GEOMORPHOLOGY, SEDIMENTOLOGY AND GEOCHEMISTRY OF MAYEM LAKE, BICHOLIM TALUKA, GOA, INDIA.

THESIS

SUBMITTED TO THE GOA UNIVERSITY
FOR THE DEGREE OF
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IN
MARINE SCIENCE

BY

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UNDER THE GUIDANCE OF
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………… In Loving Memory of
My Late Grandparents

…………

STATEMENT

As required under the University ordinance 0.19.8 (vi), I state that the present thesis entitled "**GEOMORPHOLOGY, SEDIMENTOLOGY AND GEOCHEMISTRY OF MAYEM LAKE, BICHOLIM TALUKA, GOA, INDIA**", is my original contribution and that the same has not been submitted on any previous occasion. To the best of my knowledge, the present study is the first comprehensive work of its kind from the area mentioned.

The literature related to the problem investigated has been cited. Due acknowledgements have been made wherever facilities and suggestions have been availed of.

Mohan R. Girap

CERTIFICATE

This is to certify that the thesis entitled **"GEOMORPHOLOGY, SEDIMENTOLOGY AND GEOCHEMISTRY OF MAYEM LAKE, BICHOLIM TALUKA, GOA, INDIA"**. Submitted by Mr. Mohan Ratnakar Girap for the award of the Degree of Doctor of Philosophy in Marine Science is based on the result of field surveys/laboratory experiments carried out by him under my supervision. The thesis or any part there of has not previously been submitted for any other degree or diploma in any universities or institutions.

Place : Taleigao Plateau
Date : 3/7/1997

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CHAPTER 1

INTRODUCTION

Since ancient times, lakes have been one of the main sources of water and food. The favourable conditions along the periphery of lakes were the positive factors in the development of civilization (Balek, 1983) and have played an important role in cultural and social life, especially in countries like Finland and Sweden, where lakes are abundant.

Lakes are an essential natural resource and contribute significantly to the water economy of many countries. As a storage reservoir, they provide water for domestic and agricultural (irrigation) purposes, fisheries, recreation, transport and tourism economy. In addition, they also regulate the flow of rivers, influence the climate and help in generating hydroelectric power.

In recent years, studies on lake ecosystems have gained importance due to their diversified use in the field of palaeo-environment, ecology and as a reservoir.

Studies on environmental parameters of lake water are helpful in assessing the water quality and primary productivity. This, in turn, is useful in establishing the trophic status of a lake. The primary productivity, especially of phytoplankton is one of the most important sources of energy input in lake waters (Moss, 1980). Similarly, some of the microbes in aquatic system assume paramount significance either as a biological indicator or as an agent itself for the cleaning process (Park, 1972). Study on bathymetry of a lake basin is useful in understanding the productivity of a lake (Rawson, 1955 ; Hanifa and Pandian, 1978). In recent years, study of bathymetry has gained importance as it helps in delineating the pattern of sediment movement along the lake bottom, presence /absence of sediment pockets within a basin and bottom dynamics (Siriwardena and Perera, 1986 ; Downing and Rath, 1988; Giresse *et al.,* 1991). Such studies are also useful in understanding various sedimentary processes operating within the lake (Bordovskiy, 1965) as well as rate of sedimentation (Rawat, 1987 and Hicks *et al.,* 1990). Bathymetric information was also used to describe the basinal configuration of the Naini lake (Hashimi *et al.,* 1993).

Lake sediments are used in the assessment of quality of aquatic ecosystem (Nipkow, 1920 ; Zullig, 1956). Concentration of suspended matter in lake waters plays a vital role, as it affects the water transparency (Welsh and Stewart, 1991) and in turn, the biological productivity. This parameter is used to estimate suspended sediment influx (Kumar and Rastogi, 1987). Surface sediments are widely being used as a guide of heavy metal pollution in lakes (Forstner and Wittmann, 1979). These being the result of sedimentation of suspended matter, can also give nature of influx of sediment (Eisma, 1993). Sub-surface sediment studies are helpful in deciphering the rate of sedimentation, depositional environment, history of deposition and elemental concentration and their distribution pattern with time (Kemp *et al.,* 1974; Rea *et al.,* 1980; Colman *et al.,* 1990; Xie *et al.,* 1992 and Barnett, 1994). Hence, lakes in general, are known as storehouses of information regarding the present and past climate, environment of deposition, degree of pollution or contamination, if any.

Definition

In its simplest form, lake is a land-locked body of water occupying a basin. However, very small body of such water within a basin is termed as a pond.

Unique definition of a lake does not exist. Zumberge and Ayers (1964) defined a lake as an inland basin filled or partially filled with water whose surface dimensions are sufficiently large to sustain waves. Mark and Goodchild (1982) define a lake as a body of surface water in which flow velocities are too low to transport suspended sediments. As per Kuusisto (1985), however, a water body should fulfill the following requirements to be called a lake.

i) It should fill or partially fill a basin or several connected basins.

ii) It should have essentially the same water level in all parts with the exception of relatively short period occasionally caused by wind, large inflow or ice-cover, etc.

iii) It should have a small inflow to volume ratio.

iv) It should have a size exceeding a specified area of 0.01 sq. km. and an average depth of 2 m.

Classification

There are variety of lakes on the continental land surface ranging from large, deep and permanent freshwater lakes, such as North American Great lakes, East African rift valley lakes, lake Baikal of Russia to small, shallow, ephemeral saline lakes, such as those in Western United States of America and Central Iran (Leeder, 1982). Nowadays, even coastal lagoons are grouped under lakes. Thus, there is a complete spectrum of lakes, from deep fresh to deep saline and from shallow fresh to shallow saline. Over 75% of world lakes are fresh, remaining range from brackish to hypersaline (Herdendorf, 1990). In general, however, lakes are broadly divided into two types - a) closed lakes and b) Open lakes - depending on absence / presence of an outlet.

Hutchinson (1957) offers a detailed classification of lakes based on their origin. These include eleven major categories i) Tectonic ii) Volcanic (iii) Mass wasting (landslide) iv) Glacial v) Chemical (solution action) vi) Fluvial vii) Aeolian viii) Shoreline ix) Organic x) Meteoritic and xi) Anthropogenic (reservoirs, abandoned mine pits, etc.). Of these, glacial and tectonic basins account for nearly 85% of total lakes. In recent times, anthropogenic (artificial) lakes have increased considerably (Sahagian *et al.,* 1994).

Dean and Gorham (1976) have classified lakes on the basis of water chemistry, organic matter and calcium carbonate content in sediments; and Zumberge and Ayers (1964) based on shape. Hakanson and Jansson (1983) have classified lakes based on trophic status and water temperature (thermal). They have sub-classified trophic level lakes into i) Oligotrophic, ii) Eutrophic and iii) Dystrophic. Oligotrophic lakes have low primary productivity, high Secchi-disc transparency, low algal volume, comparatively low concentration of nutrients and fish fauna. Eutrophic lakes have high productivity, low transparency and excess concentration of nutrients. Dystrophic lakes have higher amount of organic input supplied from allochthonous source and low productivity. Based on thermal characteristics of waters, lakes are classified into - i) Amictic ii) Cold monomictic iii) Dimictic iv) Warm monomictic v) Polymictic and vi) Oligomictic. Amictic lakes are those, wherein water is always frozen. Cold monomictic lakes are those which have water temperature below +4°C and within these lakes, there is only one period of circulation in summer. Dimictic lakes are those wherein water circulates twice a year and shows thermal stratification. Warm monomictic lakes are those wherein water circulate once a year and temperature never drops below +4°C. These lakes are characteristic of temperate zones and mountainous subtropical areas. Polymictic lakes are those wherein there is frequent circulation of water. Polymictic subclass is further divided into cold polymictic wherein circulation takes place at temperatures close to +4°C and warm polymictic wherein the circulation takes place at higher temperatures. Oligomictic lakes have either irregular or no circulation and temperature in such lakes is well above +4°C. These lakes are typical of tropical regions.

Distribution

It is roughly estimated on a global level that only about 2.8% of the total water available on the Earth is freshwater. Of which, 2.2% is available as surface water and 0.6% as groundwater. Even out of this 2.2% of surface water, 2.15% is freshwater in glaciers and ice-caps and only about 0.01% is available in lakes and streams. The remaining 0.04% being in other forms (Raghunath, 1990).

Lakes occur in all parts of the world, but form only 1% of the Earth's continental surface. Herdendorf (1990) has given a detailed account on the distribution of lakes. According to him, larger lakes (>500 sq. km) are present in all continents except Antarctica. There are more lakes in high latitude and at high altitude than elsewhere. Glaciated landscapes covering about 30% of the present land area of the Earth have the largest number of lakes, especially in Canadian Shield

(Mark and Goodchild, 1982). Large number of lakes on continents are freshwater and are the direct result of glaciation.

When the distribution of lakes with respect to elevation are considered, majority of the lakes lie above the sea level, highest being Kyaring in Tibet. Some, including all coastal lagoons are at sea level and a few are below the sea level, lowest being Dead sea, on Israel-Jordan border (Longwell *et al.,* 1960).

Lakes are very common in tropical belts. Most of these lakes have formed due to tectonic activity, geomorphological control, sediment deposition in a river course, sub-aerial erosion and such other processes.

In India, there are number of natural as well as man-made (artificial) lakes and occur in diversified environmental regions. Lake Gokyo (4816 m above mean sea level) in the Himalayan region represents cold climate, lake Pichola in Rajasthan represents arid and all the lakes in Bhopal, Madhya Pradesh represent temperate climate. Lake Chilka in Orissa, lake Vembanad in Kerala are lakes within the coastal plains which represent humid climate.

Lakes within the Indian continent have originated due to glacial (Dal lake, Kashmir), tectonic (lake Naini, Uttar Pradesh), meteoritic (lake Lunar, Maharashtra) and sub-aerial weathering (lake Sagar, Madhya Pradesh). Many lakes are also originated by fluvial (Ox-bow lakes) and coastal processes.

As in other continents, in India also, artificial lakes / reservoirs have increased with time in the recent past.

Factor variables and Processes

Lake is a complex ecosystem, when factors responsible are considered. The factor variables related to such environment can be grouped into two - a) External factors : are the factors operative and influential within the catchment area of a lake and b) Internal factors : are those operative and responsible for various processes within a lake.

A) External factors

These include Climate, Geomorphology & geology and Human (anthropogenic) interference.

1) Climate : Climate of a given location is defined by its latitude and altitude. Climate as an external factor, is important in the study of lacustrine ecosystems as it is a source of energy and defines other environmental parameters. Temperature, rainfall and such other environmental parameters, which are defined by the climate, are strong forcing factor variables within the catchment area of a lake. They control quantity and quality of sediment input to the lake (Hope *et al.,* 1988). Climate also regulates state and type of vegetation within a catchment area and vegetation, in turn, controls the release and transport of sediments (Gole and McManus, 1988).

2) Geomorphology and geology : Equally important are the catchment area characteristics, namely - geomorphology and geology (Stout, 1988). Topography & drainage network of catchment area and rock types, their stage of weathering, hardness of rocks are all factors to be considered. In addition, geological structures like folds and faults are also equally important.

3) Anthropogenic influence : Climate or geomorphology & geology and the processes operating within this system are 'Natural'. Human interference in this system accelerates certain processes leading to ecological imbalance in the natural ecosystem. Anthropogenic influence within the catchment area can be in the form of deforestation, agriculture, setting up of an industry and its discharge of effluents. These, in turn, will lead to soil erosion, and therefore, changing the rate of sediment input to the lake from its catchment area (Baker and Krumer, 1973; Engstrom and Wright, 1984; Rybak, 1988).

B) Internal factors

These include temperature, salinity and sediment yield.

1)Temperature and salinity : Temperature affects the thermal structure within the water column of a lake and in turn, controls the primary productivity (Jana and Kundu, 1993). In temperate climate, especially large, deep lakes show a well marked thermal stratification with an upper warm layer (Epilimnion) separated by a thermocline from a deeper, cold layer (Hypolimnion). This results in thermally induced circulation whereby the topmost water get gradually warmer by solar radiation. This change in water temperature is responsible for density gradient within the water column. Due to this phenomenon, surface warm water in lakes is less dense than bottom cold water (Nemerow, 1985). These stratified layers, in temperate climate, are disturbed due to partial mixing by another forcing parameter namely, wind. While in tropical deep lakes, water stratification is mostly permanent (Leeder, 1982) as wind action is absent or very minimal. In shallow lakes, as the depth of water column is considerably less, stratification generally does not exist. Wind also plays major role in disturbing the possibility of formation of stratification in these lakes. If the lakes are very shallow, the wind generated wave and current induced by wind may even result in disturbing the bottom, causing resuspension (Kumagai, 1988) of sediments.

Salinity is an important parameter especially in deeper saline lakes, wherein it leads to salinity gradient with depth. It is also important in coastal lagoons and plays crucial role in their chemical and biological processes.

2) Sediment yield : Sediment yield is the ultimate result of climate, geomorphology, geology and vegetation of the catchment area. Anthropogenic interference within the catchment area is responsible for increasing the release of material into the lake.

Nilsson and Hakanson (1992) have established the relation between drainage area and lake basin area. Larger the ratio of drainage area to lake basin area, relatively more is the supply of material in the form of water, nutrients and sediment to the lake. The sediment is transported from the catchment area to the lake in two different modes, namely - suspended and bedload.

Water and sediment material flow through the streams to a lake, disturbs or responsible for partial circulation of water and resuspension of surficial sediments, especially in shallow lakes. Resuspension is responsible for release of certain nutrients to water column (Munawar *et al.,* 1991) and in turn, may cause eutrophication (Vincent *et al.,* 1991). In addition, finer material brought into the lake remain in suspension for longer time and therefore, increases turbidity causing reduction in water transparency (Rasmussen *et al.,* 1989).

Distribution of material brought into the lake is controlled by physico-chemical parameters of lake water namely, Eh, pH, salinity and also morphological features of the lake bottom. In addition, productivity within a lake, which itself is dependent on nutrients available and brought into lake also affects the distribution of material. All these parameters, namely sediment material and water brought by streams, physico-chemical parameters - temperature, Eh, pH, salinity of water within the lake, biological productivity, basin morphology as well as wind, rainfall which directly affects the lake ecosystem are all interrelated.

The material entered into the lake and remained in suspension is more important, as it controls many of the factors mentioned above. The suspended matter has to be either deposited, mineralised with organic matter or get dissolved depending on the conditions and the location of the lake with regard to climatic zonality. The rate of settling of this material is proportional to the settling velocity of particles (Eadie and Robbins, 1987). Particle residence time are relatively shorter in lake water column to the ocean.

Closed lakes receive large proportion of leaves, pollens, insects and other biological products along with water and sediment material from the catchment area. The organic material decomposes in the lake water and set free nutrients (Ohyama *et al.,* 1992). Nutrients enhance the growth of planktonic and algae within the lake. As the lakes are also affected by external factor variables, the supply of nutrients and growth of phytoplanktons is not a continuous phenomenon (Neilson and Stevens, 1987). This leads to the death and decay of phytoplanktons which in turn, results in high production of organic matter.

It is observed that the mineral grains from suspended matter are generally deposited during monsoon. Organic matter dominate the deposition following the productive season while, fine-aggregates are laid down during winter (Renberg, 1981). This process is also associated with partial resuspension. The resuspension accounts for relatively higher concentration of suspended matter at deeper layers.

The interrelation. of the sediment dynamics and overlying waters at sediment water interference is responsible for release of nutrients to water column (Stone *et al.,* 1991). These processes, in turn, are responsible for changing the physico-chemical parameters of lake water. These parameters are one of the causative factors in establishing the primary productivity and trophic status of a lake (Hakanson, 1990 ; Sen *et al.,* 1992).

The whole process gets disturbed, when there is an additional input from catchment area, may be due to anthropogenic influence. Therefore, lakes are considered very sensitive to such changes especially when the lake is shallow and small.

The study of sediment components and their distribution in shallow lake, therefore, gained importance, as such studies are helpful in revealing the processes operating within a lake. The processes of sediment distribution in shallow lakes can be divided into four types namely i) Slumping ii) Intermittent complete mixing iii) Peripheral wave action (in littoral zone) and iv) Random redistribution (shallow water wave) as suggested by Hilton (1985).

The earlier studies carried out on lake sediments specially with time, have proved their importance in establishing the palaeo - processes and genetic history of a lake. Sediment components, elemental concentration within them have specially helped in delineating zones of contamination and pollution which can be related to palaeo - natural /artificial processes within the catchment area.

Each lake develops its own specific depositional environment which can be explained by the combination of the above mentioned factors - external as well as internal.

Previous work

Factors and Processes

Peach and Horne	1910	Related geology of the catchment area to limnological studies from Scottish lakes.
Birge	1916.	Related wind as an important factor in reworking and water mixing in a lake.
Dixey	1924	Related rainfall characteristics to 'a lake level - a study in Great Lake area.
Day	1926	Related rainfall within the drainage basin to lake level changes.
Fairchild	1926	Related geology of the catchment area to limnological studies from Finger lake.
Eriksson	1933	Studied the depthwise variation in light intensity within a lake water and related productivity to the extent of light penetration.
Juday and Birge	1933	Related lake water colour to transparency - study from lakes in Wisconsin.
Brown	1943	Related vegetation to lake level in Lake Catahoula.
Chandler	1944	Related various climatic factors to the phytoplankton activity in lake Erie.

Newell	1949	Related geology of the catchment area to limnological studies in Lake Titicaca, South Africa.
Deevey	1953	Studied the relation between palaeolimnology and climate.
Schleske	1962	Related primary productivity to iron, organic matter - study from Marl lake.
Fukuda and Lick	1980	Stated that resuspension depends on particle size, water content and biological mixing within the sediment.
Steenbergen and Verdouw	1982	Reported that water transparency is influenced by algal and bacterial population and also suspended matter - study from lake Vechten.
Engstrom	1987	Studied the influence of vegetation on humus content in sediments of Labrador lakes.
Fukushima *et al.,*	1987	Attempted separation of sediment flux into three fractions :1) allochthonous 2) autochthonous 3) sediment resuspension, by using a tracer and its chlorophyll content - study from Lake Kasumigaura, Japan.
Kumar and Rastogi	1987	Used total suspended matter to estimate suspended sediment flow - study from Ramganga reservoir, India.
Otsubo and Muraoka	1987	Studied wind generated wave as an important factor in erosion and

		redistribution of bottom sediments in Lake Kasumigaura, Japan.
Gole and McManus	1988	Revealed inverse relation between vegetation and total suspended matter in lake - study from Krishna basin.
Stout	1988	Studied variation in geology and geomorphology which determines the lake formation - study from a lake in New Zealand.
Hope *et al.,*	1988	Studied variation in the rate of sedimentation which reflects the control of climatic changes and human interference in the catchment area - study from New Guinea.
Glushchenko	1989	Reported that the main source of suspended organic matter is the plankton primary productivity - study from Lake Sevan, Armenia.
Duarte and kalff	1989	Revealed that catchment area geology and mean lake depth define the phytoplankton biomass.
Chakrapani and Subramanian	1990	Studied sediment discharge to Mahanadi basin. 95% of which takes place in monsoon. In the months of July, August and September, it is 90% of annual total. Factors responsible include water discharge, rainfall and geology.

Kale	1990	Established the relation between channel morphology and its variables. Maximum monsoon discharge (i.e. sediment yield) has a very strong influence on channel width and gradient. - study from Western Deccan trap upland region.
Keller and Crisman	1990	Related lake size, trophic status and pH to primary productivity.
Sandman *et al.,*	1990	Showed that increased field erosion causes change in sediment quality. - study from Lake Heinaelampi, Finland.
Sterner	1990	Established a relation between lake shape, depth and transparency - study from USA and Canada.
Vincent *et al.,*	1991	Pointed out how the river inflow in different seasons affects the eutrophication - study from Lake Rotoiti, New Zealand.
Nilsson and Hakanson	1992	Revealed the relation between drainage area and water quality. - study in oligotrophic lakes, Sweden.
Sen et al.,	1992	Detailed the factors affecting the primary productivity in tropical lakes-study from Lake Hatia, Ranchi, India.
Sondergaard *et al.,*	1992	Revealed and observed the release of certain nutrients due to resuspension of sediments in shallow lake. - study from Lake Arreso, Denmark.

Das and Sigh	1994	Detailed the factors responsible for sediment yield. These factors are - river inflow, mining activity, lithology, anthropogenic activity, erosion of loosely bound terrigenous material and deforestation.
Engstrom *et al.,*	1994	Reported that rate of sediment loadings into lake is dependant on ratio of catchment area to lake surface area. -study from Minnesota and N.Wisconsin.
Heathwaite	1994	Revealed that surface run-off from heavily grazed land yeilds high suspended sediment.
Das and Singh	1996	Related the nature of weathering with water chemistry in lake Pichola, Rajasthan.

Geomorphology and sediment input

Mill	1895	Earliest record of a bathymetric study from English lakes.
Juday	1914	Studied the relation between morphometry and hydrographic characters in Wisconsin lakes.
Wilson	1936	Studied sedimentation pattern in Winona lake based on bathymetry.
Thwaites	1947	First attempt to study the geomophology of lake basin in Lake Michigan.

Rao and Rao	1974	Studied the bathymetry of Pulicat lake and pointed out increasing depth towards the centre. Maximum depth recorded is 6 m. Catchment area geology with alluvial material is proved to be a major source. .
Murthy and Veerayya	1974	Proved that sediment distribution in a lake is dependant on bottom topography in addition to sediment texture and hydrographic features.
Clay and Wilhm	1979	Related sedimentation rate to water depth in large lakes.
Mallik and Suchindan	1984	Recorded wide variation in depth ranging from 3 m to 8.5 m in Vembanad lake.
Iyer and Wagle	1987	Studied morphometric analysis of seven river basins in Goa with emphasis on linear and areal aspects. They related low drainage density to high permeability of laterite cover.
Rawat	1987	Proved that capacity of Naini lake has reduced due to increased rate of siltation. Rate of sedimentation is estimated to be 63.37 m^3/yr. Also inferred the life of lake as 380 yrs.
Downning and Rath	1988	Pointed out bathmetry as a tool in the study of sediment distribution. They also showed the sediment heterogenity in bathymetrically uniform sampling sites.

Mosley	1988	Pointed out the relation between sediment discharge and water discharge to infer the lower sedimentation rate in Antartic than in Arctic.
Quiros	1988	Studied bathymetry of Patagonic lake, Argentina by using echosounder. The survey revealed the depth range from very shallow (2 m) to deep (111 m).
Rasmussen *et al.,*	1989	Pointed out the interrelation among drainage, watershed slopes, mean depth and transparency.
Hakanson	1990	Summerised the relation between bathymetry and eutrophication from studies on Swedish lakes.
Hicks *et al.,*	1990	Attempted to use bathymetry data in determining the rate of sedimentation - study from New Zealand.
Khanka	1991	Attempted slope analysis from a bathymetic data.
Pickrill	1993	Showed the use of morphology to infer the origin of lake Rotoiti, New Zealand. with the help of high resolution seismic reflection profiling. He also noticed gaseous sediments as a result of underlying hydrostructural field beneath lake floor.
Carignan and Neiff	1993	Established the relation of morphometry and turbidity to the distribution of

		phytoplankton with the help of remote sensing. - study from South America.
Hashimi *et al.,*	1993	Showed control of sedimentary processes by a geological structure in Naini basin. They said presence of delta indicates accelarated pace of sediment input.
Wagle	1993	Studied geomorphology of Goa and Goa coast.
Loizeau and Stanley	1994	Said that shallowness of lake results in well mixing of water with no stratification.They related productivity to transparency. - study in Lake Mariut, Egypt.
Moore *et al.,*	1994	Showed the use of seismic profiling for delineating the erosional surfaces in lake Huron, Canada.
Blais and Kalff	1995	Pointed out relation between morphology and sediment accumulation sites. Sediment focussing depends on lake form rather than its depth.
Klapper	1995	Investigated the influence of morphometry on trophic status of a lake.
Rao and Babu	1995	Carrried out morphometric analysis of Gundalkamma river basin, Andhra Pradesh. They pointed out that the stream development is a result of different structural features of the rocks in the

		catchment area and their differential weathering and erosion.
Rinaldo *et al.,*	1995	Stated that topography of a particular landscape is in balance with current climate - driven processes as well as it contains relict signatures of past climate.
Mohanty *et al.,*	1995	Studied geomorphology of lake Anshupa, Cuttack.
Tripathi and Shreshta	1995	Studied morphometric analysis of Setigandaki basin.

Surface Sediments

Hough	1955	Studied bottom sediments of Lake Chippewa and indicated the successive stages in a lake development.
Degenes *et al.,*	1964	Pointed out that organic matter content in sediments is controlled by activity of microbes and burrowing animals as well as various environmental parameters.
Tardy	1969	Suggested the role of rain water in the production of clay minerals such as kaolinite and montmorillonite.
Kemp	1971	Stated that organic carbon in surficial sediments is independant of depth of water column, eutrophication and rate of sedimentation but dependant on clay

		content. - study from three lakes, Ontario, Huron and Erie, Canada.
Murthy and Veerayya	1972	Proved that organic matter in Vembanad lake sediments is low (av. 2.55%) and also used colour to describe type of sediments.
Rao and Rao	1974	Showed that sediments of Pulicat lake are fine grained. The variation in textural characteristics is related to a varying degree of mixing between earlier deposited sand and modern silt and clay. They reported low content of organic matter (av. 0.98%) than in chilka lake (av. 1.38%). They related organic matter content to the presence of aquatic plants and their subseqent decomposition.
Gasith and Hasler	1976	Suggested an airborne litter fall as a source of organic matter in oligotrophic lakes - Lake Wingra, Wisconsin. It could be even 10% of phytoplankton productivity.
Lerman	1978	Studied physics, chemisty and geology of lakes.
Clay and Wilhm	1979	Proved that kaolinite is dominant clay mineral. They pointed out an inverse relation between sedimentation rate and depth of water column. - study of few lakes from USA.

