0	0.0	38.9	34.7	22.7	3.7
6-8	0.0	0.0	13.1	41.1	34.4	11.4
6-9	33.3	25.1	23.8	11.9	5.1	0.3
6-10	0.0	43.6	49.1	6.1	0.9	0.3
goon side- Backshore						
6-1	4.4	21.3	39.0	35.3	0.1	0.0
6-2	0.0	0.0	0.0	33.7	54.2	12.1
6-3	0.0	0.0	12.5	36.9	35.1	15.5
6-4	0.0	27.0	48.0	16.1	7.6	1.6
6-5	0.0	0.0	61.3	18.3	15.9	4.5
6-6	29.0	54.1	13.7	3.1	0.0	0.0
6-7	0.0	0.0	27.4	33.9	29.6	7.9
6-8	0.0	0.0	9.8	33.0	38.0	18.2
6-9	0.0	0.0	22.1	29.8	30.1	14.9
6-10	0.0	38.4	51.8	9.6	0.0	0.0
m side- foreshore						
6-1	0.0	14.2	34.3	38.7	12.4	0.6
6-2	0.0	42.8	39.3	13.4	4.5	0.0
6-3	0.0	35.3	38.1	12.6	9.2	4.9
6-4	0.0	28.2	36.1	19.1	6.3	0.4
6-5	0.0	0.0	87.0	10.4	2.3	0.3
6-6	7.7	45.1	37.2	7.5	0.6	0.0
6-7	1.7	57.6	27.9	7.4	2.8	0.0
6-8	33.3	25.1	23.8	11.9	5.1	0.3
side- Backshore						
	0.0	9.0	34.1	37.7	17.0	1.1
	0.0	30.9	43.7	21.4	2.3	0.0
	0.0	31.5	28.6	18.5	13.4	7.9
	2.4	29.2	40.7	22.0	5.3	0.0
	0.0	0.0	74.6	8.9	10.2	6.3
	3.6	42.5	42.2	5.6	2.5	0.0
	1.7	57.6	27.9	7.4	2.8	0.0
	27.5	25.2	28.0	11.3	5.0	2.8
proper						
	0.0	3.4	35.6	39.4	16.4	5.2
	0.0	2.0	30.6	41.3	23.2	3.0
	0.0	0.0	22.6	47.3	26.9	2.9
	0.0	0.0	21.8	54.6	21.6	2.0

Sa.No	G	VCS	CS	MS	FS	VFS
P-2						
0-10	0.0	0.0	0.8	45.6	45.6	7.9
10-20	0.0	0.0	10.9	41.4	41.4	6.2
20-30	0.0	0.0	15.7	40.3	37.6	6.4
30-40	0.0	0.7	17.3	44.9	32.4	5.4
P-3						
0-10	0.0	0.0	1.8	11.5	64.5	22.2
10-20	0.0	5.3	11.6	24.6	48.6	9.9
20-30	0.0	6.8	18.6	14.9	51.6	8.1
P-4						
0-10	0.0	0.0	0.0	1.6	39.5	57.9
10-20	0.0	0.0	0.0	1.9	43.4	54.7
20-30	0.0	0.0	0.0	0.0	46.9	53.1
30-40	0.0	0.5	0.5	0.5	49.5	49.0
40-50	0.0	0.0	23.6	43.3	26.0	7.1
50-60	0.0	0.8	17.5	43.7	30.2	7.2
60-70	0.0	1.5	19.3	40.4	31.9	6.6
P-5						
0-10	0.0	0.0	58.6	29.3	9.9	2.2
10-20	0.0	0.0	51.3	32.8	14.0	2.0
20-30	0.0	0.0	27.3	48.8	20.3	3.7
30-40	0.0	0.4	39.2	44.1	14.2	2.2
40-50	0.0	0.0	34.9	46.6	17.1	1.5
50-60	0.0	0.0	40.2	40.2	16.2	3.3
60-70	0.0	1.6	42.4	36.0	16.4	3.6
P-7						
0-10	0.0	0.0	0.0	3.9	40.9	55.2
10-20	0.0	0	0	5.33	46.9	47.77
20-30	0.0	0	0	3.4	46	50.6
30-40	0.0	1.5	2.9	11.4	59.5	24.9
40-50	0.0	0	26.7	47.4	21	4.9
50-60	0.0	2.9	23	49	24.5	0.6
60-70	0.0	3.6	22.8	44.9	24.4	2.8
P-11						
0-10	0.0	0.0	46.6	35.9	12.6	4.6
10-20	0.0	0.0	83.5	12.2	3.5	0.0
20-30	0.0	0.0	46.1	27.2	16.3	10.4
30-40	0.0	0.0	38.2	34.5	13.4	13.9
40-50	0.0	0.0	24.8	41.6	26.3	7.3
50-60	0.0	0.0	11.8	59.5	22.4	6.3
60-70	0.0	0.0	9.9	54.2	26.0	9.9
70-80	0.0	0.0	20.0	48.9	23.3	7.8
80-90	0.0	11.2	17.7	46.8	19.8	4.0
90-100	0.0	48.7	40.3	10.3	0.7	0.0
P-12						
0-10	0.0	0.0	41.6	33.8	18.4	6.2
10-20	0.0	0.0	51.3	29.4	17.8	0.5
20-30	0.0	0.0	38.8	36.4	15.6	9.2
30-40	0.0	0.0	34.6	41.5	20.1	3.8
40-50	0.0	0.0	31.4	39.3	18.2	11.1
50-60	0.0	5.6	36.3	28.4	14.6	15.1
60-70	0.0	11.2	49.4	21.4	11.4	6.6
70-80	0.0	8.9	62.5	10.4	9.3	0.0
80-90	0.0	0.0	75.0	7.6	5.6	11.8

(profiles MBP-1, MBP-2, MBP-6 & MBP-7) show marginal deposition whereas the central part of the island (profiles MBP- 3, MBP-4 & MBP- 5) experiences a little erosion.

Minicoy-Lagoon sediment: In the southern side of the lagoon (ML- 1) very coarse sand dominates (45%) whereas in ML-2 fine sand predominates (54.5%). In ML-3 the distribution of medium and fine sands vary a little (29% and 34.2% respectively). In ML-4 very coarse, coarse, medium and fine sands are equally distributed. In ML-5 coarse sand population is slightly higher than very coarse and medium sands. The phi mean size of the lagoon sediment ranges from 0.24 to 1.83 ϕ. The sediments are poorly sorted (1.21 to 1.6 ϕ), nearly symmetrical to very coarse skewed (0.03 to –0.31) and platy to mesokurtic (0.64 to 0.96) in nature (Fig. 3.10).

Minicoy-Beach sediment: Like Kavaratti, the lagoon side beach sediments are generally sandy, while in the storm side beach, the sediment vary from fine sand to conglomerate. Only the sand dominant beach sections are studied here and presented.

a) Lagoon side beach: In the southern most part of the lagoon beach (MB-1), very coarse and coarse sand predominate in the foreshore whereas coarse and medium sands are the dominant constituents of the backshore beach. The granule content is significant in this station both in foreshore and backshore Fig. 3.11). The presence of granule is recorded again at MB-6, showing as much as 34.2 % in foreshore and 29 % in the backshore. On either side of MB-6 the distribution of the textural class vary considerably (Fig. 3.11). From station MB-8 to MB-10 (northern end), the coarse sand population is getting steadily increased whereas medium, fine and very fine sands decrease in foreshore and backshore. As a result, the coarse and very coarse sands are the predominant constituents of MB-10 with negligible amount of fine and very fine sands. Towards south, ie from MB-6 to MB-3 with reduction in the content of very coarse sand , the other size grades gradually increase leading to the predominance of medium and fine sands at MB-3.

The phi mean size of the foreshore (2.13 to –0.82 ϕ) and backshore (–0.64 to 2.23 ϕ) beach shows subtle range. Except one sample of the foreshore beach all other samples are poorly sorted (0.71 to 1.45 ϕ) where as in the backshore the sediments are moderately well sorted to poorly sorted (0.65 to 1.48 ϕ). Very fine-skewed to nearly symmetrical sediments are found in foreshore (0.44 to 0.02) whereas in the backshore fine skewed to near symmetrical (0.26 to –0-06) sediments are found. The sediments vary from platy to leptokurtosis (0.85 to 1.40) in foreshore and platy to very leptokurtosis (0.81 to 1.73) in backshore (Table. 3.3). The lagoon beach of the Minicoy island shows that the phi mean size, both in foreshore and backshore, is very coarser at the centre of the island and getting finer and finer on either sides of the island and then becoming coarser at the extreme end (Fig. 3.12). The foreshore beach sediments are distinctly coarser than the backshore (Fig. 3.12). Sorting wise no clear trend is found, although the finer size sediments are relatively better sorted than the coarser one. There is a clear distinction in standard deviation values between the oreshore and backshore sediments. The foreshore sediments are slightly ill sorted than the backshore sediments (Fig. 3.12).

b) Stormside beach: The southern storm side beach of the Minicoy Island is distinctly different from the northern one as far as the distributions of different size grades of sediments are concerned (Table. 3.4). The content of coarse sand at station MB-15 is abnormally very high being 87 % in foreshore and 74.6 % in the backshore (Fig. 3.13). Towards south of this station the percentage of coarse sand steadily decreasing with concomitant increase in very coarse sand and granule. The granule content in the foreshore (33.3 %) and backshore (27.5 %) at MB-18 is very significant (Fig. 3.13). The northern part of the storm beach show the predominance of very coarse, coarse and medium sands, the respective percentage differ from station to station and with out any specific trend along the beach.

The phi mean size range from -0.26 to 1 ϕ in the foreshore and 0.02 to 1.14 ϕ in the backshore. The storm side beach sediments are moderately sorted to poorly sorted both in the foreshore (0.8 to 1.4 ϕ) and backshore (0.79 to 1.15 ϕ) beaches. Majority of the backshore beach sediments (7 stations) is moderately sorted whereas in the foreshore beach equal distribution of moderately sorted and poorly sorted sediments are found. The skewness of the sediments indicates that both in the foreshore (-0.05 to 0.6) and backshore (-0.01 to 0.45) the range is from very fine skewed to nearly symmetrical. However, most of the samples are nearly symmetrical in the foreshore whereas in the backshore region fine skewed sediments predominate. Sediments are platy to leptokurtic (0.79 to 1.3) in the foreshore region whereas the backshore sediments are platy to very leptokurtic (0.84 to 1.55) in nature. In foreshore, most of the sediments are leptokurtic in nature where as backshore sediments show abundance of leptokurtic and mesokurtic values.

Minicoy-Scatter plots of beach sediments:

The scatter plot of phi mean size vs. standard deviation shows that the Minicoy beach sediments exhibit wide range in phi mean size but a relatively narrow range in standard deviation. In general, the coarser sediments are poorly sorted than the fine sediments, which resulted in negative correlation in both foreshore and backshore beaches. About 2/3 of the sediments show a narrow range of standard deviation values from 0.8 to 1.2 ϕ. Although there is a wide range of in phi mean size, sorting wise, both moderately sorted and poorly sorted sediments are equally present (Fig. 3.14a). Phi mean size vs. skewness diagram (Fig 3.14b) shows that the foreshore sediments does not show any specific trend whereas the backshore sediments show a negative correlation with phi mean size. It is evident that a vast majority of the backshore sediments are very coarse skewed whereas the foreshore sediments are predominantly of near symmetrical and fine skewed. The mean size vs. kurtosis diagram shown in Fig. 3.14c is more or less similar to the one obtained by Folk and Ward (1957) and Cronan (1972). The above plot shows that as the phi mean size increases both in foreshore and backshore region the kurtosis changes from very eptokurtosis to very platykurtosis. Majorities of the backshore and foreshore samples fall with in the platykurtic and very platykurtic range.

Standard deviation vs. skewness diagram (Fig. 3.14d) shows that with increase of standard deviation the skewness values increase, which means that sorting and skewness are positively correlated in foreshore and backshore sediments. Further the standard deviation and skewness values show a narrow range. Most of the sediments are near symmetrical to fine skewed. Standard deviation vs. kurtosis diagram (Fig. 3.14e) does not show any specific trend for the foreshore and backshore sediments. Except a couple of samples in backshore (having very leptokurtic values), other samples range from platy to leptokurtosis. The scatter diagram of skewness vs. kurtosis (Fig. 3.14f) clearly shows a positive trend in the foreshore and backshore sediments. The variation is more in the backshore sediments than in the foreshore.

Minicoy-Sediments of the island proper

P-1 to P-4 are collected from the southwestern part of the island. P-1, P-2 and P-3 are shallow pits and are about 30 to 40 cm deep only (Fig. 3.15). P-1shows that the concentration of coarse sediment decreases steadily with depth while the contents of medium and fine sands increase. In P-2, the fine and medium sands form the major constituent of the sediments and both components steadily decrease with depth. Further, coarse sand percentages show a decreasing trend with depth. There is no appreciable change in the very fine sand mode. P-3 shows the presence of considerable very coarse sand, whose percentage increases with depth like that of the coarse sand. Fine sand and very fine sand contents show a general decrease with depth. P-4 and P-7 show similar trend with depth (Fig. 3.15) although they were collected on opposite ends of the island (Fig. 2.2). The top 40 cm of these pits mainly consists of very fine and fine sand. Below 40 cm the very fine sand content is drastically reduced whereas the coarse sand content increases appreciably (Fig. 3.15). P-5, P-11 and P-12 show more or less similar trend i.e., with increase of depth the coarse sand content steadily decreases upto the middle of the pit and then increases. The concentration of medium and fine sand population in the central part of these pits is very high.

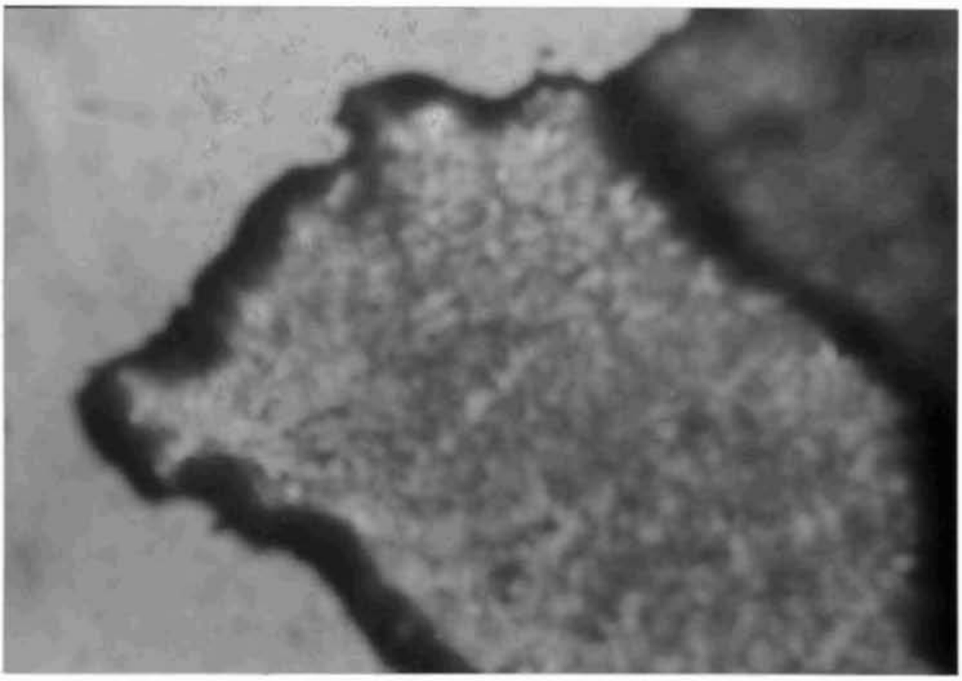
3.2.3 Constituent composition:

Microscopic identification of the island sediments consists primarily of coral debris, coralline algae, halimeda, molluscan shells, foraminifera and bryozoans. The red algae are slightly higher in Minicoy than the Kavaratti.

The photomicrographic features of the island sediments of Kavaratti and Minicoy as revealed by petrological microscope (Plate 3.1 a-d) and Scanning Electron Microscope (Plate 3.1 e-r) show excellent results. The plate 3.1 a-c indicates micritization process around the aragonite grain. The plate further shows the pore spaces in the aragonite grain. The plate 3.1d reveals the inclusion of bryozoan with in the aragonite grain. The plate 3.1 e-j exhibit the different foraminifers identified from DW-6 and P-4. The different foraminifers identified are *Calcarina calcar*, *Amphistegina lessonii*, *A. radiata*, *Quinqueloculina*

Plate. 3.1 a. An enlarge view of the algal boring along the periphery of the aragonite grains.

Plate. 3.1 b. Micritization process in aragonite.



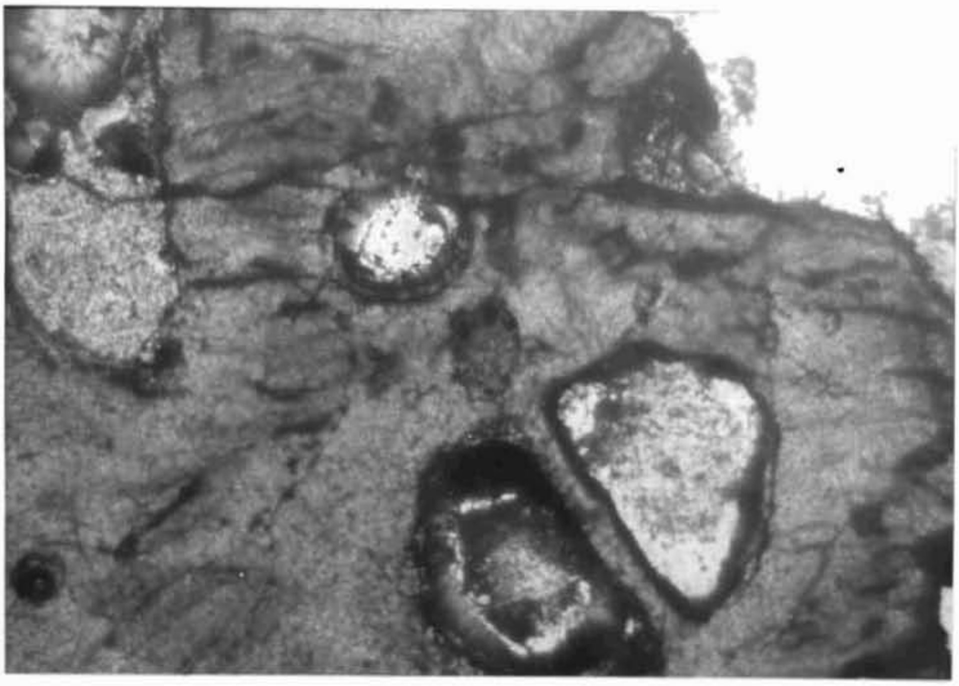
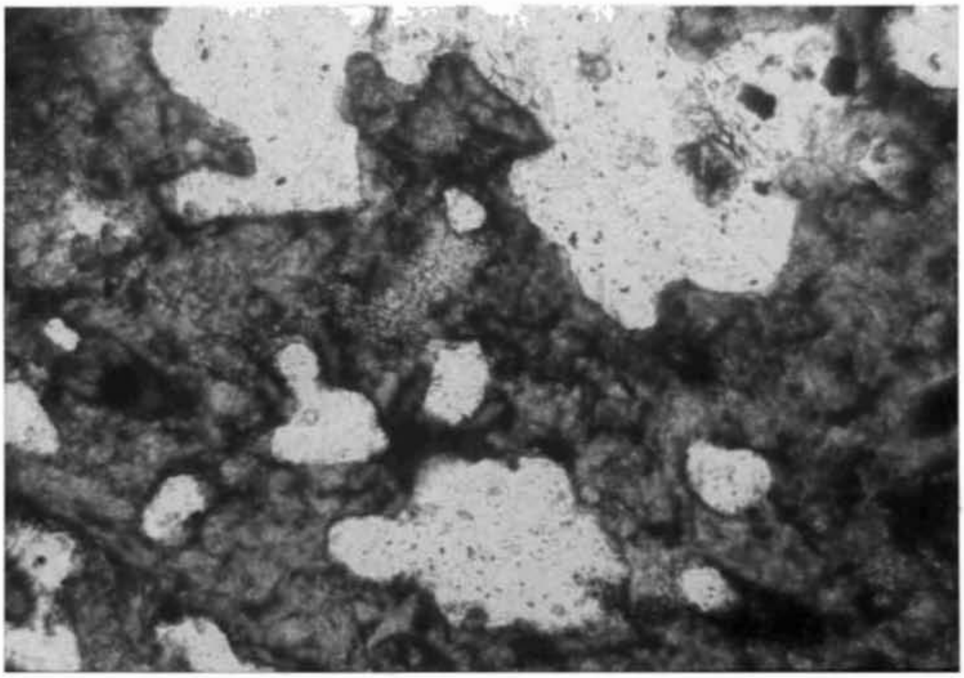


Plate. 3.1 c. A view of the porespaces in aragonite grains.

Plate. 3.1 d. showing the inclusion of bryozoan in coral skeleton.



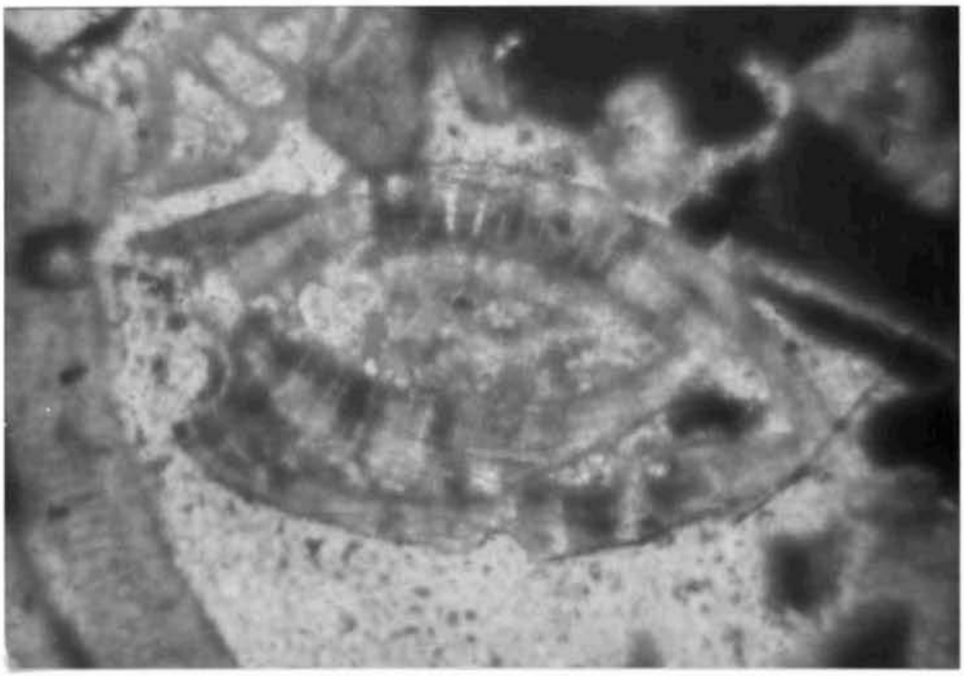


Plate 3.1 e. *Calcarina calcar*

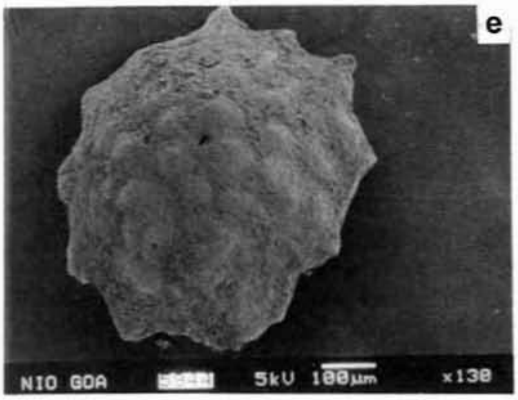
Plate 3.1 f. *Calcarina calcar*

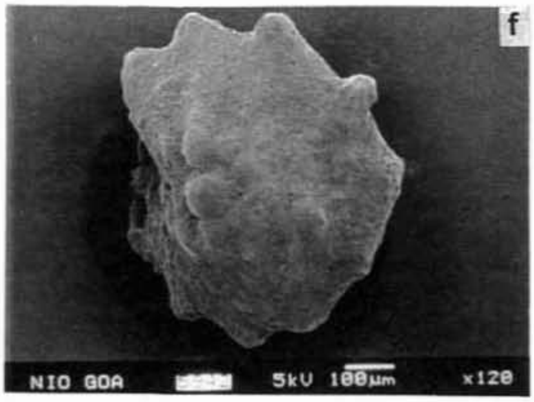
Plate 3.1 g. *Amphistegina lessonii*

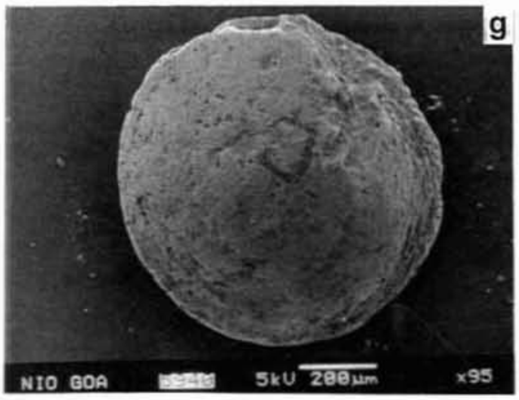
Plate 3.1 h. *Amphistegina lessonii*

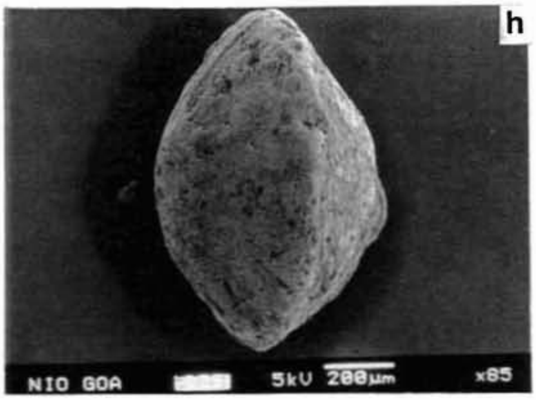
Plate 3.1 i. *Amphistegina radiata*

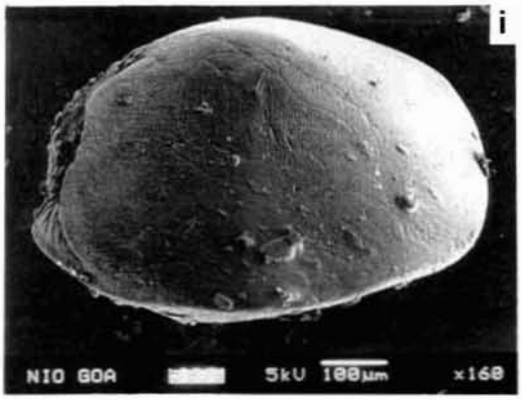
Plate 3.1 j. *Quinquiloculina parkerie*

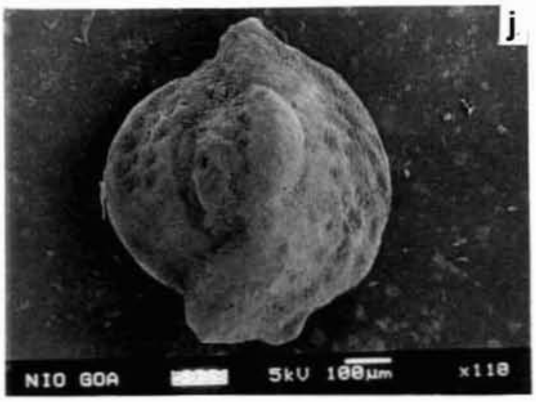

e
NIO GOA
5kV 100µm
x130


f
NIO GOA
5kV 100µm
x120


g
NIO GOA
5kV 200µm
x95


h
NIO GOA
5kV 200µm
x85


i
NIO GOA
5kV 100µm
x160


j
NIO GOA
5kV 100µm
x110

parkeri, Q. polygona, Hauerina miocenia, Lenticulina thalmani. The plates (3.1 k & l) give the skeletal structure of a coral. The fibrous aragonitic needle is shown in plate 3.1 m. The micrites in samples DW-2 and DW-6 at depths 1.8 m and 2.5 m respectively are revealed in plate 3.1 n-r.

3.3 Discussion

3.3.1 Kavaratti - beach profile and sediments:

Beach profile provides the relationship between the horizontal distance and vertical elevation. They are largely shaped by wave action, notably swash generated and the ensuing back wash (Komar, 1976, Carter and Guy, 1985). Beach profiles are often modified by wind action, when sand is blown along or across the beach, lowering some parts of the beach and building up others. Beaches are lowered and cut back by strong wave action, especially during stormy periods and during rise in sea level (Dean et al., 1993). Thus the beach profile data provide the basic information on the variability of energy conditions of coastal environments (Dubois, 1988; Chandramohan et al., 1993).

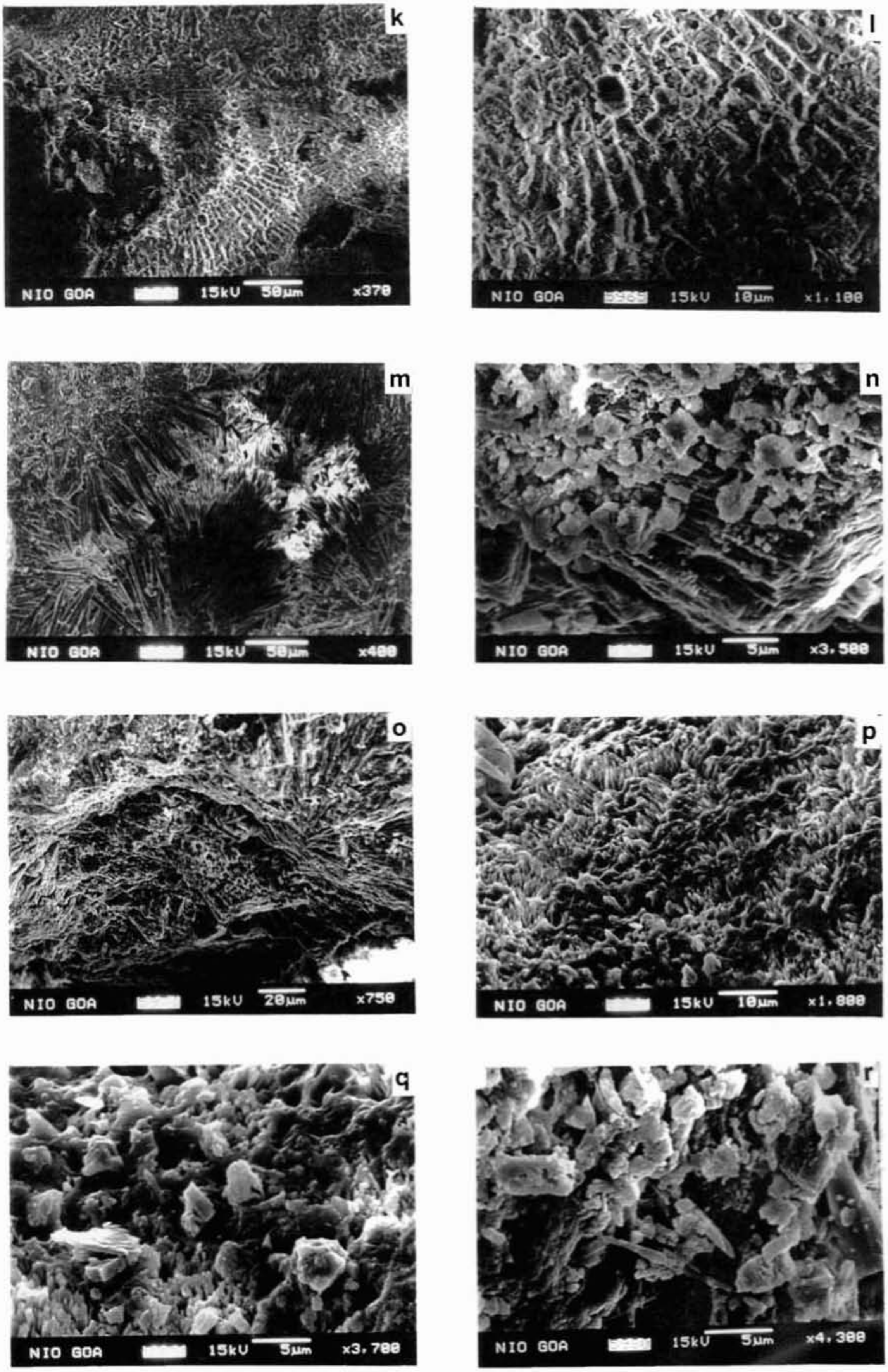
Beach profiles of the Kavaratti lagoon side (Fig. 3.1) show significant variation from south to north. The beach slope is very steep in the south, particularly at station KBP-1, showing an elevation of more than 2.5 m resembling that of a fully reflective beach (Wright et al., 1979 and Wright and Short, 1983). However, in the central region of the beach, though the beach is slightly steep, the beach elevation is about 2 m height. However, in the northern

Plate 3.1 k, l. Showing skeletal structure of a coral.

Plate 3.1 m. Showing the fibrous aragonite.

Plate 3.1 n-p. Showing micrites in DW-2

Plate 3.1 q,r. Showing micrites in DW-6


k
NIO GOA 15kV 50µm x370
l
NIO GOA 15kV 10µm x1,100
m
NIO GOA 15kV 50µm x400
n
NIO GOA 15kV 5µm x3,500
o
NIO GOA 15kV 20µm x750
p
NIO GOA 15kV 10µm x1,000
q
NIO GOA 15kV 5µm x3,700
r
NIO GOA 15kV 5µm x4,300

part i.e, KBP-6 to KBP-8, the beach slope is gentle to very gentle with a beach height ranging from 1.2 m to 1.5 m (KBP-8) and beach width is about 25-30 m resembling more of a dessipative beach (Wright et al., 1979 and Wright and Short, 1983). At KBP-8, the presence of a gentle berm is noticed. Sanil Kumar et.al, (1986) and Adiga, (1989) have also observed a similar pattern of variation in the beach profile along the lagoon side. The steep slope on the southern side is due to the presence of coarse sediments, implying that subaqueous sand storage is minimum (Short, 1979; Wright and Short, 1983) whereas the fine sediments in the north gives a very gentle beach. Therefore, in the north the possibility of having a considerable subaqueous accumulation of sand is evident (Short, 1979; Wright and Short, 1983). The steep profile at the KBP-3 of the lagoon beach (Fig. 3.1) is due to coarse texture of the sediments and this station shows the presence of a significant amount of very coarse sand and granule (Table 3.2). The coarse sediments observed in KB-3 is due to the removal of fine sands from the beach section and the proximity of the pebble beach of the chicken neck point (Adiga, 1989). Thus the distribution of sediments in the beach (Fig. 3.3) and beach profile (Fig. 3.1) show good agreement. The longshore profile of the phi mean size variations (Fig. 3.4) amply support the existence of a good relationship between the beach profile and textural class (Komar, 1979; Bascom, 1980; Komer and Moore, 1983; Medina et al., 1994). The two measurements in April 1998 and April 1999 show that a small amount of deposition takes place in the northern three stations, while a slight erosion at stations KBP-1 and KBP-4. Coral sand accumulation on the northern part of the island has been reported earlier (Sanil Kumar et al., 1986; Adiga, 1989; Prakash and Suchindan, 1994).