Davis	1980	Stated that natural organic matter gets adsorbed by the presence of alumium oxide in lake sediments.
Murthy and Veerayya	1981	Revealed the relation between elemental concentration and grain size in Vembanad lake sediments. Fe, Mn, Ni, Cu, Co are directly proportional to organic carbon. Among clay minerals from surficial sediments, kaolinite is dominant with subordinate illite. They related the differential behaviour of elements to biological productivity within a lake.
Damodaran and Sajan	1983	Related higher biogenic activity (i.e. $CaCO_3$ content) to sandy nature of substratum. Also pointed out positive correlation between clay and organic carbon content. High organic matter (av. 8.48%) is related to biogenic productivity. They found a reverse relation between organic matter and biogenic productivity due to high rate of sedimentation, greater depth of water column, salinity and reducing environment - Lake Asthamundy, Kerala.
Knedler *et al.,*	1983	Reported Fe association with montmorillonite in much higher content in fine grained sediments.

Hakanson	1984	Studied the relation between lake sediments and trophic level.
Mallik and Suchindan	1984	Revealed two processes for formation of Vembanad lake 1) initial tectonic phase and ii) Latter Natural sedimentation.
Paez Osuna	1984	Showed that kaolinite is dominant in a coastal lagoon in Mexico. He related variable proportion of illite and kaolinite to varying depositional environment (marine and non - marine). Also related the least presence of montmorillonite to smaller surface area which in turn is responsible for insignificant erosion.
Chikita	1986	Compared surficial sediments with core sediments to determine the origin of sediments - study from Lake Okotanpe, Japan.
Duck	1986	Studied bottom sediments of Loch Tummel, Scotland. Sediments here are organic rich (organic matter av.14.5%). They attempted to study the role of organic matter on grain size and confirmed that organic matter forms coating on all grain sizes but predominantly gets absorbed on finer fractions. Also revealed a positive correlation between loss on ignition and organic carbon.

Dhevendaran *et al.,*	1987	Studied sedimentology of Lake Veli, Kerala and reported that it is clayey in nature.
Kango	1987	Showed that Zn content in Himalayan lakes is more in silt fraction of sediments.
Kango *et al.,*	1987_a	Proved that sediments of Dal lake are rich in iron. Fe and Mn are two mobile elements in aquatic environment. They have high specific area that helps in binding toxic elements and nutrients. They also related the size of sediments to concentration of metal (smaller the size, higher is the metal content).
Kango *et al.,*	1987_b	Showed that illite is dominant in Himalayan lakes and related its presence to mechanical weathering and subsequent erosion. Thus, they ascertained an allogenic origin to illite in freshwater lake sediments.
Johnson and Nicholls	1988	Pointed out three sources of metal to lake - 1) Natural erosion (Background) 2) Point source (from industry) and 3) Atmosphere sources. - study from Lake Simcoe, Canada.
Rao *et al.,*	1988	Pointed out that relative abundance of clay minerals depends on energy condition at the site of deposition as well as individual property of clay mineral.

Rosen *et al.,*	1988	Recorded variable content of organic carbon 9.7% (west) to 0.6% (east) in Pellet lake, Australia.
Schroder	1988	Proved that extensive growth of macrophytes in lake retains fine grained sediments over long period.
Gupta and Pant	1989	Studied sedimentological aspects of Bhimtal lake. U.P.
Koyama *et al.,*	1989	Reported illite as a dominant clay and also high content of Al, Fe, Cr, Co, Ni in sediments of Lake Taupo and Waikaremoana, New Zealand.
Babaluk and Friesen	1990	Studied surficial sediments in Dauphin lake, Manitoba which are mainly clayey silt to silty clay with relatively higher organic carbon.
Sebastian *et al.,*	1990	Detailed the importance of study of organic matter. They related high organic matter to high sedimentation rate and fine size of sediments. - study from Mahe estuary.
Stein	1990	Stated that productivity and flux of organic matter is the dominant factor controlling the accumulation of organic matter and increased preservation of organic matter. High sedimentation rate is of secondary importance, as higher rate results in dilution

		which affects preservation of organic matter.
Urban *et al.,*	1990	Recorded high percentage of organic matter in Nova scotia lake sediments. They also revealed that lakes with pH > 5 are in equilibrium with gibbsite.
Glasby *et al.,*	1991	Observed the relation between organic carbon and finer fraction in sediments of Lake Te Anau, New Zealand.
Pandarinath and Narayana	1991	Pointed out that organic matter content supports the formation of montmorillonite.
Roonwal and Srivastava	1991	Observed that montmorillonite is an important contributor of Fe content in sediments.
Olmez *et al.,*	1991	Suggested the importance of rare earth elements (REE) in tracing anthropogenic input to sediments of lake from California.
Rowan *et al.,*	1992	Stated that sediment organic matter is not related to trophic status and is negatively correlated with sedimentation rate.
Petticrew and Kalff	1992	Proved that extensive growth of macrophytes in lake retains fine grained sediments - a study from Lake Memphremagog, Qubeck.
Radha and Seenayya	1992	Showed that surficial sediments of Hussainsagar lake are polluted with regard

		to heavy metals (Hg, Cr, Cd, Cu and Zn) due to industrial discharge.
Reddy *et al.,*	1992	Reported that Vembanad lake has relatively higher proportion of kaolinite (> 76%). Also pointed out coarser kaolinite nearer to the source than the finer montmorillonite.
Martinova	1993	Proposed the importance of macrophytes and phytoplankton as the sources of organic matter in shallow lakes. They recorded that macrophyte may account for about 1.5 - 2.5 times that of phytoplanktons.
Padmalal and Seralathan	1993	Recorded high content of Fe, Mn, Zn in surficial sediments which are well associated with each other. - study from Vembanad estuary, Kerala.
Varma *et al.,*	1993	Indicated the dependance of trace elements on distribution of clay minerals. Cu concentration is generally less in fresh water environments. Cu is found to be directly proportional to montmorillonite. Ni, Co are found to be directly proportional to Mg indicating detrital origin as well as their close association in the lattice position of clay minerals. Higher content of Cr indicates relatively more presence of

		coarse size material. - study from Vamsadhara basin.
Jauhari and Hashimi	1994	Reported that surficial sediments in Naini lake are clayey with very less spatial variation.
Loizeau and Stanley	1994	Reported that lake Mariut in Egypt is polluted. This is based on a detailed study on surficial and core sediments. They related pollution to domestic, agricultural and industrial discharge into the lake.
Mohan and Rajamanickam	1994	Related high organic matter to grain size and protective action of clays.
El - deek *et al.,*	1995	Studied surface sediment geochemistry of Lake Borollos, Egypt and recorded relatively higher proportion of Fe, Mn, Cu, Zn. and also higher content of organic matter (av. 2.66%).
Bukhari and Nayak	1996	Used clay minerals to comment on provenance and sediment transport.

Sub-surface sediments

De Terra and Hutchinson	1934	Related variation in sediment characteristics of Tibetian lakes to recent climatic changes.
Krishnaswamy *et al.,*	1971	Attempted to measure rate of sedimentation in lakes using ^{210}Pb technique .

Effler *et al.,*	1979	Reported sedimentation rate in Lake Onondaga, New York as 5 - 9 cm/yr which is resulted due to loading of industrially derived Ca. Recorded indirect evidence for upward vertical migration of heavy metals and showed that the lake sediments are Fe contaminated.
Dominik *et al.,*	1981	Used ^{210}Pb data of Lake Constance to calculate nutrient and heavy metal fluxes. They noticed fluxes of Pb and Zn in the same range as in polluted areas of Europe and America and related to anthropogenic influence.
Sabrouti El and Sokkary	1982	Detailed clay study in a core from Lake Edku, Eastern Mediterranean region. They recorded high montmorillonite content due to diagenesis of illite to montmorillonite with depth. They suggested that organic acid is also responsible for such transformation.
Paez-osuna *et al.,*	1983	Reported presence of gibbsite and abrupt change in the relative abundance of kaolinite and illite which they related to transition from oxidising to reducing environment of deposition.
Premazzi *et al.,*	1986	Revealed that about 80% of the lakes in Italy show high degree of contamination

		since 1974 and high enrichment factors for Hg, Cd, Zn due to anthropogenic influences. - study from 13 Lakes.
Provini and Gaggino	1986	Used three important elements Cr, Cu, Zn in sediments of Lake Orta, Italy to reconstruct the historical record of pollution derived from industry. They correlated the concentration with organic matter content and revealed that sediment record follows the record of lake water.
Stiller and Imboden	1986	Pointed out three different sources of ^{210}Pb in lake Kinneret, Israel a) Atmospheric input b) Through river inflow and c) Through decay of ^{222}Rn in water column. The sedimentation rate is variable and ranges from 0.155 cm/yr to 0.496 cm/yr.
Anderson *et al.,*	1987	Pointed out post-depositional mobility of radionuclide and various types of coring devices as factors responsible for affecting the rate of sedimentation by various radiometric methods. - study from Experimental lake area.
Raymahashay	1987	Used montmorillonite as a pollution control based on its diabasic nature. He found it as a decontaminating agent since it removes

		large portion of cationic pollutants compared to kaolinite.
Barten and Torgersen	1988	Recorded the rate of sedimentation in a closed basin -LakeTurkana, E. Africa as 1cm/yr.
Reasoner and Rutler	1988	Calculated sedimentation rate based on sediment thickness of gyttza and underlying clastic inorganic sediments in Lake O'Hara which ranges from 0.05 mm/yr to 0.3 mm/yr.
Shuncai	1988	Studied sedimentation rates in major lakes from China. In Lake Dongting, it is 3.5 cm/yr, in Lake Poyang, it is 2 mm/yr and in Lake Tai, it is 1.7 mm/yr.
Rukavina *et al.,*	1990	Recorded the rate of sedimentation in Lake St. Louis, Canada as 0.5 to 8 cm/yr. Revealed enrichment of Hg, Zn, Co, Cr and related it to an input from point source. They stated that uniform particle size distribution with depth indicate continous and uniform sedimentantion. Great lake sediments showed good correlation between metals and grainsize. Also noticed high Mn content and organic carbon.
Borkar and Pillai	1991	Reported rate of sedimentation in Trombay bay as 3-4 mm/yr. They related this rate to distribution of pollutants. They also

		recorded less Pb activity and related this to loss of surface sediments during coring while irregular variation in the Pb-activity is related to sediment reworking.
Jones *et al.,*	1991	Recorded elevated content of Cu and Zn within top layers in a core from Lake Llangorse and related it to industrial effluents.
Rukavina	1991	Observed the rate of sedimentation in Hamilton harbour, Canada as 0.2 - 0.8 cm/yr. Related the colour variation of sediments with depth to industrial discharge in recent times and in the past.
Sekar *et al.,*	1992	Stated that increase in alkalies indicates intensive soil erosion and biotic activity. High Na, K, Mg content indicate unstable landmass with less vegetal cover. - study from Paradip lake.
Xie *et al.,*	1992	Studied 260 cm - core from Lake Xihu, Antartica and interpreted the plaeo-climate based on interrelations among Cs/Rb, La/Yb ratios in clay fraction of sediment.
Cameron *et al.,*	1993	Pointed out that constancy in sediment accumulation rate irrespective of core sites suggests no disturbance in the catchment area . Also pointed out that, in addition to catchment area and atmospheric

		contamination, response of climate changes to lake processes is equally important. - study from lake Nicholls, Tasmania.
Doran	1993	Observed recent decrease in the rate of sedimentation in Lake Color, Canada to the order of 0.2 mm/yr, earlier it was 0.7mm/yr. He related the decrease to obscuring of a river inflow.
Aqrawi and Evans	1994	Used colour nomenclature to describe the nature of sediments. Organic rich sediments are blackish in colour. Lake sediments are silty (> 60%). Organic carbon content ranges from 0.2% - 20%. Montmorillonite is the dominant clay mineral. Clay content increases with depth. Ni is directly proportional to Al. Ni and Cr content increases with depth. However, they ruled out any possibility of anthropogenic effect.
Barnett	1994	Inferred palaeo-environmental changes based on sand-silt-clay ratio and organic carbon content. He also reasoned out the impact of settlement on mass accumulation rate. - study in Lake Alexandrina, Australia.
Bollhofer *et al.,*	1994	Recorded the sediment accumulation rate 0.16 $g/cm^2/yr$ in Lake Constance, Germany using lead-210 method.

Cornwell and Owens	1994	Revealed that sediments in shallow lakes experience strong bioturbation and show heterogeneity in sedimentation rate.
Das and Singh	1994	Studied the rate of sedimentation in few lakes of Udaipur. Lake Pichola shows 2.80 mm/yr. Such a higher rate is related to increased anthropogenic activity in recent times. This is further proved by relatively higher content of heavy metals within top layers of sediment. Furthermore, they related the fluctuation in metal content with depth to variation in sediment input at different time intervals. They also pointed out the role of organic matter and fine-grained sediments in retention of heavy metals. They reported increase of heavy metal concentrations with depth in Lake Udaisagar.
Das *et al.*,	1994	Recorded the sedimentation rate in Lake Naini, (U.P.)to the order of 11.5 mm/yr and in Lake Bhimtal (M.P.) is 4.70 mm/yr. They related higher sedimentation rate to faster erosion aided by anthropogenic activity. Dal lake has reached a critical stage of disappearance due to high sedimentation rate and eutrophication.

Dilli and Pant	1994	Used clay minerals as pathway for provenance and palaeoclimatic record from Kashmir lakes. Illite and montmorillonite show negative correlation.
Sekar *et al.,*	1994	Studied plaeo-climatic changes in Tsokar lake, Ladakh based on elemental concentration, organic carbon content and minerals present in a core. Organic matter reported is 1.90%. ^{14}C dating has revealed the rate of sedimentation as 9.5 cm/100 yr. Increase in Na, K and Mg and decrease in organic carbon has been related to dry arid climate. Higher content of Fe, Mn indicate sediment deposition in oxidising condition. Lesser content of organic carbon with depth suggest oligotrophic status of a lake.
Das *et al.,*	1995	Reported rate of sedimentation in Naini lake as 1.15 cm/yr . They revealed that such a high rate of input of terrigenous matter dilutes the heavy metal concentration.
Rowan *et al.,*	1995	Stated the importance of core site selection for inferring any palaeo-studies based on ^{210}Pb data. They also tested the utility of deposit boundary depth.
Turner and Delorme	1995	Compared and stated the variability between two models of dating lake

sediments by using ^{210}Pb method (CIC and CRS models) - study from Canadian lake.

Study area

Goa, the 25th state of Union of India is situated between 14°18' & 15°48' N and 74°20' & 75°40' E, along the Central West Coast of India. Goa is known nationally and internationally as a top tourist destination because of its natural beauty of sandy beaches, lush green hills, water bodies, religious monuments, culture and people. Goa is also known at the national level as a leading iron and manganese ore exporter. Bicholim taluka in the north Goa district is the most active mining area, which contributes more than 60% of the total iron ore production of the state.

Goa enjoys a tropical maritime and monsoonal type of climate with profound orographic influence. There are three distinct seasons.

Monsoon (June - September)
Winter (Postmonsoon : October - January)
Summer (Premonsoon : February - May)

The region experiences heavy precipitation brought in by SW monsoonal winds. Rainfall increases from about 300 cm/yr near coastal areas (west) to about 400 cm/yr towards the Western Ghats (east). The diurnal change in temperature is low, being the least (4 - 6°C) during the monsoon to the maximum (10 - 12°C) during summer. The atmospheric temperature changes with season, with the highest temperature (av. 35°C) during summer and relatively lower in winter (av. 20°C). Humidity also varies with seasons.

In Goa, in the recent past, considerable work has been done on the sediment and sedimentary processes within coastal and estuarine ecosystems (Veerayya, 1972; Murty *et al.,* 1976; N.I.O., 1979; Mehta *et al.,* 1983; Nayak and Chadramohan, 1989; D'silva and Bhosle, 1990; Algarsamy, 1991; Nayak, 1993,1994; Bukhari, 1994). On the lacustrine ecosystem of Goa, especially on sediment and sedimentary processes, however, only one work available is that of Nayak (1995). Continuation of this research on sediment and sedimentary processes on lacustrine ecosystem has resulted in preparation of this thesis.

Mayem lake - The crescent shape Mayem lake is situated in Bicholim taluka of North Goa district (Fig. 1.1). It occupies a low lying valley portion at the foothills of mountainous range of Western Ghats. It lies at an elevation of 15 m above mean sea level between 15°34'19" & 15°34'35" N and 73°56' 21" & 73°56'34" E which is about 40 km due NNE from Panaji, the capital city of Goa. The lake being a famous tourist spot, is well connected to townships like Bicholim, Mapusa and Sanquelim by road. It is the only freshwater lake in the state. Bicholim taluka is known for open - cast iron ore mining activity. Though, there is no mining activity within the catchment area of the lake, mine rejects have been and are being dumped.

There is a concrete embankment along the western bank of a lake in downstream direction. The reservoir is being used for domestic and agricultural needs. For this purpose, lake water is channelised through a small peripheral canal along its southwestern border. Based on the trophic status, Mayem lake has been classified as more oligotrophic during monsoon and less eutrophic during fairweather seasons (premonsoon and postmonsoon) (Nayak, 1995).

Objectives

i) To understand the present geomorphic set up of the catchment area as well as lake basin.

ii) To study the distribution pattern of the total suspended matter (TSM) in different seasons and present rate of sedimentation.

iii) To study the spatial and seasonal distribution of sediment component, organic carbon content, clay mineralogy, and major/minor elements in the surface sediments.

iv) To understand the temporal variation in sediment components, organic carbon content, clay mineralogy and major/minor elements.

v) To establish palaeo-depositional environment.

vi) To establish the past rate of sedimentation and compare with the present rate to understand the factors responsible for the change, if any.

vii) To prepare first hand document on Mayem lake and reveal a sedimentation history of the lake.

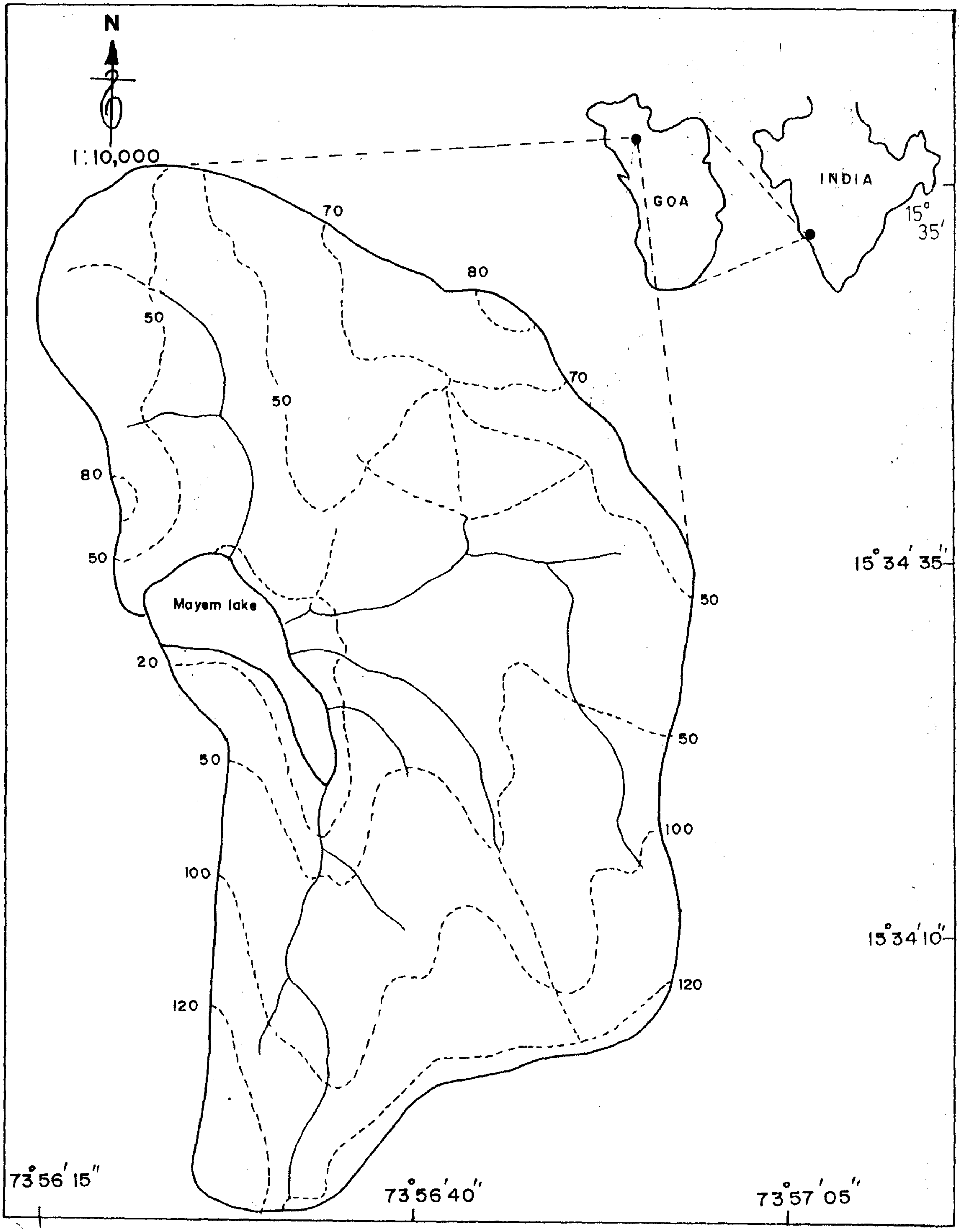


FIG. 1.1 LOCATION MAP OF STUDY AREA

CHAPTER 2

GEOMORPHOLOGY

Geomorphology is the study of relief with special reference to its forms, origin and age, which is produced due to endogenic and exogenic geological processes like tectonic movements, earthquake, metamorphism and weathering, denudation, deposition and diagenesis. In other words, geomorphology is essentially the study of evolution of landforms (Sparks, 1960). The landforms are produced due to the function of geomorphic agents such as wind, glaciers and waters. Each geomorphic agent in a way is peculiar and produces erosional and/or depositional landforms which are characteristic of that agent. It is therefore, possible to establish the origin of landforms although the processes by which they were formed may have ceased to operate. This is possible only because, these agents leave their imprint upon landforms. Lithology, structure and hardness of the rock units are also very important in the study of geomorphology.

In understanding the geomorphology of any aquatic ecosystem, emphasis is mainly laid on morphometric analysis of a drainage basin, since it is a powerful tool in the interpretation of environmental and ecological studies within the catchment area (Rao and Babu, 1995). Drainage basin is an organised segment of a landscape with geometric features that are interrelated (Chorley and Kennedy, 1971) and therefore, it is described as a response system. It provides a convenient and functional unit for the description of landforms and the measurement of inputs and outputs of energy and water. The input takes the form of thermal energy from the sun and kinetic energy from precipitation while the outputs are essentially water, sediment and dissolved solids all of them are in equilibrium in natural ecosystem

(Strahler, 1964). Thus, the proper use of a drainage basin is of vital importance to safeguard the environment (Sparks, 1960).

The most notable basin characteristic susceptible to changes is the drainage network. Drainage network of a catchment area is an inherent property of an underlying rock type. Quantitative analysis of a drainage network gives clues on the sedimentary processes operating within the system and on the rate of sedimentation and therefore, helps in the identification of sites of sediment deposition. Bottom topography of a basin is a function of the nature of sediment and its constituents that get deposited. For example, deposition of finer sediments (silt to clay size) result in a gentler gradient as against the coarser sediments which generally reflect the steeper gradient.

Parameters related to the catchment area

The drainage network can be studied by dividing the drainage basin into three geomorphic components which help to describe the morphometry of the basin. Morphometry, in turn, helps to understand the drainage network.

The three components are :- a) linear b) areal c) relief elements.

i) Linear drainage basin characteristics

The linear drainage basin characteristics namely - stream order, stream number, stream length and bifurcation ratio describe the stream network in a drainage basin. Stream order is directly proportional to the size of contributing watershed (Strahler, 1952), channel dimensions and stream discharge at a given place. Stream numbers of each order, form an inverse geometric sequence with its order number. Stream length reveals the characteristic size of a component of a drainage network and its contributing basin surface. Bifurcation ratio is the ratio of number of streams of any given order to the number of streams in the next lower order (i.e. Nu/Nu+1) and it indicates the watershed geometry (Strahler, 1957). It ranges between 3.0 to 5.0 for watersheds wherein geological structures do not distort drainage pattern (Horton, 1945). Although these parameters have no physical significance (Richards, 1982), they are used as measures to compute geometric parameters and interrelations among them especially help to give a more correct picture of the network development and anomalies therein.

ii) Areal drainage basin characteristics

Areal drainage basin characteristics namely - drainage area, stream frequency, basin shape and drainage density are related to both stream flow and sediment yield. *Drainage area* (A) is important as a hydrological integrator for run-off and sediment yield. *Stream frequency* (F) is defined as number of stream segments of each order per unit area.

$$F = \Sigma N_u / A$$

Morisawa (1959) described the basin shape on the basis of two ratios : a) circularity ratio (R_c) - Miller (1953) b) elongation ration (R_e) - (Schumm, 1956). *Circularity ratio* is the ratio of basin area (A_b) to the area of the circle (A_c) having the same perimeter.

$$R_c = A_b/A_c$$

The circle provides a maximum area with a minimum perimeter (i.e. $R_c \cong$ unity), while, an oblong basin will have a larger perimeter but small drainage area.

Elongation ratio is the ratio of diameter of a circle (A_d) with the same area (A_c) as basin and the maximum length of the basin (L_m).

$$R_e = A_d/L_m$$

These two parameters show a significant correlation with rainfall to run-off ratio, thus they are related to hydrographic characteristics of stream flow. The lag time or a time for a concentration of flow from tributaries to the main channel is less in circular basins than it is in long or narrow basins. Thus, a unit value indicates perfect circular shape while lesser the value, more is the oblongate shape of the basin.

Drainage density (D_d) is defined by Horton (1932) as the total length of streams (ΣL) within a basin divided by the drainage area (A).

$$D_d = \Sigma L/A$$

This parameter is an expression of dissection of a basin by streams and is related to rock and soil type, vegetation, climate and infiltration. Relatively higher density is obtained for the basins underlained by finer sediment than the basins underlained by coarser sediment. Thus, the drainage density depends on the porosity and permeability of the rock type and thereby, its infiltration capacity. It also indicates closeness of spacing of channels. Schumm (1956) used the inverse of drainage density as a property termed as `*constant of channel maintenance*' (c).

$$C = 1/D_d$$

This is related to the number of square units of watershed surface required to sustain one linear unit of channel, thereby suggesting a underlying lithology.