Beaches are the products of the complex system of forces and processes, including sediment supply and hydrodynamics (Visher, 1969; Dolan et al., 1979; Dolan and Hayden, 1981). The beach dynamics depend on several factors such as shoreline configuration, nature and size of sediments, slope of the beach, wave action, longshore current, tidal range etc (King, 1972; Sonu, 1973; Komar and Inman, 1970; Komar, 1976; Short and Hesp, 1982; Wright et al., 1979, 1982a & 1982b).

The distribution of different class of sediments along the lagoon side beach of Kavaratti Island clearly indicates that at the northern end (KB-7 & KB-8), the predominant constituent of the beach sediments both in foreshore and backshore is fine sands. The phi mean size indicates that only in the southern two stations, sediments are coarser in the foreshore than backshore. The reverse trend is noticed in station KB-3, whereas in all other stations practically no variation is found. The presence of coarse sediments in a beach is an indication of erosion where as fine sediments indicates deposition (Komar, 1976).

The results obtained are due to the cumulative effects of SW and NE monsoons. For most part of the year, the coral reef on the western side of the island acts as a barrier for waves and therefore the waves break on the outer margin of the reef (Prakash and Suchindan, 1994). The shelter offered by the lagoon and reef resulted in the deposition of sand along the lagoonal beach. The wave height off the Kavaratti Island is about 0.4 to 1.4 m during fair weather season and about 5 m during SW monsoon period (Chandramohan et al., 1993). Hence, during SW monsoon (June – September) the waves easily cross over the reef (Sanil Kumar et al. 1986) and dissipate their energy on the beach particularly on the south giving rise to coarse texture of sediments (Fig. 3.3). The wave induced tidal currents play a significant role in shaping the beach configuration and sediment movement. Along the lagoon beach the tidal current velocity measured at the entrance channel of the Kavaratti is about 15 cm/sec (Chandramohan et al., 1993). As the direction of littoral current movement on the lagoon side during SW monsoon period (also on the storm side) is from south to north (Chandramohan et al., 1993). This has resulted in the transportation of fine sediments from south to north and are getting accumulated in the northern beach. The absence of any variation in the phi mean size between the foreshore and backshore is an indication that the northern part of the lagoon beach is protected from strong wave action by the reef on the western side. By the time wave reaches the beach, the wave front might be loosing its energy and resulted in the uniform nature of the sediments on the north.

The littoral drift during NE monsoon is from north to south. The predominance of the fine sediments on the north indicates that the effect of longshore current during NE monsoon is less effective in redistributing the already deposited sediments in the north. According to Adiga (1989) during NE monsoon the wave front can pass only through the entrance channel on the north. The effect of wave front in the lagoon is drastically reduced due to diffraction as the lagoon width widens towards south. As a result the effect of wave on the lagoon beach is minimum. Although, Sanil Kumar (1986) observed a redistribution of sediments particularly fine sediments from north to south, the considerable deposition (as per the present beach profile studies) on the north indicates that no complete reversal of sediments is effective.

A comparison of the beach sediment with that of the lagoon sediment does not show any relation, indicating the processes of transportation and deposition are different in the lagoon than the beach. However, very coarse and coarse sands are the prime constituents in the extremes of the lagoon while at the centre of the lagoon all types of sand and even granule are formed.

The storm side beach is more open to severe wave attack than the lagoon beach during the SW and NE monsoons due to the lack of any reef protection at the outer edge. As the reef flat is so deep and very wide on the storm side (Siddique, 1975; Prakash and Suchindan, 1994), the wave directly dissipate its energy on the beach (Plate 2.1 & 2.2) As a result, along most part of the coast, the bed rock is exposed and rubbles are often found at the reef flat (Plate 2.2). The longshore current velocity along the storm side beach during pre-monsoon (Prakash and Suchindan, 1994) is 30 cm/sec. Along the storm side only at selected locations the deposition of sand grade materials are found. This indicates that the sediments are carried away along the shore or across the wide surf zone by the wave induced currents and waves respectively. The histogram (Fig. 3.5) indicates that at KB-10, KB-11 and KB-12, the content of granule, very coarse sand, coarse sand, medium sand, fine sand are more less equally distributed which means that no effective sorting is taking place. On the other hand, the northern and southern beach show the predominance of medium sand with almost equal distribution of coarse and fine sands (Fig. 3.5). This indicates that since these stations being transition in position between the storm and lagoon sides the sand grade materials are being transported from the lagoon side (Adiga, 1989 & Praksh and Suchindan, 1994).

3.3.2 Kavaratti-Island proper:

The present study indicates that there is a considerable variation in the deposition pattern from north to south. The sedimentological characteristics and beach profile studies of this investigation show that the northern part of the beach consists of high percentage of fine grained sediments accompanied by a gentle beach slope and that there is a tendency of continuous deposition. Earlier workers (Sanalkumar et.al, 1986; Adiga, 1989 and Prakash and Suchindan, 1994) have also stated that during southwest monsoon the longshore movement of sediments on either sides of the island is from south to north and as a result there is considerable deposition at the northern end of the island. The result is that the north western part of the island is getting projected out more like a giant cusp. According to Adiga (1989) the formation of cuspate spit is prominent at the northern end of the lagoon beach near the tidal inlet with about 100 m long and 75 m wide. A comparison of the sediment characteristics of the northern part of the island with that of the present day beach sediments shows a close similarity in the textural characteristics. As discussed earlier, the majority of the present day beach sediments of the northern part consists of medium to fine sand so also the sediments of DW-15, DW-16 and DW-18 show that the surface sediment consists of about 45% fine and medium sands respectively. Since the northern part of the beach resembles more of dissipative beach continuous accumulation of fine and medium sand population has been taking place in the past also. The subsurface samples of the northern part of the island also show high proportion of medium and fine sands leading to the growth of the islands towards north, northwest and west.

The central part of the island also show similar pattern of deposition like that of the northern end, however, there is considerable admixture of granules and very coarse sand particularly at the bottom of DW-9, DW-10 and DW-14. The sedimentological characteristics of DW-12 and DW-13, being located in the transition area, vastly resembles more like that of the northern part of the island. On the other hand, DW-9 and DW-14 being located close to storm side beach show high content of granule than in DW-10. The textural studies indicate that in the past also the transportation of sediment is from south to north and that the lagoon is getting filled by the continuous accumulation of sand grade material. The type of sediment deposited in the northern and central part of the island is also similar to the modern beach.

The width of the island is narrowed down to just about 350 m at DW-7-DW-8 and further to about 120 m at DW-2 and then widens. The narrow strip of the southern part of the island exhibits a contrasting pattern of deposition compared to the central and northern regions. The uniqueness of the southern part of the island is the presence of pebble cum boulder beds and these beds have not been encountered in any of the dug wells of the northern and central part of the island. Since DW-7 and DW-8 are located in the transition zone (Fig. 2.1), these wells show a considerable thickness of sand at the surficial level. So also DW-3 and DW-5, which are located along the lagoon side, show considerable thickness of sand at the surficial level followed by a pebble bed. Below this pebble bed, the thickness of sand layer is small except at DW-4. The deposition of alternate layers of sand and pebble indicate the cyclic events in the southern part. All these units dip gently towards west. It is attributed that the pebbles are brought to the coast by the storm waves and wave induced currents from reef erosion. After their deposition, the overlying sand unit is deposited mostly from the lagoon side and partly from the storm side beach as washover deposit. Siddique (1980) has stated that pebbles, cobbles and boulders of the storm beach have formed due to the erosion of reef flat by repeated cyclonic storms. As a result of severe erosion, the storm beaches (Plate. 2.1 & 2.2) are now protected by tetrapods (Plate 3.1 & 3.2). So it is presumed that the formation of the southern pebble and boulder dominant part of the island is due to severe meteorological condition accompanied by storms. The sand unit lying between the two beds indicates a more of a calm period and the southern island being so narrow the sandy material might be transported on either side by wind and wash over deposits.

But for the two dates made for this study no dating has so far been made from samples within the island proper. The samples collected from DW-6 on the storm side beach at a depth of 2.5 m (bottom pebble bed) gives an age of 3200 ± 60 yrs BP and the other sample collected at a depth of 1.5 m from DW-2 (bottom pebble bed) on the lagoon side gives an age of 1800 ± 60 yrs BP suggests that between the year 3200 and 1800 the island is not only growing vertically but also laterally. The distance between these two dug well is 1300 m which means that in about 1400 years the island has grown laterally about (1300 m) and the island is younger towards south. Siddique (1980) stated that due to fall in sea level has resulted in the growth of the islands such as Chetlat, Kiltan and Minicoy. The growth rate is 100 m in the last 473 years at Minicoy, 120 m in 1620 years at Chetlat and 30 in the last 2780 years at Kiltan.

3.3.3 Minicoy-Beach Profile and sediments:

The beach profile study indicates a very gentle slope in the south and a moderately gentle slope in the north. The beach elevation in the south is just about 1 to 1.5 m (Plate 3.3) whereas in the north the beach elevation is little over 1.5 m. This indicates that the beach volume thickness of the Minicoy is very small compared to the Kavaratti beach and hence beach protection measures are underway even on lagoon side (Plate 3.4). The beach profiles study further indicates that there is a marginal deposition in the north as well as in the southern two stations and slight erosion at MBP-4. The distribution of different class of sediments along the lagoon beach shows the presence of granule at stations MB-1 and MB-6. The histogram (Fig. 3.11) further reveals that towards north from MB-8 to MB-10 the content of medium, fine and very fine sands gradually decrease whereas coarse and very coarse sand steadily increase. This might be due to the removal of fine sediments by wave action. So also at southern end of the island coarse sediments are found. The distributions of phi mean size along the beach clearly supports the observed distribution of different class of sediments. The alongshore profile (Fig. 3.12) clearly shows coarsening of sediments at the two extreme end of the islands as well as the middle part of the islands.

Unlike Kavaratti, which has only one opening at the north, Minicoy lagoon has two openings one in the north and the other at the centre of the reef on the west (Fig. 2.2). Therefore, during SW monsoon period, the wave front cannot only easily cross over the reef, but also through the western opening. In the absence of any immediate source for the occurrence of coarse material at the centre of the lagoon beach (as compared to Kavaratti), it is attributed here that waves have played a significant role in removing fine sediments from the centre and transporting them on either side. The terminal sediments, again show slightly lower phi mean size than the adjoining sediments and this might be due to the wave convergence and removing of fine sediments.

The Minicoy foreshore beach sediments of the lagoon side beach is slightly coarser than the backshore beach (Fig. 3.10). Several studies (Komar, 1979 and Bascom, 1980) indicate coarse particles are located in the foreshore and particularly at the plunge point of the breaking waves and with a reduction in grain size towards backshore as well as deeper part of water. Most of the storm side beach sediments (MB-11 to MB- 14) consist predominantly of very coarse and coarse sediments while the southern beach section (MB-15 to MB-18) shows more of either coarse sand or a combination of coarse, very coarse sand and granule. Since the storm beach (like the Kavaratti) is more open to wave attack, the observed results are in the expected pattern.

Just like Kavaratti lagoon, the Minicoy lagoon sediments also (Fig. 3.10) do not indicate a clear trend across the lagoon or any resemblance with the beach sediments possibly due to small number of samples studied.

3.3.4 Minicoy-Island proper:

Unlike Kavaratti, which has a considerable thickness of loose sands and pebbles, the Minicoy island has a small thickness (0.5 to 1 m) of unconsolidated sediments, below which the hard coral bed is encountered. Just like the present day beach sediments of the southern end of the island, P-1 also shows the presence of considerable coarse sand at the surficial level and get decreased with depth as fine and medium sand content increase. P-2 and P-3 show close resemblance with the abundance of fine and medium sand. P-4, being located close to lagoon beach shows abundance of very fine sand at the top 40 cm level, below which the sedimentation is just like P-2 and P-3. Although P-7 is located close to storm beach it shows a close resemblance of textural characteristics to P-4 (Fig. 3.15). This indicates that both the locations have similar environment of deposition as far as the top 40 cm of the sediments are concerned. P-11 and P-12 being located east of the central part of the lagoon beach (where coarse sediments and significant erosion are observed) are showing dominance of coarse sand both at the top and bottom of the pits. Thus there is a close resemblance between the present day beach environment and the adjoining island and therefore, across the southern part of the island the sedimentation has been affected by the slow addition of loose sand from lagoon side by wave and wave induced currents.

3.3.5 Scatter diagrams (Kavaratti and Minicoy):

The scatter plots among different size parameters such as mean size, standard deviation, skewness and kurtosis have a geological significance (Folk and Ward, 1957) and therefore an attempt has been made here to bring out the mode of deposition and also to identify the environment of deposition of the beach sediments of Kavaratti and Minicoy. The mean size of clastic sediments is the statistical average of grain size population expressed in phi (ϕ) units. Standard deviation or sorting value indicates the particle spread on either side of the average (Folk and Ward, 1957; McKinney and Friedman, 1970). The sediment sorting is good if the spread sizes are relatively narrow. Skewness of sediments is a measure of the asymmetry of grain size population and reflects the environment of deposition (Folk and Ward, 1957; Folk, 1968). In textural analysis skewness is considered as an important parameter because of its extreme sensitivity in subpopulation mixing. Well-sorted unimodal sediments are usually symmetrical with zero skewness. In a fine skewed sediment population, the distribution of grains will be from coarser to finer and the frequency curve chops at the coarser end and tails at the finer. The reverse condition is characteristic of coarse skewed sediments. Martin (1965) has suggested that coarse skewness in sediments could be due to either addition of materials to the coarser terminal or selective removal of fine particles from a normal population by winnowing action. Kurtosis, according to most sedimentologists, measures the ratio of the sorting in the extremes of the distributions compared with the sorting of the central part (Folk and Ward, 1957).

Kavaratti and Minicoy beach sediments (Figs. 3.6a & 3.14a) show that with increase of phi mean size the sorting of the sediments improve. Kavaratti beach sediments are better sorted than the Minicoy. Thus it is very clear that sorting is a close function of phi mean size. However, it is difficult to demarcate the foreshore sediments from that of the backshore possibly due to the presence of coarse as well as fine sediments both in foreshore and backshore. Most of the foreshore sediments of the study area with moderately well sorted to moderately sorted nature are symmetrical with respect to skewness even though there is significant variation in phi mean size of sediments particularly in the Minicoy beach (Figs. 3.6b & 3.14b). It is pertinent to say that if the standard deviation is a function of phi mean size, sorting and skewness will bear a mathematical relationship to each other (Folk and ward, 1957). Symmetrical curve can be obtained either in a unimodal sediments with good sorting or equal mixtures of two modes which have the poorest mode of sorting. With one mode dominant and others subordinate, the sediments exhibit moderate sorting but give extreme values of skewness (Folk and Ward, 1957, McKinney and Friedman 1970) as observed for the Minicoy beach sediments. The extreme skewness values observed for the Minicoy beach sediments (Figs. 3.6c & 3.14c) are mainly due to the admixture of very coarse sand and granule to the existing fine population. The predominance of negative skewness observed in Kavaratti Island is due to the relative increase of fine sediments over the coarse sediments. In view of the vast differences in skewness values between the two islands the skewness vs. kurtosis show contrasting patterns (Figs. 3.6f & 3.14f).

Perfectly sorted, unimodal sediments have a skewness value zero and a very slight deviation in sorting results in near symmetrical skewness. A good number of sediments from the Kavaratti and Minicoy islands (Figs. 3.6d & 3.14d) are symmetrical skewness with a sorting ranging from moderately well sorted to moderately sorted. The abundance of fine skewed sediments particularly in Minicoy is due to relative increase in coarse sediment over the fine. Friedman (1967) and Cronan (1972) have indicated that polymodal sediments can show variable skewness values depending on the specific proportion of sub population abundance.

Figs. 3.6e and 3.14e indicate that a considerable number of foreshore sediments of the Kavaratti are mesokurtic in nature while that of Minicoy sediments show a wide range (very platykurtic to leptokurtic). Since the size distribution in Kavaratti is relatively narrow, particularly in the case of lagoon beach, good number of samples shows good sorting both in the coarse and fine modes resulting in mesokurtosis. On the other hand the abundance of the coarse sediments in the storm side beach and in certain sections of the lagoon beach of the Minicoy, the vast majority of the sediment show kurtosis either platy or mesokurtosis. The lepto and very leptokurtic sediments indicate abundance of fine population over the coarser.

3.3.6 *Constituent composition (Kavaratti and Minicoy):*

During the last decade, the composition of unconsolidated, shallow-marine carbonate sediments has been systematically studied to interpret the depositional patterns and pathways (Kench, 1997; Gischler and Lomando1999,), the zonation of reefal and lagoonal sediments (Chevillon 1996), and the sedimentological nature of *Halimeda* bioherms (Roberts et al. 1988). Although some compositional studies are concerned with the early diagenesis of sediments and include petrographic analysis of skeletal materials (e.g. Furukawa et al. 1997), most do not integrate detailed binocular, petrographic, mineralogical, and geochemical examinations. Thus many aspects of the origin of carbonate sand, compositional diversity, and mineralogical diagenesis is poorly known. James et al. (1994); Roy (1991) and Harris et al. (1990) have studied the sedimentation histories of carbonate sands while the accumulation of *Halimeda* bioherms has been investigated by Davies and Marshall (1985). Understanding the age of sand in various depositional environment aids in the interpretation of sediment production, transport, and residence time within diverse "shoreface" sub-environments (within the region of wave disturbance from shoreline to offshore).

Microscopic studies reveal that the constituents of the sediments collected from Kavaratti and Minicoy islands are coral fragments, grains of coralline algae, Halimeda, molluscs, foraminifers and bryozoans.

Micritization: In sedimentology of limestones, an alga acts as an important contributor as sediments and as agents of diagenesis. By repeated boring, followed by vacation of the bore and the filling of it with micrite, the carbonate grains are gradually and centripetally replaced by micrite (Plate 3.1 a-d). This process is termed as micritization (Bathurst, 1966). This micrite envelope is initially composed of micritic aragonite or high-Mg calcite, with some impurity depending on the amount of residual primary carbonate. In ancient limestones, it is a low-Mg calcite micrite and it should have formed around an aragonite grain, then that aragonite core has normally been replaced by calcite spar. This shows that at one stage, during diagenesis, the skeletal core had been dissolved away leaving the micrite envelope empty of mineral material.

There are several processes responsible for the conversion of carbonate grains and frame builders into micrite. The conversion of carbonate grains into micrite is caused by repeated algal boring (Bathurst, 1975). Micritization of coral patches and grains is caused by as a result of corrosion. These processes are synsedimentary or early diagenetic. The loss of skeletal ultra structure can convert patches of frame builders and grains into micrite. The micrite envelope caused by dissolution- precipitation at grain peripheries is essentially restricted to substrates below algal mats in littoral and supralittoral environments. The envelope and the processes of micritization associated therewith are to be considered as useful environmental indicators. Its interpretative significance is enhanced when corrosion affects the fibrous, first generation, aragonite of high-Mg calcite cement precipitated in littoral environment (Nair, 1975).

Of the coral assemblages (corals, bryozoans, mollusks, foraminifera) foraminifera are known to play a major role in the production of $CaCO_3$ and ultimately in the formation of reef rocks. The nature of foraminiferal assemblage associated with reef ecosystem is controlled by ecological conditions such as temperature, salinity, nutrient supply etc. A preliminary micropaleontological study was carried out in DW-6 of Kavaratti and P-4 of Minicoy islands in order to document temporal variation in foraminiferal assemblages. As bryozoans also constitute a significant pattern of the biogenic assemblages next to corals and foraminifera, an estimate of total bryozoan fragments in examined samples was made.

In total seven benthic foraminiferal species (*Calcarina calcar, Amphistegina lessonii, A.radiata, Quinqueloculina parkeri, Q. polygona, Hauerina miocenica, Lenticulina thalmani*) were recorded from Minicoy and Kavaratti Islands. The quantitative benthic foraminiferal data of two examined subsurface sections reflect that the assemblages are dominated mainly by three species –

Calcarina calcar, *Amphistegina lessonii* and *Amphistegina radiata*, where as miliolina group shows a moderate to rare occurrence of its abundance.

The absolute foraminiferal abundance (total number/1g) increases gradually downward in P-4 (Fig. 3.16). *Amphestigina* spp. and *Calcarina calcar* are main constituents of foraminiferal population. *Calcarina calcar* occurs in its maximum abundance in lower part of the section whereas *Amphestigina* shows its maximum in the middle part. Upper part of the section is characterized by low abundance of foraminifera and corresponding high occurrence of bryozoans. The miliolids are present only in the middle portion of section. In DW-6, the absolute foraminiferal abundance decreases gradually downwards. *Amphistegina* spp. shows its maximum abundance in middle part of the well where as *Calcarina calcar* shows its abundance in the upper part of the well. Miliolids are very rare in occurrence.

The observation made on temporal variation of foraminiferal assemblages and total bryozoans suggests a gradual change in ecological condition occurred in past. The genus *Amphistegina* is epifaunal, characterising lagoonal condition with depth preference ranging from 0 to 130 m, the abundance of *Calcarina* indicates lagoon – innershelf environment. *Quinqueloculina* prefers hypersaline lagoonal condition.

3.3.7 Evolution of Kavaratti and Minicoy islands

Although radiocarbon dating of consolidated, shallow- marine carbonates has proved as a valuable tool in palaeoenvironmental reconstructions and in the

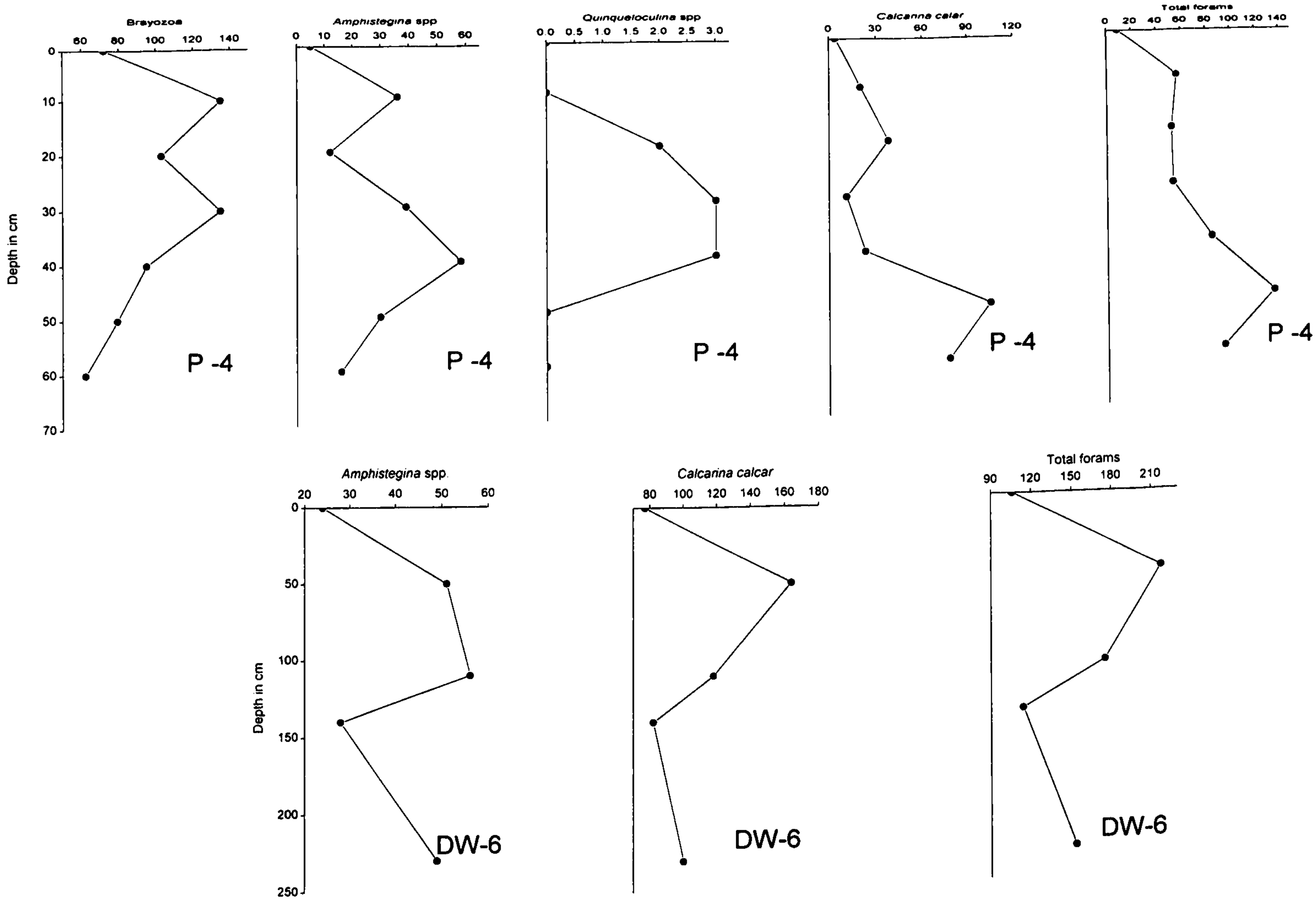


Fig. 3.16 Absolute abundance of important benthic foraminifera and brayozoans in DW-6 (Kavaratti) and P-4 (Minicoy)

study of reef stratigraphy, contemporaneous unconsolidated carbonate sands have received less attention. Athens and Ward (1991), Calhoun and Fletcher (1996), Fletcher and Jones (1996) and Grossman and Fletcher (1998) have studied the various aspects of carbonate sands in the Pacific and contributed immensely in understanding the Holocene sea level and shoreline evolution. Several studies indicate that the upper 10- 15 m of the present rim has formed as a result of reef growth in the Holocene period (Mclean and Woodroffe, 1997).Recent studies (Hopley,1987; Pirazzoli and Montaggioni,1988 b) indicate that the reef on many Pacific atolls were at or above the present sea level during 4500 – 4000 years BP .

Woodroffe et al.,(1990 a) proposed a three stage model for the Holocene evolution of the Cocos islands.

1) First Phase- Catch up reef: rapid vertical growth around 8000– 4500 yrs BP
2) Second Phase – Give up reef: reef flat formation with widespread conglomerate platform of cemented coral boulders around 4500 – 3000 yrs BP and
3) Third Phase – Island formation- from 3500 yrs BP to present.

Depending on the rate of reef growth, the formation of reef flat and there by the island itself may vary slightly from place to place. However, the three stage model can be applicable to all other coral islands (Woodroffe et al, 1990a).

According to Woodroffe (1990 a) the core of the Cocos islands was formed around 3500-3000 yrs BP,overlying the conglomerate platform.The conglomerate was formed when the sea level was higher than the present. With gradual accumulation of sediments and with several recurred spit formation, the Cocos islands has attained its present shape and size during the three stages. As per the above model the lagoon, which has been in an open environment and with uninhabited water flow from the open ocean in the first phase, has developed an atoll rim accompanied by the reef flat in the second phase. Therefore the water movement has been restricted and the lagoon started getting filled up during second and third phases .The net fall in sea level in the last few thousand years has effected the growth of many coral islands (Schofield, 1977a).

Applying the above concept, the evolution of Kavaratti and Minicoy islands is conceived .The coral rim of Minicoy and Kavaratti islands would have formed during the second stage of the island formation, thus restricting the free movement of the ocean water into the lagoon. The steady accumulation of conglomerates on the eastern front of the rim (Plates 2.1-2.2), (in view of the existing oceanographic conditions in the Arabian Sea, Siddique, 1980), would have resulted in an embryonic island formation. As the lagoon falls on the western side, steady sand accumulation made the islands to grow westward (both the islands) as revealed by the dug wells and pit samples. The accumulation of sand in Kavaratti lagoon is very much appreciable. The growth of the islands in Kavaratti towards north and west is already established by this study and earlier workers (Sanil Kumar et al.,1986; Adiga ,1987; Prakash and Suchindan,1994).Invariably a wide sand zone is found in the lagoon side in all the islands of Lakshadweep.

McLean and Woodroffe (1997) have stated that many reef islands rest upon a conglomerate platform. This concept is well exemplified in the Minicoy and Kavaratti islands as conglomerate and pebbles are seen particularly on the eastern, northern, western and southern side of the islands (Plates 2.1 & 2.6). As the sea level rose during the middle Holocene, coral reef and the island kept pace with the rising sea level. Thus in Lakshwadeep a series of storm ridges are reported to have formed and these ridges are getting younger towards the storm side sea (Fig. 3.17).

Dating of samples has so far been made only from the storm beaches of Lakshwadeep. Siddique (1980) has reported four dates for the Kavaratti storm side beaches, which are 2820±140 yrs BP, 2660±110 yrs BP, 2190±140 yrs BP and 1880±140 yrs BP (location not available). Boulder deposits, cemented into a conglomerate platform, on tropical islands have been interpreted either as evidence of higher sea level that the present (Daly,1934; Newell, 1961) or storm activities (Shepard et al, 1967; Newell and Bloom 1970). Radiometric dating of these conglomerates from reef flats and islands of atolls of the Indo-Pacific region about 4000 to 3000 years BP is closer to the ages obtained so far to the oldest storm beaches of Lakshadweep (Siddique, 1980). However, the dates available from DW6 of this study at a depth of 2.5 m below the surface is slightly older (3200 ±60 yrs BP) than other reported dates. The sample is slightly westward (75 m) from the storm beach. This indicates that the sea level was higher at that time than the present day one. The boulder conglomerates of the adjoining Maldives and Diego Garcia have been inferred to have formed when

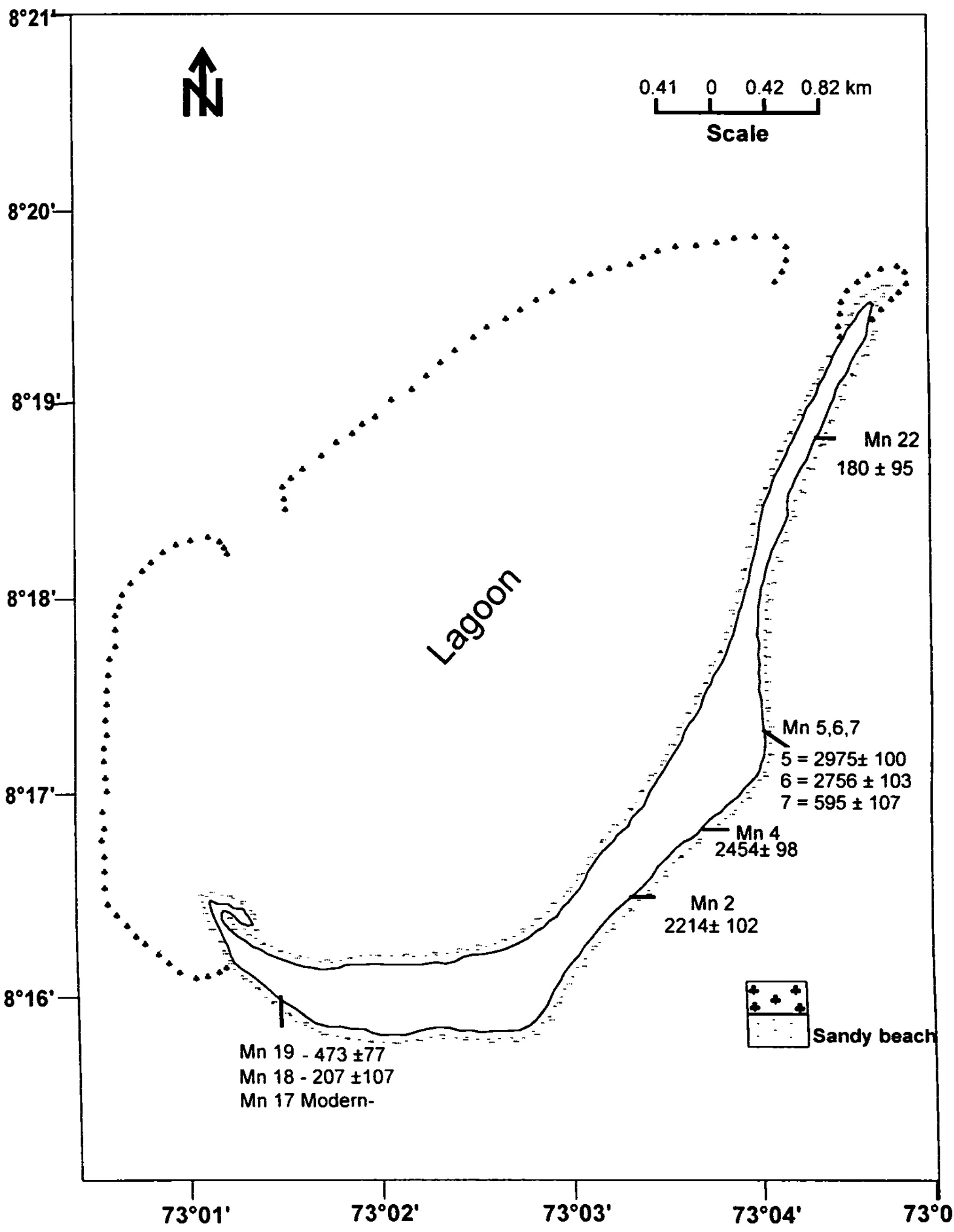


Fig.3.17. Radiocarbon dates of corals from strom beaches of the Minicoy island (source : Siddique, 1980)

the sea level was higher than the present (Stoddart et al, 1966 and Stoddart, 1972 b). Therefore, the oceanward growth of the island is mainly due to the addition of pebbles and conglomerate when the sea level was at a higher level than the present. The Kavaratti is getting younger towards south as revealed from ^{14}C dates (1800 ± 60 yrs. BP) obtained at a depth of 1.5 meter (Fig.3.7).

Siddique (1980) also presents dates for the storm side beach of the Minicoy Island (Fig 3.17). The oldest date (2975±100 yrs BP) is obtained from the inner part of the ridge and the age become younger towards ocean side. The recurved southern part of the island is formed within the last 500 years while the northern tapering part of the island have formed within the last 600 years (Siddique, 1980).

From the foregoing sedimentological and age data it is evident that the islands prograde mainly north, south and west directions from the embryonic stage which might be located on the convex (towards the storm side) portion of the central part of the island. The growth towards eastward is minimal. The growth of the other islands of Lakshadweep in relation to sea level changes has already been presented in section 3.3.2.

Chapter 4

MINERALOGY AND GEOCHEMISTRY

4.1 Introduction

The major carbonate minerals of the coral deposits are aragonite, high-Mg calcite and low-Mg calcite. Relative abundance of these minerals varies with sea water temperature, concentration of Ca and Mg in solution, salinity and pCO_2 levels. The type of carbonate minerals occurring in the sediments and their morphology varies with the concentrations of Ca and Mg and salinity in natural waters. Two major factors appear to explain the types of carbonate minerals and their morphologies in normal marine, freshwater and subsurface environments. These factors are the rate of crystallisation and the effect of magnesium and other ions in the precipitating water (Folk, 1973). As the rate of crystallisation increases the size of aragonite and high-Mg calcite crystal size decreases. Many workers (Collins, 1998; James et al., 1992, 1994; Rao, 1981c; Rao and Amini, 1995) have studied the mineralogy of temperate carbonates.

The behaviour of the major and minor elements in sediments and elucidation of different factors controlling their distribution have been the objectives of a number of geochemical investigations. The geochemistry of the corals is basically dependent on the sea water chemistry but is also influenced by other environmental variables. For many years, the behaviour of many elements in biogenic carbonates and seawater has been a matter of discussion. The trace ements distribution in corals can be infact related to the chemistry of the local ater mass as they reflect regional oceanographic pattern (St. John, 1974). any workers (Broecker, 1963; Veeh and Turekian, 1968; Livingston and homson, 1971; Kinsmann, 1969; Goreau, 1977b) studied the interrelationship etween the major and minor elements. Smith et al., (1979) and Sehneider and mith, (1982) have studied the implications of these elements in the paleo-nvironmental, paleo-ecological conditions. Trace elements in corals and ediments have been described by many other workers (Allan, 1979; Forstner nd Wittman, 1979;Belperio, 1983; Howard and Brown, 1984, 1986; Denton and urdon, 1986d; Brady et al., 1994; Jaffar et al., 1994; Rowlatt and Loreell, 1994; mill and Thomas, 1995). Because of the importance of these geochemical udies, an attempt has been made to find out the concentration of these ements in the island sediments of Kavaratti and Minicoy.

2. XRD results

2.1. Kavaratti Island: The XRD results of 2 live coral reef samples and 24 mples from 5 dug wells of Kavaratti Island show some significant variations g. 4.1 and Table 4.1). The live coral samples from the reef area are totally agonitic in nature (Fig. 4.1) while the island proper samples (Fig. 4.2) consist of agonite, high-Mg calcite (HMC) and low-Mg calcite (LMC).

agonite: The XRD patterns (Fig. 4.1 & 4.2) reveal that aragonite is the most undant mineral present in the Kavaratti island samples and its content ranges m 21.6 to 100 % (Table 4.2) with an average value of 75%. The surface mples are invariably fully aragonitic in nature. The predominance of aragonite

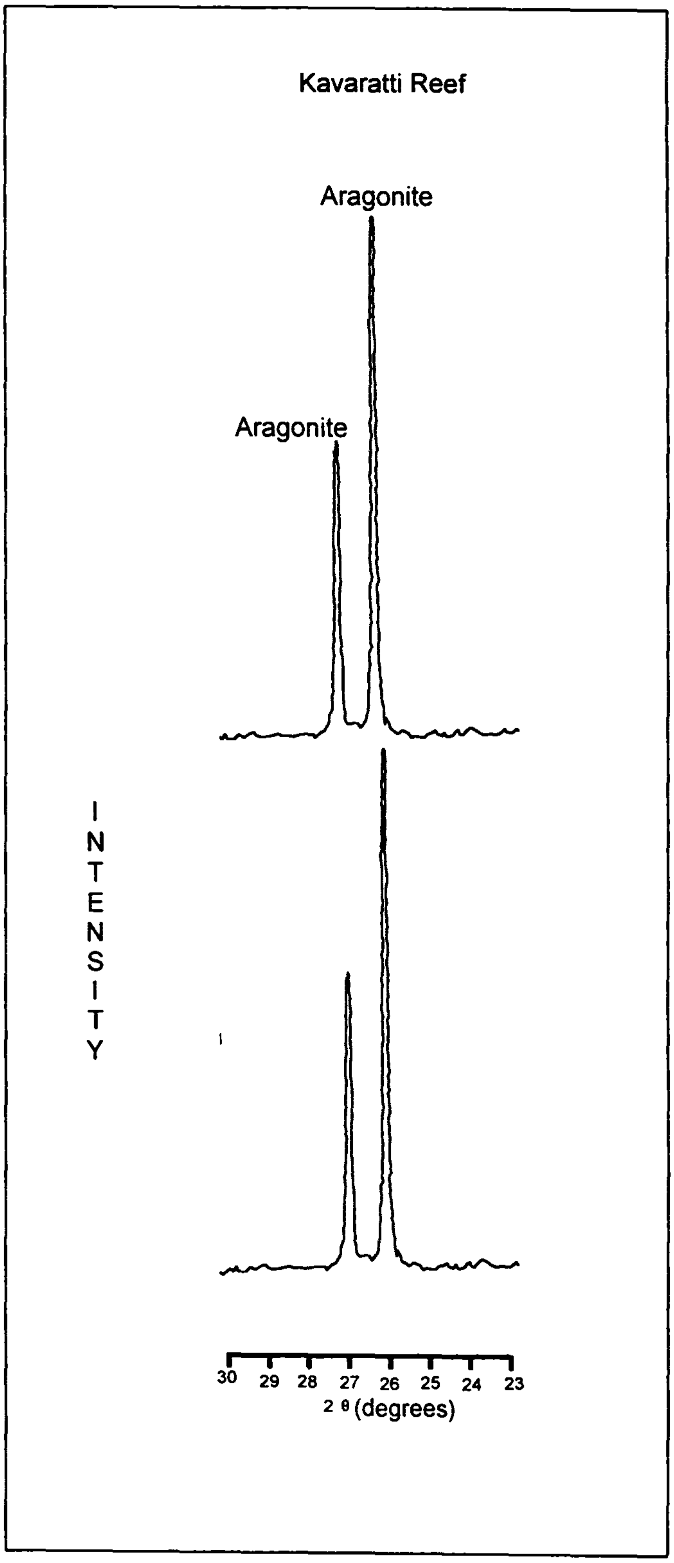
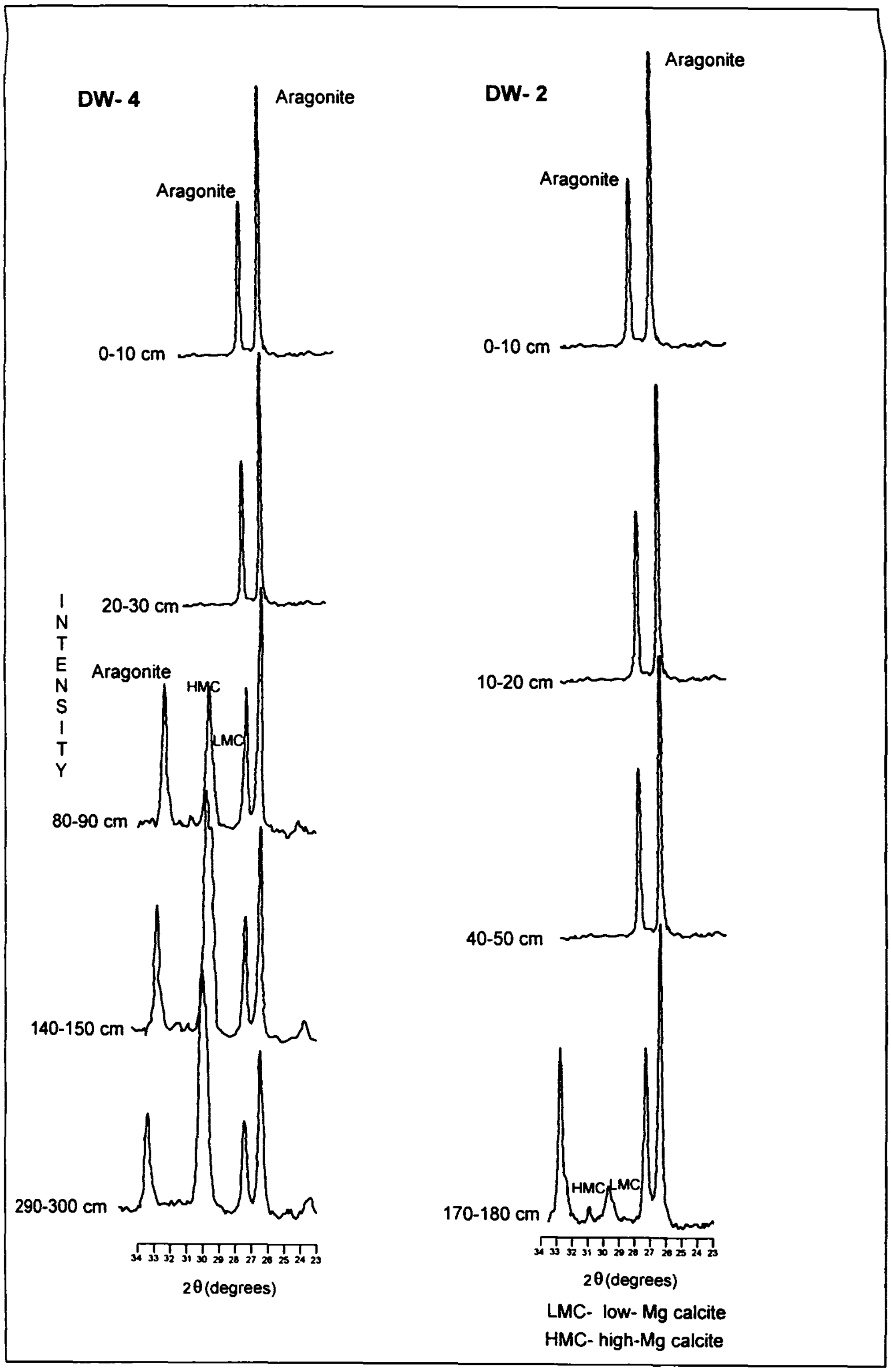


Fig. 4.1. X-ray diffractograms of the Kavaratti sediment samples



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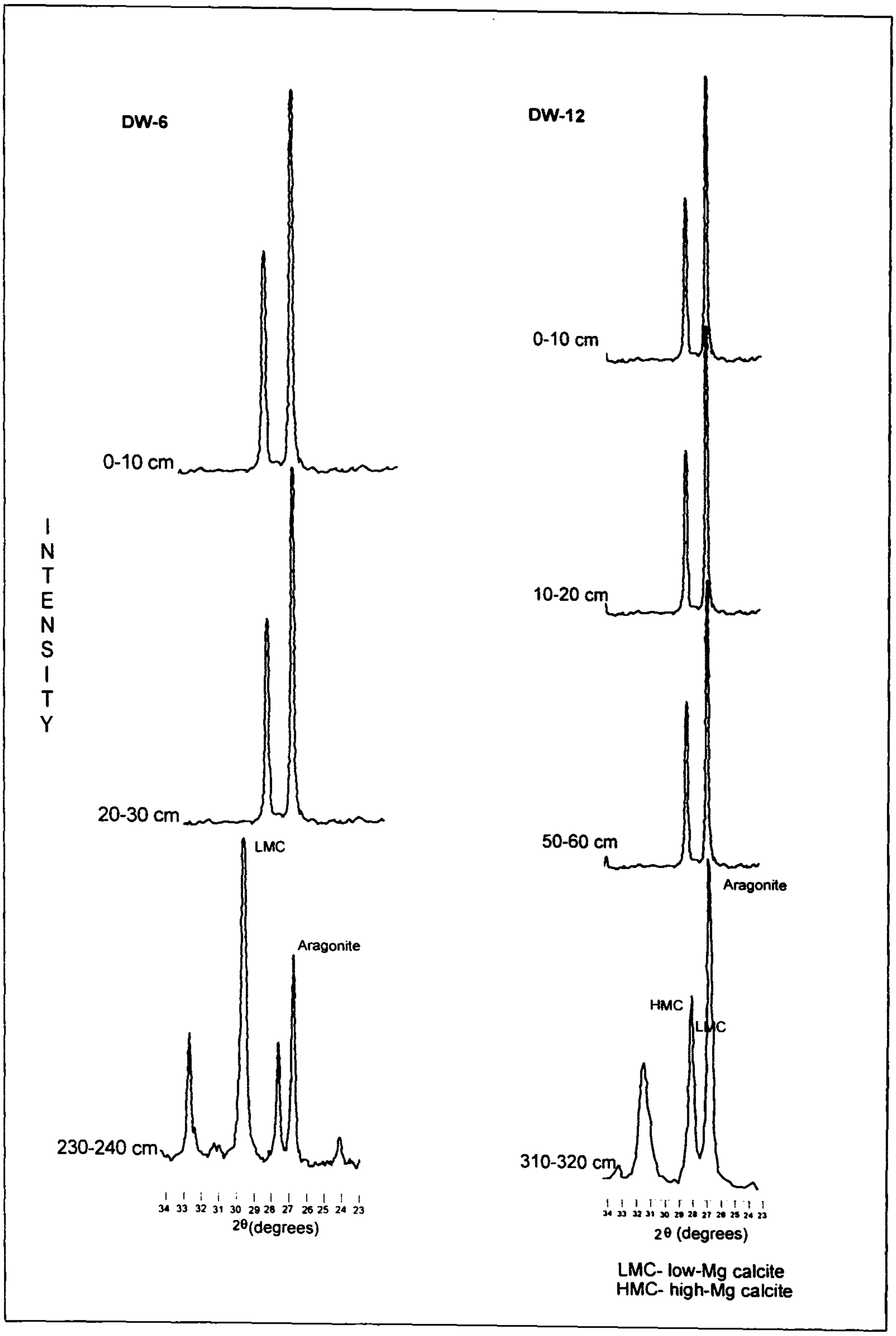

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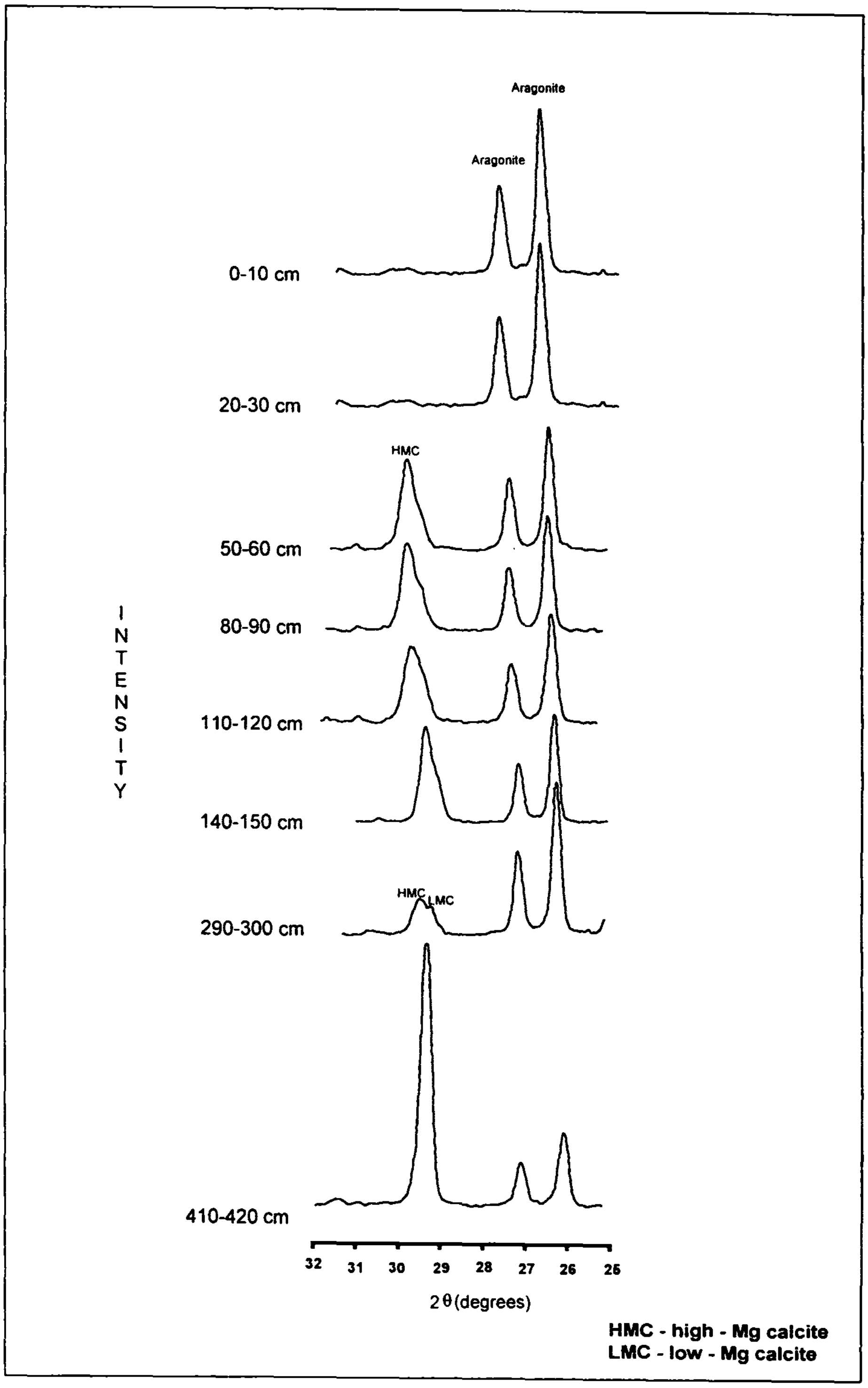

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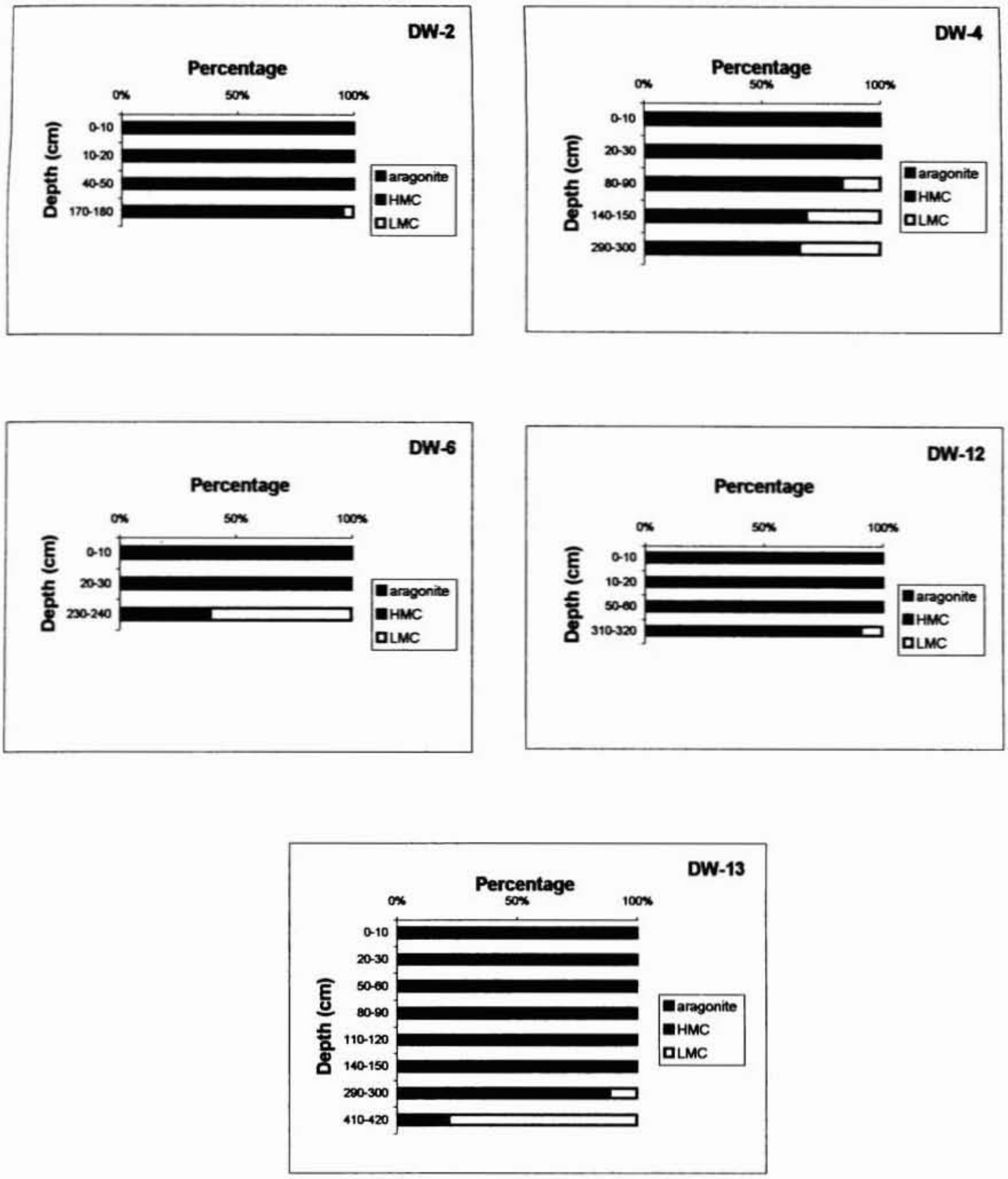


Fig. 4.2 Vertical variation of Aragonite, HMC and LMC contents of the Kavaratti Island

Table.4.1Distribution of Aragonite, HMC and LMC contents of the Kavaratti Island.

Sa.No	Aragonite	HMC	LMC
Kavaratti Island			
Coral reef			
KR-1	100.0	0.0	0.0
KR-2	100.0	0.0	0.0
Island proper			
DW-2			
0-10	100.0	0.0	0.0
10-20	100.0	0.0	0.0
40-50	100.0	0.0	0.0
170-180	85.3	10.1	4.6
DW-4			
0-10	100.0	0.0	0.0
20-30	100.0	0.0	0.0
80-90	52.3	30.9	16.8
140-150	31.7	36.8	31.5
290-300	24.8	40.7	34.4
DW-6			
0-10	100.0	0.0	0.0
20-30	92.5	7.5	0.0
230-240	39.0	0.0	61.0
DW-12			
0-10	100.0	0.0	0.0
10-20	100.0	0.0	0.0
50-60	100.0	0.0	0.0
310-320	67.6	23.2	9.2
DW-13			
0-10	100.0	0.0	0.0
20-30	100.0	0.0	0.0
50-60	58.1	42.0	0.0
80-90	56.4	43.6	0.0
110-120	57.5	42.5	0.0
140-150	52.6	47.4	0.0
290-300	73.0	15.3	11.8
410-420	21.6	0.0	78.4

Table.4.2 Distribution of Aragonite, HMC and LMC contents of the Minicoy Island.

Sa.No	Aragonite	HMC	LMC
Minicoy Island			
Coral reef			
MR-1	100.0	0.0	0.0
MR-2	100.0	0.0	0.0
Island proper			
P-1			
0-10	67.5	24.2	8.3
30-40	60.3	30.9	8.8
P-7			
0-10	58.5	25.5	15.9
30-40	55.6	31.5	12.9
80-90	47.0	30.6	22.4
P-11			
0-10	66.1	10.2	23.7
40-50	58.2	31.9	9.9
80-90	49.1	28.2	22.7
90-100	27.0	0.0	73.0
P-12			
0-10	65.1	17.9	17.0
40-50	60.7	25.4	13.9
90-100	56.7	25.4	17.9

extends to a considerable depth in the Kavaratti Island (Fig. 4.2 & Table 4.1) i.e. in the immediate subsurface sediment samples at 20-30 cm level (DW-4 & DW-13) and in some cases 40-60 cm level (e.g. DW-2 & DW-12) the constituent carbonate mineral is only aragonite. In general, the aragonite content decreases with depth, concomitantly the other two constituent minerals namely HMC and LMC increase. Exceptionally in some deeper portions of dug wells (DW-6 & DW-13) HMC is totally absent. In DW-2, aragonite ranges from 85.3 to 100 % and only at depth 170-180 cm the presence of other minerals are recorded. In DW-4, the aragonite content (range 24.8 to 100 %) drastically decreases with depth. At depth 80-90 cm the aragonite decrease is more or less 50 % (52.3 %) while, at depth 290-300 cm, the aragonite content is only 24.8 %(Table. 4.1). DW-6 shows that aragonite content (range from 39 to 100 %) starts decreasing at 20-30 cm level and the minimum value is obtained at a depth 230-240 cm. In DW-12, the aragonite values decrease to 67.6 % at depth range 310-320 cm. The aragonite show a wide range in DW-13 (21.6 to 100%), the minimum value being obtained at a depth of 410-420 cm. In this well a steady decrease of aragonite is recorded upto 140-150 cm level and the highest value (73.07 %)is obtained at depth 290-300cm (Fig. 4.2).

High-Mg calcite: HMC is the second dominant mineral present in the Kavaratti island after aragonite and the value ranges between 0% and 47.4% (av. 14 %). Almost in all dug wells the amount of HMC increases with depth. In most samples at surface and near surface level (30-60 cm), the HMC is totally absent. The presence of HMC in DW-2 (10.1 %) and DW-12 (23.2 %) is recorded at the bottom samples respectively at depth 170-180 cm and 310-320 cm level. Significant values of HMC are recorded in DW-4 (40.7%) and DW-13 (47.4 %). On the other hand in DW-6 a significant content of HMC (7.5 %) is found only at near surface level at depths 20 and 30 cm. The surface and bottom samples of DW-6 are devoid of HMC. In DW-13 (HMC ranges 0 to 47.4 %) from 50 to 150 cm the HMC content is more or less similar (Table 4.1), however HMC is absent at depth of 410- 420 cm (Fig. 4.2).

Low-Mg calcite: The LMC of the Kavaratti island ranges between 0% and 78.4 % (av.10.3%). LMC is totally absent in the surface and near surfaces samples (thickness vary considerably). In most samples the content of LMC is very low; the maximum value (78.4 %) is obtained in DW-13 at a depth of 410- 420 cm. . DW-2 shows only a trace of LMC content (4.62 %) at a depth of 170-180 cm, in all other samples LMC is absent. The LMC values in DW-4 (0 to 34.4 %0 steadily increase with depth. In DW-6 the presence of LMC (61 %) is recorded only at the bottom most sample where the HMC content is zero. DW-12 shows only a minor amount of LMC (9.2 %) being recorded at the bottom most samples Table. 4.1). In DW-13 only the bottom 2 samples (290-420 cm) show the presence of LMC. The maximum of LMC (78.4 %) is found at a depth of 410-420 cm (Fig. 4.2).

4.2.2. Minicoy Island: Two live coral samples from the reef area and 12 samples from 4 pits of the island proper are studied using XRD and the results are presented in Fig. 4.3 and Table 4.1. The carbonate minerals identified are aragonite, high-Mg calcite and low-Mg calcite (Fig. 4.3 & 4.4).

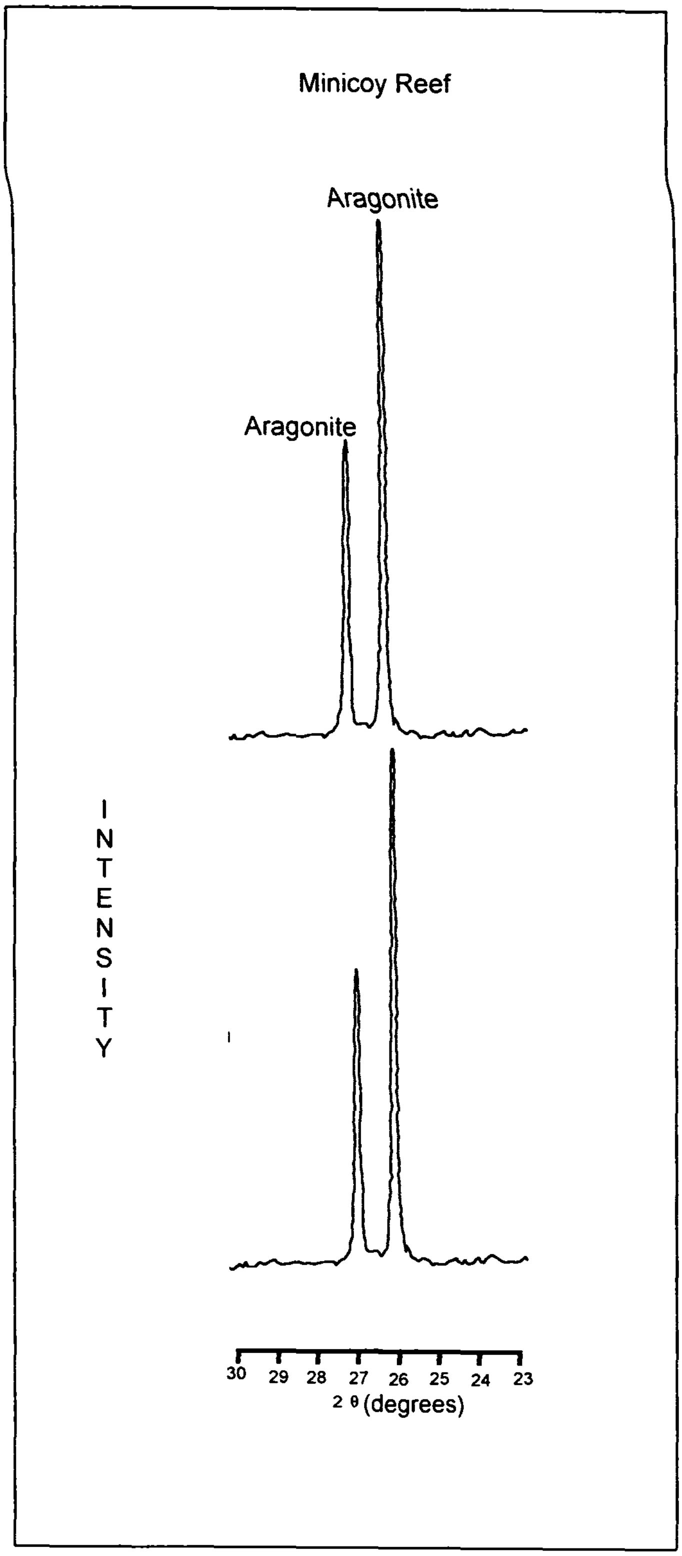
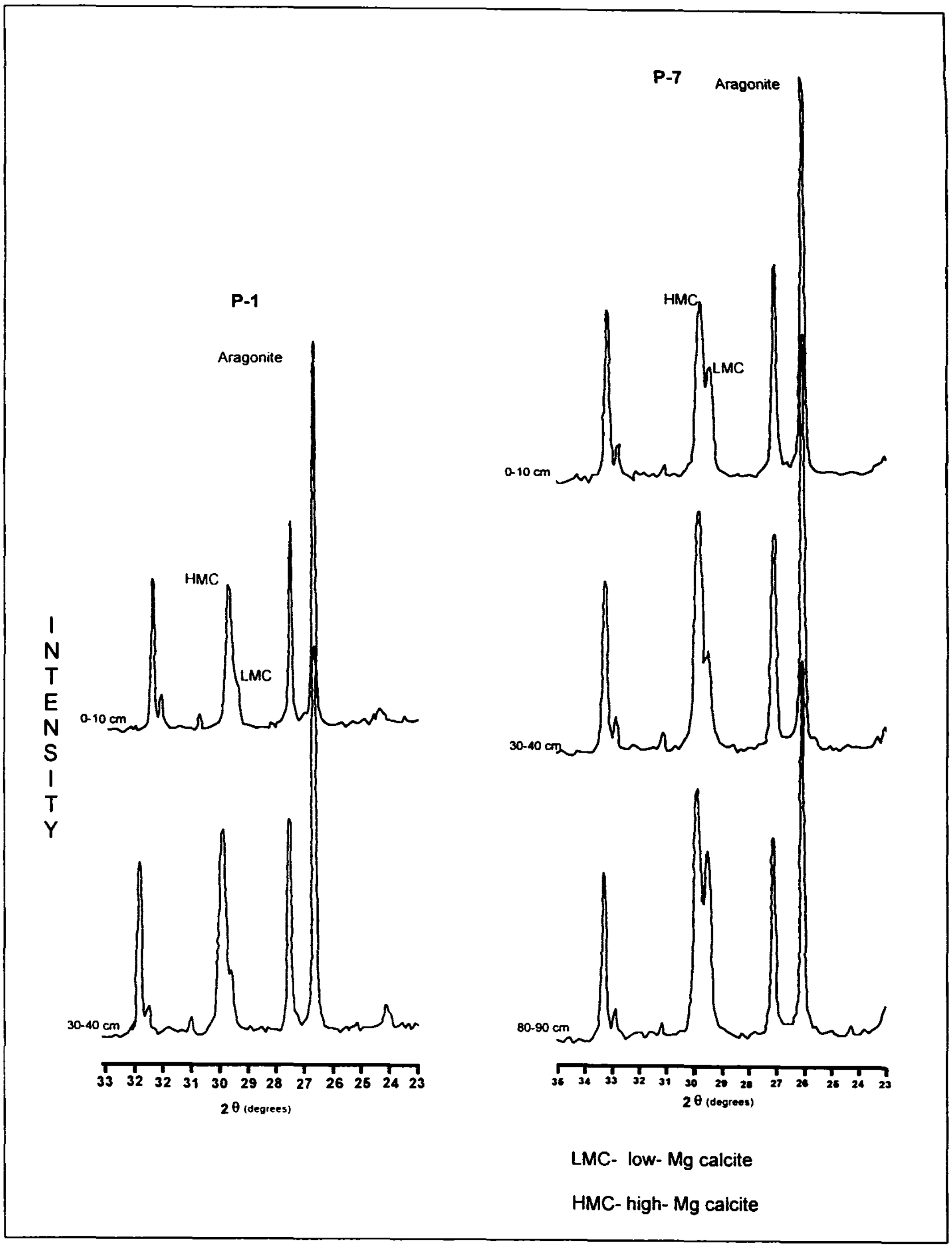