Horton (1945) suggested a term, *length of overland flow* (l_o) which is a distance that water flows over the ground surface before it is concentrated in a stream channel. This gives a rough estimate about the hillslopes. Lesser the value, steeper is the hillslopes. As average length of overland flow is generally half the distance between stream channels, it is roughly taken as reciprocal of twice the drainage density.

$$l_o = 1/(2\ D_d)$$

iii) Relief drainage basin characteristics

Relief characteristic namely - *relief ratio* (R_r) - (Schumm, 1956).

$$R_r = R/L$$

Where,

R = Difference in the elevation between the mouth of a basin and headwater divide.

L = Maximum length of the basin across the water divide which is measured essentially parallel to principal channel.

Relief ratio of a drainage basin helps to understand gradient, slope of a stream channel in a short reach, as well as angle of valley-side slopes. Relief is a simple measure of a basin slope and is an indicative of potential energy of a drainage system, by virtue of elevation above a given datum.

Thus, it is an expression of relief of drainage basin in two - dimensional form - elevation and distance; thereby measuring overall steepness of a drainage basin. It is an indicator of the intensity of the erosion processes operating on slopes of a basin.

Melton (1957) used relative relief in %

$$Rhp = 100\,H / 5820\,P$$

Where, H = maximum basin relief

P = Basin perimeter.

This parameter is better correlated with hydrological characteristics of a basin. It has a direct relation with run-off and amount of sediment yield. Thus, indirectly suggesting the nature and extent of erosion.

Another method of studying relief is by using a hypsometric curve that relates elevation of basin area in three - dimensions (Strahler, 1957). It determines the three dimensional surface of the drainage basin which is located between the cross section bounded by contour lines. Hypsometric integral (f), expressed in percentage, indicates eroded/uneroded volume of the basin. For natural basins underlained by homogenous material, it ranges from 40% to 80%, higher values indicate lesser erosion from the area.

To study the relationship among elements of climate, surface properties and geomorphology, Melton (1957) used *Thornthwaite precipitation - effectiveness index* (P-E index) as a variable in correlations with several morphometric factors. P-E index is a measure of availability of moisture to vegetation and depends on the amount and distribution of both, precipitation and evaporation. P-E index along with soil type, determines infiltration capacity of an area and is inversely proportional to drainage density (Melton, 1957). Thus, higher the P-E index, lesser is the drainage density, and relatively more is the availability of moisture to vegetation. P-E index, therefore, indirectly determines the quantity of rainfall.

Parameters related to the basin

i) Index of shoreline development

It measures the degree of irregularity of a shoreline of the lake. Thus, it illustrates the relation between circumference of the lake basin and the circumference of a circle with an area equal to total lake area. This in turn describes the shape of the lake basin. A unit value represents a circular shape, while higher values represent irregular shape for the lake basin.

ii) Relative depth

This is an important parameter in the study of the basin. It is expressed in percentage and is defined as the ratio of maximum depth to mean diameter of the lake basin. This parameter summarizes the effect of basin morphology on the pattern of water circulation (Goldman and Jassby, 1990).

GEOMORPHOLOGY OF STUDY AREA

Geomorphology of the study area is carried out with respect to two aspects - its catchment area and its basin, to understand the lake ecosystem as a whole. An attempt is made to describe geomorphic characteristics of catchment area by using the above parameters. While, morphology of a lake basin is studied with special emphasis on its bathymetry.

Such a study has been carried out for the first time in a small tropical lake ecosystem namely, Mayem lake.

a) Catchment area

This section describes the various morphological characteristics of the catchment area of Mayem lake.

As mentioned earlier, Mayem lake, in Bicholim taluka of North Goa district is located 15 m above mean sea level (Fig. 2.1) and occupies a narrow valley portion at the foothills of low lying undulating mountainous range of Western Ghats that trends in NW - SE direction. The hill range here, attains maximum elevation of about 125 m above mean sea level with moderate to steep slopes and is covered with moderate vegetation along eastern and southern portion. Along the northern portion, vegetation is very sparse indicating little or no soil cover where mine rejects are being dumped. From this region, the lake receives major surface run-off through an ephemeral stream during monsoon which runs across the area. Old mine dumps are also seen due northeast of the lake. The lake has a catchment area of 2 sq. km and perimeter of 5400 m. Maximum length across the catchment area is 2000 m and maximum height within the catchment area is 125 m above mean sea level.

The lake is fed by four ephemeral streams along its eastern border which show a maximum of third order of numbering and indicates a dendritic drainage pattern.

Methods

Geological mapping

Geological surface outcrop mapping of the catchment area of the Mayem lake was carried out using a base map of 1 : 15,000 scale.

Morphometric analysis

As a pre-requisite to morphometric analysis, a drainage network map was prepared by superimposing the drainage basin map on the topographic map using toposheets 48 E/14 and 46 I/2 which is presented in figure (Fig. 2.2). The morphometric parameters are calculated accordingly, for the catchment area of Mayem lake.

Results and Discussion

i) **Linear drainage basin characteristics** : The parameters calculated are listed below.

Stream order u	Stream Number Nu	Mean length in m. Lu	Mean Bifurcation ratio Rb Nu/N_{u+1}	Mean length ratio Rl	Mean basin area for each order Au (Sq. km.)
I	13	328.80	3.25		0.076
II	4	232.50	3.6	1.31	0.34
III	1	450	4.0		1.30

ii) **Areal drainage basin characteristics** : The parameters computed for Mayem lake are given below.

a) Drainage area - 2 Sq. km.

b) Stream frequency - 8.5 / Sq. Km.

c) Basin shape -

i) Circularity ratio - 0.42 for lake basin.
0.86 for catchment area.

ii) Elongation ratio - 0.53 for lake basin.
0.79 for catchment area.

d) Drainage density - 2.82 Km / Sq.km.

e) Constant of channel maintenance - 0.35 Km / Sq.km.

f) Length of overland flow - 0.17 km

iii) Relief drainage basin characteristics : Relief ratio calculated for Mayem lake drainage basin is 0.0525 and the hypsometric integral computed is 40%. Precipitation - Effectiveness index calculated for the basin using its drainage density and a standard curve (Melton, 1957) is 150.

The parameters calculated to understand the linear drainage basin characteristics namely stream number, stream length and drainage area are plotted against stream order (Fig. 2.3). These plots agree with the laws of drainage composition, namely - law of stream numbering (with inverse relation to stream order), law of stream length and law of drainage area (with direct relation to stream order), as expressed by Horton (1945). But these interrelations do not help in revealing significant information on stream network develpoment and anomalies therein, possibly because Mayem lake basin is a relatively small drainage basin with stream network of a maximum upto third order. Stream frequency and length of overland flow obtained clearly indicates that the hill ranges within the catchment area have moderate to relatively steep slopes, which is also supported by relief ratio obtained for the basin. Circularity and elongation ratios calculated show oblongate shape of a lake basin and near circular shape for its catchment area.

Zernitz (1932) and Miller (1953) related drainage pattern to the lithology. Dendritic drainage pattern present in the catchment area of Mayem lake clearly suggests presence of homogenous lithology. This is supported by a relatively lower value of hypsometric integral (40%) obtained. Drainage area indicates hard and relatively resistant rock types of the catchment area. This is also confirmed by hypsometric analysis, wherein, it indicated a monadnock phase (old stage) of erosion cycle when the values obtained are compared with a standard curve of the erosion cycle (Strahler, 1952). This in turn, clearly indicates the final phase of the weathering process acting upon the rocks of the catchment area i.e. laterites, which are the only surficial lithounit within the catchment area. The detailed geological surface outcrop mapping of the catchment area shows the presence of altered banded hematite quartzites, ferrugenous and limonitic quartzites which are more resistant than ferrugenous phyllites and occur at lower levels. These rock units are capped by hard, compact and at places vesicular laterite at higher elevation (Fig. 2.4). These lithounits belong to Bicholim formation (Goa Group) of Dharwar Supergroup of Archaen to Proterozoic age (Gokul *et al.,* 1985). There are no mines and mining activity within the catchment area, however, mine rejects have been and are being dumped in some portions of the catchment area. The locations of which are also shown in a prepared geological map (Fig. 2.4).

All the streams present in the catchment area are ephemeral in nature. Field survey carried out during non-monsoon season, premonsoon in particular, revealed the presence of springs at the lower levels of these stream channels. Presence of springs indicate the intersection of groundwater table, which are sources for lake water during non-monsoon season.

Precipitation-effectiveness index calculated indicates highest degree of precipitation within the catchment area and hence a sufficient availability of moisture for vegetation. Rainfall is more significant in controlling the magnitude of sediment yield. Walling and Kleo (1979) established a relationship between mean annual precipitation, run-off and sediment yield. However, their further studies have shown that this relationship is affected by factors such as relief, soil characteristics, seasonality of precipitation and magnitude of human activity. For smaller basins, such as Mayem lake, sediment yield is taken as approximately equal to gross erosion in the catchment area due to a lack of availability of valley floor and flood plain development in headwater area. The gross erosion in case of Mayem lake is low as indicated by calculated hypsometric integral. In addition to the lithological characteristics and ephemeral stream network, topography including hill slope and stream gradient (Fig. 2.5) are also responsible for such a low erosion. In areas of homogenous lithology, the simple measurement of relief ratio is useful in estimating sediment yield. Annual sediment yield calculated by this method for the catchment area of Mayem lake is 619.13 m^3 / sq. km. This is obtained from the standard curve, sediment accumulation v/s relief ratio (Hadley and Schumm, 1961).

b) Lake basin

Mayem lake is a land locked basin with a surface area of 55,000 sq. m. The lake was initially formed due to impoundment of water in a natural, geologically controlled depression. As mentioned earlier in chapter one, a concrete embankment constructed along its western bank limits the extension of the lake in the downstream direction against a plain (see Fig. 2.1). Other important physical dimensional parameters of the lake are -

Maximum length - 500 m

Maximum width - 225 m

Perimeter of the lake basin (i.e. shoreline length) is 1275 m.

Index of shoreline development is 1.53.

The relative depth calculated for Mayem lake is 2.46%.

These parameters help to classify this lake as a small, closed lake with an irregular shape. The depth of water column obtained from monthly observations (Nayak, 1995) ranges from av. 2.75 m during fair-weather seasons (non-monsoons) to av. 5.25 m during monsoon and shows a maximum fluctuation of 3.5 to 4 m.

Materials and Methods

Detailed mapping of the bottom topography was carried out using dual frequency echosounder, Echotrack DF - 3200 coupled with precise positioning with Motorola miniranger, MRS III.

Echosounder, an instrument that works on a principle of sound waves and is made up of two parts - a transducer and a recording unit. A conical shaped acoustic beam is sent from an array of transducers. This beam reaches the sub - bottom which reflects back and is received by the same transducers. Miniranger-MR III is the electronic position fixing system that works on C - band and on a line of sight principle. The basic system comprises of a Range console and Omni directional transmitter/receiver antenna to be fixed on a mobile vessel and upto four reference stations to be fixed on known onshore locations. When the system is in operation, the mobile station transmits the radio signals at 5570 MHz frequency, the shore stations reflect these at 5480 MHz frequency, which are then received by mobile station. The time elapsed is converted into a distance traveled by a range console and a distance to any two selected shore stations are displayed. The miniranger has an accuracy within 3m and range of about 70 Km.

In the present study, the echosounder was set at the higher frequency of 210 KHz and lower frequency of 24 KHz. The lower frequency provides the certain degree of sub-bottom penetration and higher frequency provides the best resolution. The chart scale is chosen according to survey requirements. A bar check was carried out before starting the survey to calibrate the echosounder. The study area being shallow, range of scale of echosounder was chosen between 0 and 10 m. For the position fixing, four reference stations were selected within the catchment area of the lake. The ranges of distance obtained from these reference stations were plotted on a lattice chart every minute to obtain the position of survey vessel and to monitor the boat track. For this study, motorised boat from Captain of Ports, Panaji, Goa was used. Systematic study was done through parallel traverses, spaced sufficiently close enough to portray the minute possible details of the lake bottom (Fig 2.6). In a broader portion of the lake, survey lines were run parallel to NW-SE (Nos. 1-1 to 15-15) and cross traverses were run perpendicular to it (Nos. E-F to I-J). While, in a elongated portion of a lake, survey lines were run in NE-SW direction (Nos. 16-16 to 28-28) and cross traverses were run perpendicular to it (Nos. A-B to C-D) The position of these tracks were constantly monitored via four base reference stations along the bank of the lake.

Two way travel time of a acoustic signal was recorded on a chart paper affording an analog representation of a water depth along these tracks. Echograms were digitised and a bathymetry map was prepared with a isobath interval of 50 cm (Fig. 2.7).

Results and Discussion

Based on the configuration of the isobaths, Mayem lake basin is divided into two sub-basins.

a) Outer reservoir segment (trending NE - SW) depth ranging from 2.2 m to 6.4 m.

b) Inner valley portion (trending NW - SE) depth ranging from 2.4 m to 5 m.

These two sub-basins are separated by a rock body that forms a prominent bathymetric feature in the middle across the lake.

i) Outer reservoir segment

The lake bottom is broader in this portion with gentle gradient along NE portion where ephemeral streams join the lake and comparatively steeper gradient along SW portion due to the construction of a concrete embankment.

The lake basin here, is filled with thick layer of fine sediments as envisaged by the depth of penetration of acoustic wave in the form of a echogram. It indicates 1 m penetration in deeper areas namely central portion to more than 2 m penetration in the shallow zones. This clearly reveals deposition of large quantity of unconsolidated material along eastern bank than the western dammed bank.

The feature revealed was the presence of delta-like structure at the confluence of the stream, along the northern corner of the lake. This must be the result of supply of sediment laden waters during monsoon by a relatively large stream which joins the lake at this point. The gentle and uniform gradient of the lake bottom around this delta-like structure also suggests gradual transport of sediment material to the deeper portion of the lake from this point. Blais and Kalff (1995) have related bathymetry to pattern of sediment movement in Qubec lakes.

Towards southeast, the outer reservoir segment converges towards the inner valley portion forming a funnel shaped feature.

ii) Inner valley portion

This portion of the lake is narrow and elongated. It has a uniform and gentle gradient along the western side and relatively steeper along the eastern. It is important to mention here that major portion of the segment, especially southeastern extreme, remains virtually isolated and cut-off from the main water body during premonsoon. This segment is also shallow and therefore, might indicate the undisturbed sites along the lake bottom. The present study has clearly identified sediment pockets within the inner valley portion.

It is clear from the present study that the entire area of a lake basin is an active site of sediment accumulation. The sediment distribution and sedimentary processes operative within the outer and inner reservoir segments of the lake basin indicates that the sedimentary processes are controlled to a large extent by a prominent bathymetric feature present in the middle across the lake (Fig. 2.8). The study also revealed that bottom topography originated by the nature of geological structure is being modified by sediment input, its distribution and finally deposition. Modification of bottom topography by sediment input and processes are observed earlier in lake Naini by Rawat (1987) and Hashimi *et al.,* 1993). In the present study, delta-like feature observed at the confluence of the stream along the northern corner of the lake strongly supports this observation.

An attempt is also made in the present study, to relate bathymetry (gradient) to the size of the sediments. Gentle gradient observed along the eastern bank within Mayem lake can be related to accumulation of finer sediments and relatively steep gradient to the presence of coarse sediments along the dammed western bank (Fig. 2.9).

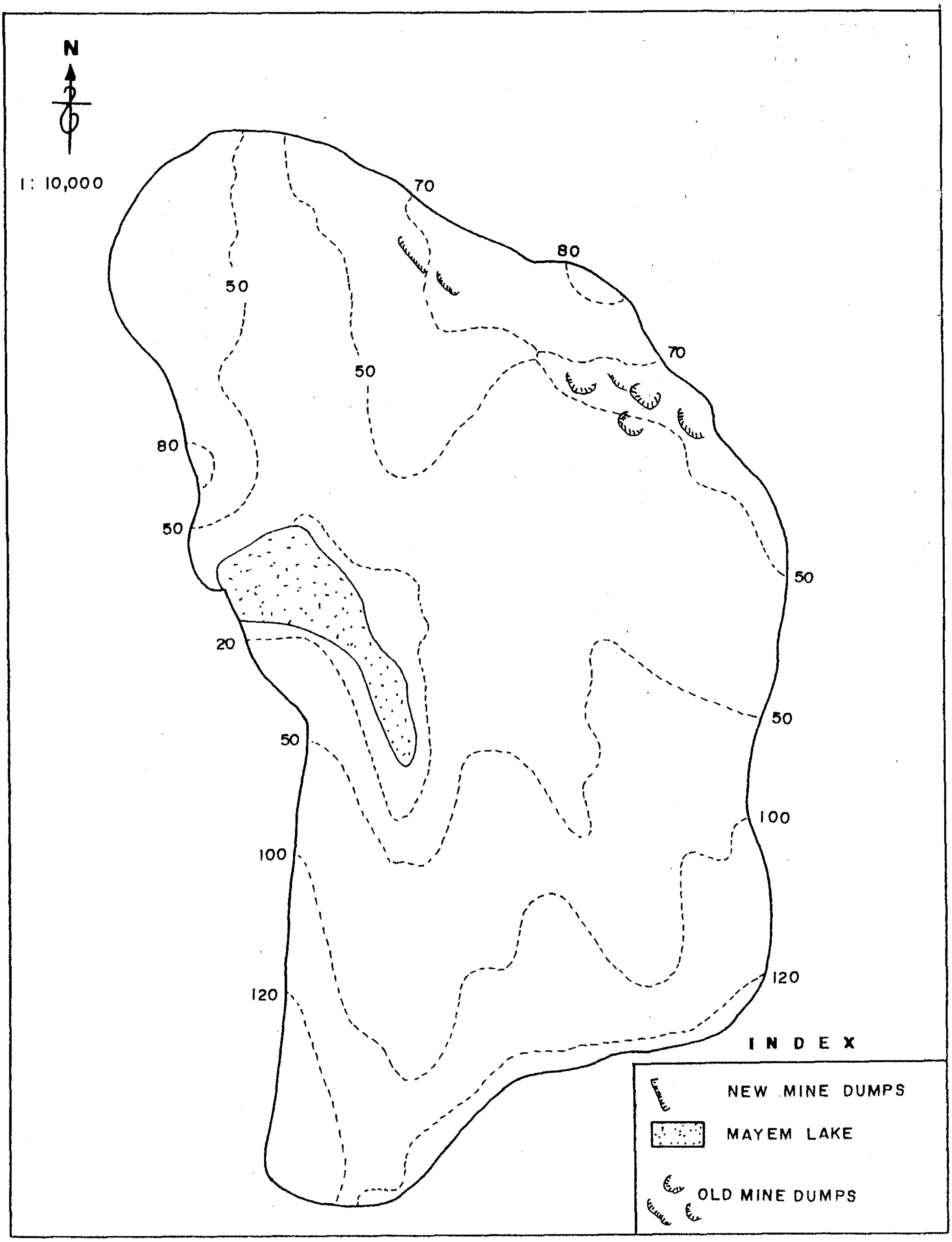


FIG. 2.1 MAYEM LAKE WITH ITS CATCHMENT AREA

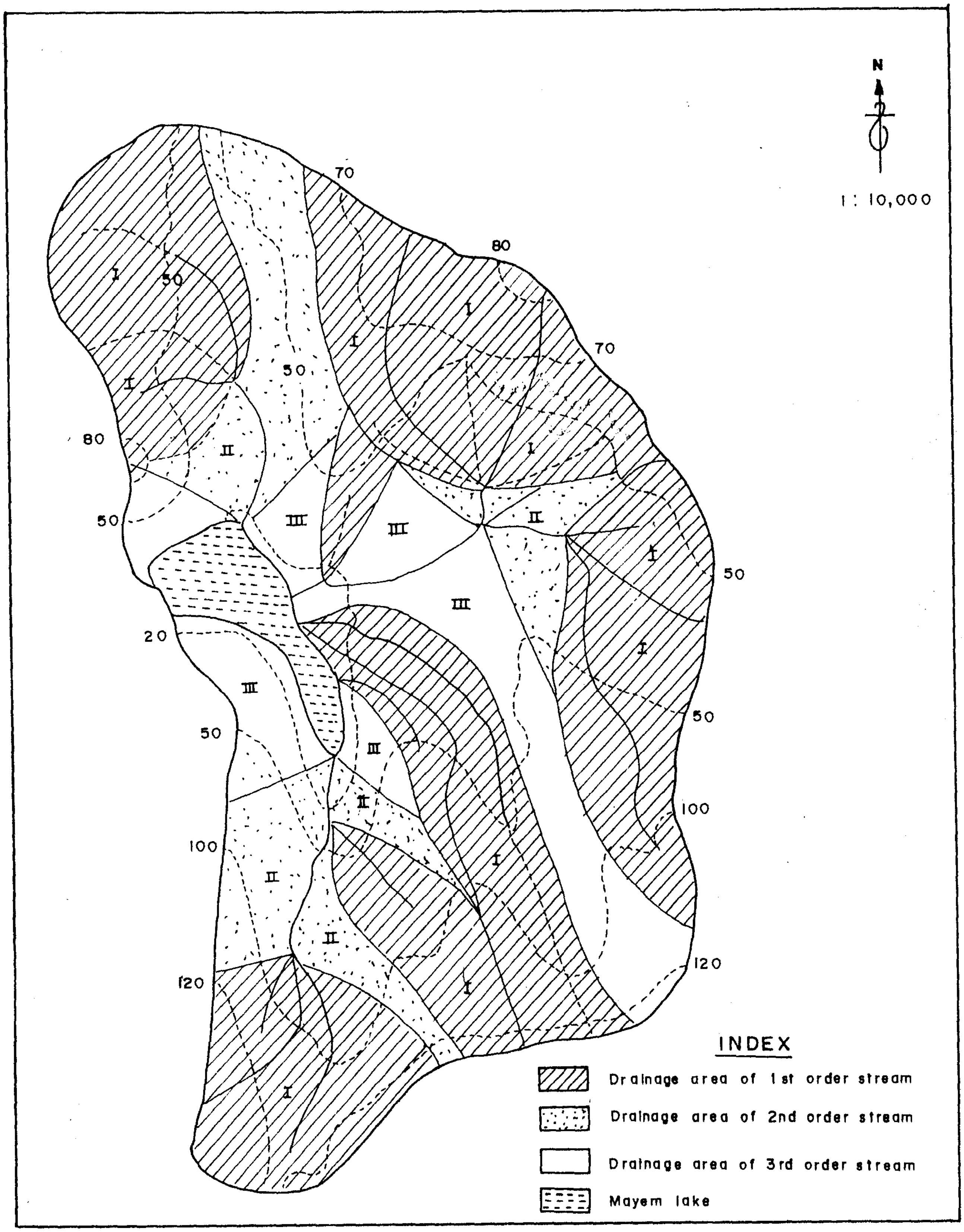


FIG. 2.2 DRAINAGE NETWORK MAP OF THE CATCHMENT AREA OF MAYEM LAKE SHOWING DEMARCATION OF DRAINAGE BASIN AREAS OF EACH ORDER

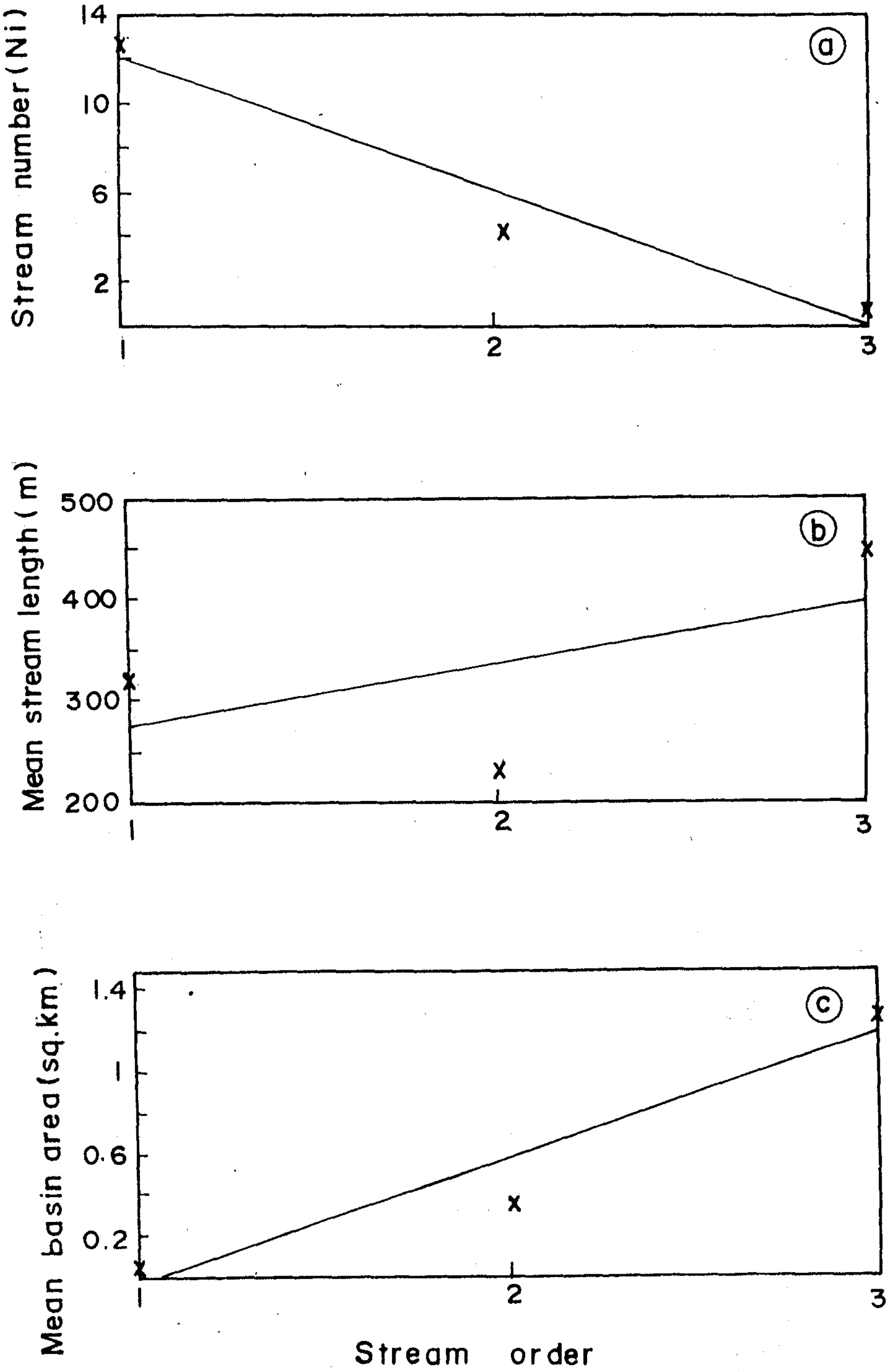


FIG. 2.3 GRAPHICAL REPRESENTATION OF a) STREAM ORDER V/S STREAM NUMBER. b) STREAM ORDER V/S STREAM LENGTH c) STREAM ORDER V/S MEAN BASIN AREA