Fig. 4.3. X-ray diffractograms of the Minicoy sediment samples



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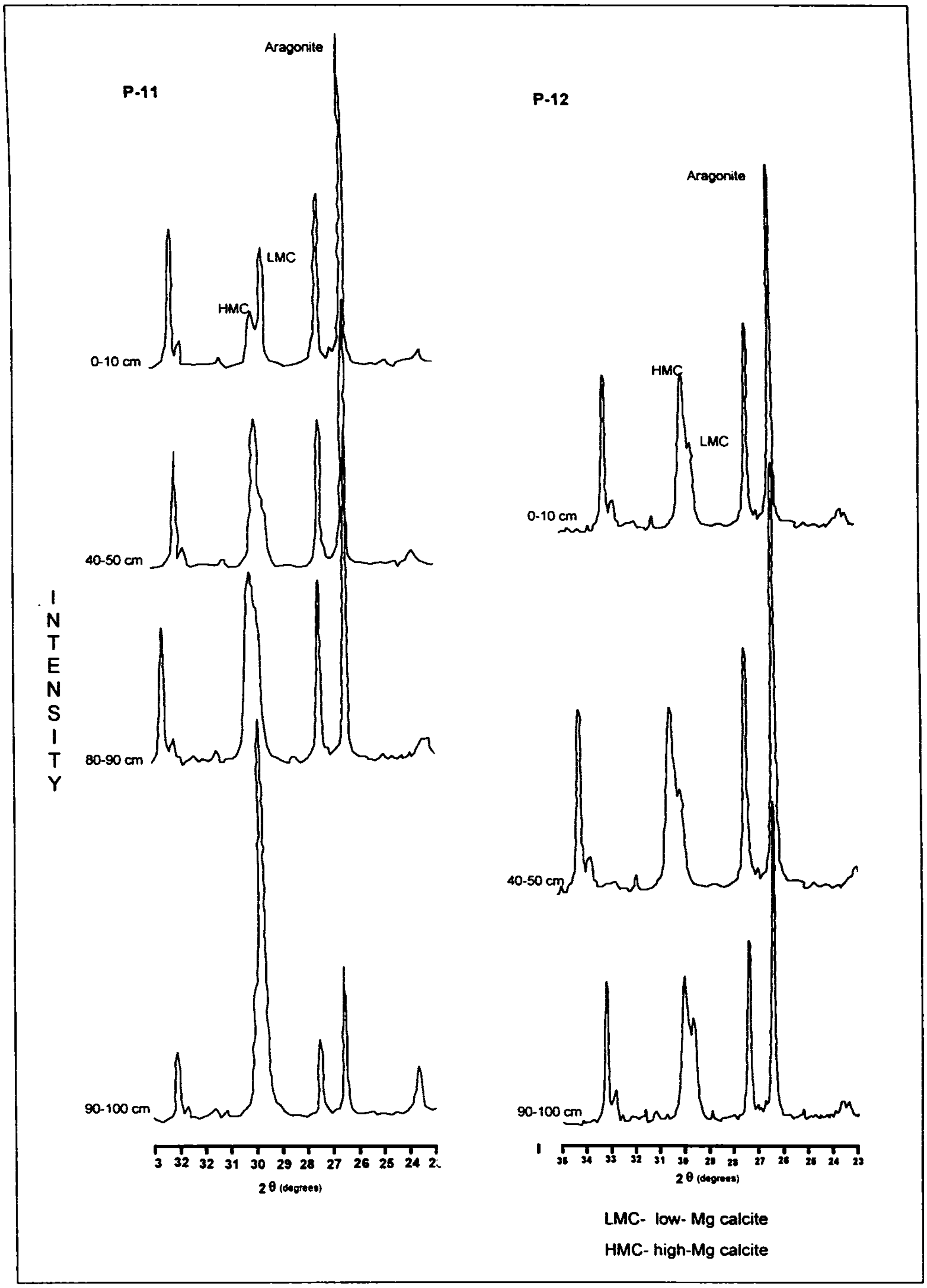

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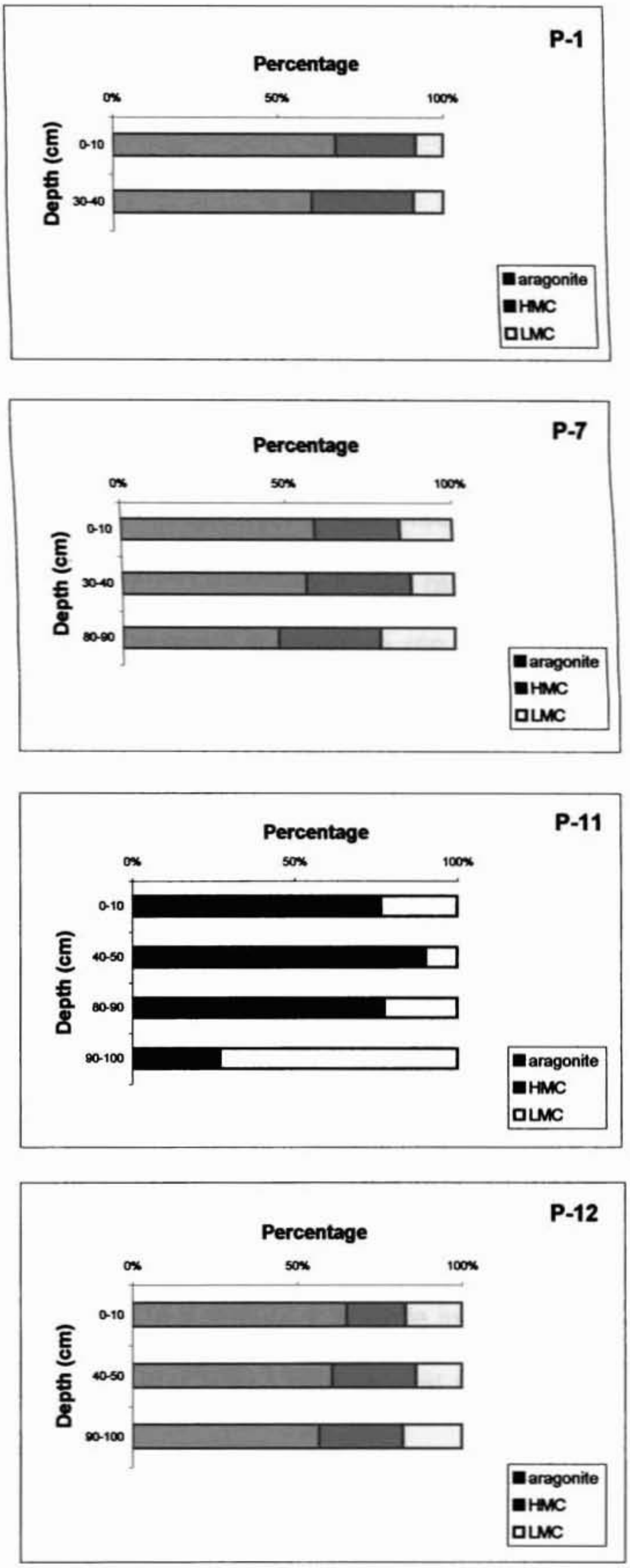


Fig. 4.4 Vertical variation of Aragonite, HMC and LMC contents of the Minicoy Island

Aragonite: XRD results reveal that aragonite is the only mineral recorded from the live corals from the reef area (Fig. 4.3). In the Minicoy Island proper, the dominant mineral is aragonite and contents range between 27 and 67.5 % (av. 56%). The maximum aragonite is obtained in P-1 and the minimum in P-11 (Table. 4.2). Invariably the surface samples exhibit high aragonite values showing a small range (58.5 - 67.5 %) between pits. Further Fig. 4.3 shows a steady decrease in aragonite content with depth. Unlike in Kavaratti, all the surface samples of the Minicoy Island exhibit the presence of HMC and LMC along with aragonite (Table.4.2). P-11 exhibits a wide range in aragonite content (27 to 66.1 %) while in P-12, the range is minimum (56.7 to 65.1 %). It is clear that at the expense of aragonite the HMC and LMC contents show a progressive increase with depth (Fig. 4.4).

High-Mg calcite: HMC content varies from 0 to 31% (av. 23%). In general HMC slightly increases with depth. However, the bottom most sample of P- 11 does not contain any HMC at all. A narrow range of HMC content (17.9 - 25.4 %) is observed in P-7 (Fig. 4.4).

Low-Mg calcite : LMC ranges between 8.3 and 73% with an average value of 21%. The minimum value (8.3 %) is observed in P-1 and the maximum is from the bottom most sample of P-11 where HMC is totally absent. In P-7 the LMC content varies narrowly between 12.9 and 22.4 % while in P-11 the LMC values show a wide variation from 9.9 to 73 %. The general tendency is that LMC increases with depth (Fig. 4.4).

4.3. Geochemistry results

4.3.1. Kavaratti Island

The concentrations of different elements and organic carbon (c-org) content of the Kavaratti island samples are presented in Table 4.3. The vertical distribution of these parameters in the Kavaratti island samples is shown in Fig. 4.5. The inter-relationships between the major constituents of the sediments (Fe, Sr, Ca, Mg and Mn) with aragonite are given in Fig. 4.6.

Ca: Among the 12 elements analysed, Ca has the maximum concentration Table 4.3). Ca content in the Kavaratti island ranges from 33.7 to 52.9% with an average value of 40.93%. The maximum value is found in DW-5 at the depth of 90-120 cm, while the minimum is from in DW-15 at a depth of 390-420 cm. The result shows that there is a general tendency of Ca decrease with depth (Fig. 4.5). DW-4, DW- 5 and DW-11 show higher Ca values while DW-15 shows lesser values. The Ca values show a small positive correlation with aragonite (Fig. 4.6).

Mg: Mg content in Kavaratti island ranges from 1.8 to 7.8 % with an average value of 4.75%. Mg values show a wide variation (Table 4.3). The maximum value of Mg is found in DW-14 at depths of 90-120 and 210-240 cm. The minimum value is found at the surficial sample of DW-13. Mg distribution with depth does not show any specific trend (Fig. 4.5). Mg content shows a slight positive correlation with aragonite (Fig. 4.6).

Na: Na content in Kavaratti island varies from 2200 to 8600 ppm with an average value of 3598 ppm. Both the minimum and the maximum values are obtained from the surface and bottom samples of DW-16. In most of the dug

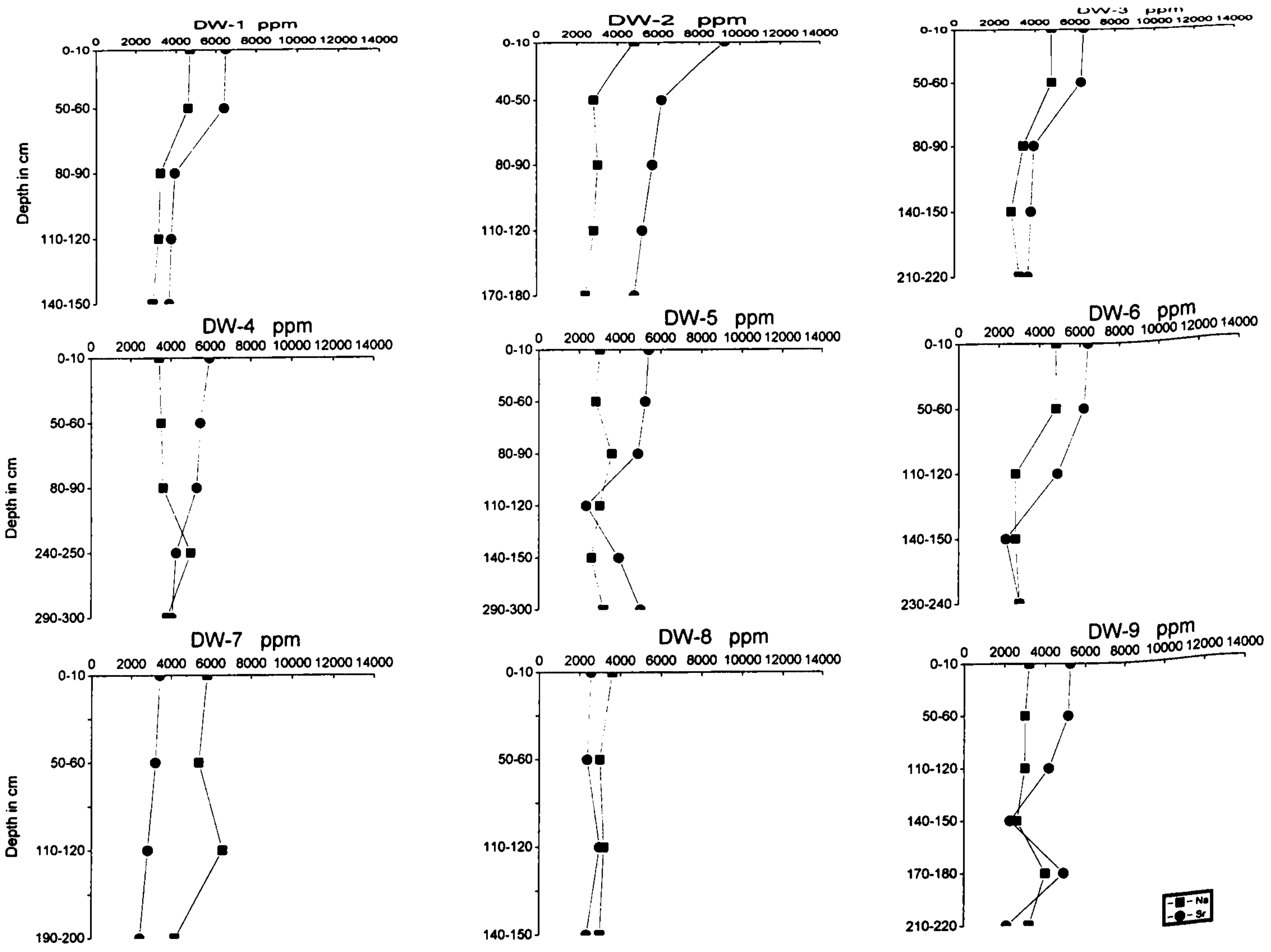
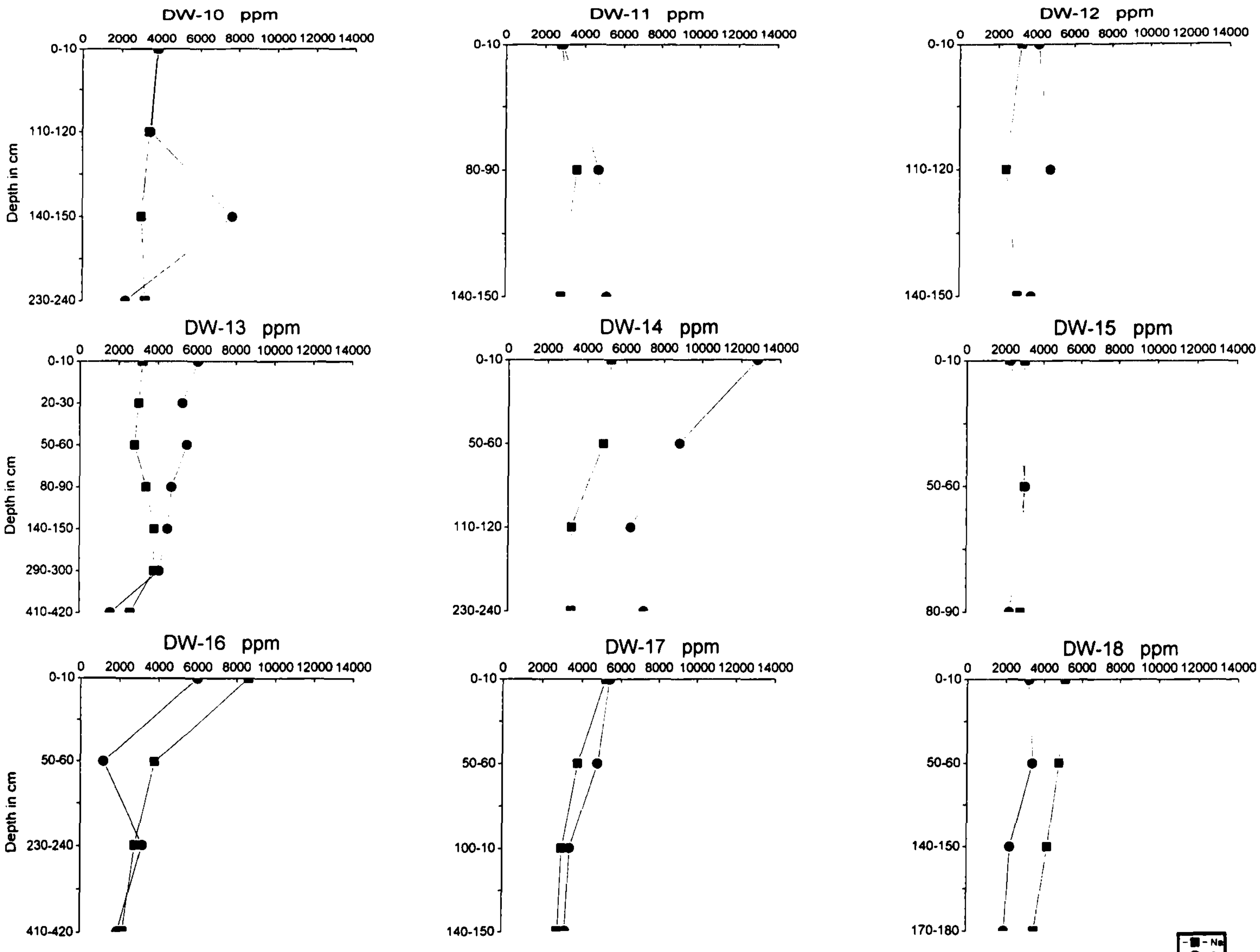


Fig. 4.5 Vertical distribution of different elements (Na, K, Ca, Mg, Sr, Fe, Mn, Cu, Co, Zn, Ni & Cr) and C-org of Kavaratti Island



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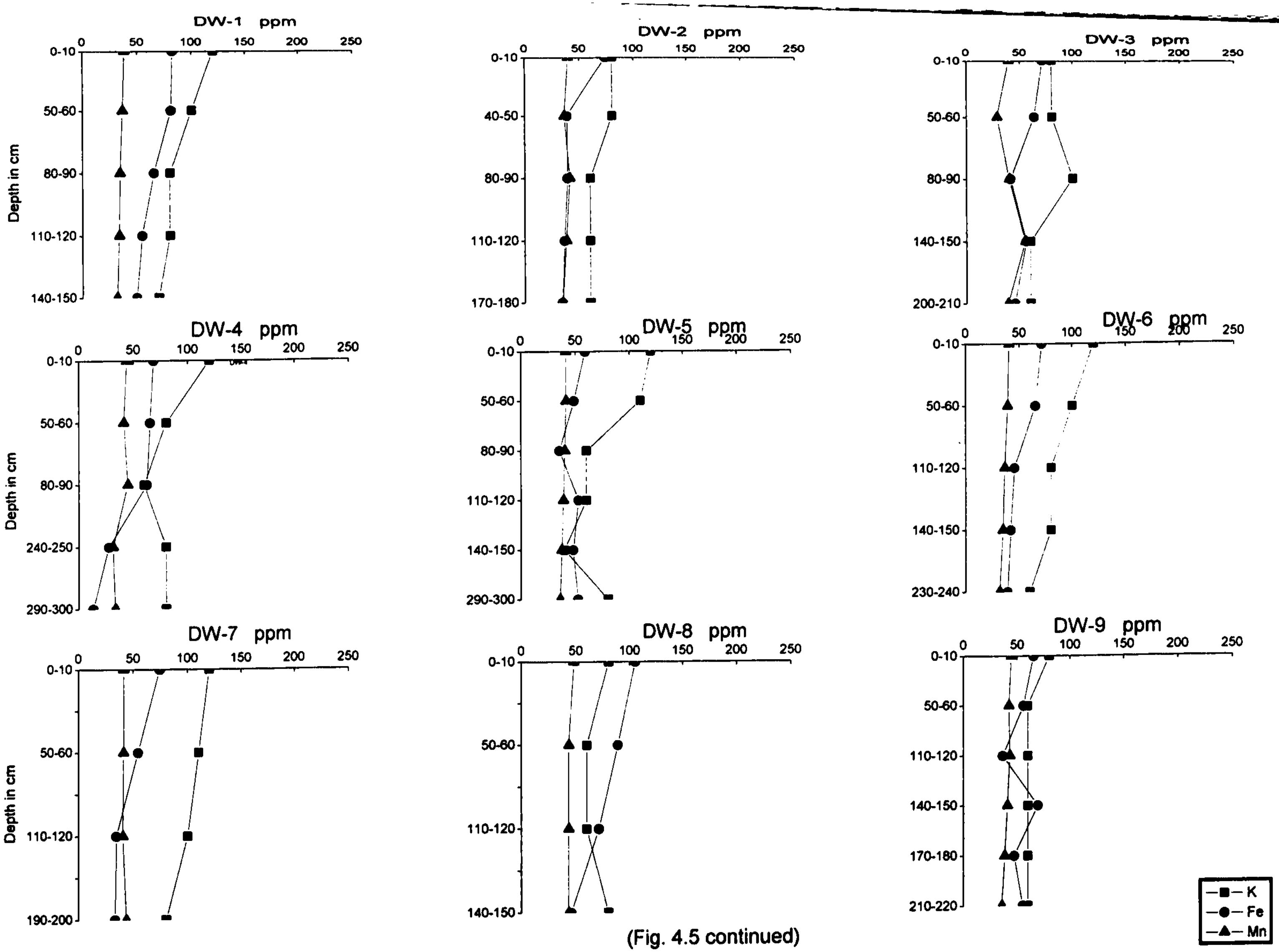

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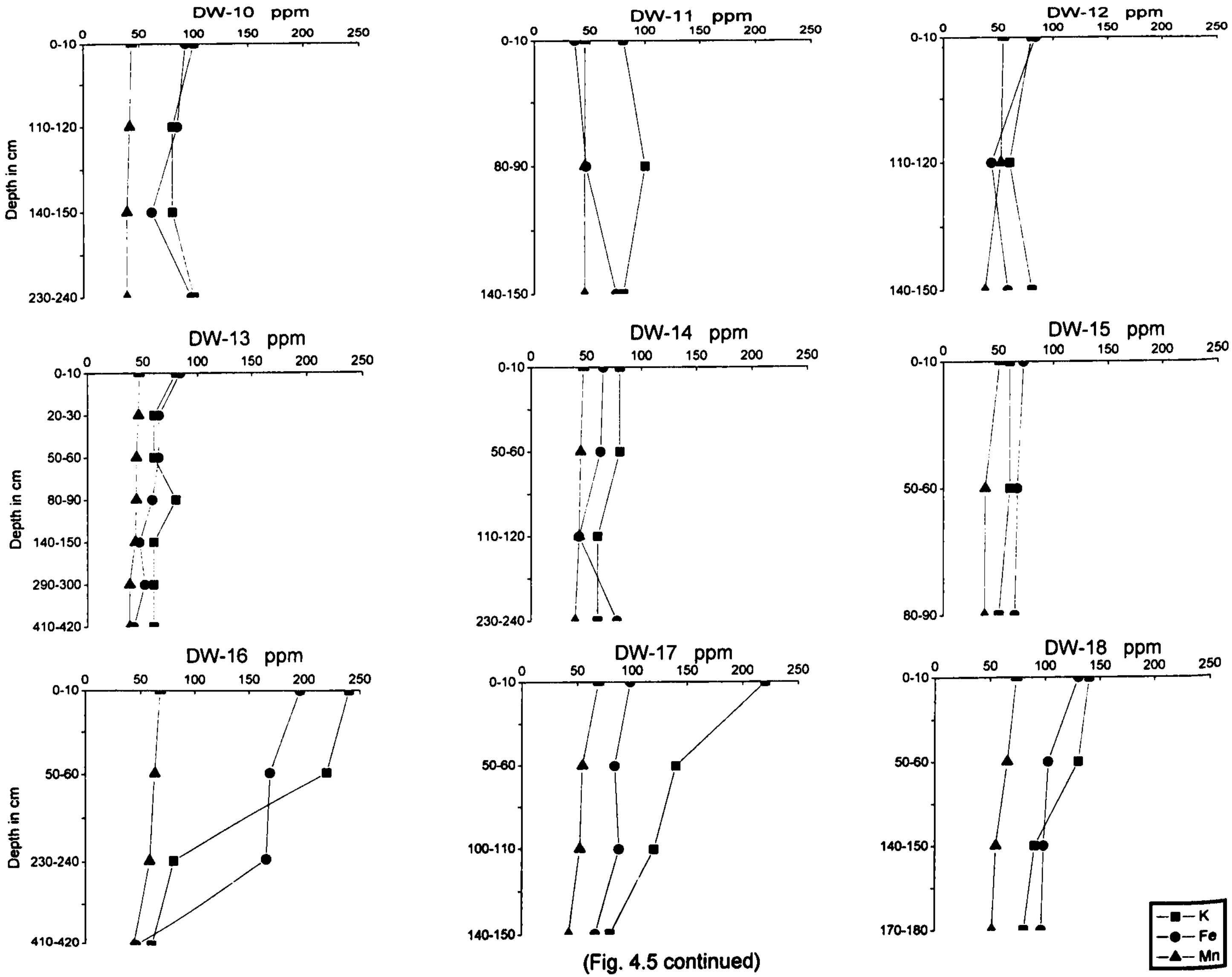

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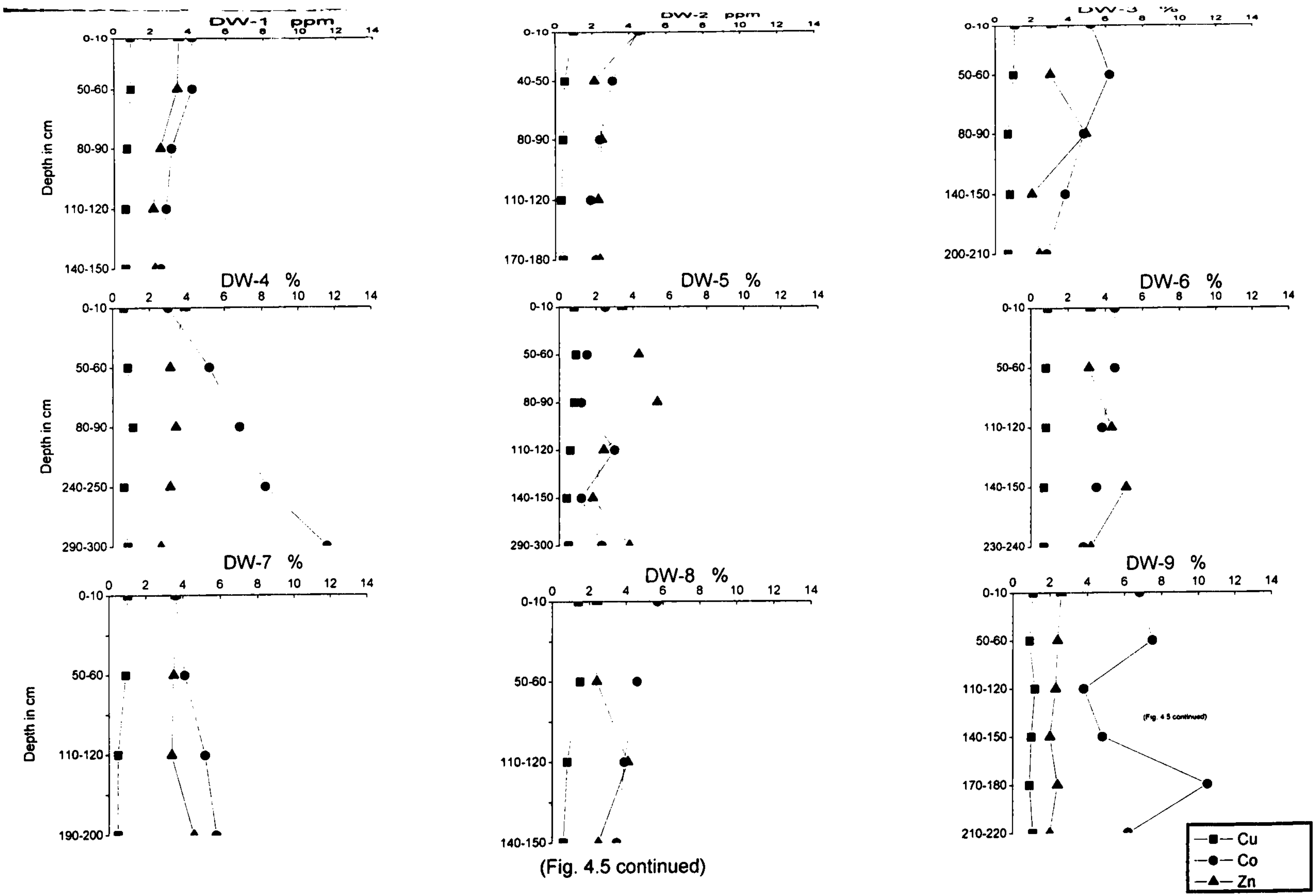

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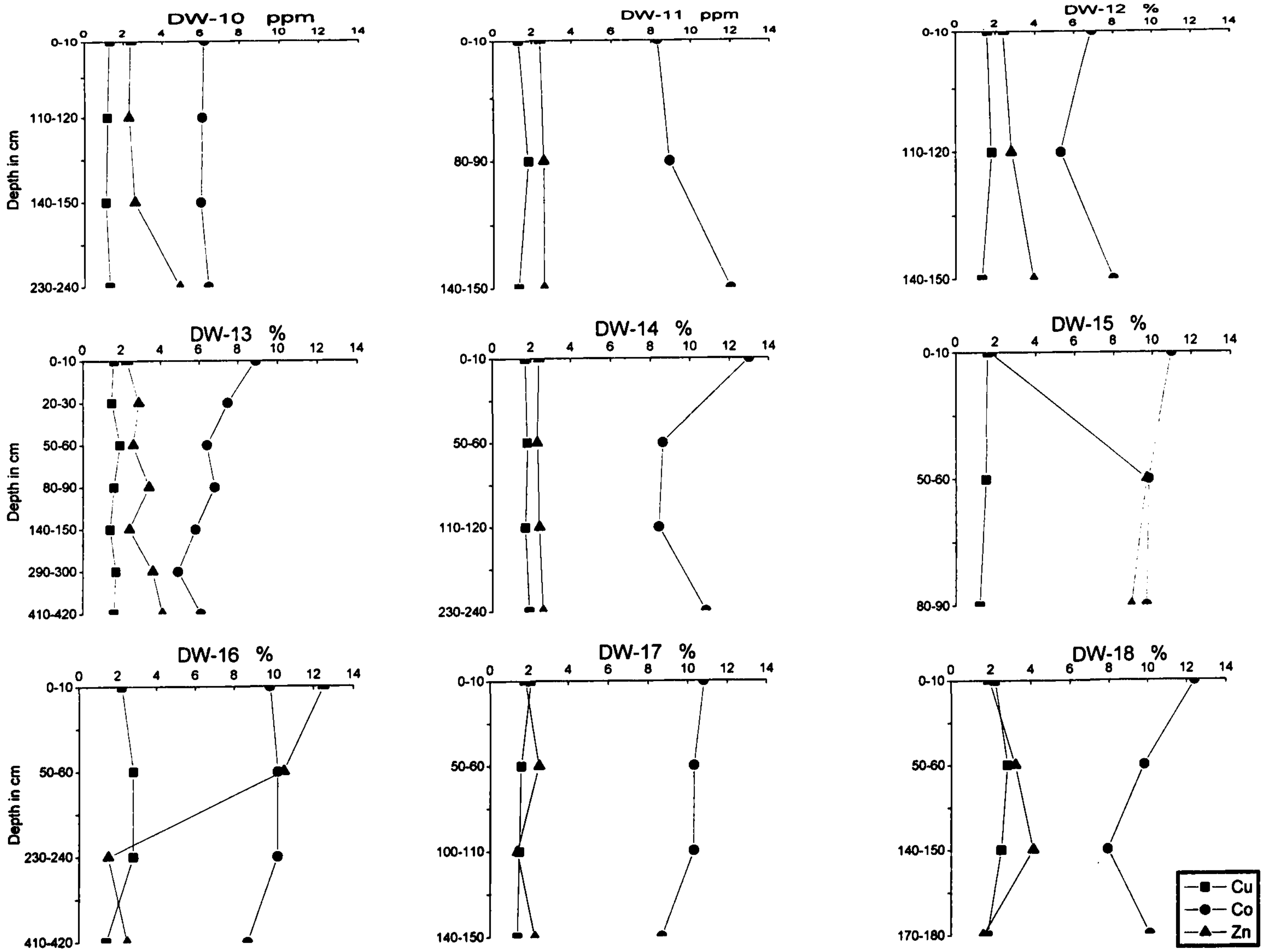

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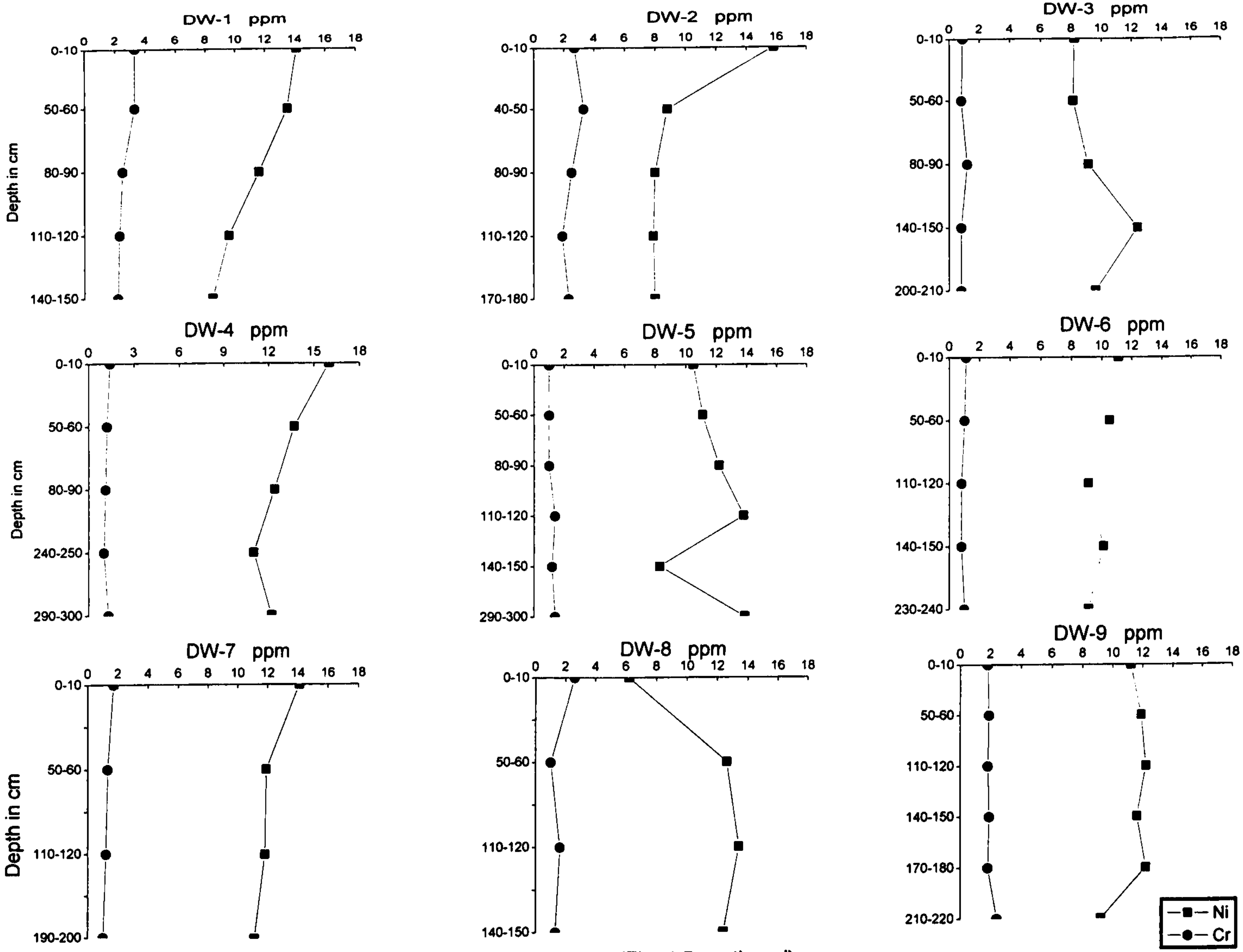

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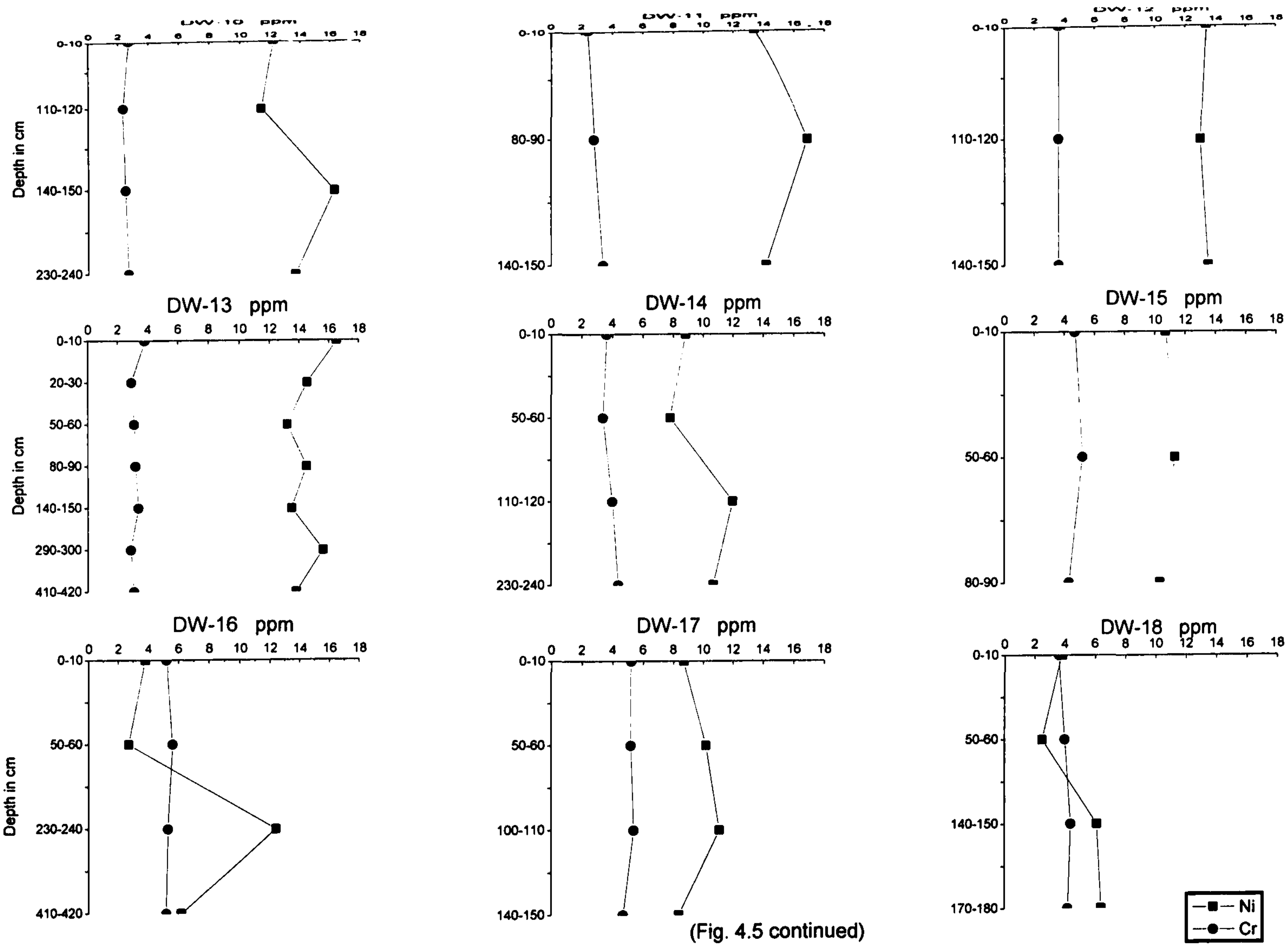

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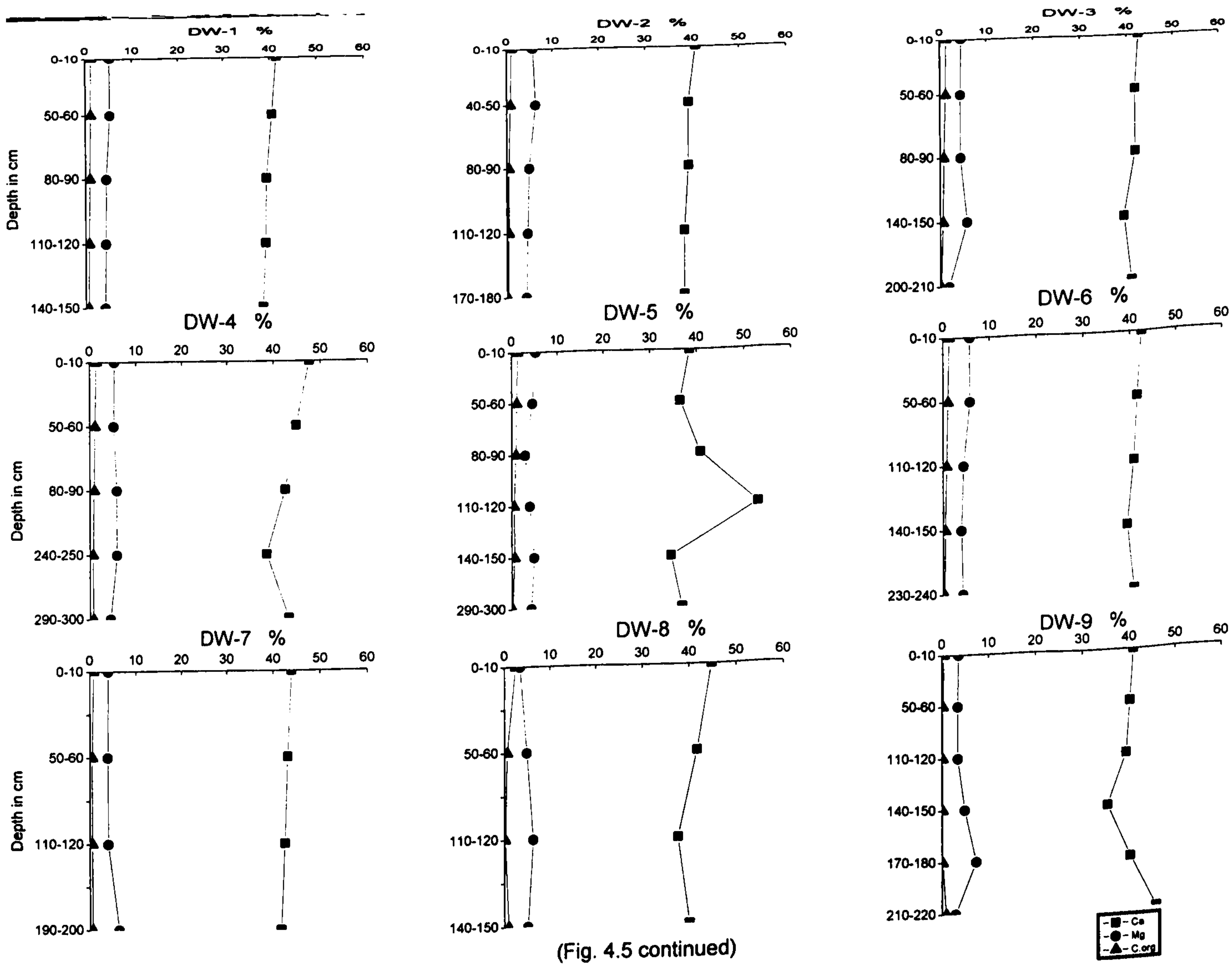

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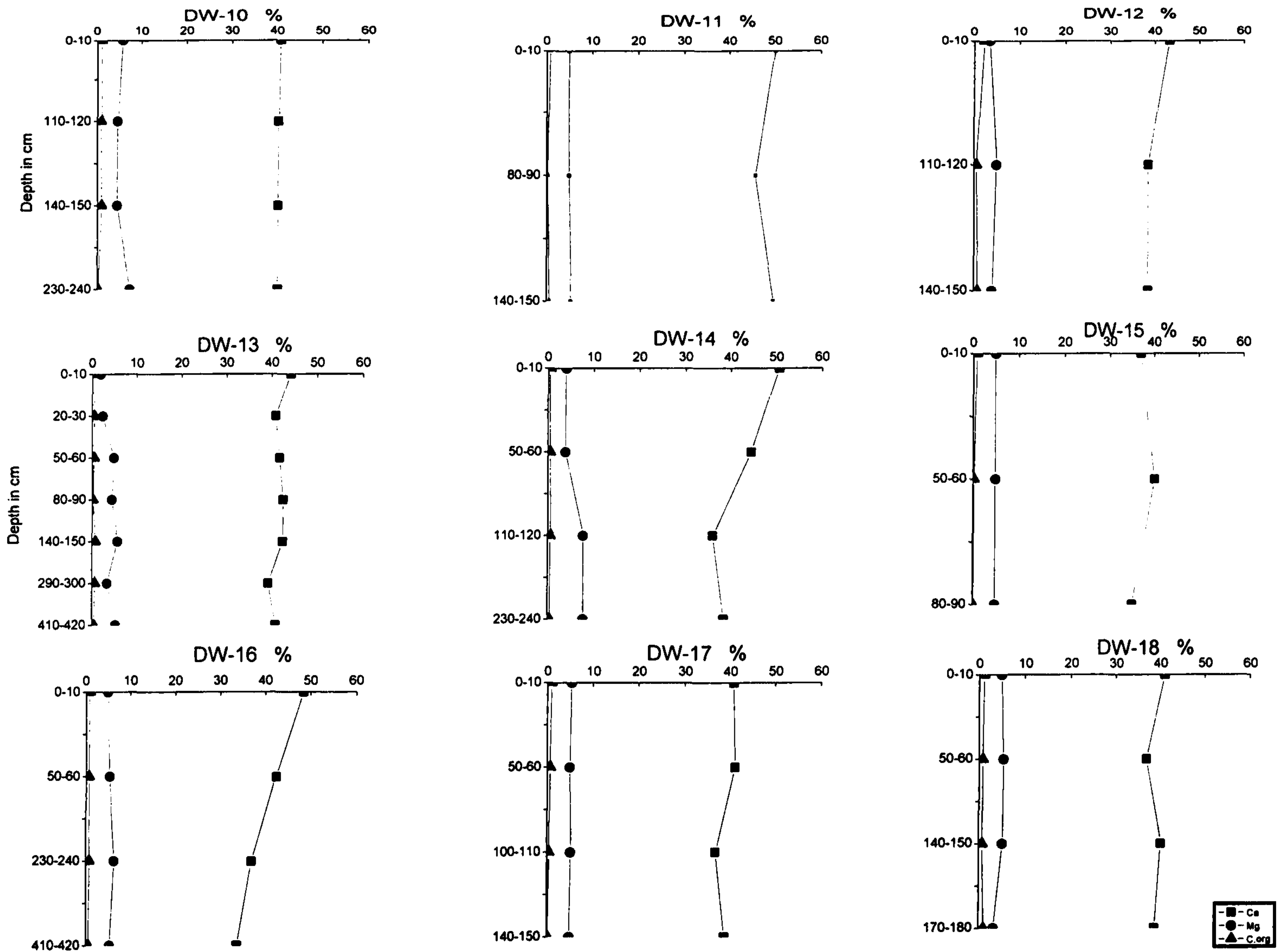

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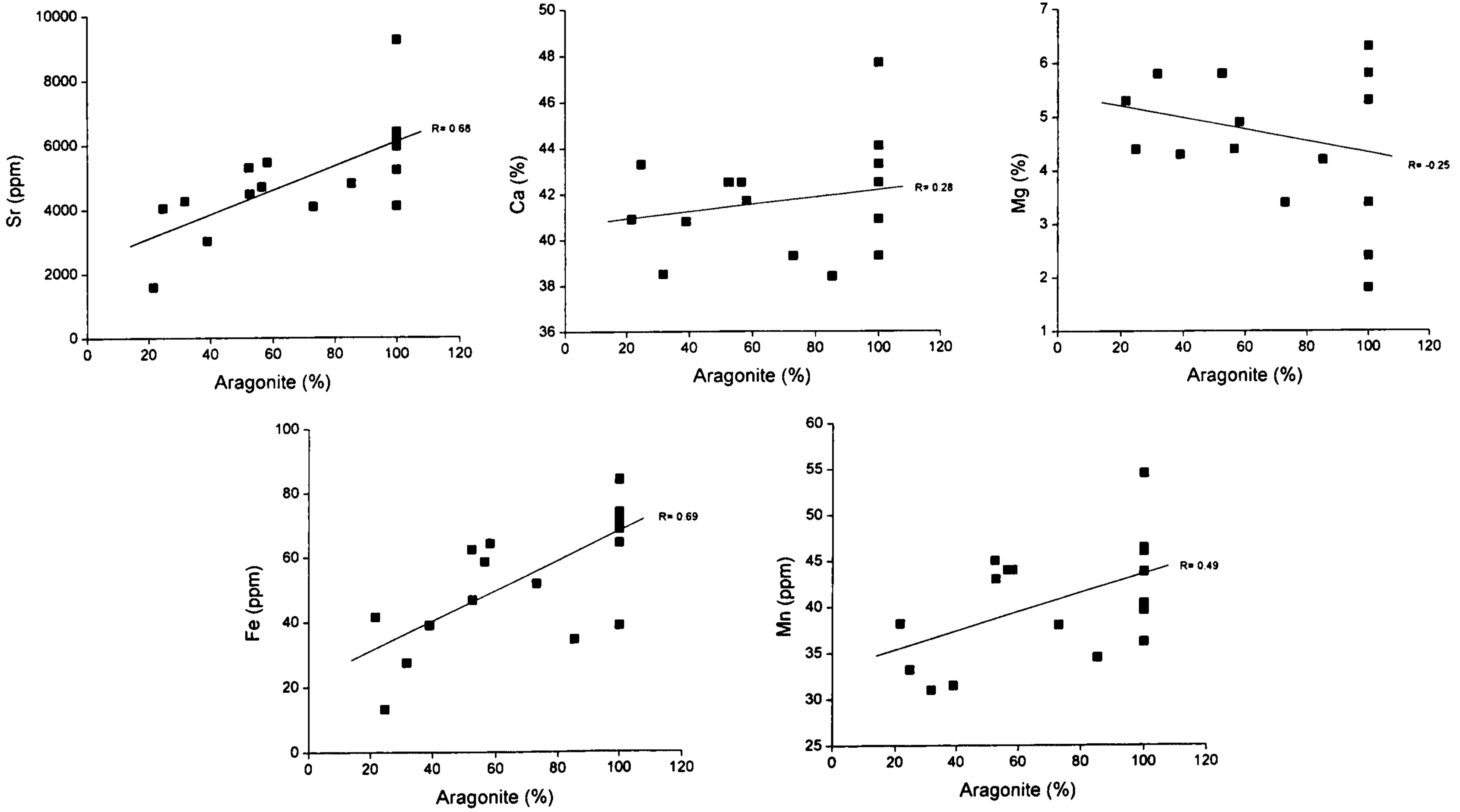


Fig. 4.6 Inter-relationship of aragonite vs. different elements of Kavaratti Island proper sediments

Table. 4.3 Major and minor element contents of island proper sediments in Kavaratti (Ca,Mg and C-org in %, others in ppm)

Depth cm	Na	K	Ca	Mg	Sr	Fe	Mn	Cu	Co	Zn	Ni	Cr	C-org
DW-1													
0-10	4700	120	41.5	5.2	6500	82.5	38.4	0.9	4.2	3.5	14.1	3.3	1.2
50-60	4600	100	40.5	5.2	6400	81.0	36.4	0.9	4.2	3.4	13.5	3.3	1.1
80-90	3200	80	39.3	4.4	3920	65.5	34.2	0.7	3.1	2.5	11.6	2.5	0.9
110-120	3100	80	39.1	4.3	3740	54.5	33.6	0.6	2.8	2.1	9.6	2.3	0.7
140-150	2800	70	38.5	4.1	3620	49.5	31.5	0.6	2.5	2.2	8.5	2.2	0.6
DW-2													
0-10	4800	80	40.9	5.8	9240	74.0	39.6	1.0	4.5	4.6	15.8	2.7	1.1
40-50	2800	80	39.3	6.3	6140	38.8	36.2	0.5	3.1	2.1	8.8	3.3	0.8
80-90	3000	60	39.3	4.9	5700	39.2	41.2	0.4	2.4	2.5	8.0	2.5	0.4
110-120	2800	60	38.4	4.5	5200	36.4	38.3	0.3	1.9	2.3	7.9	1.9	0.4
170-180	2400	60	38.4	4.2	4800	34.5	34.5	0.4	2.2	2.4	8.0	2.3	0.1
DW-3													
0-10	4800	80	42.5	4.6	6420	71.5	39.5	1.1	5.2	3.1	8.2	0.9	1.3
50-60	4800	80	41.7	4.4	6280	63.5	28.2	1.0	6.2	3.0	8.1	0.8	1.2
80-90	3400	100	41.7	4.4	3920	41.0	39.8	0.7	4.8	4.9	9.1	1.2	0.8
140-150	2800	60	39.3	5.8	3780	55.8	54.8	0.8	3.8	2.0	12.4	0.8	0.6
200-210	3200	60	40.9	1.9	3620	45.1	38.8	0.7	2.8	2.4	9.6	0.8	0.1
DW-4													
0-10	3400	120	47.7	5.3	5940	68.6	43.8	0.6	3.0	3.9	16.0	1.4	1.4
50-60	3500	80	44.8	5.1	5480	65.4	41.2	0.8	5.2	3.1	13.7	1.2	1.1
80-90	3600	60	42.5	5.8	5300	62.4	45.0	1.1	6.8	3.4	12.4	1.1	0.9
240-250	5000	80	38.5	5.8	4260	27.5	31.0	0.6	8.2	3.1	11.0	1.0	0.6
290-300	3800	80	43.3	4.4	4040	13.2	33.2	0.8	11.6	2.6	12.2	1.3	0.7
DW-5													
0-10	3000	120	38.5	5.3	5400	59.0	41.4	0.8	2.5	3.4	10.5	1.0	1.3
50-60	2800	110	36.5	4.5	5240	48.5	41.4	0.9	1.5	4.3	11.1	1.0	1.1
80-90	3600	60	40.8	2.9	4880	35.5	40.2	0.8	1.2	5.3	12.2	1.0	0.9
110-120	3000	60	52.9	3.9	2340	52.9	39.0	0.6	3.0	2.4	13.8	1.4	0.5
140-150	2600	40	34.5	4.9	3940	47.8	37.4	0.4	1.2	1.8	8.3	1.2	0.6
290-300	3200	80	36.9	4.3	5020	52.4	36.0	0.5	2.3	3.8	13.9	1.4	0.1
DW-6													
0-10	4800	120	42.5	5.8	6400	71.3	40.4	0.9	4.5	3.2	11.1	1.1	1.3
50-60	4800	100	41.5	5.8	6200	65.3	38.9	0.8	4.5	3.1	10.5	1.0	1.1
110-120	2800	80	40.8	4.4	4880	45.5	36.2	0.8	3.8	4.3	9.1	0.8	0.7
140-150	2800	80	39.3	3.9	2340	41.8	34.5	0.7	3.5	5.1	10.1	0.8	0.5
230-240	3000	60	40.8	4.3	3020	39.0	31.5	0.7	2.8	3.2	9.1	1.0	0.3
DW-7													
0-10	5800	120	43.9	3.9	3420	74.7	41.4	1.0	3.6	3.6	14.1	1.7	0.8
50-60	5400	110	43.1	3.8	3210	54.5	41.1	0.9	4.1	3.5	11.9	1.3	0.5
110-120	6600	100	42.5	3.9	2840	34.5	40.4	0.5	5.2	3.4	11.8	1.2	0.5
190-200	4200	80	41.7	6.3	2450	33.3	43.6	0.5	5.8	4.6	11.1	1.0	0.6
DW-8													
0-10	3600	80	44.8	3.4	2560	105.2	48.0	1.4	5.7	2.4	6.2	2.6	2.4
50-60	3000	60	41.7	4.9	2380	88.8	43.4	1.5	4.6	2.4	12.6	1.0	0.6
110-120	3200	60	37.7	6.3	2980	71.1	43.4	0.8	3.9	4.1	13.4	1.6	0.1
140-150	3000	80	40.1	5.1	2340	45.9	43.4	0.6	3.5	2.5	12.4	1.3	0.9

Depth cm	Na	K	Ca	Mg	Sr	Fe	Mn	Cu	Co	Zn	Ni	Cr	C-org
DW-9													
0-10	3200	80	40.9	3.6	5240	65.4	44.5	1.1	6.8	2.6	11.2	1.8	0.4
50-60	3000	60	40.1	3.4	5140	55.7	42.2	0.9	7.5	2.4	11.9	1.9	0.2
110-120	3000	60	39.3	3.4	4180	36.4	42.8	1.2	3.8	2.3	12.2	1.8	0.1
140-150	2600	60	35.3	4.9	2260	69.4	40.6	1.0	4.8	2.0	11.6	1.9	0.1
170-180	4000	60	40.1	7.3	4920	47.2	38.2	0.9	10.5	2.4	12.2	1.8	0.1
210-220	3200	60	45.7	2.9	2100	55.0	35.4	1.1	6.2	2.0	9.2	2.4	0.9
DW-10													
0-10	3800	100	40.8	5.8	3840	92.1	43.2	1.3	6.2	2.4	12.2	2.7	1.0
110-120	3400	80	40.3	4.6	3460	84.5	41.5	1.2	6.1	2.3	11.4	2.3	0.9
140-150	3000	80	40.1	4.4	7660	61.2	39.0	1.1	6.0	2.6	16.3	2.5	0.9
230-240	3200	100	40.1	7.3	2200	97.4	39.0	1.3	6.4	4.9	13.7	2.7	0.2
DW-11													
0-10	2800	80	50.1	4.9	2880	36.3	45.4	1.3	8.3	2.4	13.4	2.4	0.7
80-90	3600	100	45.7	4.9	4700	46.4	45.2	1.8	8.9	2.6	16.9	2.8	0.1
140-150	2800	80	49.7	5.3	5120	73.7	44.8	1.3	12.0	2.6	14.2	3.4	0.6
DW-12													
0-10	3200	80	43.3	3.4	4100	83.9	54.5	1.6	6.9	2.4	13.4	3.6	2.2
110-120	2400	60	38.5	4.9	4720	43.6	52.2	1.8	5.3	2.8	13.0	3.6	0.5
140-150	3000	80	38.5	3.9	3720	58.3	37.8	1.3	8.0	3.9	13.5	3.6	0.8
DW-13													
0-10	3200	80	44.1	1.8	6020	84.2	46.4	1.6	8.9	2.3	16.5	3.8	0.5
20-30	3000	60	40.9	2.4	5220	64.4	46.0	1.5	7.5	2.9	14.5	2.9	0.5
50-60	2800	60	41.7	4.9	5460	64.3	44.0	1.9	6.4	2.6	13.2	3.1	0.4
80-90	3400	80	42.5	4.4	4700	58.6	44.0	1.6	6.8	3.4	14.5	3.2	0.1
140-150	3800	60	42.5	5.8	4480	46.8	43.0	1.4	5.8	2.4	13.5	3.4	0.8
290-300	3800	60	39.3	3.4	4080	51.8	38.0	1.7	4.9	3.6	15.6	2.9	0.6
410-420	2600	60	40.9	5.3	1580	41.6	38.2	1.6	6.1	4.1	13.8	3.1	0.4
DW-14													
0-10	5200	80	50.6	3.9	12820	65.1	47.2	1.7	13.0	2.4	8.8	3.6	0.5
50-60	4800	80	44.5	3.8	8820	62.4	44.5	1.8	8.6	2.3	7.8	3.4	0.5
110-120	3200	60	36.1	7.8	6240	43.2	43.2	1.7	8.4	2.4	12.0	4.0	0.6
230-240	3200	60	38.5	7.8	6940	77.8	39.6	1.9	10.8	2.6	10.7	4.4	0.4
DW-15													
0-10	3000	60	36.9	4.9	2260	72.4	51.2	1.6	11.0	1.7	10.7	4.7	0.8
50-60	3000	60	40.1	4.9	3060	66.8	37.6	1.5	9.8	9.7	11.3	5.2	0.2
80-90	2800	50	35.1	4.8	2240	64.5	37.1	1.2	9.7	8.9	10.3	4.3	0.1
DW-16													
0-10	8600	240	48.4	4.9	5960	196.0	68.0	2.2	9.8	12.5	3.8	5.2	0.8
50-60	3800	220	42.4	5.3	1200	168.8	63.0	2.8	10.2	10.5	2.7	5.6	0.6
230-240	2800	80	36.9	6.3	3200	165.5	58.0	2.8	10.2	1.5	12.4	5.3	0.7
410-420	2200	60	33.7	5.3	1920	45.8	43.6	1.4	8.7	2.5	6.2	5.2	0.5
DW-17													
0-10	5200	220	40.8	5.3	5400	98.0	69.0	2.1	10.8	1.8	8.7	5.2	0.9
50-60	3800	140	41.1	4.9	4800	84.0	54.5	1.6	10.3	2.5	10.2	5.2	0.6
100-110	3000	120	36.8	5.1	3400	88.0	52.3	1.5	10.3	1.4	11.1	5.4	0.4
140-150	2800	80	38.8	4.8	3200	66.5	42.3	1.4	8.7	2.3	8.4	4.7	0.1
DW-18													
0-10	5100	140	41.0	4.9	3200	130.0	73.5	2.2	12.4	1.9	3.8	3.6	1.1
50-60	4800	130	36.9	5.3	3400	102.5	65.3	2.8	9.8	3.2	2.5	4.0	0.8
140-150	4200	90	40.2	5.1	2240	98.3	54.9	2.5	7.9	4.1	6.1	4.4	0.7
170-180	3500	80	38.8	3.2	1940	96.0	51.3	1.8	10.1	1.6	6.4	4.2	1.0

(Table. 4.3 continued)

wells Na values decrease towards depth, while DW-4 and DW-15 the Na values increase with depth(Fig. 4.5).

K: In Kavaratti island K value ranges from 40 to 240 ppm with an average value of 85 ppm. In most of the wells the K values increases with depth (Fig.4.5). The maximum value is obtained from DW-16 at a depth of 0-30 cm and in DW-5 at a depth of 120-150 cm.

Fe: Fe content in the Kavaratti island shows a wide range between 13.2 and 196 ppm (av. 66 ppm). Fe content decreases with depth in most of the dug wells. The maximum value is found in the surface sample of DW-16 and the minimum value at the bottom most sample of DW-4. Almost in all the dug wells, surface samples show higher concentrations of Fe (Fig. 4.5). Fe values are strongly correlated with aragonite (Fig. 4.6).

Mn:The concentration of Mn of the Kavaratti island ranges from 28.2 to 73.5 ppm (av. 43.2 ppm). Mn values show a general decreasing trend towards depth (Fig. 4.5). The maximum value is obtained from the surface samples of DW-18 and the minimum from DW-3 at a depth of 30-60 cm. The positive correlation between Mn and aragonite is shown in Fig.4.6.

Sr: In Kavaratti island the Sr values show a wide range(Table 4.3) between 1200 and 12820 ppm (av. 4397 ppm). Sr value decreases with depth in most of the dug wells. The maximum value of Sr is obtained from the surface sample of DW-14 and the minimum from DW-16 at depth of 30-60 cm. DW-7, DW- 8, DW- 15 and DW-18 show a narrow range of Sr compared to other dug wells. Sr is positively correlated with aragonite (Fig. 4.6).

Cu, Co, Zn, Ni and Cr: Concentration of these elements are very less in Kavaratti island compared to other elements described above (Table 4.3). Cu ranges narrowly from 0.3 to 2.8 ppm (av. 1.2 ppm). The concentration of Co ranges from 1.2 to 13 ppm with an average value of 6.24 ppm. Although Zn show a similar range (1.4 to 12.5 ppm) like that of Co, the average Zn content (3.3ppm) is just half of Co. The Ni content is appreciably high and falls between 2.5 and 16.9 ppm with an average value of 11 ppm. Cr value falls between 0.8 ppm and 5.8 ppm with an average value of 2.6 ppm. These elements do not show any drastic change with depth.

C-org: In Kavaratti island the organic carbon value ranges from 0.1 to 2.2% with an average value of 0.68%. In most of the dug wells, C-org values decrease with depth.

4.3.2. Minicoy Island

The concentration of the major and trace element contents of the Minicoy island is shown in Table 4.4. the vertical profiles of these elements and organic carbon values are presented in Fig. 7. The interrelationships of Fe, Mn, Sr, Ca and Mg with aragonite are plotted in Fig. 4.8.

Na: In Minicoy island the Na values show a narrow range of variation (Table 4.4) compared to Kavaratti island. Na ranges between 700 and 1900 ppm (av. 1374.7 ppm). In general, the surface samples show higher values of Na in most of the wells. There is a general decreasing tendency of Na with depth (Fig. 4.7).

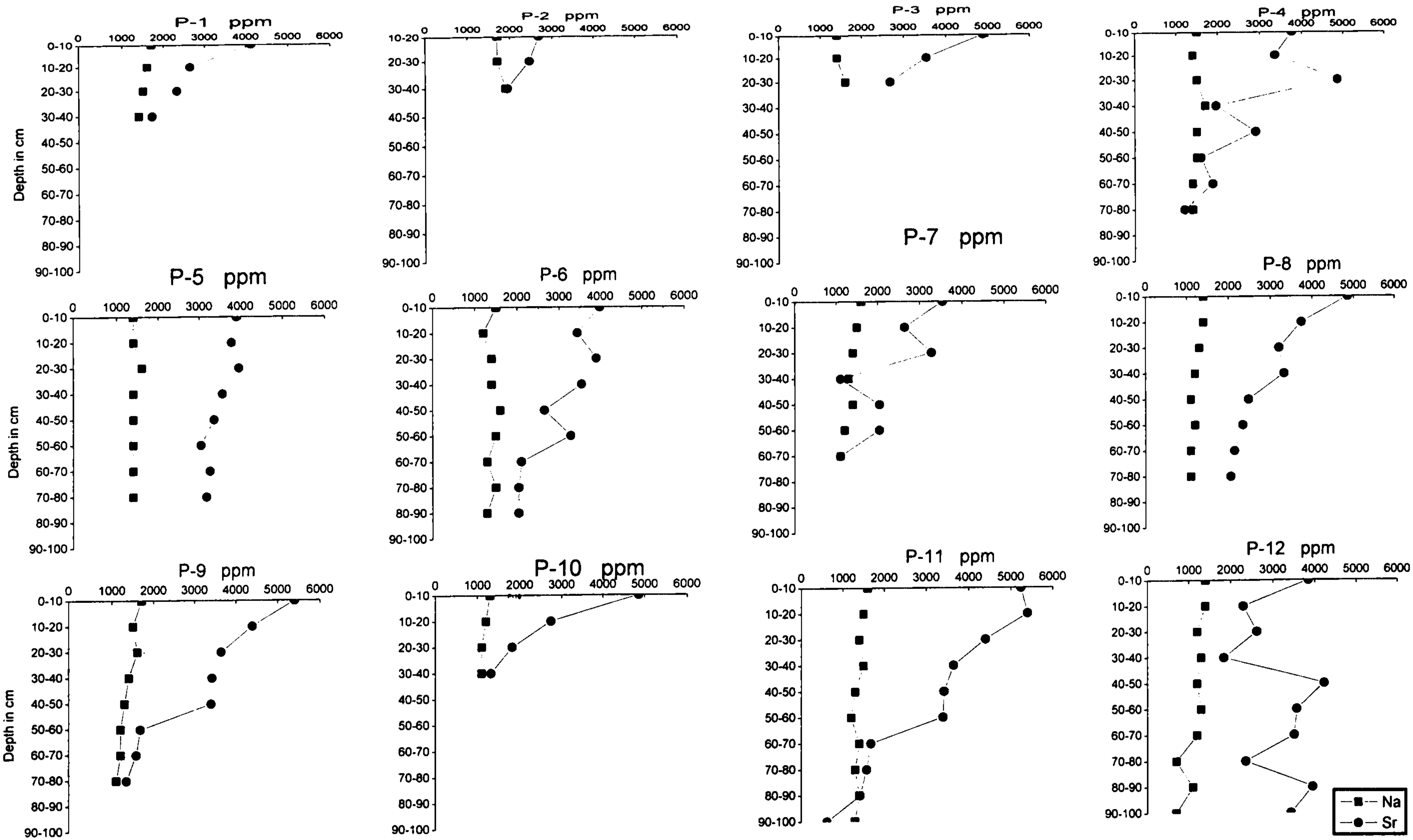
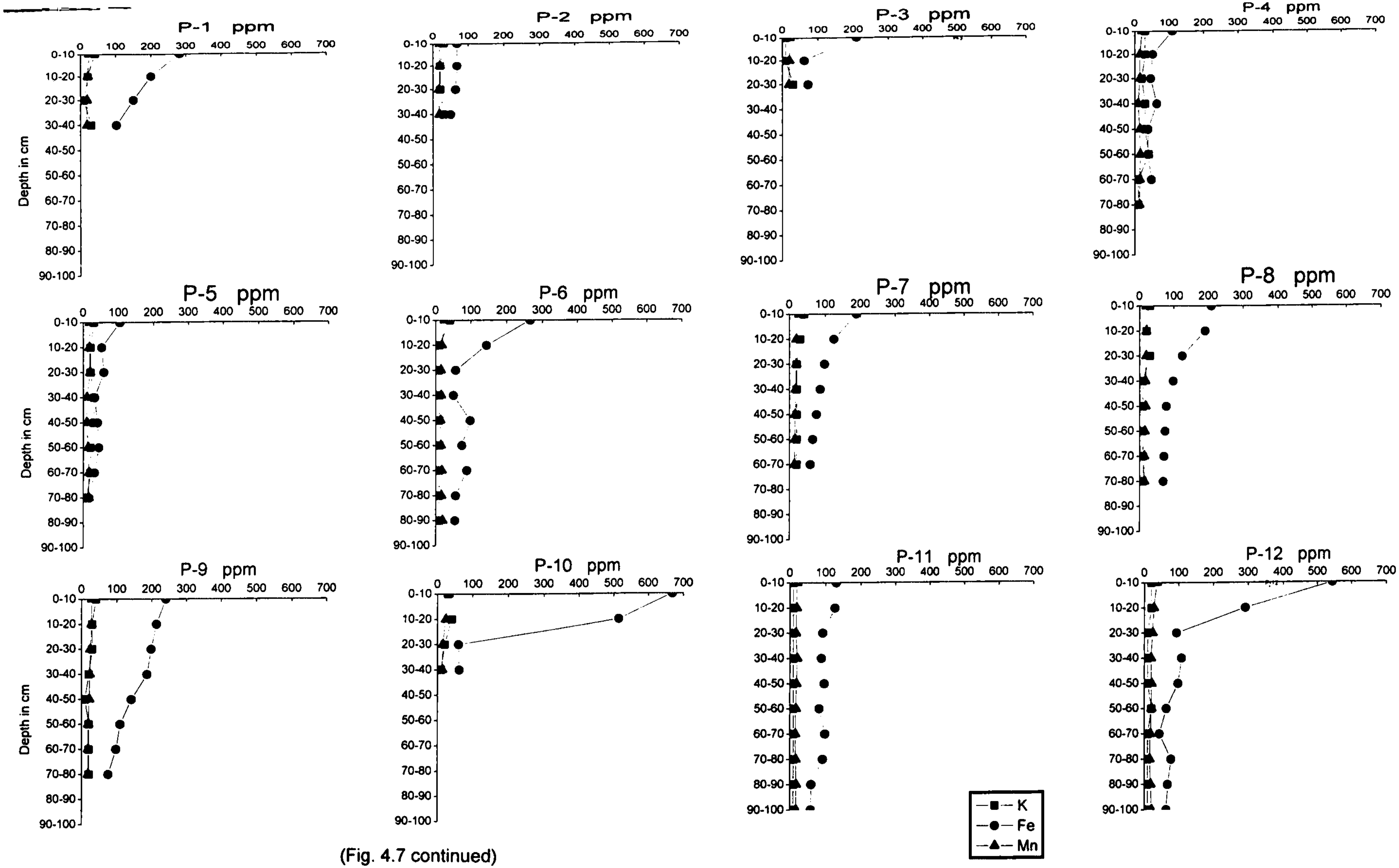
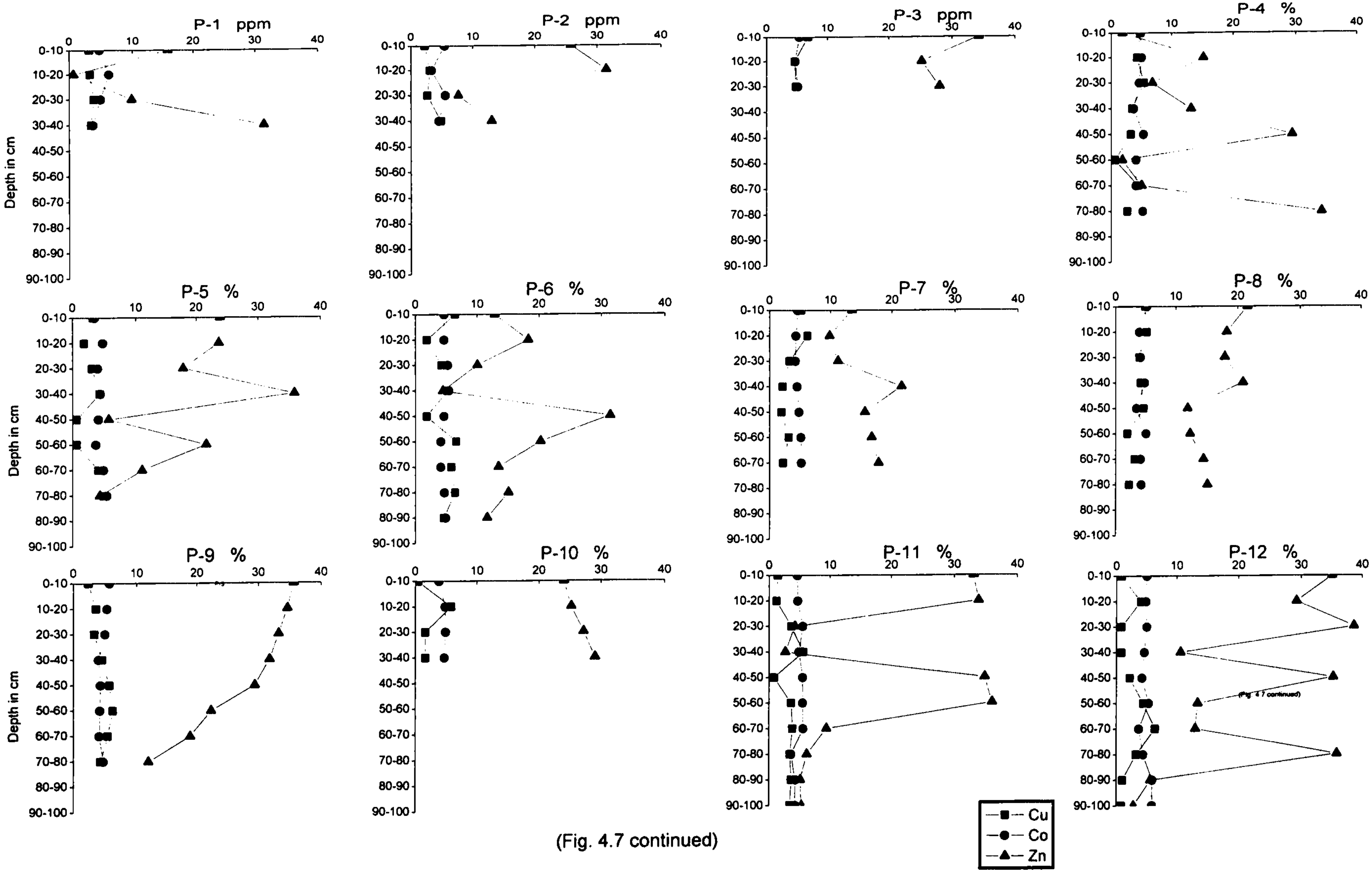