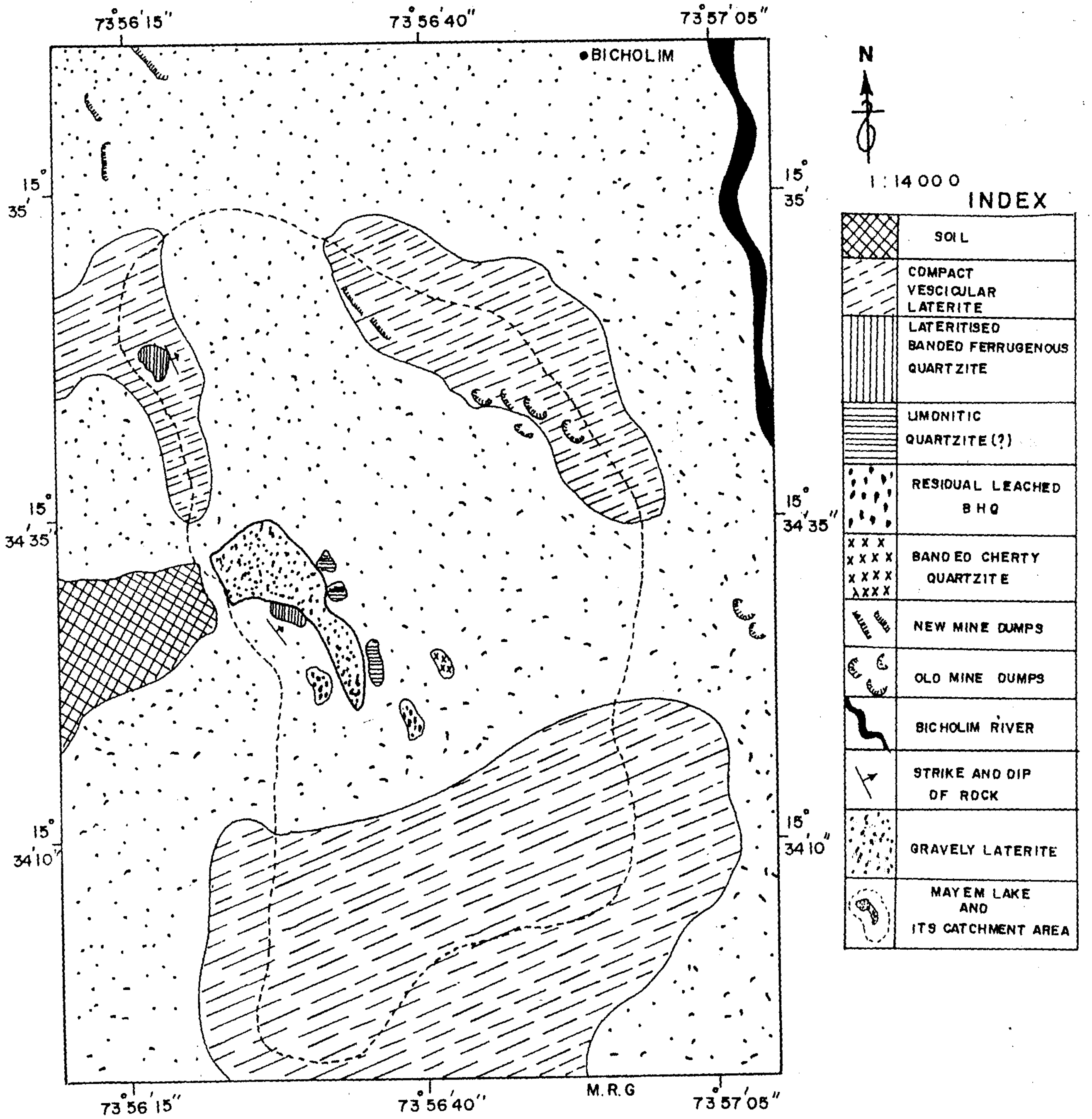


FIG. 2.4 GEOLOGICAL SURFACE OUTCROP MAP OF THE CATCHMENT AREA OF MAYEM LAKE

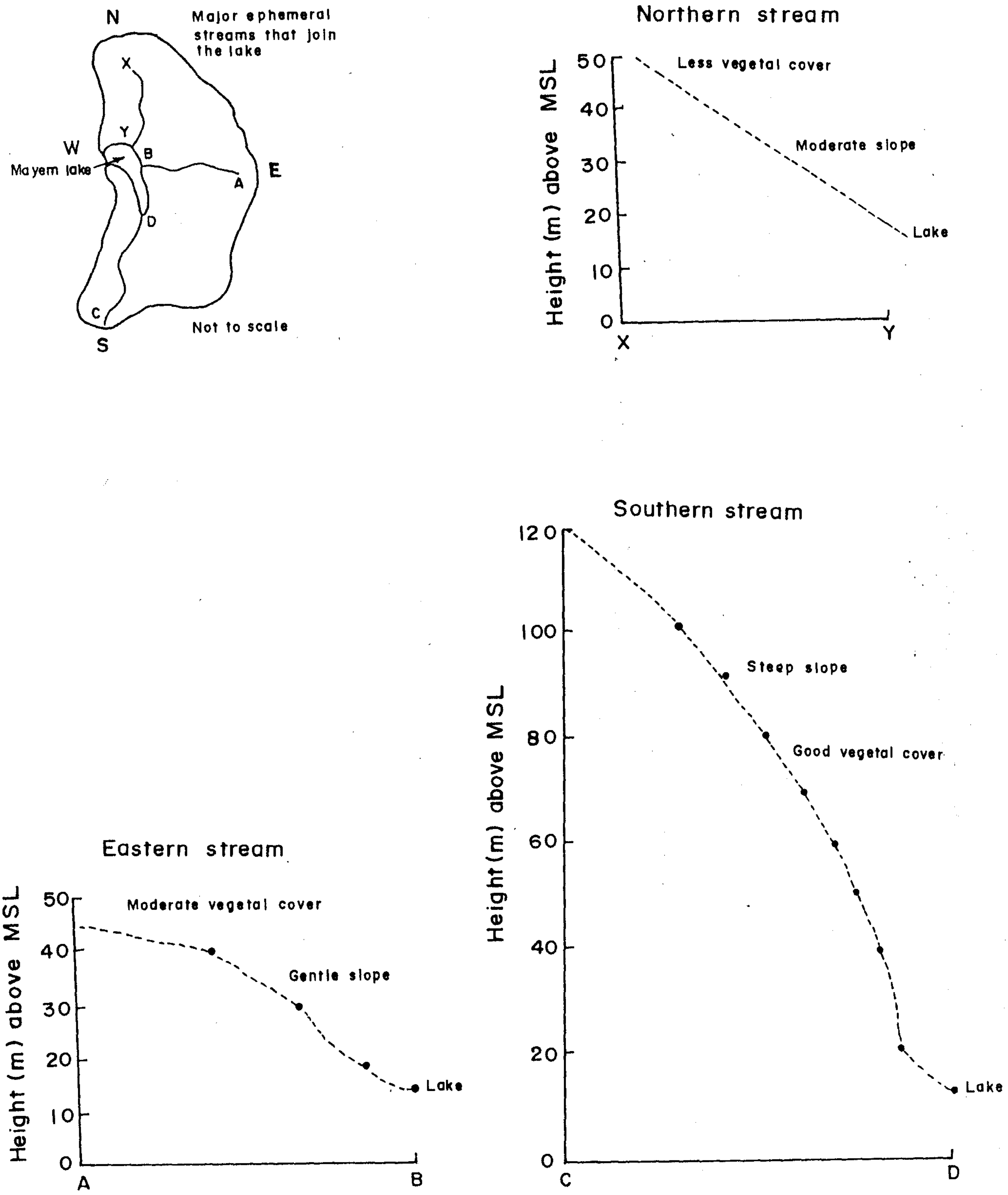


FIG. 2.5 RELATIVE RELIEF OF THE AREAS THROUGH WHICH MAJOR EPHEMERAL STREAMS RUN TO JOIN THE MAYEM LAKE

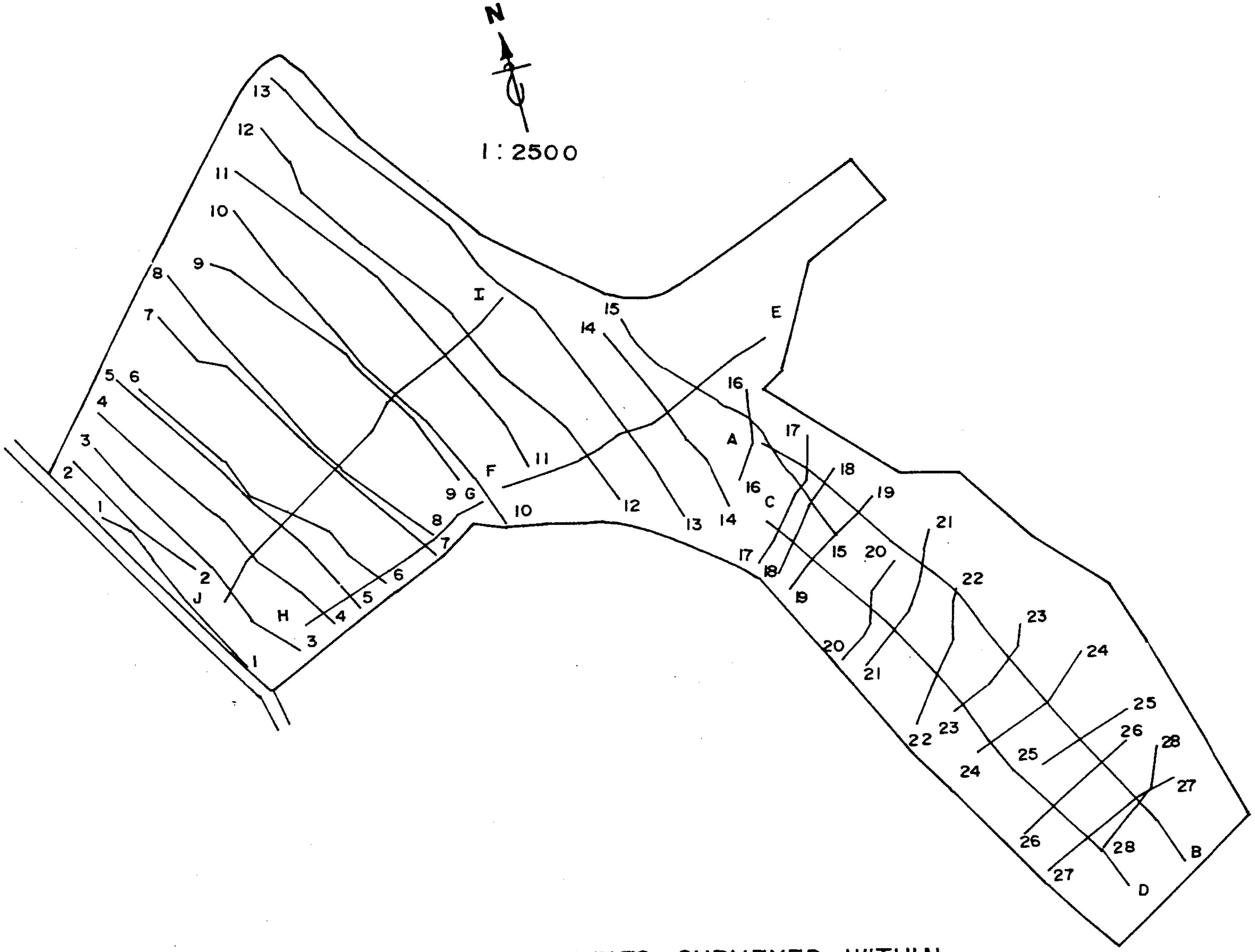
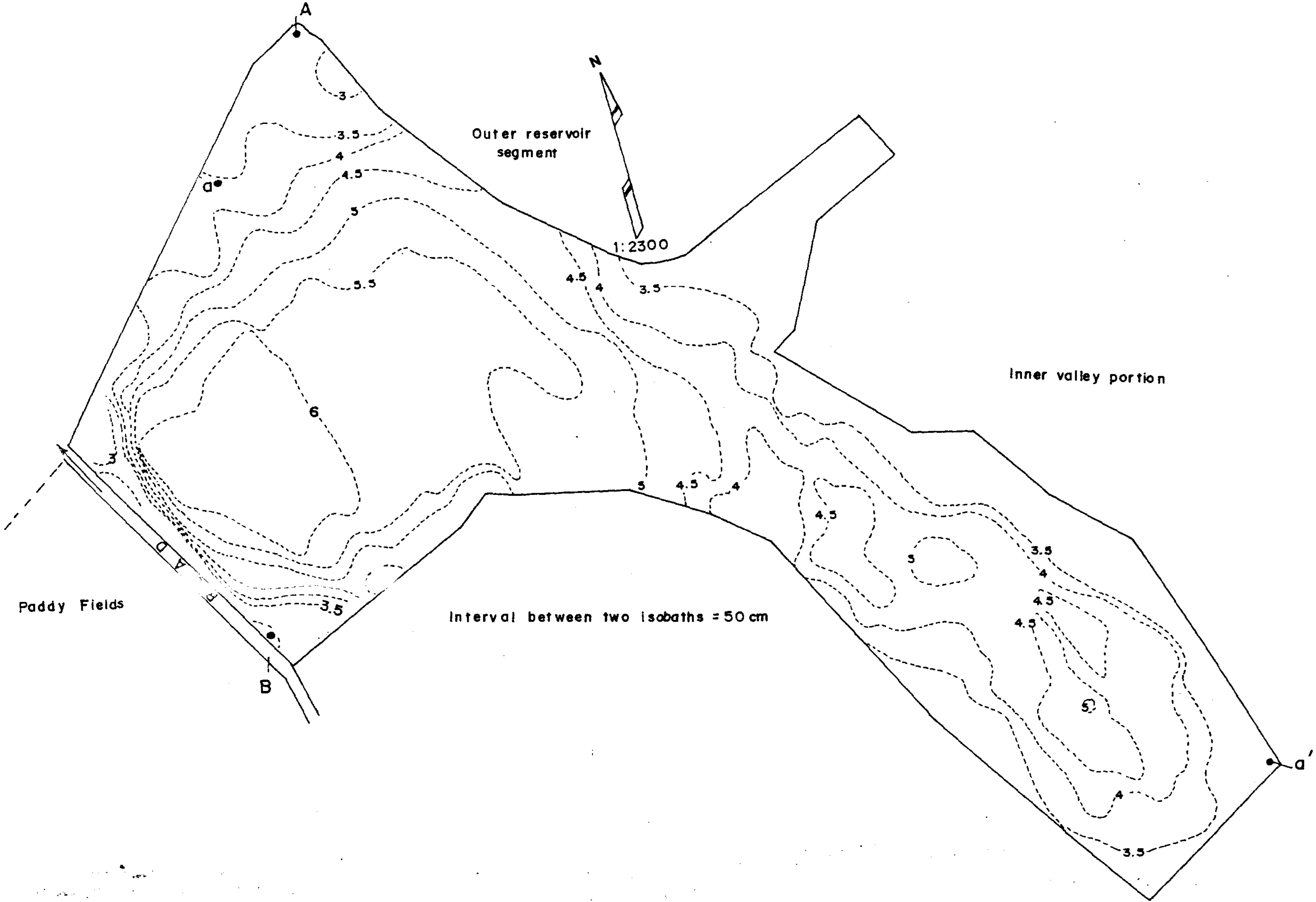


FIG. 2.6 MAP SHOWING THE TRAVERSE LINES SURVEYED WITHIN MAYEM LAKE



Interval between two isobaths = 50 cm

FIG. 2.7 BATHYMETRY MAP OF MAYEM LAKE

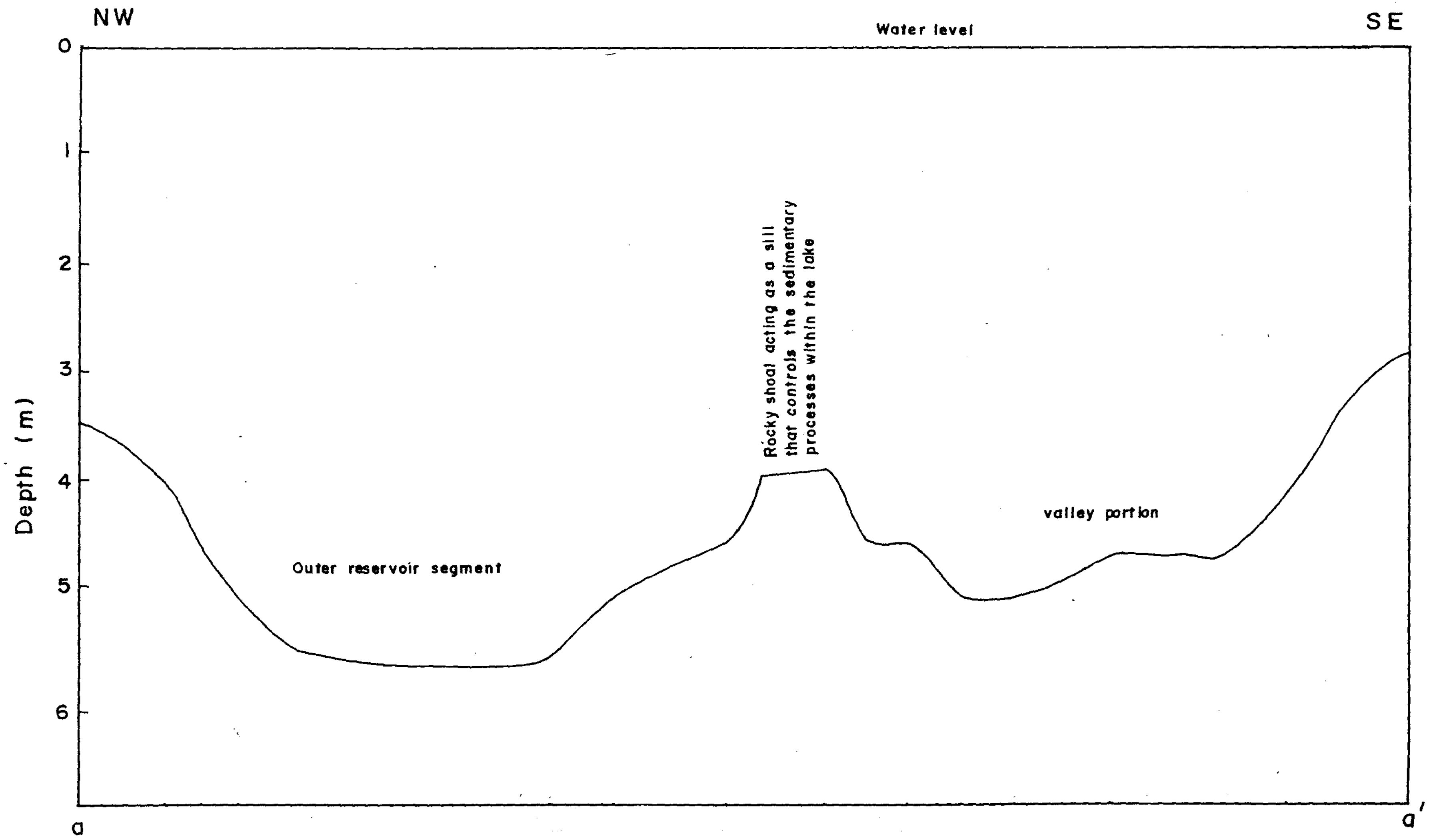


FIG. 2.8 BOTTOM TOPOGRAPHY DUE N - S ALONG a - a′ REVEALING PRESENCE OF ROCKY SHOAL WHICH SEPARATES INNER VALLEY FROM OUTER RESERVOIR

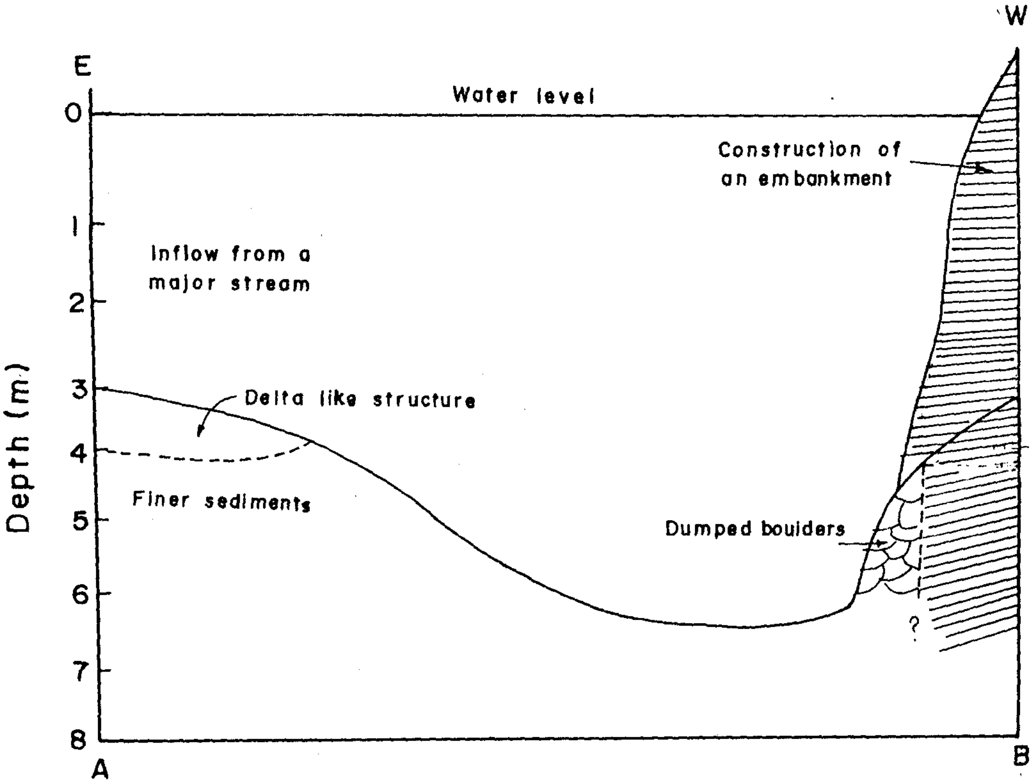


FIG. 2.9 BOTTOM TOPOGRAPHY DUE E-W ALONG A-B DEPICTING THE GENTLE SLOPE TOWARDS THE WEST AGAINST A STEEP SLOPE FORMED DUE TO A CONSTRUCTION OF CONCRET EMBANKMENT

CHAPTER 3

SEDIMENTOLOGY

Sedimentology, a term proposed in 1932 by Wadell, can be defined, in most simple words, as a scientific study of sediments with special reference to sedimentary deposits and their genesis, sedimentation and depositional environment. It is applied to various types of formations; ancient as well as recent, marine as well as terrestrial. It is based on the observation of numerous and intricate features of sediments in natural sequences with the goal of reconstructing their original environment.

Sediments are complex mixtures of a number of solid components like clays, silica, organic matter, metal oxides, carbonates, sulphides and bacterial population (Tippings, 1981). The components of the sediment are perhaps the most sensitive indicator of the type and the extent of reactions that take place between sediment particles and overlying waters (Odum, 1971) in any aquatic environment. Lacustrine environment is one such environment wherein type and extent of reactions between sediment and overlying water will be different from other environments as lake bottoms have been recognised as a continuous depositional site of materials that are transported from its catchment area. Lakes, in general, are also known for enrichment of fine grained sediments. Lake sediments, based on source can be divided into two types : firstly, allogenic sedimentary material derived from outside the lake and secondly, authigenic sedimentary material formed within the lake bottom due to changed physical / chemical environment as a result of decomposition of buried organic matter and / or physical mixing caused by bottom dwelling organisms.

Thus, the formation and behaviour of lacustrine sediments are dominated by interaction of number of physical processes particularly the form of a basin, its orientation and size as well as climatic conditions (Sly, 1978). Wind or stream flow and heating due to atmospheric temperature are principal driving forces for distribution and variation in sediment characteristics.

The study of sediments in the lake ecosystem in the present study has been divided into three major components namely -

i) Sediment in water column i.e. Total suspended matter - (TSM)
ii) Surface sediments
iii) Sub-surface sediments

Part A

Sediment in water column (Total Suspended Matter -TSM)

Sediment in water column i.e. Total suspended matter (TSM) is defined as the material that is retained on a 0.4μ - 0.5μ pore size filter (Eisma, 1993). Suspended matter is present in all the waters of the world. Its concentration may be in very small amounts, as in case of crystal clear waters, but detailed investigations have indicated presence of at least some concentration of TSM in such waters. Because of this, and due to its significant physico-chemical properties, TSM forms an integral part of sedimentological, geochemical and biological studies in aquatic environment. Within the aquatic ecosystem, TSM is a parameter that affects transparency and in turn, productivity. Virtually TSM to the aquatic ecosystem is supplied either by terrestrial erosion, or through products of organic matter, biogenic carbonate and biogenic opal. Similarly, authigenic TSM is important when geochemical processes taking place at sediment-water interface are considered and cosmogenic TSM in the reconstruction of cosmic events.

In lacustrine environment, TSM concentration determines trophic status. Supply of TSM to lakes comes from surrounding land, from biological production and chemical precipitation in the lake itself. Atmospheric input may also become an important factor in selected areas. In shallow lakes, in general, relatively higher concentration of TSM is present in bottom waters compared to surface waters (Gons and Kromkamp, 1984). A reverse trend is reported in relatively deeper lakes influenced by turbidity currents and salinity gradient. (Smith *et al.,* 1989).