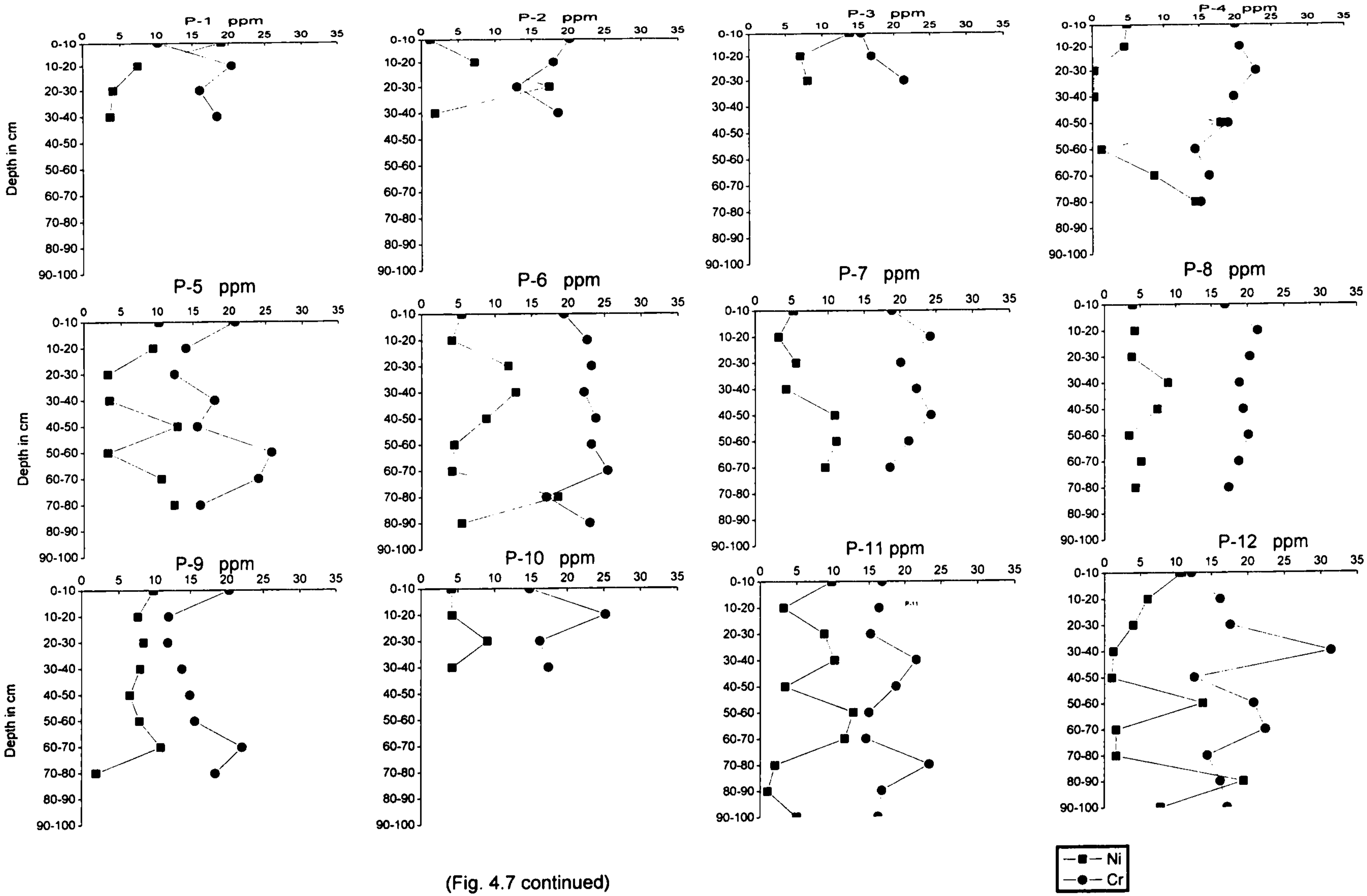
Fig.4.7 Vertical variation of different elements (Na, K, Ca, Sr, Fe, Mn, Cu, Co, Zn, Ni & Cr) and C- org of Minicoy Island sediments



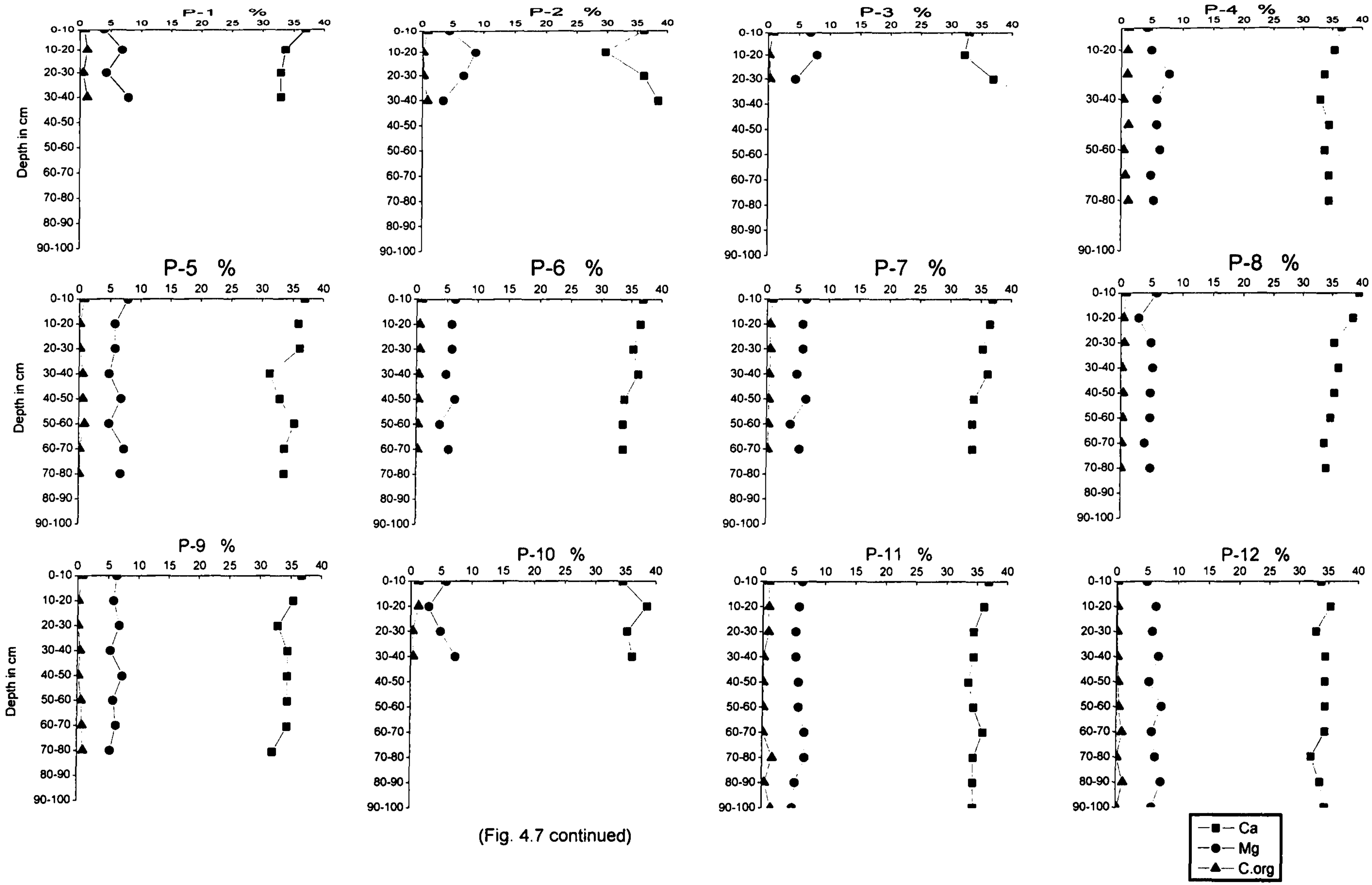
(Fig. 4.7 continued)



(Fig. 4.7 continued)



(Fig. 4.7 continued)



(Fig. 4.7 continued)

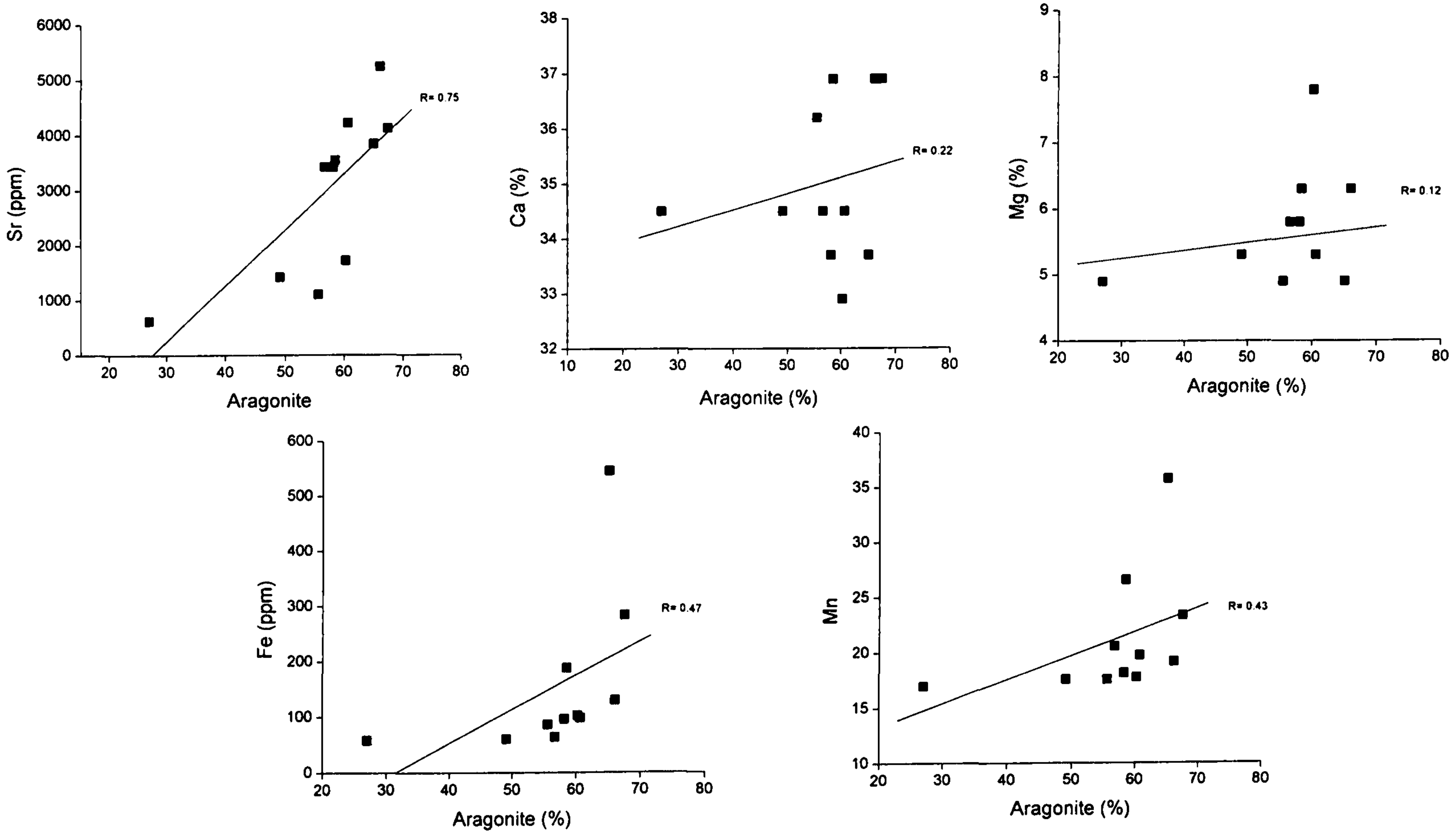


Fig. 4.8 Inter-relationship of aragonite vs. different elements of Minicoy Island sediments

Table. 4.4 Major and minor element contents of island proper sediments in Minicoy (Ca,Mg and C-org in %, others in ppm)

Depth cm	Na	K	Ca	Mg	Sr	Fe	Mn	Cu	Co	Zn	Ni	Cr	C-org
P-1													
0-10	1700	40	36.9	3.9	4120	282	23.4	3.1	4.7	15.8	19.0	10.2	0.7
10-20	1600	20	33.6	6.8	2640	200	20.2	3.2	6.2	0.6	7.4	20.4	1.1
20-30	1500	10	32.9	4.3	2320	150	18.0	3.8	4.9	9.8	4.0	16.0	0.5
30-40	1400	30	32.9	7.8	1720	102	17.8	3.4	3.7	31.4	3.6	18.4	1.1
P-2													
0-10	1800	30	36.1	4.4	2940	68	18.6	2.2	5.4	25.8	1.2	20.2	0.8
10-20	1700	20	29.7	8.7	2680	68	18.5	3.0	3.3	31.4	7.2	18.0	0.1
20-30	1700	20	36.1	6.8	2460	64	16.6	2.6	5.5	7.6	17.4	13.0	0.2
30-40	1900	30	38.5	3.4	1940	50	17.2	4.8	4.5	13.0	1.8	18.6	0.8
P-3													
0-10	1400	10	32.9	6.8	4880	208	20.8	6.8	5.4	34.2	13.8	15.4	0.7
10-20	1400	10	32.1	7.8	3540	62	19.6	4.6	4.7	25.2	7.0	16.8	0.1
20-30	1600	30	36.9	4.4	2680	72	18.0	4.8	5.1	28.0	8.0	21.4	0.3
P-4													
0-10	1500	30	36.5	4.2	3760	110	21.6	4.8	4.8	1.8	4.8	20.0	1.2
10-20	1400	30	35.3	4.9	3360	52	13.6	4.2	5.0	15.2	4.4	20.6	1.0
20-30	1500	20	33.7	7.8	4860	46	14.6	5.4	4.6	6.8	0.2	22.8	1.0
30-40	1700	30	32.9	5.8	1960	64	8.8	3.4	3.7	13.2	0.2	19.8	0.3
40-50	1500	30	34.5	5.8	2900	38	13.6	3.2	5.3	29.4	18.0	19.0	1.2
50-60	1500	40	33.7	6.3	1600	38	15.4	0.6	4.1	1.8	1.2	14.4	0.4
60-70	1400	10	34.5	4.9	1880	48	14.0	4.4	4.1	5.0	8.6	16.4	0.7
70-80	1400	10	34.5	5.3	1200	24	12.2	2.6	5.2	34.2	14.4	15.2	1.2
P-5													
0-10	1400	30	36.9	7.8	3900	104	18.4	3.2	3.4	23.8	10.2	20.8	0.7
10-20	1400	20	35.9	5.8	3780	52	16.8	1.8	4.7	23.6	9.4	14.0	0.1
20-30	1600	20	36.1	5.8	3960	58	18.6	3.0	3.9	17.8	3.2	12.4	0.1
30-40	1400	30	31.3	4.9	3560	32	10.0	4.2	4.3	35.8	3.4	18.0	0.6
40-50	1400	30	32.9	6.8	3360	40	10.0	0.6	4.0	5.6	12.8	15.6	0.6
50-60	1400	20	35.3	4.9	3040	44	13.0	0.6	3.6	21.6	3.2	25.8	0.9
60-70	1400	20	33.7	7.3	3260	32	16.0	4.0	4.8	11.0	10.6	24.0	0.1
70-80	1400	10	33.7	6.8	3180	16	14.4	4.8	5.3	4.2	12.4	16.0	0.1
P-6													
0-10	1500	40	36.9	2.4	3980	266	24.4	6.4	4.6	12.8	5.4	19.4	1.0
10-20	1200	10	33.7	6.3	3440	144	16.6	1.8	4.6	18.2	4.1	22.6	0.5
20-30	1400	10	36.1	5.8	3900	56	14.0	4.2	5.2	10.0	11.8	23.2	0.1
30-40	1400	10	36.1	5.8	3540	50	14.4	5.2	5.4	4.4	12.8	22.2	0.1
40-50	1600	10	35.3	4.9	2640	98	12.8	1.8	4.6	31.4	8.8	23.8	0.1
50-60	1500	10	35.3	6.3	3280	74	14.2	6.6	4.1	20.2	4.4	23.2	0.7
60-70	1300	10	36.9	3.9	2100	88	16.8	5.8	4.1	13.4	4.1	25.4	0.5
70-80	1500	10	36.1	5.3	2040	56	15.4	6.4	4.7	15.0	18.6	17.0	0.4
80-90	1300	10	35.3	7.3	2040	54	19.0	4.6	4.9	11.6	5.4	23.0	0.1
P-7													
0-10	1600	40	36.9	6.3	3540	188	26.6	5.1	4.6	13.5	5.2	18.9	0.8
10-20	1500	30	36.5	5.8	2640	124	18.8	6.2	4.3	9.8	3.2	24.2	0.5
20-30	1400	20	35.3	5.8	3280	98	18.9	3.2	4.2	11.2	5.6	20.1	0.5
30-40	1300	20	36.2	4.9	1100	86	17.6	2.1	4.5	21.5	4.2	22.3	0.4
40-50	1400	20	33.9	6.3	2040	76	15.2	1.9	4.8	15.6	10.9	24.3	0.3
50-60	1200	20	33.7	3.9	2040	65	15.1	3.1	5.1	16.7	11.1	21.2	0.3
60-70	1100	20	33.7	5.3	1100	58	13.4	2.2	5.2	17.8	9.6	18.6	0.2

Depth cm	Na	K	Ca	Mg	Sr	Fe	Mn	Cu	Co	Zn	Ni	Cr	C-org
P-8													
0-10	1400	30	39.5	5.8	4860	208	19.6	4.9	5.1	21.5	3.9	16.9	0.7
10-20	1400	20	38.5	2.9	3740	190	19.1	5.1	3.9	18.2	4.2	21.4	0.4
20-30	1300	30	35.3	4.9	3200	124	18.6	3.9	4.1	17.9	3.8	20.3	0.5
30-40	1200	10	36.1	5.2	3320	98	16.4	4.1	4.8	20.8	8.9	18.9	0.2
40-50	1100	10	35.4	4.8	2480	78	17.1	4.6	3.4	11.9	7.4	19.4	0.4
50-60	1200	10	34.8	4.8	2340	74	14.9	1.9	5.0	12.3	3.4	20.1	0.3
60-70	1100	10	33.7	3.9	2145	71	12.9	3.1	4.1	14.5	5.1	18.8	0.2
70-80	1100	10	34.1	4.9	2055	69	12.9	2.2	4.2	15.1	4.3	17.4	0.1
P-9													
0-10	1700	40	36.7	6.3	5400	240	28.8	2.3	5.6	35.6	9.8	20.3	0.7
10-20	1500	30	35.3	5.8	4400	213	27.9	3.5	5.2	34.6	7.6	11.9	0.1
20-30	1600	30	32.9	6.8	3640	198	24.3	3.2	4.9	33.2	8.4	11.8	0.1
30-40	1400	20	34.5	5.3	3420	186	22.9	4.4	3.9	31.8	7.9	13.8	0.4
40-50	1300	10	34.5	7.3	3400	142	21.8	5.6	4.2	29.4	6.5	14.9	0.2
50-60	1200	20	34.5	5.8	1680	110	18.6	6.1	4.1	22.3	7.8	15.6	0.6
60-70	1200	20	34.5	6.3	1580	98	17.9	5.3	4.0	18.9	10.8	22.1	0.8
70-80	1100	20	32.1	5.3	1340	76	18.0	4.2	4.6	11.9	1.9	18.4	0.9
P-10													
0-10	1300	30	34.5	5.8	4860	668	31.0	0.4	3.8	24.0	4.1	14.8	1.2
10-20	1200	40	38.5	2.9	2740	514	22.8	5.8	4.8	25.2	4.2	25.2	1.2
20-30	1100	20	35.3	4.9	1820	60	14.6	1.6	4.9	27.2	9.0	16.2	0.3
30-40	1100	10	36.1	7.3	1320	62	13.2	1.6	4.7	29.0	4.2	17.4	0.4
P-11													
0-10	1600	10	36.9	6.3	5240	129	19.2	1.4	4.6	33.0	9.8	16.8	0.9
10-20	1500	10	36.1	5.8	5400	126	19.0	1.2	4.7	33.8	3.2	16.4	0.9
20-30	1400	10	34.5	5.3	4400	92	16.8	3.6	5.5	4.2	8.8	15.2	0.9
30-40	1500	10	34.5	5.3	3640	88	20.0	5.6	4.9	2.6	10.2	21.6	0.1
40-50	1300	10	33.7	5.8	3420	96	18.2	0.8	5.5	34.8	3.4	18.8	0.1
50-60	1200	10	34.5	5.8	3400	82	17.0	3.6	5.5	36.0	12.8	15.0	0.1
60-70	1400	10	36.1	6.8	1680	98	14.8	3.8	5.6	9.4	11.6	14.6	0.1
70-80	1300	10	34.5	6.8	1580	92	15.8	3.4	3.6	6.2	2.0	23.4	1.6
80-90	1400	10	34.5	5.3	1420	60	17.6	3.6	4.3	5.1	1.0	16.8	0.4
90-100	1300	10	34.5	4.9	620	58	17.0	3.4	4.3	5.3	5.0	16.3	1.4
P-12													
0-10	1400	20	33.7	4.9	3840	544	35.8	0.8	5.0	35.0	10.8	12.2	0.1
10-20	1400	20	35.3	6.3	2300	292	27.0	4.0	4.9	29.2	6.0	16.2	0.1
20-30	1200	10	32.9	5.8	2620	94	23.6	0.8	5.0	38.6	4.0	17.6	0.1
30-40	1300	10	34.5	6.8	1840	108	18.8	0.8	4.6	10.6	1.2	31.4	0.1
40-50	1200	10	34.5	5.3	4220	98	20.8	2.2	4.2	35.2	1.0	12.6	0.3
50-60	1300	20	34.5	7.3	3560	64	19.8	4.4	5.3	13.4	13.8	20.8	0.4
60-70	1200	10	34.5	5.8	3500	44	17.4	6.4	3.7	13.0	1.6	22.4	0.9
70-80	700	10	32.1	6.3	2360	78	15.0	3.2	4.4	35.8	1.6	14.4	0.1
80-90	1100	10	33.7	7.3	3940	68	17.8	1.0	5.9	5.6	19.4	16.2	1.1
90-100	700	10	34.5	5.8	3420	64	20.6	0.8	5.9	2.8	7.8	17.2	0.1

(Table. 4.4 continued)

K: In Minicoy Island, K values fall in a narrow range of variation from 10 to 40 ppm (av. 18.9 ppm). In most of the pits, K shows a decreasing trend with depth while some pit samples show no specific trend with depth (Fig. 4.7).

Ca: Ca varies between 29.7 and 39.5 % with a mean value of 34.8 %. The maximum value is obtained from the surface sample of P-8 and the minimum from P-2 at a depth of 10-20 cm. The Ca values show a decreasing trend with depth.

Mg: The concentration of Mg extends from 2.4 to a maximum value of 8.7 %. The maximum value of Mg is obtained from P-2, while the minimum value is from P-6. The Mg values do not show any specific trend with depth. Also the relation of Mg with Aragonite is only moderate (Fig. 4.8).

Sr: Concentration of Sr grades from 620 to 5400 ppm. The minimum value is obtained from P-11, whereas the maximum is obtained from P-9 and P-11. In almost all pit samples, the Sr values show a general decreasing trend with depth. Sr shows a strong positive correlation with aragonite (Fig. 4.8).

Fe: The Fe values show a wide range from 26 to 668 ppm. The minimum value is obtained from P-5 (70-80 cm) and the highest is from the surface sediments of pit 10. In most of the pit samples, the Fe contents decrease with depth. The Aragonite content show a positive correlation with Fe (Fig. 4.8)

Mn: Unlike Fe, Mn values fall in a narrow range of 8.8 to 35.8 ppm. Mn shows a general decreasing trend with depth. Mn is slightly positively correlated with aragonite (Fig. 4.8).

Cu, Co, Zn, Ni and Cr: The concentrations of these metals are very less and do not show a any specific trend with depth. Cu values fall from 0.4 to 6.8 ppm, while Co values range between 3.3 and 6.2 ppm. Ni values have a variation of 0.2 to 19.4 ppm whereas Cr exhibits values from 10.2 to a maximum of 31.4 ppm. Zn varies from 0.6 to 38.6 ppm.

C-org: The concentrations of organic carbon show a narrow range from 0.1 to 1.4 %. Organic carbon values do not show any specific trend with depth.

4.4.Discussion

The sediments of the Kavaratti and Minicoy islands as well as the live coral samples from the reef area show distinct mineralogical characters. The coral reef sediments and also the surface and near surface samples of the Kavaratti island consist solely of aragonite (Figs. 4.1 & 4.3). According to Gladfelter(1983), Johnson et.al. (1984), Pitzold (1988) etc. the main constituent of the modern corals is aragonite. However, the bottom sediments of Kavaratti as well as the Minicoy sediments starting from surface itself show a mixture of HMC and LMC with small amounts of aragonite. Such occurrence of these constituents has been reported by many workers (Barner, 1970; Houck et.al, 1975; Schneider and Smith, 1982; Gladfelter,1983; Yoshioka et.al, 1985; Rao and Adabi, 1992; Rao, 1996). The XRD patterns of Kavaratti (Fig. 4.1) and Minicoy (Fig. 4.3) indicate the occurrence of the aragonite, HMC and LMC. The calcite peaks are assymetric with a broad base ranging from 29.3 to 29.9^0 and this is due to the presence of HMC and LMC. The clear separation of the HMC and LMC is revealed by the Kavaratti sample, DW-13 collected at a depth of 290-300 cm

(Fig. 4.1) and most of the Minicoy samples (Fig. 4.3). The drastic change of unstable aragonite to LMC, which is the stable form of calcite, is clearly shown by sample DW-13 (Fig. 4.2). The bottom most sample of DW-13 shows only 21.6% of aragonite, the rest being LMC, thus indicating that the aragonite is reaching the stable form of calcite. The Minicoy samples show that the change over of aragonite to LMC is recorded in most of the surficial samples itself. In Minicoy, the bottom most sample of P-11 does not have any HMC at all indicating that the available calcite in this sample has reached its stable form. So the vast changes are attributed to the major geochemical difference found in the Kavaratti and Minicoy sediments. The aragonite values show a positive correlation with major elements such as Sr, Ca, Fe and Mn (Fig. 4.6) in the sediments of Kavaratti, while aragonite is positively correlated with Sr, Ca, Mg, Fe and Mn of the Minicoy sediments (Fig. 4.8).

Mg: In Kavaratti Island, the presence of aragonite is found at the surficial and subsurficial level even upto a depth of 50- 60 cm, where as in the Minicoy island all the surface samples contain appreciable amount of HMC and LMC. This differences between the islands are related to the concentration of Mg. Kavaratti Island samples exhibit a low Mg concentration where as in Minicoy a very high Mg values are observed. When the unstable aragonite converts to HMC, the Mg concentration increases. Thus the HMC recorded at the surficial level of Minicoy, is due to high concentration of Mg. Rao and Adabi (1992) have observed a negative relationship between Mg and LMC. Since Mg is related to HMC and

LMC, the Mg does not show significant relation with aragonite (Fig. 4.8). This also resulted in the unsteady nature of the Mg variation with depth (Fig. 4.5).

Na: Na concentrations from different dug wells of Kavaratti and pit samples of Minicoy show a clear decreasing trend with depth. The high concentrations of Na at the surface level is attributed to the abundance of aragonite in the surface samples and therefore they are related to each other. Rao (1994) and Rao and Adabi (1992) have observed a good relationship between Na and aragonite for the temperate carbonates of Australia. The high concentration of Na in carbonate sediment are related to salinity , biochemical fractionation and mineral assemblages (Land and Hoops,1973; Rao,1990) . Since aragonite is the sole mineral present at the surficial level of the Kavaratti (Like reef sample) rather high Na content of the Kavaratti is attributed to the amounts of this elements absorbed during the lift history of the constituent corals. Since no mineralogical changes are observed at the surficial level of the Kavaratti, the Na content is much higher in the Kavaratti samples than the Minicoy (Table 4.3). Thus the Na concentration in Minicoy Island is very low having a small range from 700 – 1800 ppm.

Ca: Results show that Ca is the major constituent of the carbonate deposits of these islands. The Ca content in the Kavaratti Island ranges from 33.7 to 52.9 % while in Minicoy the range is 29.7 to 39.5 %. Rao (1996) has reported a similar range of Ca in LMC rich bulk sediments (31.7 - 40%). Most of the dug wells of Kavaratti show a small reduction in Ca values with depth whereas in Minicoy the

Ca content shows appreciable decrease with depth. The wide discrepancy in Ca values between the islands is due to the variation in the mineralogical composition between these islands. Since HMC and LMC are recorded at the surficial level of the Minicoy, the low Ca observed is due to the replacement of Ca by Mg. Since aragonite is the soul constituent of the surface and subsurface samples of Kavaratti Island, the Ca concentrations is more. This has resulted in a positive correlation with aragonite though with small r values (Fig. 4.6 & 4.8).

Sr: Sr is considered as a dominant element present among the trace elements in Ca and Mg carbonates (Rao and Adabi, 1992). Sr is highly concentrated in Kavaratti, ranging from 1200 to 12820 ppm whereas in Minicoy, the value is just half of the Kavaratti (620 to 5400 ppm). With depth Sr shows a steady decrease n Kavaratti (Fig. 4.5) whereas the decrease of Sr with depth in Minicoy is drastic particularly in P-4, P-6, P-8, P-9 and P-11. The high concentration in Kavaratti is the result of high aragonite content. Sr concentrations increase with increase in aragonite (Rao,1996). In accordance with above finding the Sr of the sediments of Kavaratti and Minicoy show a strong positive correlation with aragonite (Fig. 4.6 & 4.8). Milliman (1974) has reported a high value of Sr (8000-10000) in aragonite rich sediments.

Fe and Mn: Mn concentrations increase with the enhanced concentrations of aragonite (Rao and Adabi, 1992). According to Milliman (1974), the aragonite can concentrate Mn upto 20 ppm. Rao (1996) has given a wide range of Mn content in the bilk sediments of modern carbonates (av. 53 ppm). In the present study, the Mn concentration in Kavaratti ranges from 28.2 to 73.5 ppm where in Minicoy a slightly lower value is observed (10 to 35.8 ppm). Mn shows a linear relationship with aragonite (Figs. 4.6 & 4.8).

Like Mn, concentrations of Fe also show a good correlation with aragonite content (Figs 4.6 & 4.8). Although Fe and Mn are related to aragonite, the Fe has a good relation with aragonite, particularly Kavaratti sediments. Rao (1996) has shown a high range for Fe (212 – 4435 ppm) for the bulk sediments of the modern cabonate. In this study Fe shows a small range (Table 4.3 & Fig.4.5).

The distributions of Cu, Co, Zn, Cr and organic carbon show very low values in the sediments of Kavaratti island. Only Ni show relatively high values with a mean of 11 ppm. The average concentration of Cu, Co, Zn and Cr fall with in range between 1 and 6 ppm. The average organic carbon content is abnormally very low (0.68%) . Likewise the concentration of Cu and Co in the sediments of Minicoy island is low. On other hand the mean value of Zn (18.8 ppm), Ni (7.1 ppm) and Cr (18.6 ppm) is appreciably high. The organic carbon value also is slightly higher in Minicoy sediments. As these parameters do not involve in a major way in the diagenetic changes taking place in the island sediments, these parameters show a monotonous value without having any appreciable change with depth. Only few elements like Zn show either an increasing or decreasing trend with depth, particularly in Minicoy (e.g. P9, P8 and P7). In spite of the unsteady nature of these elements in the island it gives an idea about the concentration level in the carbonate sediments. Overall all these values are generally lower than lithogenic sediments of continental origin.

Chapter - 5

DIAGENESIS

5.1 Introduction

Diagenesis is defined as all chemical, physical and biological changes undergone by sediment after its initial deposition and during and after its lithification, exclusive of surficial alteration (weathering) and metamorphism (Bates and Jackson, 1980). In some rocks, diagenesis may include only one of the above processes while in others several of the processes act simultaneously or one at a time. In carbonate sediments and rocks the main diagenetic changes are cementation, compaction and mineralogical changes.

Diagenesis of sediments largely occurs under normal atmospheric pressure and temperature conditions. It may occur even by subareal exposure. Diagenesis also occurs by submarine exposure as described by Logan et al. (1969) and many others. Diagenetic processes transform most carbonate sediments into rocks. However, extensive diagenetic modifications may occur either before or after lithification of the carbonate sediments.

5.2 Hydrology and diagenesis

The rates, distributions and mechanisms of fluid transport through carbonate sediments or rock bodies are vital to the understanding of diagenetic processes. Although some mineralogical changes may occur in a closed system, others such as dolomitization require the passage of enormous volume of pore water through the system. Thus the hydrogeological parameters of a formation viz porosity, permeability, the forces available to drive fluids through the system and the evolution of these parameters over a period of time will exert important control over the rate, nature and extent of diagenesis.

5.3 Hydrogeology of reef and atolls

The oceanic islands like the ones under consideration generally hold a lens of fresh water which floats over the saline water further below. The percolation of meteoric waters and presence of the freshwater lens are the most important and prime movers for the diagenetic changes of the sediments examined. The thickness of this lens is described by Ghyben-Herzberg relationship (Buddemeier and Oberdorfer, 1986) based on density differences, which states that for every meter of freshwater head above the mean sea level, there should be a corresponding 40 m of fresh water below the mean sea level (Fig. 5.1) The density contrast is primarily a function of salinity and temperature and may therefore vary from this 1:40 generalization. Therefore smaller and elongated islands may exhibit a reduced near surface salinity thickness due to rain water infiltration without having a permanent freshwater lens.

5.4 Diagenesis in fresh water environment

The changes undergone by carbonate sediments and rocks having metastable minerals of aragonite and HMC in the freshwater diagenetic environments are many and far reaching. The major processes that are active in the sub-aerial freshwater diagenetic environments are mineralogical stabilization,

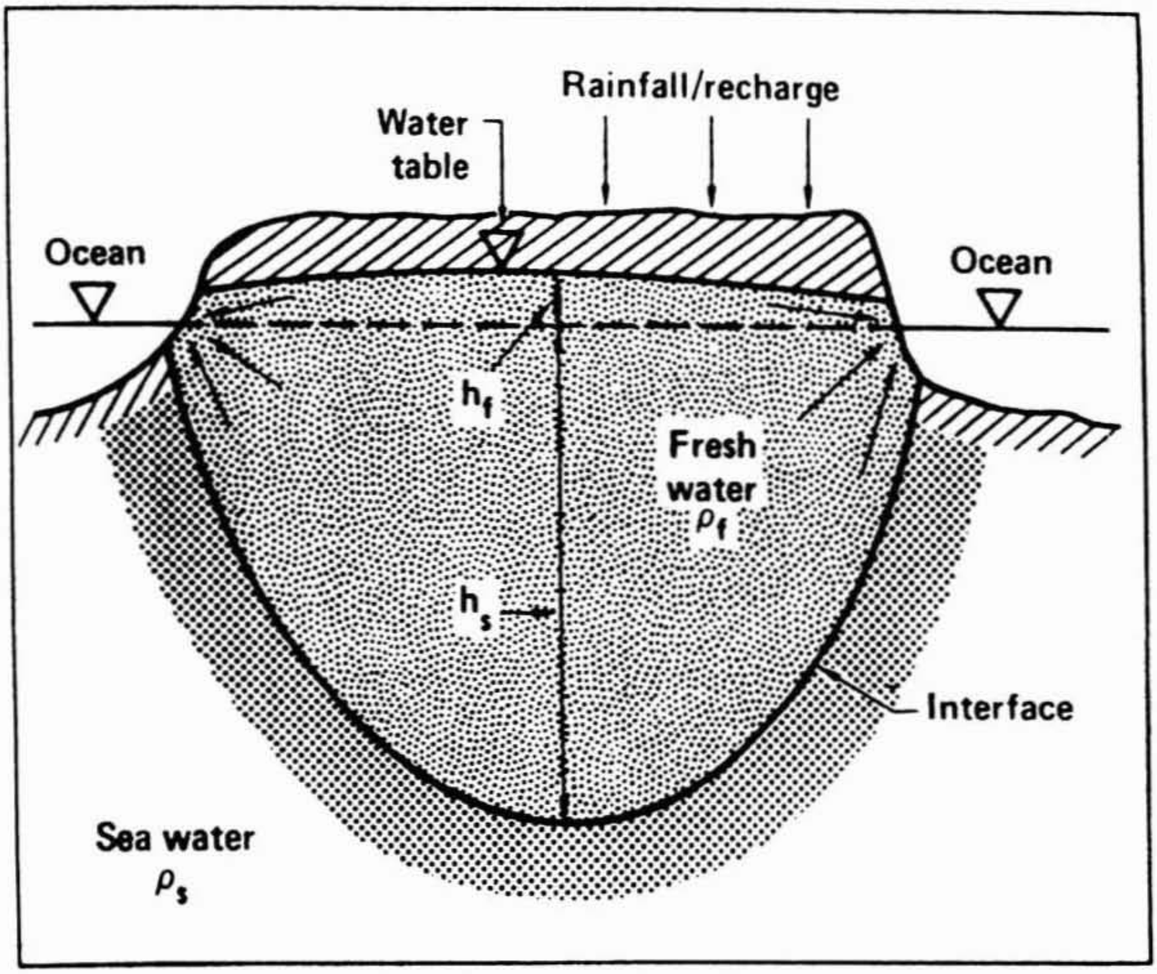


Fig. 5.1. Ghyben-Herzberg conceptual model of a fresh water lakes in an island consisting of homogenous porous material.

neomorphism and cementation. Many workers such as Bensonn (1974), Friedman (1964), Land (1967 &1970), Mathews (1967 & 1968), Pingitore (1970), Schroeder (1969 & 1973), Steinen and Mathews (1973), Thorstenson et al. (1972), Bathurst (1975), Nair, (1976), Rao and Adabi (1992) and Rao (1996) have studied the process of transformation of the unstable aragonite and metastable HMC and aragonite to stable LMC and the consequent textural and fabric alterations during subaerial diagenesis of carbonate sediments and rocks. The cause- effect concepts of in the formation of the metastable phases and their transformations as reflected by their textures during diagenesis have been discussed by Folk (1965 & 1974). Friedman (1975) has admirably summed up the effect of cementation and neomorphism.

The subaerial freshwater diagenetic environments are conventionally divided into vadose and phreatic zones (Bathurst, 1971). The zone above the ground water table is vadose and that below the ground water table is phreatic.

5.5 Physiography and hydrogeology

In Kavaratti Island three distinct physiographic units can be identified from east to west (Ajayakumar Verma, 1997). They are (1) a flat, low relief ridge composed of wave transported cobble and boulder-size corals and other reef detritus near the shoreline adjacent to the fringing reef. (2) the central depression zone with coalescing wash over fans consisting of coarse sand pebbles and (3) a low dune composed of wind and current transported sand adjoining lagoon. Based on the sedimentological characteristics of this study, the Kavaratti Island can be divided into two zones. (i) The northern sand dominant block which occupies the wider part of the island and (ii) the narrow southern strip consisting of sand and pebbles.

In Minicoy, a rim like ridge, similar to that found at Kavaratti, formed by the coral debris on the eastern storm side is evident. However, here neither the three physiographic units nor the two distinct sedimentological entities as described above are very distinct. This island exhibits a flat surface with gentle slopes from east to west and from NE-SW. The southern half of the island is a low lying and accompanied by a marshy area by the presence of a mangrove environment (Plate 2.9).

The lithocolumns revealed by dug wells and pits show that the sediment are largely uniform in colour and texture. However, vast differences in texture (pebble bed) have been noticed in dug well sections of the southern part of the Kavaratti Island. During low tides, the reef top is exposed whereas during high tides waves act on the reef top eroding parts of the reef material and depositing them along the adjacent beach.

5.6 Results and Discussions

The figures 4.1 and 4.2 show that there is a general reduction in the quantity of aragonite with depth. The surface and near surface of the Kavaratti Island is aragonitic nature while in Minicoy the surface sediments are made up of about 60 % aragonite. This shows the dominance of corals, and other aragonite secreting organisms in contributing to the sediments. However, the presence of about 10-25 % HMC in the surface sediments of Minicoy suggests that there are organisms like rhodolithic algae (red algae), bryozoans, foraminifera and molluscs (having a mixture of aragonite, Mg- calcite skeletal structure) which contribute substantially to the sediments of the island. Needless to say that all these organisms are found in various ecological zones of the reef structure as well as in various parts of the lagoon.

The sediments having a mixture of metastable aragonite and HMC undergo progressive downward reduction in their content and a corresponding increase in the LMC. The maximum reduction of aragonite is seen in DW-13 at a depth range of 410-420 cm and about 4/5 of aragonite is changed to LMC. On the other hand in P-11 of Minicoy, about 3/4 of aragonite is changed to LMC at a shallower depth of 90-100 cm level. LMC occurrence in Kavaratti is considerably at deeper levels (Table 4.1) i.e. around 100 cm depth. The sample at 230-240 cm from DW-6 having approximately 39 % aragonite and 61 % low- Mg calcite has yielded a ^{14}C date of 3200 ± 60 years. Although this work does not have enough ^{14}C dates to generalize, it seems possible to infer that a major aragonite-calcite inversion takes place in a matter of a few thousand years. It has to be mentioned that all the samples studied have been collected from various depths within the vadose zone. This kind of mineralogical changes can be accomplished by continuos passage of meteoric waters passing through the vadose zone which is quite dissimilar to the vadose zone of carbonate provinces situated in arid and semi arid zones of the world. This directly points to the peculiarities of the rainfall pattern experienced by these islands. The total rainfall of Minicoy is 250cm/year

(Kavaratti rainfall is still less) and is distributed in SW monsoon (June- Sept), NE monsoon (Oct- Dec) and pre-monsoon periods (Jan- May). Although the total rainfall would appear to be lower than that experienced by the Indian mainland, the Lakshadweep islands experiences more number of rainy days (90 days during SW monsoon alone). Also it has to be emphasized that the entire rainwater gets infiltrated into the carbonate sediment body covering the islands. Being sandy and pebbly in nature the surface run off is negligible in these islands. There is a considerable difference in the ground water potentials between Kavaratti (Fig. 5.2) and Minicoy (Fig. 5.3). The total area of freshwater lens for Kavaratti and Minicoy are respectively 1.34 km^2 and 1.23 km^2. The porosity of Minicoy Island is 35 % while that of Kavaratti is 15 % and therefore the total fresh groundwater potential for Minicoy island is 1.31 MCM while that of Kavaratti is just half of Minicoy (0.64 MCM) (Ajayakumar Verma, 1997). It is this freshwater percolating through the vadose zone, over a larger period of time in every year that is responsible for the mineralogical changes that are observed in these sediments.

These mineralogical changes taking place in the vadose zone are further confirmed by the distribution of Sr and Mg. The organisms and the temperature in which they lived essentially control the incorporation of Sr in the aragonite lattice. Despite this initial difference in incorporating the Sr in the aragonite structure it has been found in this study that there is consistent downward reduction in the Sr content (Figs. 4.5&4.7) and this reduction is directly correlated

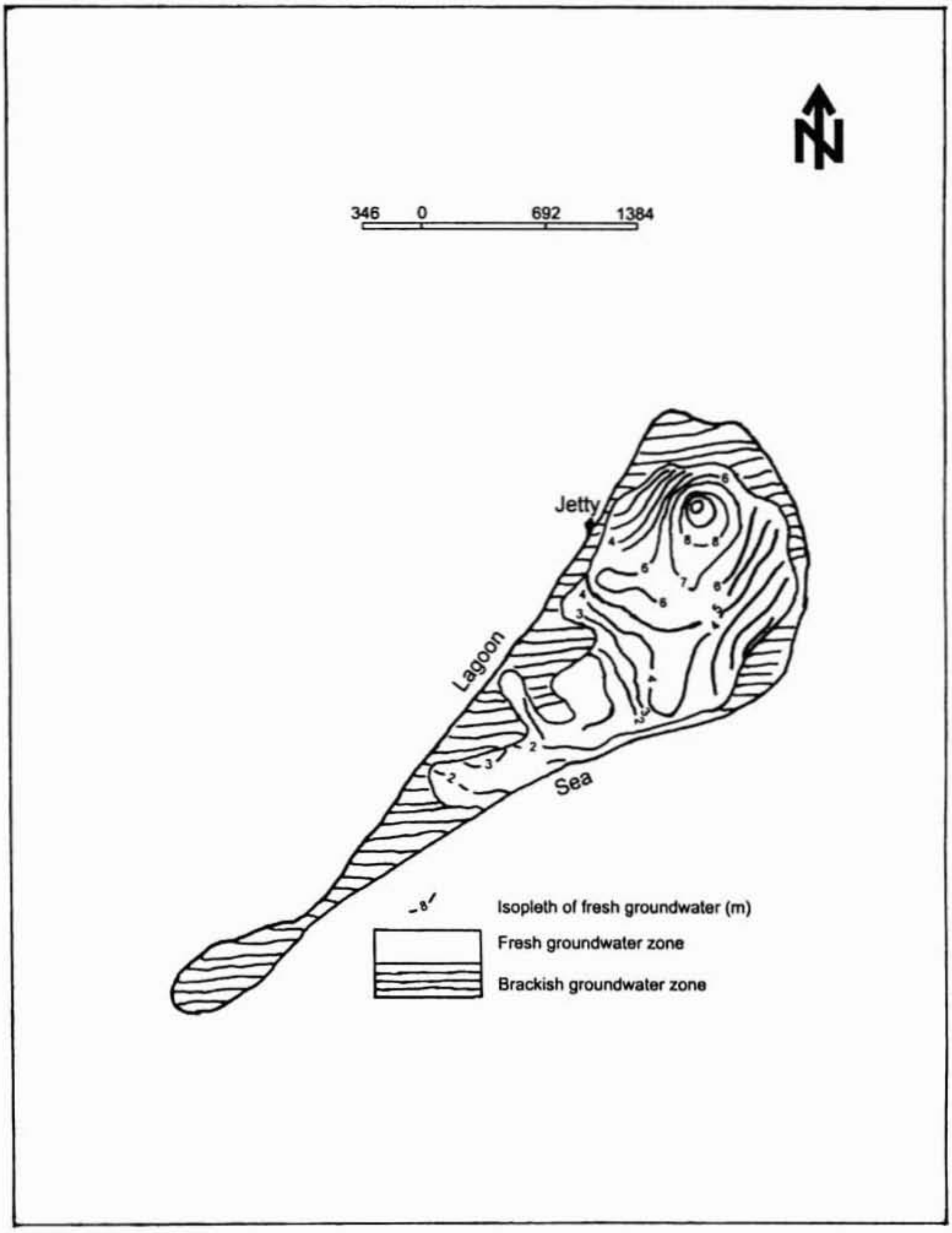


Fig. 5.2. Lateral extent of isopleths of fresh water layer at Kavaratti (source : Ajayakumar Verma, 1997).

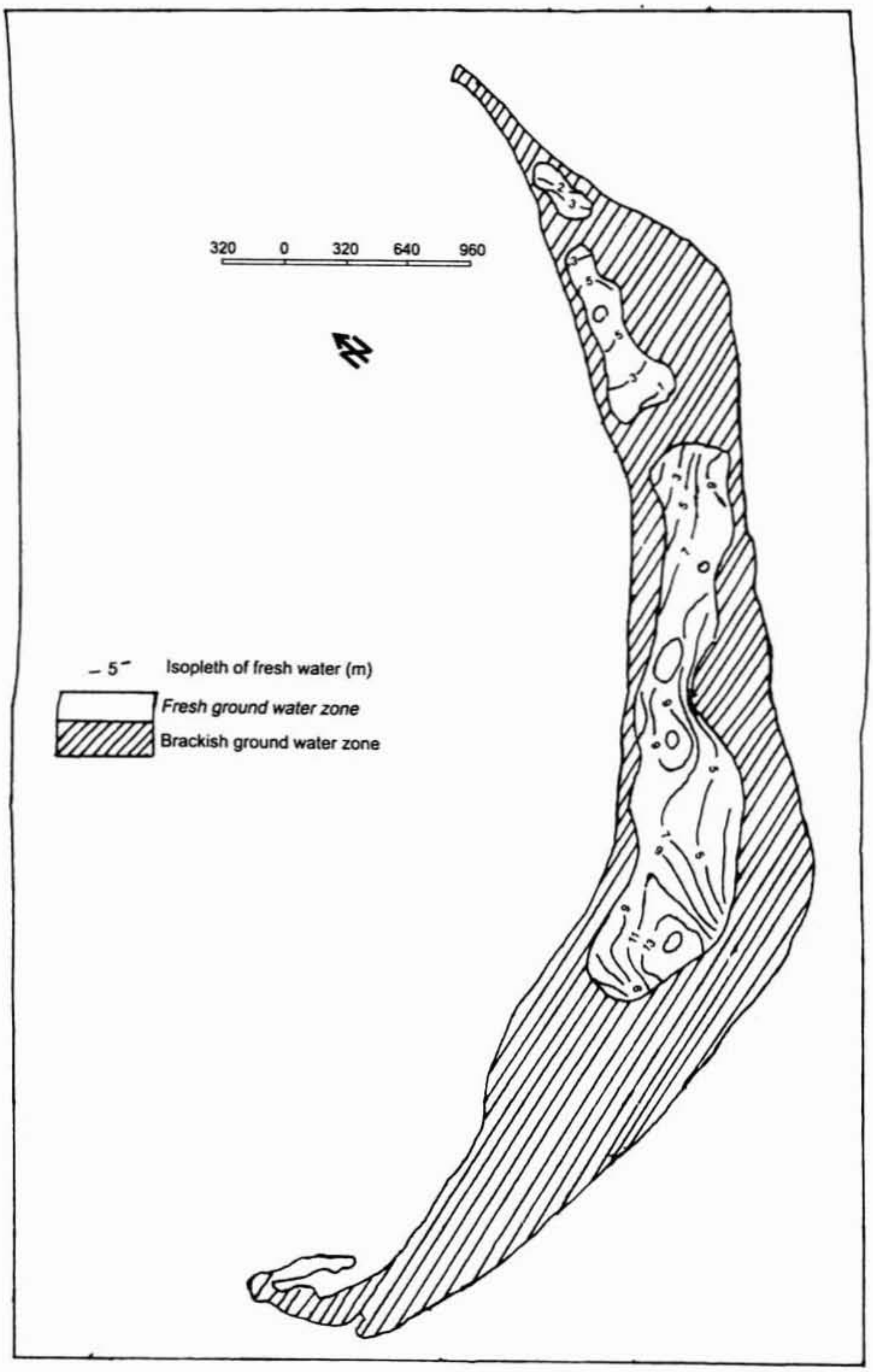


Fig. 5.3. Lateral extent of isopleths of fresh water layer at Minicoy (source : Ajayakumar Verma, 1997).

with the reduction in the quantity of aragonite and an increase in the quantity of LMC.

The change in the distribution of Mg in the vertical profiles (Figs.4.5&4.7) does not seem to be as uniform or consistent as in the case of Sr. This can be attributed to the skeletal ultra structure of Mg- calcite secreting organisms. For example Mg- calcite secreting live forms such as red algae are highly porous and it can transmit water very freely. The small cellular `building blocks' that make up the red algae have enormous surface area open to flushing by ground water. This lead to the removal of Mg faster than other less porous Mg – calcite grains. Thus the distribution of Mg in the vertical profile may appear to be random or systematic depending on the mixture of skeletal grains that make up the sediments.

The carbonate samples collected for this study have not been subjected to cementation. However, in small intra-skeletal pores, occasional precipitation of equant calcite (micro crystalline calcite) has been noticed in a few cases.

Summary:

(1). The main diagenetic change observed in this study is the transformation of aragonite to LMC and the vertical column examined shows that the entire aragonite has not been transformed.

(2). This transformation is not accompanied by a change in the texture or skeletal ultra structure of the grains. Normally aragonite to calcite inversion is accomplished through solution precipitation with an intervening stage of creation of moldic pores. This mode of inversion does not retain the skeletal ultra structure intact and what is preserved is the outlined shape of grains. However, the samples examined under this study show that no such large scale dissolution of skeletal grains and creation of moldic pores as well as the distribution of skeletal ultra structure have taken place. Thus the aragonite to calcite inversion seems to have taken place through an alternative phase of molecule by molecule change. It is not difficult to visualize that the aragonite to calcite inversion, which takes place in vadose zone, is accomplished by a limited quantity of water that passes through the system. In a specialized diagenetic environment like this, the inversion need not be accomplished by creation of moldic pores. This may be a simple process of mineralogical change on a molecule for molecule basis.

Chapter 6

SUMMARY AND CONCLUSIONS

Keeping in line with the objectives outlined in chapter 1, the petrographic, geochemical and diagenetic variability of the sediments in the islands of Kavaratti and Minicoy has been investigated and the following salient conclusions have been drawn.

The beach profile studies show that in the Kavaratti lagoon beach, the slope is steeper in the southern and south central part than in the northern end. A marginal deposition is taking place in the northern end of the Kavaratti island, whereas a marginal erosion is observed at the southern end. In Minicoy the slope of the lagoon beach is gentle in the south and is slightly steeper at the northern part of the beach. The southern and northern beach sections show a marginal deposition.

In the Kavaratti lagoon, the different classes of sediments vary considerably. Towards north of the lagoon the proportion of medium and fine sand increases. The sediments are moderately to poorly sorted. The southern side of the Minicoy lagoon consists of very coarse sandy sediments. The sediments are poorly sorted.

Textural studies indicate that the Kavaratti lagoon beach is dominated by medium and fine sands. In the northern beach sections, the content of fine sand is very high. The standard deviation values show a steady increase from south to the central region of the beach. The northern beach sediments is better sorted than in the rest of the beach. Sorting value of beach shows a narrow range. The sediments of the foreshore and backshore are moderately well sorted to moderately sorted. Sediments range from fine to coarse skewed.

The southern lagoon beach of the Minicoy show predominance of very coarse and coarse sands in the foreshore whereas coarse sands are the dominant constituent of the backshore beach. The granule content is significant, both in foreshore and back shore. Very coarse materials are found in the central part of the beach. In the northern end coarse sand population is getting steadily increase steadily whereas medium, fine and very fine sand diminishes in foreshore and backshore. The phi mean size of the foreshore and backshore beach shows subtle difference. Foreshore sediments are poorly sorted.

The northern part of the storm side beach of Kavaratti island is dominated by medium sands both in foreshore and backshore, while in the central part of the storm side beach is characterized by a more or less uniform concentration of granule and sand grades. The textural framework of the southern beach is more or less similar to that of the northern end. The southern part of the storm side beach of Minicoy consists of appreciable granule content, whereas the northern part is dominated by very coarse, coarse and medium sand.

Dug well samples collected from different part of the Kavaratti Island show a drastic change in sediment characteristics from north to south. The sediment of the northern part of the island consists mainly of coarse, medium and fine sands. The sediment characteristic of the dug well of the northern part of the island is having a close resemblance to that of the present day lagoon beach. Coarse sand and granule are restricted to the deeper parts of the dug wells as well as along the storm side part of the island. The sediments of the central section show the presence of appreciable granules in addition to the other class of sands. Dug wells in the southern side of the island show alternate layers of sand and pebbles. There is a tendency that dug wells closer to lagoon beach show appreciable thickness of sand. The radio carbon dating indicates that the pebble bed found at a depth of 2.5 m is estimated to have formed 3200 ± 60 yrs BP while the pebble bed at the southern end of the island show an younger age (1800± 60 yrs BP). It is inferred that the evolution of the island is of recent origin mainly by filling of the lagoon.

The sedimentological characteristics indicate that the Minicoy island has only a meter of loose sediments and they are similar to the modern lagoon beach. The chief constituent of the Minicoy island sample ranges from coarse to fine sand.

The XRD results indicate that aragonite is the sole mineral present in the surficial and sub surficial sediments of Kavaratti Island. The unstable aragonite is steadily getting decreased with depth while HMC and LMC increase. A few samples at the bottom of the dug wells show only LMC, which is the stable form of calcite. On the other hand, in the Minicoy Island surface sediments consists of a mixture of HMC and LMC. The aragonite content diminishes with depth while HMC and LMC show an increasing trend. Based on this investigation it is inferred that early diagenesis can occur at shallow depth in a matter of a few thousand years

The geochemistry of Mg is related to HMC content. A strong positive correlation of aragonite with Sr, Ca, Fe and Mn is observed. The micritization is observed in thin section. The constituent composition consists primarily of coral debris, coralline algae, Halimeda, foraminifera and bryozoans.

Based on the mineralogical and geochemical studies it is concluded that the main diagenetic changes observed is the transformation of aragonite to LMC. The transformation takes place mainly in the vadose zone and is caused by the abundance of fresh water infiltration.

Salient conclusion of this investigation		
1	In Kavaratti, loose friable sandy sediments are found to a considerable depth of more than 5m in the northern part of the island.	In Minicoy only about 1m of loose sediments are found , below which the hard coral bed is encountered
2	The Kavaratti lagoon beach sediments consists, mainly of medium and fine sand and there is a unidirectional movement of sediments towards north. Considerable accretion of sediments on the northern side.	The lagoon beach of Minicoy consists appreciable amount of coarse sand. No unidirectional movement is found. A little accretion is found on the northern and southern end of the lagoon beaches.
3	Relatively good sorting is found in Kavaratti beach sediments	Poor sorted sediments is predominant in Minicoy
4	The sediment characteristic of the northern part of the Kavaratti island is similar to that of the modern lagoon beach sediments	The sediment characteristic of the southern part of the Minicoy island is similar to that of the modern lagoon beach sediments
5	Stormside beach of Kavaratti consists primarily of coarse and very coarse sands.	Coarse, very coarse sands and granules are abundant in the stormside beaches of Minicoy.
6	The surficial sediments of the Kavaratti island consist solely of aragonite. HMC and LMC are found only at considerable depths. Aragonite show a steady decrease with depth while HMC and LMC increases.	In the Minicoy island sediments, HMC and LMC are recorded in the surficial sediments itself. Aragonite decreases with depth with concomitant increase in HMC and LMC.
7	The concentration of Na, Sr, K, Fe, Mn decreases with depth.	The concentration of Na, Sr, K, Fe, Mn decreases with depth.
8	Fe content is considerably less when compared with Minicoy Island	Fe content is high in Minicoy.
9	Mg content is low in Kavaratti.	Mg concentration is considerably high in Minicoy, which is due to the abundance of HMC.
10	Lagoon filling is the chief process responsible for the evolution of the Kavaratti island accompanied by a fall in sea level in the recent past	Lagoon filling is the chief process responsible for the evolution of the Minicoy island accompanied by a fall in sea level in the recent past

References

Adiga, K.S. (1989). Geomorphic configuration of the lagoonal shore of Kavaratti Island, Lakshadweep. Geol. Surv. Ind., Spl. Pub. no. 24, pp. 287-290.

Agrawal, D.P., Gupta, S.K. and Kusumgar, S. (1971). Tata Institute Date list IX: Radio carbon., v. 13, pp. 442-449.

Ajaykumar Verma, R. (1997). Studies on groundwater resource potential and management of the coral atoll of Lakshadweep, Union Territory of India. PhD Thesis, University of Kerala, Thiruvananthapuram.

Al-Asam, I.S. and Veizer, J. (1986). Diagenetic stabilization of aragonite and low-Mg calcite. I. Trace elements in rudites. Jour. Sed. Petrol., v. 56, pp. 138-152.

Alexanderson, E.T. (1978). Destructive diagenesis of carbonate sediments in eastern Skagerrak. North Sea. Geology., v. 6, pp. 324-327.

Allan, R.J. (1979). Heavy metals in bottom sediments of Great Slave lake, Canada: A reconnaissance. Environ. Geol., v.3, pp. 49-58.

Allen, J.R.L. (1970). Physical process of sedimentation. George Allen and Unwin Ltd., Unwin University Books, London, 248 p.

Amiel, A.J., Friedman, G.M. and Miller, D.S. (1973a). Distribution and nature of incorporation of trace elements in modern aragonitic corals. Sedimentology., v. 20, pp. 47-64.

Amiel, A.J., Miller, D.S. and Friedman, G.M. (1973b). Incorporation of Uranium in modern corals. Sedimentology., v. 20, pp. 523-528.

APHA. (1981). Standard methods. (15th Edition), American Public Health Association, Washington, 1134 p

Athens, J.S., Ward, J.V.(1991) Paleoenvironmental and archaeological investigations, Kawainui Marsh flood control project, Oahu. US Army Engineering Division, Pacific Ocean Environmental Section, Ft Shafter, Hawaii. International Archaeological Research Institute, Honolulu, pp.129.

Attrill, M.J. and Thomas, M.R. (1995). Heavy metal concentration in sediment from the Thames Estuary, UK. Mar. Poll. Bull., v.30, pp. 742-744.

Ayers, J.F. (1984 a). Geologic construction of atolls. In Water Rsources of Small Islands . Tech. Publ. Series No.154, Commonwealth Science Council , London., v. 2, pp. 69-78.

Barner, D.J. (1970). Coral skeleton: An explanation of their growth and structure. Science, v.170, pp.1305-1308.

Bascom, W. (1980). Waves and Beaches, Anchor Books, Garden City, N.Y

Bates, R.L. and Jackson, J.A. (1980). Glossary of Geology (2nd Ed). American Geological Institute, Falls Church, Va., 751p.

Bathrust, R.G.C. (1966). Boring algae, micrite envelopes and lithifiaction of molluscan biosparites. Jour. Geol., v.5, pp 15-32

Bathurst, R.G.C. (1971). Carbonate sediments and their diagenesis, Elsevier, Amsterdam., p. 620.

Bathurst, R.G.C. (1975). Carbonate sediments and their diagenesis, Elsevier, Amsterdam., pp. 1-658.

Belperio, A.P. (1983). Terregenious sedimentation in the central Great Barrier Reef lagoon: a model from the Burdekin Region. BMR. Jour. Australian Geol. and Geophy., v. 8, pp.179-190.

Bensonn, L.V. (1974). Transformation of a polyface sedimentary assemblage into a single face rock: A chemical approach. Jour. Sed. Petrol., v. 44, pp. 123-135.

Brady, B.A., Jhons, R.B. and Sith, J.D. (1994). A trace metal geochemical association in sediments from the Cairns Region of the Great Barrier Reef, Australia. Mar. Poll. Bull., v. 28, pp. 230-234.

Brand, U. and Veizer, J. (1980). Chemical diagenesis of a multi component carbonate system I. Trace elements Jour. Sed. Petrol., v. 50, pp. 1219 - 1236.

Broecker. (1963). A preliminary evaluation of uranium series in equilibrium as a tool for absolute age measurement on marine carbonates. Jour. Geophy. Res., v.68, pp.2817-2834.

Buddemeier, R.W. and Oberdorfer, J.A. (1986). Internal hydrology and geochemistry of coral reefs and atoll islands: Key to diagenetic variations. Reef diagenesis, eds. Schroeder, J.H. and Purser, B.H., pp. 91-111.

Calhoun, R.S., Fletcher, C.H III (1996) Late Holocene coastal plain stratigraphy and sea-level history at Hanalei, Kauai, Hawaiian Islands. Quat Res., v.45, pp.47–58.

Carter, C.H. and Guy, Jr., D.E. (1985). Coastal erosional processes, timing and magnitudes at the bluftoe, Mar. Geol., v.84, pp. 1-17.

Chandramohan, P., Anand, N.M. and Nayak, B.U. (1993). Shoreline dynamics of the Lakshadweep Islands. Ind. Jour. Mar. Sci., v. 22, pp. 198-202.

Chauhan, O.S. (1986). On some geological and geophysical observations at Lakshadweep islands. Futurology workshop for Lakshadweep, held at Trivandrum. Abst. pp. 21-23.

Chauhan, O.S. and Chaubey, A.K. (1990). Submarine physiography off Lakshadweep islands, Northern Indian Ocean. Int. Symp. On the Oceanography of the Indian Ocean, held at NIO, Goa. Abst. pp. 52.

Chave, K.E. (1954). Aspects of the biogeochemistry of magnesium. 1. Calcareous marine organisms. Jour. Geol., v. 62, pp. 266-283.

Chevillon, C.(1996). Skeletal composition of modern lagoon sediments in New Caledonia: coral, a minor constituent. Coral Reefs., v.15, pp. 199–207.