Concentration of TSM in a lake is due to combined result of one or many of the following factors :

a) Smaller ratio of lake area to its catchment area coupled with intricate streams / rivers network.

b) Resuspension caused by wind, waves and currents.

c) Changes in physico-chemical characteristics of water i.e. salinity, Eh-pH and temperature.

d) Anthropogenic disturbance within a catchment area.

e) Geochemical processes taking place at sediment-water interface and resulting turbulence.

The easiest and indirect method to determine the suspended matter concentration in lakes is by measuring the relative transparency, either horizontally - with a beam transmissometer (Peterson, 1934) or a nephlometer or vertically by measuring the penetration of sunlight using a Secchi disc (Forel, 1877). The direct measurement of TSM concentration is by water sampling followed by filtration process (McCave, 1979).

The review of literature has shown that there are very few studies on TSM and their dispersal in lake ecosystem. An attempt is made in the present study to understand TSM distribution and its seasonal variation in a shallow Mayem lake using direct measurements.

Methodology

Fourteen representative stations were selected for the sediment study considering size and shape of the lake and also distribution of streams joining the lake. Water samples were collected from surface and near bottom levels from these selected stations (Fig. 3.1) within Mayem lake using Niskin water sampler to study the total suspended matter (TSM). TSM was determined by filtering one litre of water sample through pre-weighed 0.45μ nuclepore membrane filter using a vacuum pump. Its concentration is represented in mg/l.

Sampling was carried out during May, August and December of 1993 to represent three seasons namely premonsoon (February - May), monsoon (June - September) and postmonsoon (October - January).

Results and discussion

The data obtained on total suspended matter (TSM) are presented in table (Table 3.1) and is graphically represented in figures, separately for surface and bottom waters (Fig. 3.3).

It is clear from the figure that the TSM concentration shows a profound variation corresponding to seasons. During premonsoon, TSM ranges from 1.50 mg/l (st. no.5) to 5.80 mg/l (st. no.15) in surface waters and from 1.65 mg/l (st.no.2) to 21.90 mg/l (st. no. 13) in bottom waters. In this season, relatively higher values are recorded in surface waters at st. nos. 12,14,9,13 and 1. Among these st. nos. 1, 9 and 14 are in a line along NE bank of the lake and all these stations fall in the outer reservoir segment. In bottom waters, relatively higher values are recorded at st. nos. 7,9,12,13 and 14, st. no.13 being the highest (21.90 mg/l). Relatively low values of TSM in bottom waters are recorded at st. nos. 2 and 1. The difference between the highest and the least value in surface waters is 4.3 mg/l, while in bottom waters, it is 20.25 mg/l. From the data collected from this shallow lake during this season, it is clear that TSM concentration is higher in bottom waters compared to their surface water concentrations except at st. nos. 1 and 2.

During monsoon, TSM concentration ranges from 0.57 mg/l (st. no. 13) to 3.39 mg/l (st. no. 5) in surface waters and from 0.86 mg/l (st. no. 9) to 53.32 mg/l (st. no.13) in bottom waters. In this season, relatively lower values are recorded at st. nos. 9,1,12 and 11 while, relatively higher values are recorded at st. nos. 2 and 6 in surface waters. In bottom waters, the least concentration is recorded at st. no. 9 and the highest at st. no. 13. Relatively higher values of TSM are also recorded at st. nos. 10,7,8,15 and 1. The difference between the highest and least value in surface waters is only 2.82 mg/l while in bottom waters, it is very large (52.46 mg/l). In this season, higher concentration is seen in bottom waters as compared to their respective concentration in surface waters except at st. no. 6.

During postmonsoon, TSM concentration ranges from 0.70 mg/l (st. no. 7) to 2.95 mg/l (st. no. 11) in surface waters and from 1.54 mg/l (st. no. 9) to 49.21 mg/l (st. no. 13) in bottom waters. In this season, relatively lower concentration are recorded at st. nos. 2,12,6,3 and 1 and higher at st. nos. 15 and 5, in surface waters. Here also, the difference between the highest and least concentration in surface waters is very less (2.25 mg/l). In bottom waters, the least value is recorded at st. no. 9 and the highest at st. no. 13 and the difference is 47.67 mg/l. Relatively higher values are also recorded at st. nos. 11, 6, 7, 14 and 10. In this season also, higher values are recorded in bottom waters as compared to their respective concentrations in surface waters except at st. no. 9.

It is clear from the data obtained from the shallow Mayem lake that, TSM concentration in near bottom waters is always higher than respective surface waters, which is fully in accordance with the Gons and Kromkamp (1984) studies. This feature is observed at most of the stations in all seasons.

From the data, it is also clear that the range of variation in TSM concentration is the highest, when both surface and bottom waters are considered during monsoon (0.57 mg/l to 53.32 mg/l) compared to premonsoon (1.50 mg/l to 21.90 mg/l) and postmonsoon (0.70 mg/l to 49.21 mg/l). The value of TSM concentration, on an average, decreases from premonsoon followed by postmonsoon to monsoon in surface waters. Higher TSM concentration in surface waters during premonsoon indicates addition of TSM possibly from primary production. Earlier studies carried out elsewhere (Eisma, 1993) have proved that during summer months large quantity of organic particulate matter is produced due to primary production which is responsible for increasing TSM concentration. Eisma (1993) has reported 90% of the production of organic particulate matter in summer months. In Mayem lake, the higher TSM concentration obtained during premonsoon can only be explained by considering such a process. In bottom waters the value of TSM concentration, on an average, decreases from postmonsoon followed by monsoon to premonsoon. However, when the stations where higher values of TSM in bottom waters are compared, it is clear that the values decrease from monsoon through postmonsoon to premonsoon. This distribution seems to be controlled by influx of material from the catchment area through streams to the lake. For example, the concentration of TSM at st. no. 1 in bottom waters during monsoon is 18.53 mg/l which is followed by the concentration in bottom waters in postmonsoon at st. no. 2 (14.21 mg/l) and further to st. no. 3 in bottom waters in premonsoon (10.5 mg/l). This distribution can be related to the stream that joins the lake near st. no.1. Similar observations are also seen at st. nos. 7 and 8 in monsoon to st. nos. 6, 7 in postmonsoon and followed by st. nos. 6, 7, 8 in premonsoon. The highest concentration in all the seasons in bottom waters is recorded at st. no. 13 (21.90 mg/l during premonsoon, 53.82 mg/l during monsoon and 49.21 mg/l during postmonsoon). Higher concentrations are also recorded at st. nos. 9, 10, 12 and 14 in one or the other seasons. The higher concentration recorded at these stations cannot be explained only with the help of influx of sediment to the lake through streams. The higher concentration here must be due to slower settling or also due to localised resuspension. Slower rate of settling is stronger, as all these stations represent the deeper portion of the lake wherein finer sized particles and organic particulate matter tend to remain in suspension for longer time before settling. Duck (1987) stated that dispersal of suspended matter in lakes is a very complex process, as very fine particles (near to colloid size) and nannoplanktons have been regarded as non-settling suspended matter. Resuspension as a responsible factor for higher concentrations of TSM in bottom waters in shallow lakes has also been considered by Gons and Kromkamp (1984) and Verdouw *et al.,* (1987).

The data also revealed larger range of TSM concentration during monsoon which can be explained by taking into account the addition of material from streams during this season. The material from streams during monsoon is generally a mixture of large range of size particles. The coarser particles settle through the water column faster and become responsible for increasing the concentration in bottom waters in this season and succeeding seasons. The finer particles remain in suspension for a long time before they settle. In addition, all the four streams join the Mayem lake along the eastern side. That means, input of water and sediment from this end. This must be responsible for a distribution of TSM with larger range.

When average TSM concentration, separately for surface and bottom waters are taken, the data reveal that TSM concentration increases from eastern side (st. nos. 1 to 8 and 15) to western side of the lake (st. nos. 9 to 14) in all the seasons, which is due to inflow of material from the streams to the lake only along the eastern side. An exception to this distribution is seen during monsoon in surface waters. The present study for a period of one year, therefore has clearly shown that the major supply of TSM to the Mayem lake comes from the catchment area through surface run-off.

Considering this characteristic variation in TSM concentration from the eastern side of the lake to its western, the lake basin is broadly divided into three zones namely -

i) Eastern zone (st. nos. 1 to 8 and 15)

ii) Central zone (st. nos. 9 to 11)

iii) Western zone (st. nos. 12 to 14)

It was also attempted here to quantify the TSM data for the Mayem lake for three different seasons by using the formula suggested by Hakanson (1981), based on average TSM concentration in surface and bottom waters and using the bathymetry data.

$$V = \sum_{i=0}^{n} I_c \, (A_i + A_{i+1}) / 2$$

Where, Ic = Isobath interval

Ai = The cumulative area within the limits of isobaths.

n = Number of isobaths

Thus, the estimated TSM loads in the Mayem lake during the three seasons comes out as follows

• TSM during premonsoon	446 tons
• TSM during monsoon	1785 tons
• TSM during postmonsoon	1168 tons

Part B

Surface sediments

Sediment components

"Surface sediments" consist of variable proportions of sand-silt-clay fractions that help to identify the environment of deposition. Lake sediments are, in general, fine-grained owing to its less dynamic environment as compared to other more dynamic environments such as riverine, coastal, estuarine or marine. Distribution pattern of sediments in lakes depends on sediment source, texture of sedimentary material supplied, bottom topography (Mallik and Suchindan, 1984) as well as hydrographic features of lake waters (Sankarnarayanan and Qasim, 1969).

Grain size parameters namely mean size, standard deviation, skewness and kurtosis of lacustrine sediments are important tools to delineate the transport mechanism and depositional processes (Solohub and Klovan, 1970). All these parameters are interdependant of each other and help to understand the sedimentary processes especially in dynamic environments. In the lacustrine environment, mean size is commonly used to comment on sediment distribution and transport mechanism.

Organic matter

Organic matter, quantitatively is a negligible component in the sediments. However, it plays a very important role in all stages of sedimentation and controls distribution of elements; in other words, composition of sediments (Lisitzin, 1972).

Organic matter is produced within the aquatic ecosystem by the process of primary production i.e. biological productivity through the fixation of carbon dioxide by photosynthesis and therefore termed as autochthonous, when derived from the continents it is termed as allochthonous; however, atomospheric transport, though small, is also important (Gasith and Hasler, 1976). Concentration of organic carbon in sediments is many a time related to productivity of overlying waters and rate of sedimentation (Paropkari, 1979; Doyle and Garrels, 1985). Organic carbon content has been used as an indicator of organic pollution (Karickhoff, 1979), as a source of palaeo-environmental significance (Stein, 1990), as well as to reconstruct the history of nutrient loadings and eutrophication (Schleske and Hodell, 1995). The former (as a pollution indicator) is specially so because, it removes organic pollutants from water column during sedimentation (Mackereth, 1965). It also controls bio-geochemical cycles. Close association of certain heavy minerals with organic matter has also been reported (Pita and Hyne, 1974).

As the lake sediments are fine-grained, their larger surface area, high cation exchange capacity and adsorptive cohesive action acts as a storehouse of organic matter and trace elements (Thoman, 1969). Concentration of organic carbon in lake sediments plays an important role in the prevalence of reducing environment (Sebastian *et al.,* 1990).

It is reported that organic matter is generally associated with finer fraction of the sediments and accumulates instead of decomposing specially in shallow lakes (Foth, 1984).

Clay minerals

Clay minerals, in sedimentological context, refers to a size class finer than 8 ϕ while mineralogically, it refers to a distinctive group of minerals - Hydrous alumino silicates . Structurally , these minerals are made up of two dimensional silicon - oxygen framework in a sheet like structure and are categorized under the family of phyllosilicates .

Clay minerals generally originate from the weathering of a variety of rocks on the continent. Their quantitative and qualitative characters are dependent on the climate and intensity of weathering (Konta,1985). They also result from hydrothermal alteration of acidic or basic rocks and diagenesis of argillaceous sediments (Velde,1985).

Based on structural type, Newman (1987) has classified clay minerals into six groups namely, Kaolinite - Serpentine group, The micas

(Illites), Smectites (montmorillonites), Pyrophylite - Talc group, Chlorites and Vermiculites.

Among these, only first three clay mineral groups occuring in Mayem lake are described below with special reference to their structure, chemical composition and the mode of formation.

i) *Kaolinite*

Kaolinite is an important neutral lattice mineral, wherein one octahedral sheet (O) is linked to one tetrahedral sheet (Si) giving rise to uncharged 1:1 layer . It is a non-expanding type of mineral as it does not contain inter-layer water (Strahler, 1981). It has a general formula - $Al_4Si_4O_{10}(OH)_8$. Kaolinite is basically a mineral related to the surficial zones of earth's crust. It is often regarded as excellent indicator of climate (Singer, 1984).

ii) *Illite*

Illite is a low potassium aluminum mica with a general formula $K_{1-2.5}\ Al_4\ (Si,Al)_8\ O_{20}\ (OH)_4$. This mineral is also grouped under non - expanding type. Velde (1985) recognises four different origins of illite - i) Material crystallised during weathering, ii) Reconstituted degraded mica, iii) Detrital mica formed at high temperature and iv) Unaffected detrital illite from sedimentary rocks.

The general character of low charge and high Si content of illite is attributed to solid solutions with pyrophyllite in the alluminous form of Fe-Mg system. It is apparently stable, or unaffected by transport for relatively short periods of time (Hurley *et al.,* 1961).

iii) *Gibbsite*

Gibbsite has a general formula - $8\{Al\ (OH)_3\}$ and has a neutral lattice structure. It is the most common pedogenic form of $Al\ (OH)_3$. It occurs commonly in laterites, in warm, humid climate with high rainfall, suitable topography (Schoen and Roberson,1970) and good drainage (Segalen,1971).

It is frequently identified as a mineral formed during early stages of rock weathering. However, it exists in different weathering zones under a wide variety of climatic conditions, which makes it difficult to decipher its actual genesis. A trend of the distribution of gibbsite in various types of soils and minerals with which it is commonly associated is given in the bibliography published by the Commonwealth Bureau of Soils (1957-1967). It can only persist under conditions where aqueous fluids have very low dissolved mineral content - either at the very beginning of the weathering process or in its final stages in lateritic soils (Velde, 1985). Thus, it forms either from the parent rock or from kaolinite (Hashimi and Nair, 1989). Kittrick (1969) concluded that gibbsite should be found in association with kaolinite and hence, is very common in highly weathered soil profile.

iv) ***Montmorillonite***

Montmorillonite is an aluminum rich dioctahedral smectite. It has a structural formula $Al_4Si_8O_{20}(OH)_4. nH_2O$ with Mg and As. Owing to the substitution in the octahedral layer, it allows the weak binding of the exchangeable cations and water molecules. Thus, it is a expandable type of mineral as against kaolinite and illite (Strahler, 1981). More commonly , it is also referred to as swelling clay.

Montmorillonite is derived either from sub-aerial weathering of Deccan traps or their laterite products (Kolla *et al.,* 1981). In general, a weathering profile which produces abundant smectite (i.e.montmorillonite) indicates that the weathering process is moderately advanced. Thus, it is a product of limited leaching (Irion, 1983). It is also a typical mineral of laterites, when rainwater reemerges at low level and reacts with primary rock material (Tardy, 1969). Recently, Pandarinath and Narayana (1991) have stated that montmorillonite forms within the sediments containing high organic carbon.

In moist climate, a soil produced as a result of weathering tends to be rich in montmorillonite and illite. With further leaching, kaolinite becomes prominent and in extreme condition, it becomes rich in gibbsite (Jackson, 1959). Cation exchange capacity (CEC) is the capacity of the given quantity of soil to hold and to exchange cations. High value of CEC is a general indicator of high degree of chemical leaching.

Thus, clay minerals may be arranged in their descending order of CEC.

Montmorillonite → illite → kaolinite → gibbsite

The finer size of lake sediments demands their detailed study on clay mineralogy. Constituents of these clay minerals provide an unique plastic behaviour that causes to lose or to take up moisture according to the temperature and water present in a system. Some clay minerals contain loosely bonded cations that can be exchanged for others depending on base exchange capacity (BEC) (Cauwet, 1987). Such study helps in defining and redefining the sedimentological and geochemical characteristics of sediments and thus, plays a vital role in understanding the provenance and extent of weathering. More importantly, clay minerals of surface sediments have been widely used as a guide to the transport path of fine grained sediments. (Grim, 1953) Clay minerals as indicator of provenance has also been used recently by Bukhari and Nayak (1996). They have also been used to comment on depositional environment, palaeo-climatic record (Dilli and Pant, 1994) as well as to control the pollution (Raymahashay, 1987).

Methodology

Surface sediment samples were collected from the same fourteen stations, from where TSM data was collected (Fig. 3.1), using Van - Veen grab during the same three seasons. Colour of the sediment was noted during every collection. Surface sediment samples were preserved in a refrigerator till further analysis.

The surface sediments were analysed by using standard wet sieving and pipette methods (Friedman and Sanders, 1978) to find out the components of the sediment samples. In this method, a known quantity of each dried sediment sample was soaked overnight with 25 ml of 10% sodium hexametaphosphate which acts as a deflocculating agent. Later, it was passed through 230# sieve. +230 fraction was weighed to calculate sand component. Whenever sand fraction was more than 5%, their constituent minerals were identified under a polarised microscope. The -230 fraction was used for pipette analysis after making the volume to 1000 ml in a cylinder. The content in the cylinder were homogenised by stirring for about two minutes using a sieved stirrer. Different size fractions were withdrawn using a pipette (20 ml), following Stoke's law.

The data obtained were used to compute relative percentages of sand - silt - clay components. Further, grain size parameters were calculated following Folk and Ward's (1957) formulae.

From the analysis carried out on sediments of Mayem lake, it was found that silt and clay fractions predominate and therefore, organic carbon analysis was also taken up, as it is associated with finer fractions of the sediments. Surface sediment samples were analysed for total organic carbon by wet - oxidation method as described by Elwakeel and Riley (1957).

In this method, 0.2 gm of each powdered sediment sample was treated with 10 ml of chromic acid in a stoppered glass tube, which was later heated on boiling water bath for an hour. After cooling, 200 ml of distilled water was added. To this, one drop of ferrous phenanthroline was added as an indicator and the solution was titrated with 0.2 N ferrous ammonium sulphate until pinkish color just persists. The same procedure was followed for blanks without using a sample.

1 ml of 0.2 ferrous ammonium sulphate = 1.15 x 0.6 mg/gm of C

Owing to the dominance of finer sized fractions in sediments, it was decided to study clay minerals present. For this purpose, selected surface sediment samples were chosen. The sample required for this study was collected from 1000 ml cylinder at the end of pipette analysis i.e. after collecting the last fraction. 250 ml of the remaining content was siphoned out. To this was added 15 ml of hydrogen peroxide to remove organic matter. Sample was then washed to clear - off the reagents taking all the care not to loose any fraction of sediment. 1 ml each of the samples was pipetted onto a glass slide to obtain oriented sections. These slides were air-dried and were scanned for clay minerals using Phillips X-ray Diffractometer - PW with Nickel filtered Cu kα radiations, proportional counter and pulse height analyser and with following specifications.

Time constant : 5 seconds.
Receiving slit : 0.2 nm.
Speed : 0.05 2θ /Sec.
Range : 2 x10^3 cps
Chart speed : 10 mm / $^{o}2\theta$

Clay minerals were identified by their principal reflection peaks using the JCPDS cards. Standard tests were also carried out for the confirmation of presence of montmorillonite by glycolation (Carrol, 1970; Thorez, 1975). The relative percentages of the identified clay minerals are calculated as described by Biscay (1965).

Results and discussion

One of the notable features of the Mayem lake surface sediments is its colour. It is different in outer reservoir segment from that of inner valley portion, delineated earlier using isobath configuration presented in chapter 2. Sediments in outer reservoir segment (st. nos.1 to 5 and 9 to 14, (Fig. 3.1) are reddish brown in colour while those in inner valley portion (st. nos. 6 to 8, and 15) are greyish black in colour. Colour has been used to comment on sediment constituents by Murthy and Veerayya, (1972); Aqrawi and Evans, (1994). The variation in colour observed in mayem lake can throw light on relative proportions of various constituents of sediments.

Sediment components

Sediment components analysis (sand - silt - clay) of Mayem lake surface sediments in percentage is presented in table (Table 3.2A) and graphically represented in figure (Fig. 3.4A). When plotted in a triangular diagram (Fig. 3.6) proposed by Lindholm (1987), these sediments fall in a very fine grained category and therefore, are classified as clayey silt or more commonly as mud. It may be interesting to note here that mud is a common sediment type of majority of lakes (Rao and Rao, 1974).

The range of sand, silt and clay in surface sediments during premonsoon varies from 2.03% (st. no.4) to 16.87% (st. no.12), 35.14% (st. no.3) to 75.40% (st. no.10) and 21.60% (st. no.10) to 59.57% (st. no.3) respectively. During monsoon, the concentration of the three components ranges from 1.09% (st. no.4) to 11.96% (st. no.15), 46.76% (st. no.6) to 57.45% (st. no.4) and 36.12% (st. no.1) to 51.25% (st. no.6) and during postmonsoon, they range from 0.65% (st. no.10) to 16.49% (st. no.5), 44.24% (st. no.7) to 62.70% (st. no.13) and 34.23% (st. no.13) to 54.25% (st. no.7) respectively.

Sand fraction during premonsoon is less than 10% at all the stations except st. nos. 8 and 12. Relatively higher sand fraction concentrations are recorded in the inner valley portion i.e. between st.nos. 5 and 8. In addition, high concentration is also seen at st. nos. 2, 3, 11 and 12 that represents outer reservoir segment bordering the inner valley portion. In monsoon, concentration of sand fraction is less than 10% at all the stations except at an additional st.no.15. Concentrations are relatively higher at st. nos 1, 2, 5 and 12. Very low concentrations are recorded at st. nos. 3, 4, 7 and 8. During postmonsoon, except at st. no.5 and 8, at all other stations, concentration of sand fraction is less than 10%. Very low percentages of sand fraction are recorded at st. nos. 2, 3, 6, 7, 10 and 12. Concentration is relatively higher at st. no. 1 and 14.

The distribution of TSM discussed in earlier part has helped in the delineation of three definite zones namely eastern, central and western. An attempt is made to compare an average value of sand fraction among these zones. The data (Table 3.2B) plotted (Fig. 3.4B) reveals that the sand fraction within each zone decreases from premonsoon to postmonsoon. Concentration is relatively higher in eastern and the western zone compared to central zone. In general, sediment grain-size distribution in lake is concentric, with grain-size increasing outward (Twenhofel, 1933 ; Downing and Rath, 1988: Giresse *et al.,* 1991) whereby concentration of sand fraction decreases away from the bank. This is also true in case of Mayem lake sediments. The data shows relatively higher sand fraction concentration at st. nos. 1 and 5 during monsoon and postmonsoon, which supports input of sand fraction from the catchment area through streams. It is also clear from data that in addition to the streams, coarser material, although in smaller quantity, is also being added from the banks of eastern as well as western sides possibly as a result of slumping. Supply of material due to slumping has been pointed out by Duck (1982) in Loch Tummel, Scotland. The data presented in figure (Fig. 3.4A) shows higher concentration at stations near the banks for example at st. nos.11 and 12 especially during premonsoon and monsoon. This strongly supports input from banks adjacent to these stations.

From the seasonal distribution of sand fraction within the lake it is clear that the concentration is higher during premonsoon and it decreases through monsoon to postmonson. This can be explained by taking into account the large quantity of influx of silt and clay sized material which is brought during monsoon and subsequently settles through water column in this season and postmonsoon season.

Silt is a major component of the Mayem lake surface sediments. Dominance of silt, is said to be a product of progressive process of weathering in tropical areas (Pye and Sperling, 1983).

Silt fraction during premonsoon varies with a wider range. It is relatively higher at st. nos. 10,1,9 and 14 and lesser at st. nos. 3 and 6. During monsoon, silt distribution at different stations is almost uniform. During postmonsoon, distribution of silt is with wider range similar to premonsoon. Here, relatively higher concentrations are recorded at st. nos. 2, 4 and 9 to 14 and lower concentration at st. nos. 1, 3, 5 and 7. The data (Table 3.2B) when plotted with reference to three zones for different seasons (Fig. 3.4B) makes it clear that silt concentration is higher in central and western zones especially during premonsoon and postmonsoon. It is also clear from figures (Fig. 3.4A and B) that silt concentration is higher in the outer reservoir segment in all the seasons with a few exceptions like st.no. 3.

Clay fraction is found to be a second dominant fraction to silt in surface sediments. The data shows that the distribution of clay fraction is inverse to that of silt fraction especially during premonsoon and postmonsoon (r = - 0.9111). During premonsoon, clay concentration is the highest at st. no. 3 (59.57%) followed by st. no.6 (55.80%) and the least at st. no. 10 (21.60%) with relatively lower concentrations at st. nos. 1, 12 (31.53%). In monsoon, distribution of clay is almost uniform. In postmonsoon, the highest concentration of clay is recorded at st. nos. 7 followed by st. nos. 3, 1 and 6. When data of clay fraction (Table 3.2B) are plotted to represent zonal distribution with seasons (Fig. 3.4B), it shows that concentration of clay is higher in eastern zone especially during premonsoon and postmonsoon and less in central and western zone. During monsoon, its concentration is higher in all the zones as compared to other seasons. Although, there is sediment transport of fine grained material from high energy shallow areas to low energy deep areas, as seen from distribution of isobaths, there is general evidence that low energy shallow areas owing to the extensive growth of macrophytes also retain fine grained sediments (Schroder, 1988; Petticrew and Kalff, 1992).

From the above discussion, it is clear that relatively large quantity of clay is being added to the eastern zone in all the seasons and to other zones during monsoon. The uniform distribution of silt and clay during monsoon compared to other two seasons can be directly related to material influx during this season. The non uniformity in distribution of silt and clay during premonsoon and postmonsoon can be explained with the rate of deposition (i.e. settling velocity) of material with respect to their size.

The distribution of silt and clay content plotted (Fig. 3.4B) with respect to three identified zones clearly indicates movement of large quantity of silt from eastern through central to western zone during the period following the monsoon. Absence of biogenic material clearly indicates the terrigenous nature (Mallik and Suchindan, 1984) of sediments in Mayem lake especially during monsoon.