Collins, L.B. (1988). Sediments and history of the Rottenest Shelf, southwest Australia: A swell dominated, non-tropical carbonate margin. In:C.S.Nelson (Ed.) Non–tropical Shelf Carbonates- Modern and ancient sediments. Geol., v.60, pp. 15-49.

Cronan, D.S. (1972). Skewness and Kurtosis in polymodal sediments. Jour. Sed. Petrol., v. 42, pp. 102-106.

Daly, R.A. (1934). The changing world of the Ice Age. New Haven: Yale University Press. 271p.

Davies, P.J. and Marshall, J.F. (1985). *Halimeda* bioherms – low energy reefs, northern Great Barrier Reef. Proc 5th Int Coral Reef Cong. V. 5 pp. 1–7.

Davies, P.J., and Marshall, J.F. (1980). A model of epicontinental reef growth. Nature., v. 287, pp. 37-38.

Dean, R.G., Healy, T.R. and Dommerholt, A.P. (1993). A blind folded test of equilibrium beach profile concepts with New Zealand data. Mar. Geol., v. 109, pp. 253-266.

Denton, G.R.W. and Burdon, J.C. (1986 d). Trace metal in corals from Graet Barrier Reef. Mar. Poll. Bull., v. 17, pp 201-209.

Howard, L.S. and Brown, B. E. (1986). Metals in tissues and skeleton of Fungia Fungites from Phuket, Thailand., Mar. Poll. Bull., v. 17, pp. 569 –570.

Jaffer, J.T.M. Ashraf, M. and Moazzam, M. (1994). Distribution oftrace metals in sediments and sea water from continental shelf of Pakistan. Ind. Jour. Mar. Sci., v. 23, pp. 147-151.

Dolan, R., Hayden, B. (1981). Storms and shoreline configuration, Jour. Sed. Petrol., v. 51 (3), 737p.

Dolan, R., Hayden, B., Rea., C. and Heywood, J. (1979). Shoreline erosion along the middle Atlantic coast, Geology., v. 7, p. 602.

Dubois, R.N. (1988). Seasonal changes in beach topography and beach volume Delaware. Mar. Geol., v.81, pp. 79-86.

Edworthy K.J., ,Heard T.R. and Ibrahim M. (1990). Consequences of intensive development of an oceanic island aquifer , Male island , Republic of Maldives ,Proc. Aut. Conf. In Grand water. Res. Management ,Bangkok,Thailand, pp. 267-277.

El Wakeel, S.K. and Riley, J.P. (1957). The determination of organic carbon in marine muds. Jour. der. Cons. Inter. Pour. Explor. de. Mer., v. 22, pp. 180-183.

Eremenko, N.A. and Dutta, A.K. (1968). Regional geological framework and evaluation of petroleum prospects of Laccadive Archipelago and adjoining offshore territory, SW India, Bull. ONGC., v.5, pp. 29-40.

Flaganan, F.J. (1976). Description and analysis of eight USGS rock standards. USGS. Prof. Pap., No.840, pp. 192-220.

Fletcher CH III, Jones AT (1996) Sea-level highstand recorded in Holocene shoreline deposits on Oahu, Hawaii. J .Sed.Res. v. 66, pp. 623–641.

Folk, R.L. (1965). Some aspects of recrystallization in ancient limestones. In L.C. Pray and R.C. Murray (eds.). Dolomitization and limestone diagenesis. SEPM Spl. Pub., v. 13, pp. 14-48.

Folk, R.L. (1966). A review of grain size parameters. Sedimentology., v.6, pp. 73-96.

Folk, R.L. (1968). Petrology of sedimentary rocks. Hemphill's, Texas.

Folk, R.L. (1973). Carbonate petrography in the Post-Sorbian Age In R.N.Ginburg: EVOLVING CONCEPTS IN SEDIMENTOLOGY., pp. 118-158.

Folk, R.L. (1974). The natural history of crystalline calcium carbonate: Effects of Magnesium content and salinity. Jour. Sed. Petrol., v. 44, pp.40-53.

Folk, R.L. and Robbles, R. (1964). Carbonate sands of Isla Perez. Alac Reef Complex. Youcatan. Jour. Geol., v. 72, no.3, pp. 255-292.

Folk, R.L. and Ward, W. (1957). Brazos river bar: A study in the significance of grain size parameters. Jour. Sed. Petrol., v. 27, pp. 3-26.

Force, L.M. (1969). Calcium Carbonate size distribution on the West Florida shelf and experimental studies on the microarchitecture control of skeletal breakdown. Jour. Sed. Petrol., v. 39, pp.902-934.

Forstner, V. and Wittmann, G.T.W. (1979) Metal pollution in the aquatic environment. Springer, Berlin.

Forstner, V. and Wittmann, G.T.W. (1983). Metal pollution in the aquatic environment. Springer Verlag, New York, 486 p.

Friedman, G.M. (1961). Distinction between dune, beach and river sands from their textural characteristics. Jour. Sed. Petrol., v. 37, pp.327-354.

Friedman, G.M. (1962). On sorting coefficients and the lognormality of grain size distribution in sandstones. Jour. Geol., v. 70, pp. 737-753.

Friedman, G.M. (1964). Early diagenesis and lithification in carbonate sediments. Jour. Sed. Petrol., v. 34, no. 4, pp.777-813.

Friedman, G.M. (1967). Dynamic processes and statistical parameters compared for size frequency distributions of beach and river sands. Jour. Sed. Petrol., v. 37, pp. 327-354.

Friedman, G.M. (1975). Address of the retiring president, Society of Economic Paleontologists and Mineralogists. The mazking and unmazking of limestones or the downs and ups of porosity. Jour. Sed. Petrol., v. 45, pp.379-398.

Furukawa, Y, Lavoie, D and Stephens, K (1997). Effect of biogeochemical diagenesis on sediment fabric in shallow marine carbonate sediments near the Dry Tortugas, Florida. Geo-Marine Lett., v.17, pp.283–290.

Gardiner, J.S. (1903). The Fauna and Geography of the Maldive and Laccadive Archipelagoes. Cambridge Univ. Press., v. 1, pp. 12-50.

Gischler E and Lomando A.J. (1999). Recent sedimentary facies of isolated platforms,Belize–Yucatan system, Central America. Jour. Sedi. Res., v. 69, pp. 47-763.

Gladfelter,E.H. (1983). Skeletal development in Accropora cervicornis. Diel patterns of calcium carbonate accretion. Coral Reefs ., v.2, pp.91-100.

Glynn, P.W and Stewart, R..H. (1973). Distribution of coral reefs in the pearl islands (Gulf of Panama) in relation to thermal conditions. Limnol. and Oceanogr., v. 18 (3), pp. 367-379.

Goreau, J.T. (1961). Problems of growth and calcium deposition in reef corals. Endeavour., v. 20, pp. 32-39.

Goreau, J.T. (1977b). Coral skeletal chemistry: Physiological and environmental regulation of stable isotopes and trace metals in Montastrea annularis. Proc. Royal Soc. of London B., v. 196, pp. 291-315.

Griffiths, J.C. (1967). Scientific methods in analysis of sediments. New York, McGraw- Hill Book Co., 508 p.

Grossman, E.E. and Fletcher, C.H. (1998). Sea level higher than present 3500 years ago on the northern main Hawaiian Islands. Geology v.26., pp. 363–366.

Hails, J.R. and Hoyt, J.H. (1969). The significance and limitations of statistical parameters for distinguishing ancient and modern sedimentary environments of the lower, Georgia coastal plain. Jour. Sed. Petrol., v. 39, pp. 559-580.

Hardas, M.G. (1987). A textural attributes in carbonate sands of beach and lagoonal environments, Agatti atoll, Lakshadweep. Geol. Surv. Ind. Spl. Pub. ,v.24, pp. 21-34.

Harney, J.N., Hallock, P., Fletcher, C.H. and Richmond, B.M. (1999). Standing crop and sediment production of reef-dwelling foraminifera on Oahu, Hawaii. Pac. Sci., v. 53, pp. 61–73.

Harris. P.T., Davies, P.J. and Marshall, J.F. (1990). Late Quaternary sedimentation on the Great Barrier Reef continental shelf and slope east of Townsville, Australia. Mar. Geol., v. 94, pp. 55–77.

Hopley, D.(1987). Holcene sea-level changes in Australasia and southern Pacific. In sea surface studies: a global review. .R.J.N. Devoy (ed), pp. 375-408.

Houck, J.E., Boddeiner, R.W. Chave, K.E. (1975). Skeletal low magnesium calcite in living scleractinian corals. Science., v. 189, pp. 997-999.

Jacobson, G. and Taylor, F.J. (1981). Hydrogeology of Tarawa atoll , Kiribati, Record No. 1981/31 Bureau of Mineral Resources, Geology and Geophysics, Australia.

James, N. P. and Bone, Y. (1989). Petrogenesis of Cenozoic temperate water calcarenites, South Australia: A model for meteoric/shallow burial diagenesis of shallow water calcite cements. Jour. Sed. Petrol., v. 59, pp. 191-203.

James, N.P., Bone, Y., von der Borch, C.C. and Gostin, V.A. (1992). Modern carbonate and terrigenous clastic sediments on a cool- water, high energy, mid-latitude shelf: Lacepede Southern Australia. Sedimentology, v. 39, pp. 877-904.

James, N.P., Boreen, T.D., Bone, Y and Feary, D.A .(1994). Holocene carbonate sedimentation on the west Eucla Shelf, Great Australian Bight: a shaved shelf. Sed. Geol., v. 90, pp. 161–177.

James, N.P., and Choquette, P.W.(1983). Diagenesis 5. Limestones: Introduction. Geoscience Canada., v.10, pp.159-161.

Johnson, D., Cristopher, C. and Rhodes, E. (1984). Holocene reef sequences and geochemistry, Britomart reef, Central Great Barrier Reef, Australia. Sedimentology., v.31, pp. 515-529.

Joseph, S., Thrivikramaji, K.P. and Anirudhan, S. (1997). Textural parameters, discriminant analysis and depositional environments of Teri sands, Southern Tamil Nadu. Jour. Geol. Soc. Ind., v.50, pp.323-329.

Kalluraya, V.K.K., Charlu, T.K., Adiga, K.S., Nair, E.V., Lakshmipathy, N.S. and Ramachandran, K.V (1989). Morphology and sediment characteristics of northern part of Trans- Lakshadweep ridge. Geol. Surv. Ind. Spl. Pub. No. 24, pp. 51-57.

Kench, P.S. (1997). Contemporary sedimentation in the Cocos (Keeling) Islands, Indian Ocean: Interpretation using settling velocity analysis. Sed. Geol., v.114, pp. 109–130.

King, C.A.M. (1972). Beaches and Coasts, 2nd ed., St. Martin's Press, New York.

Kinsman, D. J. J. (1969). Interpretation of Sr^{+2} concentrations in carbonate minerals and rocks. Jour. Sed. Petrol., v.39, pp. 486-508.

Komar, P.D. (1976). Beach processes and sedimentation, Prentice – Hall, Englewood Cliffs, N.J

Komar, P.D. (1979). Beach slope dependence of longshore currents. Jour. Waterway Port Coastal Eng., WW4, 460 p.

Komar, P.D. and Inman, D.L. (1970). Longshore sand transport on beaches. Jour. Geophys. Res., v. 75, p. 5914.

Komar, P.D. and Moore, J.R., editors. (1983). CRC handbook of coastal processes and erosion. CRC Press, Inc. Boca Raton, Florida.

Krinsley, D.H. and Doornkamp, J.C. (1973). Atlas of quartz sand surface textures. Cambridge University Press, Cambridge, 91 p.

Ladd, H. and Schlarger S.O. (1960). Drilling operations on Enewatok Atoll, Prof. Paper 260 –k ,U.S. Geological Survey, Washington D.C.

Land, L.S. (1967). Diagenesis of skeletal carbonates, Jour. Sed. Petrol., v. 37, pp.914-930.

Land, L.S. (1970). Phreatic versus vadose meteoric Diagenesis of limestones: Evidence from fossil water table. Sedimentology., v. 14, pp. 175-185.

Land, L.S. and Hoopes, G.K. (1973). Sodium in carbonate sediments and rocks : a possible index of salinity of diagenetic solutions. Jour.Sed.Petrol., v.43, pp. 614-617.

Land, L.S. and Moore, C.H. (1980). Lithification, micritization and syndepositional diagenesis of biolithites on the Jamaican island slope. Jour. Sed.Petrol., v. 50, pp. 357-70.

Lewis, M.S. (1969). Sedimentary environments and unconsolidated carbonate sediments of the fringing coral reefs of Mahe. Seychelles. Mar. Geol., v.7, pp. 95-127.

Livingston, H.D. and Thompson, G. (1971). Trace element concentrations in some modern corals: Limnology oceanography., v.60, pp. 786-796.

Loeblich, A.R.Jr. and Tappan,H.(1988). Foraminiferal genera and their classification. Pubs. Vcn Nostrand Reinhold, 970 p.

Logan, B.W., Harding, J.L., AHR, W.M., Williams, J.D and Snead, R.G. (1969). Carbonate sediments and reefs, Yucatán shelf, Mexico. Amer. Assoc. Petrol. Geologists, Mem., v. 11, pp. 1-198.

Macintyre, I.G. (1977). Distribution of submarine cements in a modern Carribean fringing reef, Galeta Point, Panama. Jour. Sed. Petrol., v. 47 (2), pp. 503-516.

Macintyre, I.G. (1984). Extensive submarine lithification in a cave in the Belize Barrier Reef platform. Jour. Sed. Petrol., v.54, pp. 221-35

Macintyre, I.G. (1988). Modern coral reefs of western Atlantic: new geological perspective. Bull. Amer. Asso. Petroleum ., v.72, no. 11, pp 1360-1369.

Majumdar, P. and Ganapathi, S. (1998). Grain-size frequency distribution in ancient depositional environment - A case study from Lower Gondwana sediments, Pranhita Godavari Basin, Andhra Pradesh. Jour. Geol. Soc. Ind., v. 52, pp. 219-228.

Mallik, T.K (1976). Grain size variation in the Kavaratti lagoon sediments, Lakshadweep, Arabian Sea. Mar. Geol., v. 20, pp. 57-75.

Mallik, T.K. (1979). Some sedimentological and biological aspects of the Kavaratti and Kalpeni atolls Lakshadweep, Arabian Sea, Indian Ocean. Mar. Geol., v. 29, pp. 357-385.

Mallik, T.K. (1981). A brief report on the study of problems related to dredging in the Kavaratti lagoon Lakshadweep. Unpublished report G.S.I, Calcutta.

Mallik, T.K. (1985). Geology of Kavaratti and Kalpeni atolls (Lakshadweep, Arabian Sea, Indian Ocean). Proc. of the Fifth Int. Coral reef Cong., Tahati., v.6, pp. 419-426.

Marshall, J.F. (1983a). Marine lithification in coral reefs. Perspective on coral reefs.. Manuka, ACT, Australia: Brian Clouston Publisher. ed D. J. B. pp. 231-239.

Marshall, J. F. (1983b). Submarine cementation in a high-energy platform reef: One Tree Reef, southern Great Barrier Reef. Jour.Sed. Petrol., v. 53 pp. 1133-1149.

Martin, L.R. (1965). Significance of skewness and kurtosis in environmental interpretations. Jour. Sed. Petrol., v.35, pp. 768-777.

Mascarenhas, A., Siddique, H.. and Topgi, R.S. (1980). Distribution of strontium in sediments of the Minicoy atoll, Lakshadweep. Indian Jour. Mar. Sci., v.9, pp. 281-283.

Mason, C.C. and Folk, R.L. (1958). Differentiation of beach, dune and eolian flat environments by size analysis, Mustang Island, Texas. Jour. Sed. Petrol., v. 28, pp. 211-226.

Mathews, R.K. (1967). Diagenetic fabrics in biosparites from the pleistocene of Barbados. Jour. Sed. Petrol., v. 37, pp.1147-1153.

Mathews, R.K. (1968). Carbonate diagenesis, equlibration of sedimentary mineralogy to the subaerial environment; coral cap of Barbados, West Indies. Jour. Sed. Petrol., v. 38, pp. 1110-1119.

Maxwell. W.G.H. (1968). Atlas of the Great Barrier Reef. Elsevier, Amsterdam, 258 p.

McKinney, T.F. and Friedman, G,M. (1970). Jour. Sed. Petrol., v.40, pp. 213-248.

Mc Lean R.F. and Woodroffe, C.D. (1997). Coral attols in coastal evolution. R.W.G.Carter and C.W. woodroffe (eds.), Cambrdge press.517p.

Medina, R., Losada, M.A., Losada, I.J and Vidal, C.(1994). Temporal and spatial relationship between sediment grain size beach profile. Mar. Geol., v. 118, pp. 195-206.

Millman, J.D. (1974). Marine Carbonates, Recent Sedimentary Carbonates, Part I. Springer, NY,375p

Mishra, S.K. (1969). Heavy mineral studies of the fifth of Tag region, Scotland., Jour. Geol. Soc. Ind., v.5, pp. 37-48.

Moiola, R.J., Spenser, A.B. and Weiser, D. (1974). Differentiation of modern sand bodies by linear discriminant analyses. Trans. Gulf Coast. Assoc. Geol. Soc., v. 24, pp. 324-332.

Muraleedharan, M.P. and Kumar, P.P. (1995). Geological and geomorphological studies in Kavaratti Island. Abst. Workshop. Status of Sci. Database on Lakshwadeep, Geol. Surv. Ind. p.31.

Nair, K.M. (1975). First generation cement in beach rocks along east coast of South India. Proc. IX Int. Cong. Sedimentology., pp. 149-159.

Nair, K.M. (1976). Sedimentology of Carbonates in Cauveriy Basin. Ph.D. Thesis, Osmania University, Hyderabad.

Nair, K.M. (1982). Cementation of carbonate sands in Lakshadweep. Bull. ONGC., v. 19, no.1, pp. 1-12.

Nair, R.R. and Qasim, S.Z (1978). Occurrence of a bank with living corals off the south-west coast of India. Indian J. Mar. Sci., v.7, pp. 55-58.

Nakada, M. (1986). Holocene sea levels in oceanic islands: implications for the rheological structure of the Earth's mantle. Tectonophysics.,v.121, pp. 263-276.

Naqvi, S.W.A. and Reddy, C.V.. (1979). On the variation in the calcium content of the waters of Lakshadweep. Tech. Rep. (1805), N.I.O, Goa, pp. 1-98.

Narain, H., Kaik, K.L., and Verma, R.K. (1968). Continental margins of India, Can. Jour. of Earth Sci., v.5, pp.1051-1058.

Nelson, C.S., Hancock, G.E. and Kamp, P.J.J. (1982). Shelf to basin temperate skeletal carbonate sediments, Three Kings Plateau, New Zealand. Jour. Sed. Petrol., v. 52, pp.717-732.

Neslon, C.S., Keane, S.L. and Head, P.S. (1988). Non- tropical carbonate deposits on the modern New Zealand shelf. Sed. Geol., v. 60, pp. 71-94.

Newell, N.D. (1961). Recent terraces of tropical limestone shores. Zeitsehrift fiir Geomorphologi, N.F., Suppn. Bd., v.3, pp.87-106.

Newell, N.D. and Bloom, A.L., (1970). The reef flat and ' two- meter eustatic terrace ' of some Pacific atolls. Geol.Soc.Amer.Bull., v.81, pp. 1881-1894.

Nordstrom, E.F. (1977). The use of grain size statistics to distinguish betweer high and moderate energy beach environments. Jour. Sed. Petrol., v. 47 pp.1281-1294.

Padmalal, D. (1992). Mineralogy and geochemistry of the sediments o Muvattupuzha river and Central Vembanad estuary, Kerala, India. Ph.D Thesis, Cochin University of Science and Technology, Kochi.

Padmalal, D. and Seralathan,P. (1991). Interstitial water- sediment geochemistry of P and Fe in the sediments of Vembanad lake, West coast of India Ind.Jour.Mar.Sci., v.20, pp.263-266.

Passega, R. (1957). Texture as a characteristic of clastic deposition. Bull. Amer. Assoc. Petrol. Geol., v. 14, pp. 1952-1984.

Passega, R. (1964). Grain size representation by CM patterns as a geologic tool. Jour. Sed. Petrol., v. 34, pp. 830-837.

Passega, R. (1977). Significance of CM diagrams of sediments deposited by suspensions. Sedimentology., v.24, pp. 723-733.

Patro, B.C., Sahu, B.K. and Guru, S. (1989). A study of heavy mineral sands of Gopalpur beach, Orissa. Jour. Geol. Soc. Ind., v. 33, pp. 243-252.

Pettijohn, F.J. (1957). Sedimentary rocks. Harper and Row, New York, 718 p.

Pillai, C.S.G. (1977). The distribution of shallow water stony corals at Minicoy atoll in the Indian Ocean with a checklist of species. Atoll Res. Bul., v. 141, pp. 1-12.

Pingitore, N.E., Jr. (1970). Diagenesis and porosity modification in Adropora palmata, pleistocene of Barbados. Jour. Sed. Petrol., v. 40, pp.712-721.

Pirazzoli,P.A. (1991). World atlas of Holocene Sea-level changes. Amsterdam: Elsevier Oceanography series., v.58, pp.330.

Pirazzoli, P.A. and Montaggioni, L.F. (1988b). Holocene sea-level changes in French Polynesia. Paleogeography, Paleoclimatology, Paleoecology., v.68, pp.153-175.

Pitzold, J. (1998). The effect of early lithification on the stable oxygen and carbon isotopic composition of Porites lobata. Proc. Of the sixth Int. Coral Reef Symp.,Australia., v.3, pp559-564.

Prakash, T.N. and Suchindan, G.K. (1994). Coastal erosion studies in the Lakshadweep Islands. Proc. Ind. Natn. Conf. on Harbour and Ocean Engg. pp. D31- D41.

Raiverman, V.(1986). Sedimentation pattern and its controlloing factors in the Cenozoic basins of the Indian subcontinent ,Bull of ONGC , v.23, pp. 1-16.

Rajaguru, S.N., Gupta, A., Kale, V.S., Mishra, S., Ganjoo, R.K., Eli, L.L., Enzel, Y. and Baker, V.R. (1995). Channel forms and processes of the flood-dominated Narmada River, India. Earth Surface Processes and Landforms., v.20, pp. 407-421.

Rajamanickam, G.V. and Gujar, A.R. (1985). Indications given by medium distribution and CM patterns on clastic sedimentation in Kalbadevi,Mirya and Ratnagiri base, Maharashtra, India. Gordanale di Geologia.,v.47, pp. 237-251.

Rajamanickam, G.V. and Gujar, A.R. (1997). Grain size studies on the near shore sediments of Jaigad, Ambwah and Varvada Bays, Maharashtra . Jour. Geol. Soc. Ind., v.49, pp.567-576.

Ramamurthy, K.K. (1995). Archaeological Vestiges of Lakshadweep. Abst. Workshop. Status of Sci. Data base on Lakshadweep; Geo. Surv. Ind., p 33.

Ramanujam, N and Mukesh, M. (1999). Metal concentrations in coral skeletons in Tuticorin group of islands, Gulf of Mannar, India. Mitt. Geol. -Paläont pp. 279-283.

Rao, C.P. (1981a). Cementation in cold water bryozoan sand, Tasmania, Australia. Mar. Geol., v. 40, pp. M23-M33.

Rao, C.P (1981c). Geochemical differences between tropical (Ordovician) and subpolar (Permian) carbonates, Tasmania, Australia. J. Sediment. Petrol., v. 51, pp. 491-506.

Rao, C.P. (1986). Geochemistry of temperate water carbonates, Tasmania, Australia. Mar. Geol., v. 71, pp. 363-370.

Rao, C.P. (1989). Geochemistry of Gordon Limestone (Ordovician), Mole Creek, Tasmania, Australia. Aust. J. Earth Sci., v. 36, pp. 65-71.

Rao, C.P. (1990a). Geochemical characteristics of cool-temperate carbonates, Tasmania, Australia. Carbon. Evap.., v. 5, pp. 209-221.

Rao, C.P. (1990b). Petrography, trace elements and oxygen carbon isotopes of Gordon Group carbonates (Ordovician), Florentine Valley, Tasmania, Australia. Sediment. Geol., v. 66, pp. 83-97.

Rao, C.P. (1992). Carbonate minerals, major and minor elements and oxygen and carbon isotopes and there variation with water depth in cool, temparate carbonates, western Tasmania, Australia. Mar. Geol., v. 103, pp. 249-272.

Rao,C.P. (1994). Implications of isotopic fractionation and temperature on rate of formation temperature shelf carbonates, eastern Tasmania, Australia. Carbon Evap., v.9, pp.3-41.

Rao, C.P. (1996). Oxygen and carbon isotope composition of some skeletons from temperate shelf carbonates, eastern Tasmania, Australia. Carbon Evap..(accepted).

Rao, C.P. and Adabi, M.H.(1992). Carbonate minerals, major and minor elements and oxygen and carbon isotopes and their variation with water in cool, temperate carbonates, western Tasmania, Australia. Mar. Geol., v.103, pp.249-272.

Rao, C.P. and Amini, Z.Z. (1995). Faunal relationship to grain-size, mineralogy and geochemistry in Recent temperate shelf carbonates, western Tasmania, Australia. Carbon. Eva., v. 10, pp. 114-123.

Rantala, R.T.T. and Loring, D.H.(1975). Multielement analysis of silicate rocks and marine sediments by atomic absorption spectrophotometry. At. Absorb. News. Lett., v.14, pp. 117-120

Roberts, H.H, Aharon, P. and Phipps, C.V. (1988) Morphology and sedimentology of *Halimeda* bioherms from the eastern Java Sea (Indonesia). Coral Reefs., v.6, pp. 161–172.

Rowlatt, S.M. and Lovell, D.R. (1994). Lead, Zinc and Chromium in sediments around England and Wales. Mar. Poll. Bull., v. 28, pp 324-329.

Roy, P.S. (1991). Shell hash dating and mixing models for palimpsest marine sediments. Radiocarbon., v. 33, pp. 283–289.

Samsuddin,M.(1990). Sedimentology and mineralogy of the beach, strand plain and innershelf sediments of the northern Kerala coast. Ph.D. Thesis, Cochin University of Science and Technology, cochin.

Sanakaranarayanan, V.N. (1973). Chemical characteristics of waters around Kavaratti atoll (Laccadives). Ind. Jour. Mar. Sci., v. 2, pp. 23-26.

Sanil Kumar, K.V., Shyam, K.R., Udaya Varma, P and Sivadas, P. (1986). Topography andd sedimentary characteristics of the sandy beach of Kavaratti (Lakshadweep) – A premonsoonal study. Ind. Jour. Mar. Sci., v. 15, pp- 75-77.

Schneider, R.C. and Smith, S.V. (1982). Skeletal Sr content and density in Porates spp. in relation to the environmental factors. Mar.Biol., v.66, pp121-131.

Seralathan,P. (1979). Studies on texture, mineralogy and geochemistry of the modern deltaic sediments of Cauvery river, India, Ph.D. Thesis, Andhra University, Waltair.

Seralathan, P. (1984). Use of textural (CM) pattern for identification of depositional processes and environment of sediments of cauvery delta. Bull. Dept. Mar. Sci., University of Cochin., v. 14, pp. 17-26.

Scheer, G. (1984). The distribution of reef corals in the Indian Ocean with a historical review of its investigation. Deep Sea Res., v. 31, pp. 885-900.

Schofield, J.C. (1977a). Effects of late Holocene sea-level fall on atoll development. New Zealand Jour. Geol. Geophy., v.20, pp.531-536.

Schroeder, J.H. (1969). Experimental dissolution of calcium, magnesium and strontium from recent biogenic carbonates. Petrology., v. 39, pp. 1057-1073.

Schroeder, J.H. (1973). Submarine and vadose cements in pleistocene, Bermuda, reef rock. Jour. Sed. Petrol., v. 10, pp.179-204.

Scott G.A.J. and Rotondo, G.M. (1983) A model to explain the differences between the Pacific plate island atoll types, Coral reefs., v, 1 pp. 139-150

Shepard, F.P.,Curray, J.R., Newman, W.A., Bloom, A.L., Newell, N.D., Tracey,J.I. and Veeh, H.H. (1967). Holocene changes in sea level: evidence in Micronesia. Science., v.153, pp. 542-544.

Short, A.D. (1979). Three dimensional beach stage model. Jour. Geol., v. 87, p. 553.

Short, A.D. and Hesp, P.A. (1982). Wave, beach and dune interactions in southeastern Australia. Mar. Geol., v. 48, p.259.

Siddique, H.N. (1975). Submerged terraces in the Laccadive island, India. Mar. Geol. v. 18, pp. M95-M101.

Siddique, H.N. (1980). The ages of the storm beaches of the Lakshadweep (Laccadives). Mar. Geol., v. 38, pp. M11-M20.

Siddique, H.N and Mallik, T.K (1973). Unpublished report, G.S.I.

Silliman, B.(1953). Elementary chemical composition of marine organisms. Elementary composition of Coelenterata. Sears Foundation of Marine Research.

Smith, S.V. (1978). Coral reef area and contributions of reef to processes and resources of the world oceans. Nature, Lond., v. 273, pp. 225-226.

Smith, et.al. (1979). Strontium –Calcium thermometry in coral skeletons. Science., v. 204, pp.404-406.

Sonu, C.J. (1973). Three dimensional beach changes. Jour. Geol., v. 81 (1), p. 42.

Srivastava, J.P., Nair, K.M. and Ramachandran, K.K.(1978). Report on the geological expedition to Lakshadweep islands, ONGC, Calcutta. p.83

St. John, B, E. (1974). Heavy metals in the skeletal carbonates of scleractinian corals. Proc. Sec. Int. Coral Reef Symp., v. 2, pp. 461-469.

Stapor, F.W. and Tanner, W.F. (1975). Hydrodynamic implications of beach ridges and dune grain size studies. Jour. Sed. Petrol., v. 45, pp. 926-931.

Steinen, R.P. and Mathews, R.K. (1973). Phreatic vs. vadose diageneisis: stratigraphy and mineralogy of a cored borehole on Barbadose, West Indies, Jour. Sed. Petrol., v. 43, pp.1012- 1020.

Stoddart, D.R., Spencer Davies, P. and Keith, A. C., (1966). Geomorphology of Addu Atoll. Atoll. Res. Bull., v.116, pp. 13-41.

Stoddart,D.R. (1972b). Geomorphology of Diego Garcia Atoll. Atoll Res. Bull.; v. 149, pp. 7-26.

Thompson, T.J. and Livingston, (1970). Sr and U concentrations in aragonite precipitated by some modern corals. Earth Planet Sci. Lett.., v.8, pp, 439-442.

Thorstenson, D.C., Mac Kenzie, F.T. and Ristvet, B.L. (1972). Experimental vadose and phreatic cementation of skeletal carbonate sand. Jour. Sed. Petrol., v. 42, pp.327-354.

Veeh, H.H. and Turekian, K.K. (1968). Cobalt, silver and uranium concentrations of reef- building corals in the Pacific ocean: Limnology Oceanograpy., v. 13, pp.304-308.

Vinithkumar, N.V., Kumaresan, S., Manjusha, M. and Balasubramanian, T. (1999). Organic matter, nutrients and major ions in the sediments of coral reefs and sea grass beds of Gulf of Mannar bioshere reserve, south east coast of India. Ind. Jour. Mar. Sci, v. 28, pp. 383-393.

Visher, G.S. (1969). Grain size distributions and depositional processes. Jour. Sed. Petrol., v. 39, pp. 1074-1106.

Waterhouse B.C.(1984 a). Geological and geomorphologic evolution of small islands , Pacific region .in water resources of small islands. Tech. Publ. Series No. 154 Commonwealth Science Council, London, 2-86-105.

Weber, J.M .(1973). Incorporation of Strontium into reef coral skeletal carbonate, Geochim. Cosmochim. Acta., v. 37, pp. 2173-2190.

Weber, J.M. (1974). Skeletal chemistry of scelractinian reef corals. Uptake of magnesium from sea water. Amerr. J. Sci., v. 274, pp. 84-93.

Williams, S.C., Simpson, H.J., Olsen, C.R. and Bopp, R.F. (1978). Sources of heavy metals in sediments of the Hudson river estuary. Mar. Chem., v. 6, pp. 195-213.

Woodroffe, C.D., Stoddart, D.R., Spencer,T., Scoffin, T.P. and Tudhop, A.W. (1990a). Holocene emergence in the Cook Islands, South Pacific. Coral Reefs., v. 9,pp. 31-39.

Wright, L.D. and Short, A.D. (1983). Morphodynamic variability of surf zones and beaches: A synthesis. Mar. Geol., v.56, pp. 93-118.

Wright, L.D., Chappel, J., Thom, B.G., Bradshaw, M.P., and Cowell, P. (1979). Morphodynamics of reflective and dissipative beach and inshore systems: south eastern Australia, Mar. Geol., v. 32, p. 105.

Wright, L.D., Guza, R.T.,and Short, A.D. (1982b). Dynamics of a high energy dissipative surf zone. Mar. Geol., v. 45, p.41.

Wright, L.D., Nielson, P.N., Short, A.D. and Green, M.O. (1982a). Morphodynamics of a macro tidal beach. Mar. Geol., v. 50, p. 97.

Yamanouchi, H (1980). Preliminary note on bioclastic sands of coral reefs and beaches at southwestern islands of japan. Science Report of the Faculty of Education, Gunma University v. 29, pp. 73-97.

Yamanouchi, H. (1982). Distribution of sediments on coral reefs and beaches in Okinoerbu-jima. Science Report of the Faculty of Education, Gunma University., v. 31, pp. 33-53.

Yamanouchi, H. (1984).The distribution of sandy sediments on the coral reef and beach at Yoshihara in Ishigakijima. Science Report of the Faculty of Education, Gunma University., v. 33, pp. 61-83.

Yamanouchi, H. (1988). The distribution of sandy sediments around coral reefs and the effect of reef topography. Proc. VI International Coral Reef Symp. Townsville., v.3, pp. 497-502.

Yamanouchi, H. (1993). Sandy sediments on the coral reef and beach of northwest Sesoko island, Okinawa. Galaxea v.11, pp. 107-133.

Yamanouchi, H. (1998). Sandy sediment distribution on coral reef and beaches at several islands of the Ryukyu island arc. Geographical review of Japan, v. 71(1), pp. 72-82.

Yamanouchi, H and Hasegawa, H (1988). The distribution of sandy sediments on the coral reef and beach at northeastern coast of Ikei-jima, Science Report of the Faculty of Education, Gunma University v. 36, pp. 19-37.

Yoshika, S., Ohde, S., Oomori, T and Kitano, Y. (1985). Dissolution of magnesium and strontium during the transformation of coral aragonite to calcite in aqua solution. Galaxea., v.4, pp. 99-111.

Zutshi, P.L., Murty, M.S.N and Thakur, S.S (1995). Exploration for hydrocarbons in and around Lakshadweep Islands. Abst. Workshop. Status of Sci. Data base on Lakshadweep islands, Geol. Surv. Ind.