Grain size analysis

Grain size parameters computed for surface sediments namely mean size M_Z (ϕ), standard deviation (σ_I), skewness (SK_I) and kurtosis (K_G) and their seasonal variation with spatial distribution is presented in table (Table 3.3A) and graphically represented in figures (Fig. 3.5A(i) to (iv)).

a) ***Mean size (M_Z)*** - Seasonal variation in mean size is presented in figure (Fig. 3.5A(i)). During premonsoon, it ranges from 6.56 ɸ (st. no. 10) to 7.35 ɸ (st. no. 3). During monsoon, it ranges from 6.86 ɸ (st. no. 11) to 7.29 ɸ (st. no. 6) and during postmonsoon, it ranges from 6.60 ɸ (st.no. 1) to 7.42 ɸ (st. no.3). Thus, the range of variation in mean size is relatively less during monsoon.

During premonsoon, mean size is relatively finer at st. nos. 3,6,4,8 and 2 than the remaining sampling stations. It is also clear from the data that, in general, sediments in the inner valley portion (between st. nos. 5 to 8) are relatively finer (M_Z= 7.11 ɸ) than sediments in the outer reservoir segment (st. nos. 1 to 4 and 9 to 14; M_Z= 6.88 ɸ). During monsoon, the range of variation in mean size is narrow and the values are relatively finer at all the stations except st. nos. 2,3 and 11. It is also clear that sediments in the inner valley portion are relatively finer (M_Z= 7.16 ɸ) than sediments in outer reservoir (M_Z= 6.8 ɸ). During postmonsoon, mean size is relatively finer at st. nos. 3,7,6,2 and 5 than the remaining sampling stations. Here also, the sediments in the inner valley portion are relatively finer (av. 7.06 ɸ) than the outer reservoir (av. 6.16 ɸ).

Thus, it is clear that on an average, mean size of Mayem lake surface sediments in inner valley portion is relatively finer than sediments in outer reservoir segment in all the seasons. The smaller range of mean size obtained during monsoon with relatively finer size indicates influx of large quantity of finer size sediments during this season.

When the values of mean size (ϕ) (Table 3.3B) are plotted to understand the zonal distribution with seasons (Fig. 3.5B(i)), it is clear that mean size increases from eastern (finer) to western (coarser) zone irrespective of the seasons with a minor difference. Relatively finer sized sediments are present in the eastern zone during all the seasons. The central and western zones contain relatively finer sediments during monsoon compred to other seasons.

b) ***Standard deviation (σ_I)*** - Seasonal variation in standard deviation is presented in figure (Fig. 3.5A(ii)). It is seen from this figure that standard deviation values obtained during premonsoon ranges from 1.23 ϕ (st. no. 3) to 1.65 ϕ (st. no. 5). During monsoon, it ranges from 1.19 ϕ (st. no. 5) to 1.44 ϕ (st. no. 2 and 3) and during postmonsoon, it ranges from 1.19 ϕ (st. no. 3) to 1.52 ϕ (st. no. 14). In this case also, the range of variation in standard deviation is relatively less during monsoon.

During premonsoon relatively poor sorting is recorded at st. nos. 5,2 and 12. and relatively better sorting is recorded at st. nos. 6,8 and 4 with the least value at st. no.3. It is also clear that relatively lower values are recorded in outer reservoir segment ($\sigma_I = 1.39$) as compared to inner valley portion ($\sigma_I = 1.42$). During monsoon, although the range of variation in standard deviation is less, relatively poor sorting is recorded at st. nos. 2, 3, 12, 13 and 11. Comparatively low values are recorded at st. nos. 5, 1, 14, 8 while constant value ($\sigma_I = 1.25$) is recorded at st. nos. 6,7,9,10. In this season, relatively lower values are recorded in inner valley portion ($\sigma_I = 1.24$) as compared to outer reservoir segment ($\sigma_I = 1.33$). During postmonsoon, relatively poor sorting is recorded at st. nos. 14, 4, 8, 13. Comparatively lower values are recorded at st. nos. 6, 7 and the least at st. no. 3. In postmonsoon, relatively lower values are recorded in inner valley ($\sigma_I = 1.35$) as compared to outer reservoir segment ($\sigma_I = 1.40$). The data obtained shows that values of standard deviation are lower during monsoon than during premonsoon and postmonsoon. When the values (Table 3.3B) are plotted to know the zonal distribution with the seasons (Fig. 3.5B(ii)), it is clear that standard deviation values obtained are the least in the central zone relative to eastern and western zone irrespective of the seasons. However, difference is very insignificant.

c) ***Skewness (SK_I)*** - Seasonal variation in skewness is presented in figure (Fig. 3.5A(iii)). During premonsoon, it ranges from - 0.10 (st. no. 1) to - 0.81 (st. no. 2). During monsoon, it ranges from - 0.40 (st. no. 1 and 11) to - 0.76 (st. no. 6). During postmonsoon, it ranges from - 0.09 (st. no. 1) to - 0.81 (st. no.2). It may be noted that all the sediment samples analysed from Mayem lake show negative skewness irrespective of the seasons. Here again, the range of variation in skewness values is the least during monsoon. St. no. 1 shows the highest skewness value irrespective of the seasons while st. no. 2 shows the least value except during monsoon.

During premonsoon, lower skewness values are recorded at st. nos. 2,6,3,4,10,7 and 8 while, relatively higher values are recorded at st. nos. 13, 14, 11, 12 and 9. Sediments of inner valley portion show lower skewness value (- 0.66) compared to sediments of outer reservoir segment (- 0.36). During monsoon relatively lower values are recorded at st. nos. 6,10, 12, 5 and 7. Uniform values are recorded at st. nos. 1 and 11 (- 0.40). Sediments of inner valley portion show lower skewness (- 0.61) compared to outer reservoir segment (- 0.59). During postmonsoon lower values are recorded at st. nos. 2 7,6,3 and 5 but relatively higher values are recorded at st. nos. 8,4 and 13. Sediments from inner valley portion have lower skewness (- 0.59) compared to sediments from outer reservoir segment (- 0.39).

When skewness values obtained (Table 3.3B) are plotted to understand the zonal distribution with seasonal variation (Fig 3.5B(iii)), it is clear that the lowest skewness values are recorded for sediments from the eastern zone in all the seasons and relatively lower values are also obtained in central and western zone only during monsoon. It is also clear that skewness is the highest in western zone especially during fairweather seasons.

d) *Kurtosis (K_G)* - Seasonal variation in kurtosis is presented in figure (Fig. 3.5A(iv)). During premonsoon, it ranges from 0.52 (st. no. 12) to 1.04 (st. no. 2). During monsoon, it ranges from 0.63 (st. no. 12) to 0.80 (st. no. 6). During postmonsoon, it ranges from 0.45 (st. no. 13) to 1.18 (st. no. 3) Here again, the range of variation in kurtosis is the least during monsoon.

During premonsoon, relatively higher values are recorded at st. nos. 2,6,5,3 and 14. During monsoon, relatively higher values are recorded at st. nos. 6,13, 4, 14. During postmonsoon, at station nos. 3 and 7, very high values are recorded which are the highest, followed by the values obtained at st. nos. 6, 2 and 14. Relatively lower values are observed at st. nos. 1 and 8. Sediments in inner valley portion and outer reservoir segment do not show any variation in kurtosis, although the values obtained are relatively less during monsoon.

When the values obtained (Table 3.3B) for kurtosis are plotted to know the zonal distribution with the seasons (Fig 3.5B(iv)), it is clear that, in general, the kurtosis values decrease from eastern through central to western zone except during monsoon, wherein the distribution is almost uniform in all the zones.

In the eastern zone, values obtained are relatively higher during premonsoon and postmonsoon than in monsoon, but somewhat reverse trend is recorded in central and western zone wherein, kurtosis values are relatively higher during monsoon than during fair-weather seasons (premonsoon and postmonsoon).

Thus, it is seen from the above description on size parameters that mean size of Mayem lake surface sediments, on an average, is 6.92 ϕ and ranges between 6 ϕ to 8 ϕ which agrees with the most of the earlier studies on tropical lakes in India (Rao and Rao, 1974) as well as in African lakes (Giresse *et al.,* 1991). However, these sediments are relatively coarser than most of the Canadian lakes (Rea *et al.*, 1994). It is also clear that all the size parameters of Mayem lake surface sediments have the least range of variations. during monsoon. On an average, sediments during this season are relatively finer and therefore, better sorted, very negatively skewed and less platykurtic compared to other seasons. It may be noted here that Mayem lake receives water and sediments from four ephemeral streams. It is also clear from earlier section of this chapter that surface sediments in this lake are predominantly silt and clay mixture. This means, sediments brought by these streams are mainly silt+clay, out of which relatively coarser material settles faster keeping very fine clay particles in suspension and the stream inflow is also responsible for localised disturbance and hence, localised resuspension of surface sediments during early monsoon. This leads to high concentration of TSM in bottom waters.

The material within surface sediments during monsoon, therefore, is relatively uniform in its characteristics. However, in other seasons, as there is no further addition of material from streams, sedimentation of finer material which was in suspension and addition of sand fraction from banks due to slumping is responsible for wider variation in parameters of sediments. The deposition of finer sediments within the lake is also dependent on many internal factors and therefore, will be selective and vary from one place to another. In Mayem lake, this particular phenomenon is clear when the sediment characteristics are compared between inner valley portion and outer reservoir segment, or between eastern, central and western zones. It is noticed that sediments are always finer in the eastern zone than central and western zones irrespective of the seasons, although with a narrow difference. It may be also recalled here that eastern zone is shallower relative to other zones. It has already been seen earlier that relative proportion of silt to clay is near uniform in eastern shallower zone and highest in the western, deeper zone in all the seasons.

An attempt was made to correlate mean size with other size parameters using bivariant plots. The plot (Fig. 3.7A) between mean size and standard deviation revealed that finer the sediments, better the sorting, irrespective of the seasons. However, the relation is more significant during monsoon. This indicates selective sorting and therefore, uniform nature of sediments. When mean size was plotted against skewness (Fig. 3.7B), the relation obtained showed that finer sediments are very negatively skewed. This indicates that finer sediments are under relatively faster rate of movement, which is observed during monsoon. Similarly, when mean size was plotted against kurtosis (Fig. 3.7C), it is found that finer sediments are less platykurtic. This also supports uniform characteristics of sediments during monsoon.

Organic carbon

Organic carbon concentration in Mayem lake surface sediments is presented in table (Table 3.4A) and is graphically represented in figure (Fig. 3.8A).

From the data, it is seen that organic carbon content during premonsoon ranges from 5.34% (st. no. 13) to 13.98% (st. no.6). During monsoon , its concentration ranges from 2.76% (st. no. 13) to 11.41% (st. no.2). Sediment sample at st. no. 15, collected only during monsoon from southernmost portion of the lake, records the highest organic carbon content (15.46%). During postmonsoon, organic carbon content ranges from 5.70% (st. no.13) to 13.98% (st. no. 8). Thus, from seasonal variation in organic carbon content, it is clear that, on an average, its concentration is the least during monsoon (av. 8.12%) compared to premonsoon (av. 9.46%) and postmonsoon (av. 8.84%). It is also clear that st. no 13 which represents the deepest portion of the lake, shows the least organic carbon content irrespective of the seasons.

During premonsoon, concentration of organic carbon is higher than 10% at all the stations from st. nos. 1 to 8 except at st. no. 5 (9.01%) which were delineated as eastern zone earlier. At other stations, its concentration ranges between 6% to 8% except at st. no 13 where it is the least (5.34%). During monsoon, concentration of organic carbon is higher than 7.5% in the eastern zone at st. nos. 1 to 8 and 15 except at st. no. 1 (4.78%). At all other stations, i.e. st. nos.

9 to 14, the concentration is less than 7%, with the least at st. no. 13 (2.76%). During postmonsoon, concentration of organic carbon is higher than 7.7% at st. nos. 1 to 8 (i.e. the eastern zone) and at st. no.9 (8.09%) while, its concentration is less than 7% at st. nos. 10 to 14 .

When the values obtained (Table 3.4B) were plotted to understand the zonal distribution with seasons (Fig. 3.8B), it is clear that organic carbon concentration decreases from eastern through central to western zone irrespective of the seasons. The relatively higher concentration recorded at st. no. 1 to 8 (eastern zone) irrespective of the seasons can be related to high growth of phytoplanktons and macrophytes within this portion of the lake. Similar observations have been made earlier specially with respect to macrophytes by Martinova (1993) in few Russian lakes. When compared between the seasons, with closer observation, it is seen that, on an average, concentration of organic carbon is less during monsoon, which is also clear from its zonal distribution. This observation is very noticeable at st. nos. 1 and 6 where the seasonal streams join the lake. It is clear from this study that organic matter input from the streams which flow only during monsoon is less as these streams (major) run through rocky terrain with less soil cover. In addition, it is clear from the study on sediment components that large quantity of silt and clay is added to the lake during this season which dilutes the concentration of organic carbon. Also finer clay material goes into suspension, especially in deeper localised places during early monsoon retaining uniform silt material. The localised resuspension will also remove organic matter from the sediments. Higher organic carbon content during fair-weather seasons (premonsoon and postmonsoon) can indirectly be related to biological primary productivity (Bordovskiy, 1965) within the lake, which is responsible even for higher TSM values in surface waters during the same period as explained earlier. In addition, organic matter which was in suspension during monsoon slowly settles along with finer sediment particles, which is responsible for increasing organic carbon content in sediments during postmonsoon season.

It is also seen that relative concentration of organic carbon decreases from st. no. 1 followed by st. no. 9 and 14 which lie along the NE border of the lake. Similar decreasing trend is also recorded from st. nos. 2-10-13 and st. nos. 3-11-12 irrespective of seasons. Only exception to this distribution pattern is along st. nos. 1-9-14 during monsoon. This exception is mainly due to the low value obtained at st. no. 1 (4.78%). It is clear from earlier section of this chapter that large quantity of inorganic material (silt and clay) enters the lake near to this location during monsoon. This inorganic material must be responsible for diluting or reducing the organic carbon content at this station.

Morphological studies (bathymetric) carried out in Mayem lake and presented in chapter two have shown that eastern zone is shallower compared to central and western, which is seen specially in case of outer reservoir segment. Organic carbon content obtained for the stations that represent the deeper portions of the lake (st. nos. 9 to 14) i.e. central and western zone, is relatively less in all the seasons, with least concentration at st. no. 13 - which is the deepest of all the stations.

To establish and understand the variation of organic carbon content with depth of water column, the values of organic carbon and water depth were plotted separately for three seasons (Fig. 3.9). It confirms that concentration of organic carbon decreases with depth irrespective of the seasons.

It has already been seen earlier from sediment component analysis of surface sediments that, deeper regions of the lake contain relatively lower proportions of clay fraction and higher silt fraction. This proves the well accepted view that organic carbon is more associated with finer fraction of sediments owing to its affinity of adsorption on the surfaces of finer particles (Kuenen, 1950) and their similarity in settling velocities (Trask, 1939; Kemp, 1971). To establish this relation, organic carbon content was plotted against silt and clay fractions of sediments separately (Fig. 3.10). The Mayem lake surface sediments fall in agreement with the accepted view which shows direct relationship with clay and inverse relationship with silt. Such relations were also recorded for Vembanad and Ashtamundy lakes by Murthy and Veerayya (1972) and Damodaran and Sajan (1983) respectively.

It is clear from the present study that on an average, organic carbon concentration is higher than other tropical lakes of India (Venkatrathanam, 1967; Murthy and Veerayya, 1972; Rao and Rao, 1974 and Damodaran and Sajan, 1983). Such a high concentration of organic carbon obtained for Mayem lake surface sediments can be directly related to its shallow and closed nature. The present study has also shown that there is a large growth of macrophyte, especially along the eastern margin and within inner valley portion of the lake. Svedrup *et al.* (1955) related the organic matter in shallow and isolated environments to aquatic plants. Martinova (1993) also related organic matter to macrophyte growth. Surface sediments of Mayem lake also contain some traces of forest litter as a refractory matter. Matsumoto *et al.* (1987) and Downing and Rath (1988) have pointed out that refractory material may contribute, although to lesser extent, as a probable source of organic carbon. It is clear from the present study that large quantity of organic matter is produced within Mayem lake and as it is a closed and shallow ecosystem, the material produced is being incorporated within the sediments. However, small quantity of organic matter coming from catchment area through surface run-off especially during monsoon cannot be ruled out. It is also proved that organic matter accumulates without decomposition in shallow lakes (Foth, 1984).

Clay Minerals

Three sets of sediment samples (premonsoon, monsoon and postmonsoon) from selected stations (st. nos. 1,3,5,7,9,11 and 13) were collected and analysed for clay minerals. Besides, one more sample from st. no. 15 was collected during monsoon. Clay minerals identified from X-ray diffractograms (Fig.3.11 A, B, C and D) include kaolinite, illite, gibbsite and montmorillonite in their decreasing order of relative abundance. The relative percentage of clay minerals with reference to spatial distribution and seasonal variation within the surface sediments of Mayem lake is presented in table (Table 3.5A) and graphically represented in figures (Fig. 3.12 A, B and C) for premonsoon, monsoon and postmonsoon respectively.

Kaolinite : Kaolinite is the most abundant clay mineral in surface sediments of Mayem lake. This observation is clear from the data obtained, as its relative abundance is over 50% except at two stations during premonsoon and one station during postmonsoon. Relative abundance, as high as 89.32% has been recorded during monsoon at st.no.13. Dominick *et al.* (1983) have pointed out the dominance of kaolinite, in general, in recent sediments especially from tropical climates. Similarly, relatively high abundance of kaolinite was also recorded earlier from Vembanad lake, Kerala - >60% (Murthy and Veerayya, 1981; Reddy et al.,1992) as well as in lake Barombi Mbo, Cameroon (Giresse *et al.,* 1991), in lake Ham and Arbuckle, U.S.A. (Clay and Wilhm, 1979).

During premonsoon, relative abundance of kaolinite ranges from 45.67% (st. no. 3) to 73.87% (st.no.13). Except at st. no.13, its relative abundance is less than 70%. During monsoon , it ranges from 52.53% (st.no.7) to 89.32% (st.no.13). Relatively higher abundance is also recorded at st. nos. 3 and 11, while at remaining stations, it is less than 70%. During postmonsoon, it ranges from 42.68% (st. no. 3) to 76.13% (st. no 13). Relatively higher abundance is also recorded at st. nos.7 and 1, while at remaining stations it is less than 70%. It is seen from the data that st. no.13 shows the highest kaolinite abundance irrespective of the seasons. It is clear that relative abundance of kaolinite is higher during monsoon at most of the stations. It is revealed from the data that the relative abundance of kaolinite is more in outer reservoir segment (st. nos.1,3,9,11,13) as compared to inner valley portion (st. nos. 5,7) in all the seasons, although the variation is very narrow during postmonsoon.

When the values (Table 3.5B) are plotted to understand the zonal distribution with the different seasons (Fig. 3.13), it is seen that relative abundance of kaolinite gradually increases from eastern shallower zone to western deeper zone, irrespective of the seasons. Thus, it indicates the depth control over the kaolinite distribution; similar observations were also recorded in lake Ham and lake Arbuckle from United States of America (Clay and Wilhm,1979). It is also clear from the present study that the relative abundance of kaolinite is higher during monsoon compared to other seasons in all the zones.

Illite : Illite is the second abundant clay mineral in surface sediments of Mayem lake. Its relative abundance shows wide seasonal fluctuation.

During premonsoon, relative abundance of illite ranges from 13.79% (st. no.9) to 32.35% (st. no.11). Relatively higher abundance is also recorded at st. nos. 5, 3 and 1, while at remaining stations, it is less than 20%. During monsoon, it ranges from 0% (st. nos.1 and 13) to 35.82% (st. no.7). Relatively higher abundance is also recorded at st. nos. 9 and 5, while at remaining stations, it is less than 12%. During postmonsoon, it ranges from 7.82% (st. no.1) to 44.27% (st. no.3). Relatively higher abundance is also recorded at st. nos. 9 and 13, while at remaining stations, it is less than 20%. Data has revealed that relative abundance of illite is more in inner valley portion as compared to outer reservoir segment except during postmonsoon.

When the values (Table 3.5B) are plotted to understand the zonal distribution with seasons (Fig. 3.13), it is seen that it does not show any systematic variation. However, in general, its relative abundance is less in western deeper zone. It is observed that illite abundance is less during monsoon compared to other seasons.

Gibbsite : Gibbsite is less abundant in surface sediments of Mayem lake. It shows a wide variation in relative abundance with different seasons. During premonsoon, the relative abundance of gibbsite ranges from 5.18% (st. no.13) to 26.44% (st. no.3). Relatively higher abundance is also recorded at st. no. 5, while at remaining stations, it is less than 20%. During monsoon, it ranges from 4.14% (st. no.13) to 14.28% (st. no.1). Remaining stations have recorded the relative abundance less than 10%. During postmonsoon, it ranges from 3.29% (st. no.13) to 16.94% (st. no.5). At remaining stations, relative abundance is less than 10%. It is clear from the data that on an average, relative abundance of gibbsite is higher in inner valley portion as compared to outer reservoir segment irrespective of the seasons. However, the range of variation is very narrow during monsoon.

It is seen from the data that st. no. 13 has recorded the least relative abundance of gibbsite irrespective of the seasons. Moreover, data has also revealed that in general, gibbsite abundance is less during monsoon as compared to other seasons.

When the values (Table 3.5B) obtained are plotted to understand the zonal distribution with seasons (Fig. 3.13), it is clear that relative abundance of gibbsite decreases from eastern shallower zone through central to western deeper zone irrespective of the seasons.

Montmorillonite : Montmorillonite is the least abundant clay mineral in surface sediments of Mayem lake. However, it shows a wide variation in relative abundance with different seasons.

During premonsoon, relative abundance of montmorillonite ranges from 0% (st. no. 3 and 11) to 9.09% (st. no. 7). Relatively higher abundance is also recorded at st. no. 1 (8.18%), while at remaining stations, its abundance is less than 5.5%. During monsoon, its relative abundance ranges from 0% (st. no. 5) to 17.14% (st. no. 1). Relatively higher abundance is also recorded at an additional st. no. 15 (10.47%), while at remaining stations its abundance is less than 8%.

During postmonsoon, it ranges from 0% (st. no. 5) to 5.86% (st. no.1). At remaining stations, its relative abundance is less than 5%. It is clear from the data that relative abundance of montmorillonite is higher at st. no. 1 irrespective of the seasons. Relatively higher values are also obtained at st. no. 7 specially in premonsoon and monsoon periods.

When the values (Table 3.5B) are plotted to understand the zonal distribution with seasons (Fig. 3.13), it is clear that montmorillonite abundance is relatively less in deeper areas (central and western zones) than the eastern shallow zone irrespective of the seasons. It is also clear that montmorillonite abundance is higher during monsoon as compared to other seasons in all the zones.

In addition to these clay minerals, ***goethite*** is also found in surface sediments of Mayem lake within a clay-sized fraction. Goethite has a general formula - $Fe(OH)_2$. It belongs to iron oxide groups of minerals and forms under humid and tropical conditions in all climatic zones (Schwertmann and Taylor, 1977) in which wide variations in parent materials are encountered. Its presence indicates a major oxide phase (Roonwal and Srivastava, 1991) especially in laterite profiles (Khanadali and Devaraju, 1989). Goethite is considered to be a common contaminant of the clay minerals (Pecuil *et al.,* 1967). In Mayem lake, its presence at st. no. 1, especially during monsoon is quite noticeable (see Fig. 3.11A).

From the study of clay minerals in surface sediments of Mayem lake, it is clear that the kaolinite and illite dominate over gibbsite and montmorillonite. It is also clear that relative abundances of kaolinite and gibbsite follow exactly an opposite trend, i.e. higher the kaolinite abundance, lesser is the gibbsite abundance. This relation is confirmed from a negative correlation between kaolinite and gibbsite (Table 3.6).

It is seen from the data that st. no.13, which represents the deepest portion of the lake contains the highest abundance of kaolinite and the least abundance of gibbsite irrespective of the seasons. From the sediment component analysis, it was seen in the earlier section that st. no.13 contain the least organic carbon content irrespective of the seasons. This clearly suggests close association of organic carbon with gibbsite and not with kaolinite. This is well supported by a positive correlation of organic carbon with gibbsite and a negative correlation with kaolinite (Table 3.6).

It is also clear that illite abundance is relatively more in eastern zone compared to central and western zones. Distribution of illite also follows that of gibbsite. It was seen from sediment component analysis that eastern zone has relatively higher proportion of clay as well as higher organic carbon content. Thus, a close association of clay, illite and organic carbon is supported by a positive correlation of illite and clay as well as illite and organic carbon (Table 3.6). The data has also revealed that abundance of kaolinite is contrary to that of illite, which is also supported by a strong negative correlation between them ($r = -0.8076$) (Table 3.6). This opposite trend also suggests the inability of illite, inspite of being coarser among the clay minerals (Gray *et al.,* 1963) to get transported to the deeper areas. It is well known that illite is generally lost on transport (Ingerson, 1960; Nelson, 1963). Montmorillonite, owing to its finest size causes adsorption of organic carbon onto itself as coatings. This is supported in the present study by a positive correlation between them. Higher relative abundance of montmorillonite obtained for eastern shallow zone can be explained with the help of such a process. However, montmorillonite does not show such a relation with organic carbon during monsoon (Table 3.6). Availability of relatively higher abundance of montmorillonite and lower organic carbon content in surface sediments during this season must be the possible reason for such a behaviour.

Clay minerals have been widely used as a first order guide to the source, environment and the transport paths of fine grained sediments (Biscay, 1965; Griffin *et al.,* 1968; Grim, 1968 and Hashimi and Nair, 1989). Bukhari and Nayak (1996) deciphered the source of sediments by the study of spatial and seasonal variation in the relative abundance and the association of clay minerals of Mandovi estuary. An attempt is made here to identify the characteristics of the source rocks by using clay minerals. It is well known that the laterites are the prime sources of clay minerals especially in tropical climate (Millot, 1970; Stow and Piper, 1984) and as mentioned earlier, catchment area of Mayem Lake is covered to a large extent by laterites and lateritic soil. Bhattacharya and Sinha (1976) have pointed out that kaolinite is a product of initial strong leaching while gibbsite is a product of further intense leaching. Hence, the higher relative abundance of kaolinite in the surface sediments of Mayem Lake clearly indicates release of kaolinite from laterites due to the process of initial strong leaching and gibbsite by less intense leaching.

Kaolinite is known to be relatively coarser compared tc montmorillonite, as settling velocity of kaolinite is 0.0135, that of illit 0.083 and montmorillonite 0.0015. Higher relative abundance c kaolinite in the deeper regions of the lake thus, may further b explained as a result of selective transport of relatively coarser clay fraction to the deeper regions of the lake. It has also been seen earlier that surface sediments in deeper region contain relatively higher proportion of silt fraction. This is well supported by a positive correlation between kaolinite and silt (Table 3.6).

Illite has it is origin from phyllites (Velde, 1985). Ferrugenous phyllites exposed within the catchment area of Mayem lake are responsible for the illite abundance within the surface sediments of Mayem lake. However, relatively low abundance of this mineral may be attributed to dilution by kaolinite rich detritus as pointed out for the Kumbla - Shiriya estuary by Narayana and Sureshkumar (1994). Illite is relatively stable and almost remains unaffected in lacustrine environment (Hurley *et al.,* 1961), hence, it has a typical allogenic origin (Jones and Bowser, 1978).

Surface sediments of Mayem lake contain less abundance of montmorillonite. It is found to be closely associated with organic carbon specially in inner valley segment and eastern shallow zone. However, in monsoon such an association is not seen. As the rock types and the processes operating within the catchment area can not release observed abundance of montmorillonite, its presence in Mayem lake can be attributed to an aeolian source.

Thus, from the above discussion, it is clear that clay minerals in surface sediments of Mayem lake have a mixed origin - namely kaolinite and gibbsite from laterites. Illite from ferrugenous phyllites and montmorillonite from aeolian source. Presence of goethite is due to anthropogenic source from mine rejects dumped within the catchment area of Mayem lake.

Part C

Sub-surface sediments

"Sub-surface sediments" represent the sedimentary column deposited through a geological past and thus, records successive and uninterrupted events in the environment of deposition. To study the past, sediment cores are to be collected which are particularly useful in understanding rate of sedimentation, and palaeo-environment. The dating of such cores is done by means of certain granulometric characteristics, by pollen assemblages or by radioisotopic measurements.

The significance of cores in assessing the palaeo-quality of aquatic systems is well illustrated from lacustrine environment by Frink (1967); Muller (1967); Anderson (1973) and Rose *et al.,* (1979). Lake sediment cores have increasingly been employed as a tool to trace sources and input rates (Leshnoiwsky *et al.,* 1970; Hites *et al.,* 1977). Also, core studies are especially suited for differentiation of natural metal enrichment and anthropogenic effects occurring in certain areas as a consequent of mining and smelting activities (Allan, 1974 ; Girap and Nayak, 1996).

Methodology

Sub-surface sediment samples were collected using a gravity corer of 2 m in length. Three such cores were collected from Mayem lake, locations of which are shown in figure (Fig 3.1). After thei retrieval, cores were kept in vertical upright position to dry-off exces water. Later, they were subsampled with uniform interval of 3 cm eac Every subsample was further subdivided into three fractions. From th two fractions were used for present study and remaining one fraction is kept as a reference.

Every sub-sampled fraction of each core (core -1, core - 2 and core - 3) was analysed for sediment components (sand-silt-clay), organic carbon content and selected sub-sampled fractions for clay mineral analysis following the same procedures as mentioned in the surface sediments. However, grain size parameters were not calculated for the analysed sub-sampled fractions.

Preliminary estimation of past rate of sedimentation calculated for core - 2 with the help of analysis of 3 sub-samples was about 0.8 to 0.9 cm/yr (Nayak, 1995). As this range was based on only 3 sub-samples, an attempt was made to get more accurate rate with the help of analysis of more number of samples. Accordingly, more number of selected core sub-samples from different core depths of core - 2 (11 nos.) and core - 3 (12 nos.) were analysed for age determination by ^{210}Pb (Half life - 22.2 yr.) radiometric method (Krishnaswamy *et al.*, 1971). In this method, Pb-activity was assessed by alpha detection that involves the measurement of its grand-daughter nuclide ^{210}Po (Half life - 138 days) using α-particle spectrometer (Joshi, 1989). It is a known fact that ^{210}Pb reaches lake sediments in two forms : a) an "unsupported" component from an atmosphere and b) a "supported" component derived directly from soil/substrate of the drainage basin (Lerman,1978). Activity of supported ^{210}Pb was assumed to be constant and is considered equivalent to decay of ^{226}Ra content in sediments (El-Daoushy, 1988). Unsupported activity of ^{210}Pb was calculated by subtraction of this "constant" from the total activity measured for each fraction at corresponding depth in a core (Robbins and Herche, 1993). In the present study, average $^{210}Pb_{(total)}$ activity of the last three bottom fractions of respective core is considered as "Parent supported" i.e. supported ^{210}Pb activity as they show near constancy in ^{210}Pb activity.

Thus, $^{210}Pb_{(excess)} = {}^{210}Pb(total) - {}^{210}Pb$ (parent supported), Wherein, $^{210}Pb_{(excess)}$ is equivalent to $^{210}Pb_{(unsupported)}$ and is considered as a source from atmospheric fall-out.

Prior to the measurement of radioactivity, all the selected core sub-samples were plated onto a silver planchet following procedures as described by Flynn, (1968); Fleer and Bacon, (1984) and Smith and Hamilton, (1984) for age dating. ^{208}Po tracer is also added for improved efficiency and accuracy (Benoit and Hemond, 1988). Samples being Fe-rich, ferric ion interference with Po-deposition on silver planchet was suppressed using ascorbic acid as a reducing agent (Bennet and Carpenter, 1979). The $^{210}Pb_{(excess)}$ activity was plotted against respective depth to estimate the past rate of sedimentation.

In addition, data presented in a report (Nayak, 1995) which is based on collection from five trap locations (Fig.3.2) for a period of thirteen months with monthly interval to estimate present rate of sedimentation using a sediment trap (Fernandes and Nayak,1996), is used to compare the past with the present rate of sedimentation.

Results and discussion

Core - 1 represents inner valley portion while core - 2 and core -3 represents outer reservoir segment. Core - 2 is from the deepest portior of a lake, while core - 3 is from relatively shallower region of a lak along the NE corner, at which the lake receives majority of surface rur off through an ephemeral stream within the outer reservoir segment. (see Fig. 3.1).

Length of the cores recovered are 51 cm, 78 cm and 99 cm for core - 1, core - 2 and core - 3 respectively.

Sediment components and organic carbon

Depthwise variation in sediment components in these cores are given separately in tables (Table 3.7, 3.8 and 3.9) and organic carbon variation with depth in all cores is given in a table (Table 3.10). These are graphically represented in figures (Fig. 3.14, 3.15 and 3.16) for core -1, core - 2 and core - 3 respectively.

Based on relative proportions of sand - silt - clay, sediment composition in core - 1 varies from silty-clay near the top to sandy-silty-clay at the bottom. In core -2, it varies from clayey-silt near the top to sandy-clayey-silt at the bottom. While in core - 3, it varies from silt-clay near top to sandy-clay at the bottom.

Sand fraction in core - 1 ranges from 0.16% near top to 7.89% near bottom level (av. 2.17%). In core - 2, its concentration ranges from 0.14% near top to 11.20% near bottom level (av. 1.69%). While in core - 3, its concentration ranges from 0% within upper layers to 30.50% in bottom level (av. 6.18%).

Sand fraction, in general shows an increasing trend towards downcore (r = 0.8078 for C-1, r = 0.6472 for C-2 and r = 0.7889 for C-3). When observed closely, It is clear from the data obtained that first sand fraction in top portion (0 - 3 cm) of all the cores is slightly higher (0.75% in C-1, 1.46% in C-2 and 1.80% in C-3) than the portion below.

In core - 1, sand fraction almost remains the least and constant (av. 0.34%) between 3 and 30 cm. Then, its concentration increases further with two relatively higher values at 36 cm (5.60%) and 45 cm (7.89%) and a lower values at 42 cm (3.37 cm) and 51 cm (4.22%). In core -2, sand fraction is the least and almost remains constant (av. 0.39%) between 3 and 40 cm. Then, gradually increases further with relatively less concentration at 60 cm (1.33%) and 69 cm (1.64%) depths and higher concentration at 63 cm (4%) and 78 cm (11.21%). While in core - 3, sand fraction is the least and almost remains constant (av. 0.20%) between 3 and 50 cm. Then, its concentration gradually increases with relatively less concentration at 78 cm (3.20%) and 84 cm (9.30%) depths and higher concentration at 72 cm (12.80%) and 93 cm (30.5%).

Silt content in core - 1 ranges from 14.20% to 45.66% (av. 34.13%), in core - 2 its concentration ranges from 42.53% to 56.63% (av. 49.01%). While in core - 3, it ranges from 5.30% to 41.40% (av. 27.48). In general, in core - 1 silt content shows an increasing trend with the depth (r= 0.5468). While in core - 2, it shows a decreasing trend (r= - 0.3699) with few high values and core - 3 show a decreasing trend with depth (r= - 0.7229).

Based on silt content, core - 1 may be divided into two parts : an upper part from near surface to a depth of 24 cm and a lower part from a depth of 24 cm till bottom. Upper part has relatively less silt content (av. 27.46%) than the lower part (av. 40.05%). Core - 2 and core - 3 do not show such a distinct separation. In core - 2, silt content decreases from surface upto a depth of 18 cm, then further its conten slightly increases till a depth of 36 cm below which it decreases wit relatively higher values at 51 cm, 60 cm, 59 cm and 75 cm depths. In core - 3, in general, silt content decreases with depth.

Clay content in core - 1 ranges from 53.55% to 85.60% (av. 63.12%), in core - 2 its concentration ranges from 48.29% to 55.66% (av. 49.23%). While, in case of core - 3, clay content ranges from 58.40% to 76.25% (av. 66.34%). In general, clay content in core - 1 shows decreasing trend with depth (r= - 0.6817). Relatively higher clay content is recorded within upper part i.e. from surface to a depth of 24 cm. In core - 2, clay content gradually increases from surface upto a depth of 18 cm, then further, its content decreases with relatively lower values at 51 cm, 60 cm, 69 cm, and 75 cm depths. In core - 3, clay content, in general, decreases with depth.

Slightly higher percentage of sand fraction obtained for the topmost sub-sample of all the three cores indicates input of additional sand to the lake in recent years.

From the data obtained, it is clear that sand fraction is more than 10% only in bottom fractions of core - 2 and between 72 cm and 99 cm depths of core - 3 i.e. in the outer reservoir segment. Such a higher percentage of sand fraction in core - 3 clearly indicates higher input of sand fraction in the past from a major stream which directly joins at the NE corner of the lake near to this core.

The constancy in the sand fraction and its low concentration within the upper part of all the three cores indicates an uniform and continuous deposition of material dominant in finer fractions. Similar observation was made earlier by Rukavina *et al.,* (1990) in lake St. Louis, Canada. The depth at which this particular feature is observed is varying from core to core. It is the least in case of core - 1 (30 cm) followed by core - 2 (40 cm) and the highest for core - 3 (50 cm). This reveals the relative rates of deposition at these core sites. The least in core - 1 which is in the inner valley portion and the highest in core - 3 which was collected near the point where a major ephemeral stream joins the lake in the outer reservoir segment. Higher and lower peak values of sand fraction obtained for all three cores, when correlated also reveals variation in the rate of deposition of coarser / finer sediments at different core sites.

Variation of the silt content with that of clay when compared closely, is seen to show an opposite relation except in core - 3, wherein both silt and clay decrease with depth. It may be important to note here the presence of relatively higher percentage of sand fraction especially in the lower portion of this core (core -3), which must be responsible for such a behaviour of silt and clay. Opposite relation between silt and clay is very significant in core - 1. While in core - 2, higher and lower peaks of silt content correlates very well with lower and higher peaks of clay respectively.

The range of variation between silt and clay is relatively wide in upper part (from surface to a depth of 24 cm) than bottom part in core - 1. In core - 2, the range of variation between silt and clay is narrow and almost uniform. While in case of core - 3, the range of variation between silt and clay is wide and variable. It is observed that the clay content is very high between 30 - 51 cm depths and silt content is very low between 90 - 99 cm depths in core - 3. In addition, sand fraction increases with depth, with high concentration of sand within the bottom fractions. All these variations are responsible for a variable range between silt and clay in this core. When silt and clay contents are compared, it is found that clay content is always higher than silt except in upper layers of core - 2. This means more silt is being added to deeper portion in recent years.

Within the upper part, relative proportion (ratio) of silt to clay is less in core - 1 and core - 3, which represents the inner valley portion and eastern shallow portion of the outer reservoir segment of the lake from where material is brought into the lake through four ephemeral streams. While relative proportion of silt to clay is more in core - 2 which represents deeper portion within outer reservoir segment of the lake, farther away from sediments input sources. This suggests that in the recent years, there is relatively larger supply of material dominant in silt and clay fraction along the eastern portion of the lake. This is also supported by relatively less and near uniformity in sand fraction. From this mixture of silt and clay, relatively finer fractions (clay) remains entrapped within the eastern shallower portion of the lake due to the presence of macrophytes. While, relatively coarser fraction (silt) get selectively transported to the deeper area of the lake which is evident from higher ratio between silt and clay. This supports the different sedimentation pattern in case of core-2 and that of core-1 and core-3.

Sand fraction, when observed under petrological microscope revealed the dominance of quartz grains with very few feldspars. The increase in sand fraction with the depth and its mineral composition suggest the nature of then existing material within the catchment area. It also indirectly reveals the palaeo-weathering processes which once operated within the catchment area. i.e. relatively less degree of erosion and release of coarser material. This may be further related to more vegetal cover and less anthropogenic interference within the catchment area of the lake in the past. The vegetal cover must have played an important role in arresting the transport of finer particles produced during the weathering process.

Higher percentage of finer fraction (silt and clay) obtained for the upper layer suggests higher degree of erosion, presence of less vegetal cover and anthropogenic influence within the catchment area of the Mayem lake.

Organic carbon content in core - 1 ranges from 2.3% to 13.43% (av. 6.96%), in core - 2 its concentration ranges from 5.15% to 16.56% (av. 10.10%). While in core - 3, organic carbon content ranges from 3.68% to 14.35% (av. 7.22%). In general, organic carbon content decreases with depth, which is significant in core - 1 with high values at deeper levels in core - 2 and insignificant in core - 3.

When observed closely in core - 1, concentration of organic carbon increases upto a depth of 18 cm then decreases till a depth of 27 cm and afterwards almost remains constant (av. 4.99%) till the bottom. Its concentration is relatively higher in upper part (av. 9.29%) than the lower part (av. 4.88%). In core - 2, organic carbon concentration is relatively higher at the depths of 6 cm, 27 cm, 57 cm and 72 cm. However, layer above 42 cm has average concentration of 11.32%. Further below, organic carbon concentration, on an average, is relatively less (av. 9.12%). In core - 3, it is clear from the data that relatively higher organic carbon concentration is recorded from a depth of 54 cm to 69 cm. In fact, this particular portion contains the higher organic carbon than any of the remaining portion of a core. It is also clear that, on an average, organic carbon concentration in core - 3 is relatively less (av. 6.09%) in the upper part from surface to a depth of 51 cm than below (av. 8.41%).

Thus, it is seen from the depthwise variation in organic carbon concentration in all cores that its content is relatively higher in upper layers of core -1 and core - 2 and lesser in core - 3. It was seen earlier from sediment components analysis that core - 1 and core - 3 have relatively higher proportion of clay fraction in upper layers.

Organic carbon concentrations when compared with clay content distribution, core - 1 shows a direct relation (Fig. 3.17A). In core - 2 and in core - 3, when high and low values are compared, clay content and organic carbon concentration show an inverse relation. Most of the higher organic carbon concentrations agree with high values of silt content in core - 2 and core - 3 (Fig. 3.17B and 3.17C).

Organic carbon concentration within the sediments is controlled by primary productivity as well as macrophyte growth within the lake and supply of organic matter from the catchment area. From the data obtained, it is clear that core - 1 contains less and almost uniform organic carbon in the bottom part and relatively higher concentration in the upper part. This indirectly reveals that supply of organic matter to the sediments is higher during the recent years within inner valley portion of the lake. It may be important to note here that there is a large macrophyte growth along the eastern side of this portion of the lake. In addition, the catchment area from where material is received to this portion of the lake has an appreciable soil cover and vegetation. This justifies higher supply of organic matter to inner valley portion of the lake.

Although the average organic carbon percentage is higher in core - 2 and core - 3 as compared to core - 1, its distribution with depth not being regular, to explain the process operated is quite difficult taking one or two parameters. The data revealed association of organic carbon with silt component than clay especially at peak values. It is also noted that, in general, organic carbon concentration is relatively higher in upper part of core - 2 and bottom part of core - 3. It is important to note here that the catchment area from which outer reservoir segment receives water and sediment material is relatively barren with little or no soil cover and wherein mine rejects are being dumped. The higher organic carbon content in bottom layers of core - 3, therefore can be related to organic detritus input during earlier years before the catchment area became barren. With the anthropogenic interference like dumping of mine waste in recent years within this part of the catchment area, input of material relatively rich in inorganic detritus must have increased causing higher rate of siltation and dilution of organic carbon content in core - 3. This can also be supported by taking the sediment composition of core - 2 into account, wherein silt percentage compared to other core is relatively high. However, macrophyte growth in recent years is responsible for adding organic carbon to the upper layers of core - 2 and core - 3. Sediment input being higher in outer reservoir segment, organic matter which is in suspension must be settling along with finer sediment material and therefore, associated with silt especially at peak values.

From this discussion, it is clear that the nature and pattern of sedimentation are different in inner valley portion as compared to outer reservoir segment. Sediment components and organic carbon content variation also have helped to delineate the weathering condition existed in the catchment area at different periodic times, effect of anthropogenic activity and environmental changes occurred within the catchment area.

Clay Minerals

All the sub - sampled fractions of core - 2 and selected sub - sampled fractions of core - 1 and core - 3 were analysed for clay minerals to support the interpretation made based on other parameters. In case of core-1, fractions selected include C_1-1 (0 - 3 cm), C_1-5 (12 - 15 cm), C_1-9 (24 - 27 cm), C_1-13 (36 - 39 cm) and C_1-17 (48 - 51 cm), and from core - 3 fractions selected include C_3 - 1 (0 -3 cm), C_3 - 5 (12 -15 cm), C_3 - 9 (24 - 27 cm), C_3 - 14 (39 -42 cm), C_3 - 17 (48 - 51 cm), C_3 - 22 (63 - 66 cm), C_3 - 25 (72 - 75 cm), C_3 - 29 (84 - 87 cm) and C_3 - 33 (96 - 99 cm).

The clay minerals identified are kaolinite, illite, gibbsite and montmorillonite. Goethite is also considered, as it's presence in clay-sized fraction is quite noticeable. X-ray diffractrograms of few fractions obtained for core - 1, core - 2 and core - 3 are presented in figures (Fig. 3.18A, 3.18B and 3.18C) respectively.

Depthwise variation in the relative percentage of clay minerals of all the cores (core - 1, core - 2 and core - 3) are presented seperately in tables (Table 3.11, 3.12 and 3.13) and graphically represented in figures (Fig. 3.19 A, B and C) respectively.

Relative abundance and depthwise variation of each clay mineral in core - 2 is described. Data from core -1 and core - 3 are used as a supporting data since only selected fractions from these cores were analysed.

Kaolinite : Kaolinite is the dominant clay mineral irrespective of the depth in core - 2 (Table 3.12). Its relative abundance ranges from 48.46% to 88.93%. In general, kaolinite abundance decreases with depth. Relatively higher kaolinite abundance is recorded at 18 - 21 cm, 39 - 42 cm and 48 - 51 cm depths and relatively lower abundance at 6 cm, 33 cm depths and within bottom levels. It is also clear from the data that the relative abundance is higher in upper part (av.73.69%) from surface to a depth of 39 cm than the bottom part (av.71.61%). From sediment component analysis, it was seen earlier that this upper part has relatively higher silt content. This shows a close association of kaolinite with silt, which is also supported by a positive correlation between them.

Kaolinite is also a dominant clay mineral irrespective of the depths in core - 1 (Table 3.11) and core - 3 (Table 3.13). In core - 1, relative abundance of kaolinite ranges from 67.04% to 73.19% while, in core - 3, its abundance rages from 42.82% to 93.76%. In general, in core - 1 and core - 3 also relative abundance of kaolinite decreases with depth. As observed in core - 2, higher relative abundance of kaolinite is seen in upper part of core - 1 and core - 3 as compared to lower part. However, in core - 3 slight increase in relative abundance is recorded between 51 cm and 99 cm depths.

Illite: Relative abundance of illite in core - 2 ranges from 0% to 44.35% (Table 3.12). In general, its abundance shows a decreasing trend with depth. Relatively higher illite abundance (av. 14.09%) is recorded within the upper part, from the surface to a depth of 39 cm than the bottom part (av. 7.94%). Thus, illite also follows the trend of kaolinite. However, the relative abundance of illite is opposite to that of kaolinite at high values. This is also supported by negative correlation between them.

As in core - 2, in general, illite abundance decreases with depth in core - 1 and its concentration is higher in upper part. Its relative abundance ranges from 5.71% to 17.22% (Table 3.11). In core - 3, illite abundance ranges from 0% to 41.78% (Table 3.13). Its concentration is relatively less (av. 5.59%) in the upper part i.e. upto a depth of 42 cm from the surface. Further down, its relative abundance is higher (av. 24.88%). Closer observation has shown that higher illite abundance is recorded at a depth of 51 cm and further below its abundance decreases gradually.

Gibbsite : Relative abundance of gibbsite in core -2 ranges form 0% to 25.80% (Table 3.12). In general, its abundance shows a increasing trend with depth (r=0.7739) (Table 3.14B). Relative abundance of gibbsite is less (av. 4.83%) within the upper part from surface to a depth of 39 cm than the bottom part (av. 13.87%). It is clear from the data that relative abundance of gibbsite shows an opposite trend, to that of kaolinite.

The relative abundance of gibbsite in core - 1 ranges from 5.26% to 23.18% (Table 3.11) and in core - 3 its abundance ranges from 2.66% to 7.57% (Table 3.13). As in case of core - 2, in general, relative abundance of gibbsite increases with depth in core - 1 (r= 0.8031) (Table 3.14A) with relatively higher abundance at 27 cm depth. However, core - 3 does not show any defined trend. Higher relative abundance is recorded in this core at 15 cm, and 75 cm depths and the least at 66 cm depth. Opposite trend of gibbsite to that of kaolinite is also clear in core - 1 (r= - 0.7930) (Table 3.14A) and core - 3 (r= - 0.5186) (Table 3.14C).

Montmorillonite : Relative abundance of monmorillonite in core - 2 ranges from 1.08% to 27.08% (Table 3.12). Its abundance does not show any definite trend with depth. However, in general, its abundance is relatively more in bottom part. Relative abundance of montmorillonite in core - 1 and core - 3 is low as compared in core - 2. Its abundance ranges from 3.07% to 6.32% in core - 1 (Table 3.11) and from 2.47% to 8.46% in core - 3 (Table 3.13). As in case of core - 2, the trend of variation with depth is not very clear. Higher relative abundance is recorded at 15 cm and bottom most fraction in core - 1 and at 51 cm, 87 cm depths in core - 3.

From the data described above, it is clear that the kaolinite is the dominant clay mineral in all three cores. Its relative abundance varies between 42.82% and 93.76% and is higher in upper part of all cores and decreases with depth. Higher relative abundance of kaolinite in upper part suggest strong leaching of lateritic rocks within the catchment area in recent years. It also suggests increased erosional rate and material transport to the lake.

In core - 2, kaolinite shows a good correlation with silt (Table 3.14B) and in core - 1, it shows a good correlation with organic carbon (Table 3.14A). Association of kaolinite with silt can be attributed to its settling velocity as explained earlier in the surface sediments. Core -1 being representative of inner valley portion with lesser sediment input, higher growth of macrophytes and relatively quieter conditions, kaolinite association with organic carbon agrees with a general principal of finer sediment association with organic matter. In this core, illite and montmorillonite which are associated with kaolinite show a very good correlation with organic carbon. Gibbsite abundance, however, increases with depth. In case of core - 2 and core - 3, such association is not very significant, possibly due to wider range of size and larger inorganic sediment input to the lake within the outer reservoir segment.

Core - 2 represents deeper water conditions wherein silt and clay are equal in proportions. Here, illite is second predominant clay mineral to kaolinite, and it decreases with depth. As organic carbon also decreases with depth, it shows a positive correlation with illite (Table 3.14B). Illite being a characteristic mineral of mechanical weathering of phyllitic rocks, it is detrital in origin. Higher abundance of illite in the upper layers of core - 1 and core - 2 suggest greater degree of mechanical degradation of ferrugenous phyllites from catchment area in recent years. In core - 3, however, its abundance is diluted due to predominance of kaolinite.

Gibbsite abundance increases with depth in core - 2 as well as core - 1 and shows negative correlation with kaolinite (Table 3.14 B,A). In core - 3, its variation with depth is not uniform.

Relative abundance of montmorillonite is higher in core - 2, as compared to core - 1 and core - 3. In core - 2, it is especially concentrated more in bottom part and shows a positive correlation with organic carbon. Montmorillonite formation due to alteration of illite during diagenesis has been explained by Hamdi (1977) in lake Edku, Egypt (Sabrouti El and Sokkary, 1982). Montmorillonite association within organic carbon is observed to be very strong in the present study except in core - 3, wherein montmorillonite abundance is considerably less. Alteration of illite to montmorillonite possibly requires sufficient time which may be difficult in the present case as the rate of material input is relatively higher. Montmorillonite addition to this lake, therefore, may be due to aeolian source.

Rate of sedimentation

Past rate

The data obtained from radiometic dating on cores (11 sub-samples from core - 2 and 12 sub-samples from core - 3) is presented in tables (Table 3.15 A and 3.15 B) respectively and the relationship between ^{210}Pb (excess) and depth for core - 2 and core - 3 is graphically represented in figures (Fig. 3.20A and 3.20 B).

Rate of sedimentation is estimated from the graph of core - 2 (Fig. 3.20A) and is in the order of 0.340 cm/yr. While the rate estimated from graph of core - 3 (Fig. 3.20B) is 0.404 cm/yr. The rate of sedimentation obtained for core - 2 can be taken as an average sedimentation rate for Mayem lake, as this core was collected from the central deepest portion of the lake. As mentioned earlier, core - 3 was collected from NE corner of the lake, where major ephemeral stream joins the lake and the lake receives large sediment input from the stream. The higher rate of sediment obtained for core - 3, therefore, can be attributed to the influx of material and deposition at this site.

Present rate

The trap location no. 1 was near TSM sampling st. no. 7 (inner valley portion), trap no. 2 was between TSM sampling st. nos. 4 and 5, trap no. 3 was near TSM sampling st. no. 1, trap. no. 4 was near TSM sampling st. no. 10 and trap no. 5 was near TSM sampling st. no. 13 (all four traps in the outer reservoir segment, out of which, trap nos. 4

and 5 represent deeper portion of the lake). The significant points from the report (Nayak, 1995) is presented below on the present rate of sedimentation to compare with the past rate of sedimentation obtained.

Average of 13 months, when compared between inner valley, shallow portion of the outer reservoir segment and deeper portion of the outer reservoir portion shows that the sediments trapped in the inner valley is relatively very less (0.308 cm/cm^2/month - trap no. 1) compared to outer reservoir segment (0.7511 cm/cm^2/month - trap nos. 2,3,4 and 5). Within the outer reservoir segment, trapped sediment material is higher in shallow zone (0.8495 cm/cm^2/month - average of trap nos. 2 and 3) as compare to deeper portion (0.6647 cm/cm^2/month - average of trap nos. 4 and 5). Between trap nos. 2 and 3, material trapped is relatively higher at trap no. 3 (1.0045 cm/cm^2/month) which is near to the TSM sampling st. no. 1 as compared to trap no. 2 (0.6945 cm/cm^2/month). Within the deeper portion, trap no. 4 seems to contain more sediment material (1.1471 cm/cm^2/month) as compare to trap no. 5 (0.1823 cm/cm^2/month).

When the sediment trapped was observed with respect to seasons, it is clear that material trapped is very high during monsoon months (June - July - August) especially at trap nos. 3 and 4. The sediment material trapped at trap no. 3 in the month of July is 5.36 cm/cm^2 (av. 1.0045 cm/cm^2/month) and at trap no. 4, it is 3.15 cm/cm^2 (av. 1.1471 cm/cm^2/month). It is interesting to note here that trap no. 3 is located near TSM sampling st. no. 1 at the north-eastern corner of the lake, wherein major ephemeral stream joins.

The trap study (Nayak, 1995) carried out in Mayem lake for a period of 13 months clearly indicates material input from the catchment area through ephemeral streams during monsoon. It also confirmed higher sediment influx to the outer reservoir segment as compared to inner valley portion.

Using the monthly data, average present rate of sedimentation calculated for Mayem lake, by taking into account 87% of moisture content, is 0.936 cm/yr (Nayak, 1995).

Thus, it is seen that the present rate is very high compared to the past rate. This clearly shows an increased rate of material influx during recent times, which is attributed to increased anthropogenic interference within the catchment area of Mayem lake. Assuming the continuation of present rate of sedimentation and considering the average depth of the lake as 4 m, it may be foresighted that the Mayem lake may become a plain - land or disappear within the next 500 years, which in geological context is a very short time span.

Table 3.1 Seasonal and spatial Variation in total suspended matter (TSM) in Mayem lake waters (mg/l)

Sampling st. nos.		Premonsoon (May)	Monsoon (August)	Postmonsoon (December)
1	S	3.80	1.12	1.54
	B	1.87	18.53	2.44
2	S	2.60	2.94	0.96
	B	1.65	3.83	14.21
3	S	2.90	2.05	1.31
	B	10.50	2.94	2.26
4	S	2.10	2.07	1.74
	B	2.70	2.56	2.88
5	S	1.50	3.39	2.11
	B	2.20	3.23	13.57
6	S	2.00	2.42	1.18
	B	8.10	1.99	22.47
7	S	3.10	1.66	0.70
	B	15.50	29.85	19.14
8	S	2.60	1.60	1.65
	B	7.60	24.28	6.35
9	S	4.20	0.80	1.67
	B	12.20	0.86	1.54
10	S	2.30	1.75	1.70
	B	7.70	34.62	18.47
11	S	2.30	1.29	2.95
	B	4.60	1.96	23.17
12	S	5.10	1.17	1.17
	B	10.70	3.25	2.03
13	S	3.90	0.57	1.86
	B	21.90	53.32	49.21
14	S	4.70	1.32	0.75
	B	10.30	2.86	18.61
15	S	5.80	1.70	2.41
	B	N.D.	23.32	N.D.

N. D. = Not determined S = Surface B = Bottom.

Table 3.2A Seasonal and spatial variation of sediment components of surface sediments (Percentage).

Sampling St.no's	Premonsoon			Monsoon			Postmonsoon		
	Sand	Silt	Clay	Sand	Silt	Clay	Sand	Silt	Clay
1	3.98	64.40	31.78	8.36	55.43	36.12	4.32	44.24	51.43
2	7.84	40.35	51.75	4.41	55.32	40.00	0.94	59.29	39.76
3	5.28	35.14	59.57	1.19	55.80	43.00	1.12	44.76	54.11
4	2.03	46.50	51.46	1.09	57.45	41.45	2.00	58.65	39.35
5	5.01	49.91	45.04	4.85	51.23	43.88	16.49	44.88	38.62
6	5.98	38.21	55.80	1.98	46.76	51.25	1.00	48.38	50.62
7	6.04	50.81	42.36	1.29	53.82	44.88	0.68	45.12	54.25
8	13.95	45.85	40.20	1.65	54.64	43.46	10.29	52.94	36.76
9	2.90	57.73	39.73	2.82	53.52	44.35	2.29	58.76	38.94
10	2.85	75.40	21.60	2.12	51.99	45.87	0.65	61.29	38.06
11	7.55	57.00	35.40	2.54	55.28	42.17	1.59	62.41	36.00
12	16.87	51.60	31.53	7.93	49.65	42.41	N.D.	N.D.	N.D.
13	2.84	59.69	37.43	2.04	56.51	41.44	3.06	62.70	34.23
14	3.17	58.65	38.17	3.48	56.28	40.23	4.29	56.64	39.05
15	N.D.	N.D.	N.D.	11.16	51.35	37.43	N.D.	N.D.	N.D.

N.D. = Not determined

Table 3.2B Zonal distribution of sediment component with seasons in surface sediments (Percentage) .

Zone	Premonsoon			Monsoon			Postmonsoon		
	Sand	**Silt**	**Clay**	**Sand**	**Silt**	**Clay**	**Sand**	**Silt**	**Clay**
Eastern	6.26	46.40	47.25	3.99	53.55	42.38	4.60	49.78	45.61
Central	4.43	63.37	32.24	2.49	53.59	44.14	1.51	60.82	37.66
Western	7.63	56.64	35.71	4.48	54.15	41.36	3.68	59.67	36.64

Table 3.3A Seasonal and spatial variation in grain size parameters of surface sediments.

Sampling St.Nos.	Mean size (ϕ)			Standard deviation (σ_1)			Skewness (SK_I)			Kurtosis (K_G)		
	Premonsoon	Monsoon	Postmonsoon	Premonsoon	Monsoon	Postmonsoon	Premonsoon	Monsoon	Postmonsoon	Premonsoon	Monsoon	Postmonsoon
1	6.66	6.99	6.60	1.38	1.28	1.40	- 0.10	- 0.40	- 0.09	0.66	0.69	0.57
2	7.14	6.96	7.15	1.63	1.44	1.41	- 0.81	- 0.56	- 0.81	1.04	0.68	0.72
3	7.35	6.89	7.42	1.23	1.44	1.19	- 0.78	- 0.52	- 0.77	0.84	0.66	1.18
4	7.29	7.09	6.63	1.27	1.28	1.48	- 0.77	- 0.54	- 0.18	0.76	0.74	0.67
5	6.95	7.23	7.00	1.65	1.19	1.40	- 0.71	- 0.64	- 0.64	0.87	0.67	0.67
6	7.31	7.29	7.29	1.32	1.25	1.25	- 0.79	- 0.76	- 0.78	0.93	0.80	0.85
7	7.03	7.16	7.36	1.44	1.25	1.29	- 0.69	- 0.62	- 0.79	0.66	0.65	1.10
8	7.16	7.09	6.61	1.30	1.29	1.45	- 0.67	- 0.56	- 0.16	0.67	0.69	0.63
9	6.87	7.14	6.81	1.35	1.25	1.39	- 0.37	- 0.56	- 0.35	0.65	0.69	0.66
10	6.56	7.20	6.75	1.37	1.25	1.41	- 0.70	- 0.69	- 0.30	0.65	0.69	0.66
11	6.72	6.86	6.77	1.43	1.34	1.39	- 0.24	- 0.40	- 0.33	0.62	0.66	0.65
12	6.62	6.99	N.D.	1.57	1.42	N.D.	- 0.37	- 0.66	N.D.	0.52	0.63	N.D.
13	6.79	6.99	6.67	1.34	1.39	1.44	- 0.23	- 0.54	- 0.25	0.63	0.75	0.45
14	6.84	7.03	6.77	1.35	1.28	1.52	- 0.22	- 0.51	- 0.48	0.69	0.73	0.71
15	N.D.	7.00	N.D.	N.D.	1.28	N.D.	N.D.	- 0.46	N.D.	N.D.	0.68	N.D.

N.D. = Not determined

Table 3.3B. Zonal distribution with seasons in grain size parameters of surface sediments.

Zones	Premonsoon				Monsoon				Postmonsoon			
	Mean size	Std. Deviation	Skewness	Kurtosis	Mean size	Std. Deviation	Skewness	Kurtosis	Mean size	Std. Deviation	Skewness	Kurtosis
Eastern	7.11	1.40	- 0.67	0.80	7.08	1.30	- 0.58	0.69	7.01	1.39	- 0.53	0.79
Central	6.75	1.38	- 0.44	0.64	7.07	1.28	- 0.55	0.68	6.78	1.36	- 0.33	0.66
Western	6.72	1.42	- 0.27	0.61	7.00	1.36	- 0.57	0.70	6.72	1.48	- 0.36	0.58

Table 3.4A Seasonal and spatial variation in total organic carbon content of surface sediments (Percentage).

Sampling St.No's	Premonsoon	Monsoon	Postmonsoon
1	10.30	4.78	9.38
2	12.33	11.41	7.73
3	11.41	10.30	10.30
4	12.14	10.86	8.83
5	9.01	9.94	8.09
6	13.98	7.54	12.14
7	11.77	11.23	11.04
8	12.69	9.94	13.98
9	6.67	6.99	8.09
10	6.99	5.15	6.81
11	7.54	4.23	6.92
12	6.26	5.7	N.D.
13	5.34	2.76	5.70
14	6.62	5.52	5.94
15	N.D.	15.46	N.D.

Table 3.4 B Zonal distribution of total organic carbon content in surface sediments (Percentage).

Zone	**Premonsoon**	**Monsoon**	**Postmonsoon**
Eastern	11.70	10.16	10.18
Central	7.06	5.46	7.27
Western	6.07	4.66	5.82

Table 3.5A Seasonal and spatial variation of clay minerals in surface sediments (relative percentage).

Clay minerals	Premonsoon St. No's.							Monsoon St. No's.								Postmonsoon St. No's.						
	1	3	5	7	9	11	13	1	3	5	7	9	11	13	15	1	3	5	7	9	11	13
Kaolinite	50.94	45.67	45.85	54.54	68.96	58.09	73.87	68.57	81.76	70.35	52.53	63.49	78.31	89.32	68.99	73.87	42.68	64.48	74.46	56.36	70.00	76.13
Illite	23.89	27.88	28.46	19.25	13.79	32.35	16.41	0.00	9.41	22.10	35.82	25.39	11.27	0.00	10.85	10.82	44.27	18.58	17.32	36.36	20.00	19.44
Gibbsite	16.98	26.44	23.32	17.11	11.78	9.56	5.18	14.28	5.58	7.54	4.18	8.39	4.79	4.14	9.69	9.44	8.69	16.94	4.33	5.75	6.00	3.29
Montmo-rillonite	8.18	0.00	2.37	9.09	5.46	0.00	4.54	17.14	3.23	0.00	7.46	2.72	5.63	6.54	10.47	5.86	4.34	0.00	3.89	1.51	4.00	1.23

Table : 3.5B Zonal distribution with seasons of clay minerals in surface sediments (relative percentage)

Clay minerals	Premonsoon			Monsoon			Postmonsoon		
	Eastern	**Central**	**Western**	**Eastern**	**Central**	**Western**	**Eastern**	**Central**	**Western**
Kaolinite	49.25	63.52	73.87	68.44	70.90	89.32	63.87	63.18	76.13
Illite	24.87	23.07	16.41	15.64	18.33	0.00	22.75	28.18	19.44
Gibbsite	20.96	10.67	5.18	8.25	6.59	4.14	9.85	5.88	3.29
Montmorillonite	4.91	2.73	4.54	7.66	4.17	6.54	3.52	2.76	1.23

Table 3.6 Simple correlation between silt and clay fractions, organic carbon content and clay minerals in surface sediments.

Premonsoon

	Clay	**Gibbsite**	**Illite**	**Kaolinite**	**Montmorillonite**	**Org.Carb.**
Gibbsite	0.7260					
Illite	0.2185	0.4430				
Kaolinite	- 0.4759	- 0.9036	- 0.7129			
Montmorillonite	- 0.4784	- 0.1805	- 0.6527	0.1998		
Org.Carb.	0.4520	0.7865	0.3829	- 0.8381	0.1760	
Silt	- 0.9801	- 0.7373	- 0.3470	0.5534	0.5107	- 0.5335

N=7

Monsoon

	Clay	**Gibbsite**	**Illite**	**Kaolinite**	**Montmorillonite**	**Org.Carb.**
Gibbsite	- 0.7399					
Illite	0.7231	- 0.3277				
Kaolinite	- 0.1745	- 0.2428	- 0.7808			
Montmorillonite	- 0.8484	0.6395	- 0.4712	- 0.1428		
Org.Carb.	0.0061	0.0641	0.4499	- 0.4706	- 0.0946	
Silt	- 0.0489	- 0.2306	- 0.5161	0.5300	0.2323	- 0.7325

N=8

contd /-

Postmonsoon

	Clay	**Gibbsite**	**Illite**	**Kaolinite**	**Montmorillonite**	**Org.Carb.**
Gibbsite	0.0214					
Illite	0.1284	- 0.0840				
Kaolinite	- 0.2533	- 0.2511	- 0.9292			
Montmorillonite	-0.6892	- 0.2674	- 0.0981	0.0242		
Org.Carb.	0.9471	0.1313	0.1805	-0.3185	0.5280	
Silt	- 0.8062	- 0.5730	0.0522	0.2213	- 0.3157	- 0.8305

N = 7

Significance level 90% - 0.67

95% - 0.75

Table 3.7 Depthwise variation in sediment components of core-1 (Percentage).

Fraction no.	Range of depth in cm	Sand	Silt	Clay
1	0-3	0.75	27.75	71.50
2	3-6	0.16	23.66	76.00
3	6-9	0.30	37.00	62.66
4	9-12	0.25	23.00	76.50
5	12-15	0.30	26.30	73.30
6	15-18	0.76	34.80	64.40
7	18-21	0.33	33.00	66.00
8	21-24	0.20	14.20	85.60
9	24-27	0.22	42.11	57.66
10	27-30	0.77	45.66	53.55
11	30-33	2.70	41.30	56.00
12	33-36	5.60	38.00	56.40
13	36-39	3.80	41.89	54.22
14	39-42	3.37	41.25	55.37
15	42-45	7.89	31.56	60.55
16	45-48	5.30	40.80	53.90
17	48-51	4.22	37.89	57.88

Table 3.8 Depthwise variation in sediment components in core-2

Percentage)

Fraction No.	**Range of depth in cm**	**Sand**	**Silt**	**Clay**
1	0-3	1.46	53.9	44.7
2	3-6	0.14	53.8	46.1
3	6-9	0.16	52.7	47.2
4	19-12	0.28	50.0	49.7
5	12-15	0.46	46.3	53.2
6	15-18	0.46	43.9	55.7
7	18-21	0.30	47.5	52.1
8	21-24	0.47	47.2	52.4
9	24-27	0.25	49.8	48.0
10	27-30	0.60	50.9	48.5
11	30-33	0.18	51.4	48.5
12	33-36	0.60	51.7	47.8
13	36-39	0.50	47.4	52.1
14	39-42	0.67	47.4	51.8
15	42-45	1.17	49.5	49.4
16	45-48	2.00	52.2	45.8
17	48-51	2.91	56.6	40.5
18	51-54	3.09	48.1	48.8
19	54-57	2.00	46.9	51.1
20	57-60	1.33	48.3	50.4
21	60-63	4.00	43.9	52.1
22	63-66	1.83	48.3	49.9
23	66-69	1.64	50.7	47.7
24	69-72	2.17	45.0	52.8
25	72-75	4.00	42.5	53.5
26	75-78	**11.20**	48.5	40.3

Table 3.9 Depthwise variation in sediment components of core -3 (Percentage).

Fraction no.	Range of depth in cm	Sand	Silt	Clay
1	0-3	1.80	37.60	60.60
2	3-6	0.20	41.40	58.40
3	6-9	0.20	36.00	63.80
4	9-12	0.20	35.80	64.00
5	12-15	0.20	30.00	69.80
6	15-18	0.16	30.60	69.20
7	18-21	0.40	34.80	64.80
8	21-24	0.20	40.40	59.40
9	24-27	0.25	33.00	66.75
10	27-30	0.00	26.80	73.20
11	30-33	0.25	23.50	76.25
12	33-36	0.20	30.00	69.80
13	36-39	0.20	27.00	72.80
14	39-42	0.14	23.80	76.00
15	42-45	0.00	24.40	75.60
16	45-48	0.00	26.40	73.60
17	48-51	0.60	25.60	73.80
18	51-54	2.40	30.20	67.40
19	54-57	6.40	29.60	64.00
20	57.60	3.80	34.00	62.20
21	60-63	7.50	27.75	64.75
22	63-66	5.40	30.40	64.20
23	66.69	9.40	21.00	69.60
24	69-72	12.80	29.60	60.30
25	72-75	5.00	32.40	62.60
26	75-78	3.20	33.50	63.30
27	78-81	15.10	16.30	68.60
28	81-84	9.30	24.90	65.80
29	84-87	10.30	25.30	64.40
30	87-90	19.40	20.30	60.30
31	90-93	30.50	5.30	64.20
32	93-96	30.10	11.11	58.80
33	96-99	28.40	10.70	60.90

Table 3.10 Depthwise variation in total organic carbon content (Percentage) in sediments of all the three cores.

Fraction no.	Range of depth in cm	core - 1	core - 2	core - 3
1	0-3	6.99	8.10	6.44
2	3-6	7.36	12.33	7.73
3	6-9	9.38	11.96	6.44
4	9-12	12.51	11.60	6.26
5	12-15	11.77	11.00	5.70
6	15-18	13.43	9.30	5.52
7	18-21	8.83	10.50	6.99
8	21-24	4.05	7.70	8.10
9	24-27	4.05	16.56	8.83
10	27-30	5.34	14.35	7.18
11	30-33	5.70	12.90	7.73
12	33-36	6.25	13.30	4.97
13	36-39	4.97	7.50	4.60
14	39-42	2.39	5.15	4.42
15	42-45	4.78	7.54	3.68
16	45-48	5.15	8.83	4.05
17	48-51	5.34	9.57	4.97
18	51-54		9.75	10.67
19	54-57		10.67	13.25
20	57.60		10.12	14.35
21	60-63		8.83	13.06
22	63-66		11.56	11.77
23	66.69		7.91	9.20
24	69-72		9.57	6.26
25	72-75		8.10	7.18
26	75-78		8.10	7.18
27	78-81			7.18
28	81-84			8.65
29	84-87			7.36
30	87-90			5.70
31	90-93			4.42
32	93-96			4.43
33	96-99			3.86

Table 3.11 Depthwise variation in relative abundance of clay minerals in core - 1 (relative percent)

Fraction	Kaolinite	Illite	Gibbsite	Montmorillonite
1st (0-3)	73.19	17.72	5.36	3.73
5th (12-15)	71.58	16.84	5.26	6.32
9th (24-27)	67.04	6.70	23.18	3.07
13th (36-39)	71.74	5.71	19.36	3.19
17th (48-51)	67.72	7.56	20.39	4.33

. Values in the brackets indicate the depth (cm) range for the respective fraction.

Table 3.12 Depthwise variation in relative abundance of clay minerals in core -2 (relative percent).

Fraction	Kaolinite	Illite	Gibbsite	Montmorillonite
1st(0-3)	73.83	18.44	6.45	1.08
2nd(3-6)	48.46	44.35	1.03	6.16
3rd(6-9)	84.62	10.77	1.54	3.08
4th (9-12)	83.00	7.84	5.56	3.59
5th(12-15)	70.45	13.64	6.82	9.09
6th(15-18)	83.04	9.11	3.29	4.55
7th(18-21)	82.75	11.82	0.00	5.42
8th(21-24)	76.15	15.06	5.86	2.93
9th(24-27)	74.49	13.41	7.31	4.79
10th(27-30)	62.50	6.67	3.75	27.08
11th(30-33)	56.71	13.16	6.83	23.29
12th(33-36)	73.09	13.03	11.19	2.69
13th(36-39)	88.93	5.84	3.13	2.09
14th(39-42)	86.30	8.27	4.13	1.29
15th(42-45)	65.93	28.13	3.08	2.86
16th(45-48)	83.38	8.00	3.38	5.23
17th(48-51)	84.74	3.60	5.54	6.09
18th(51-54)	76.79	6.19	12.47	4.55
19th(54-57)	69.35	6.43	15.98	8.24
20th(57-60)	63.81	2.68	23.12	10.39
21st(60-63)	75.17	0.00	11.74	13.09
22nd(63-66)	63.09	7.59	21.88	7.43
23rd(66-69)	74.65	5.57	13.65	6.13
24th(69-72)	69.31	8.32	13.86	8.51
25th(72-75)	59.43	7.29	25.80	7.47
26th(75-78)	59.00	11.11	25.67	4.21

Values in the brackets indicate depth (cm) range for the respective fraction.

Table 3.13 Depthwise variation in relative abundance of clay minerals in core - 3 (relative percent).

Fraction	Kaolinite	Illite	Gibbsite	Montmorillonite
1st (0-3)	93.76	0.00	3.25	2.98
5th (12-15)	82.22	7.41	5.93	4.44
9th (24-27)	79.44	12.77	4.96	2.84
14th(39-42)	88.57	2.18	3.48	5.77
17th (48-51)	42.82	41.78	7.57	7.83
22nd (63-66)	61.03	33.81	2.68	2.47
25th (72-75)	70.28	20.19	6.17	3.36
29th (84-87)	70.65	16.58	4.31	8.46
33rd (96-99)	79.60	12.04	5.01	3.34

Values in the brackets indicate the depth (cm) range for the respective fraction.

Table 3.14A Simple correlation between sand, silt and clay fractions, organic carbon content, clay minerals and depth in core - 1.

	Clay	Depth	Gibbsite	Illite	Kaolinite	Montmorillonite	Org.Carb.	Sand
Depth	- 0.8318							
Gibbsite	- 0.9534	0.8031						
Illite	0.9890	- 0.8481	- 0.9738					
Kaolinite	0.5840	- 0.6294	- 0.7930	0.6636				
Montmorillonite	0.6876	- 0.2306	- 0.6339	0.6104	0.2255			
Org.Carb.	0.8420	- 0.5207	- 0.8329	0.7889	0.5107	0.9333		
Sand	- 0.6575	0.8335	0.4887	- 0.6006	- 0.1470	- 0.2467	- 0.4302	
Silt	- 0.1741	- 0.3213	0.1252	- 0.1755	0.1941	- 0.4439	- 0.1979	- 0.4025

N = 7

Significance level 98% - 0.934

90% - 0.8054

Table 3.14B Simple correlation between sand, silt and clay fractions, organic carbon content clay minerals and **in core- 2** .

	Clay	**Depth**	**Gibbsite**	**Illite**	**Kaolinite**	**Montmori llonite**	**Org.Carb.**	**Sand**
Depth	- 0.0464							
Gibbsite	- 0.0434	0.7739						
Illite	- 0.1765	- 0.5086	- 0.4004					
Kaolinite	0.1414	- 0.2182	- 0.4635	- 0.4324				
Montmorillonite	0.0645	0.1090	0.0701	- 0.1812	- 0.4784			
Org.Carb.	- 0.1241	- 0.3362	- 0.1151	0.1263	- 0.2884	0.4401		
Sand	- 0.4383	0.6472	0.6510	- 0.2185	- 0.2581	- 0.0585	- 0.3231	
Silt	- 0.8036	- 0.3699	- 0.3817	0.3355	0.0106	- 0.0218	0.2979	- 0.1726

N = 26

Significance level 99% - 0 .537

99.99% - 0 .652

Table 3. 14C Simple correlation between sand, silt and clay fractions, organic carbon content, clay minerals and depth in core - 3.

	Clay	Depth	Gibbsite	Illite	Kaolinite	Montmorillonite	Org.Carb.	Sand
Depth	- 0.2744							
Gibbsite	0.2867	0.0842						
Illite	0.1390	0.4035	0.4035					
Kaolinite	- 0.2307	- 0.4057	- 0.5186	- 0.9819				
Montmorillonite	0.5236	0.2239	0.3598	0.2576	- 0.4146			
Org.Carb.	- 0.3175	-0.0112	- 0.4293	0.3540	- 0.2208	- 0.3796		
Sand	- 0.5427	0.7478	- 0.0490	- 0.0227	0. 0391	- 0.0948	- 0.2611	
Silt	- 0.0765	- 0.6899	- 0.1471	- 0.0719	0. 1185	- 0.2644	0.5390	- 0.7959

N=9

Significance level 95% - 0.6664
99.99% - 0.898

Table 3.15 A Variation in ^{210}Pb activity with depth in selected fractions of core - 2.

Fraction	Range of depth (cm)	$210Pb_{(total)}$	$210\ Pb_{(excess)}$
1st	0 - 3 (1.5)	128.38 ± 0.46	114.69
2nd	3 - 6 (4.5)	117.58 ± 2.343	103.89
4th	9 - 12 (10.5)	61.88 ± 0.386	48.19
6th	15 - 18 (16.5)	31.89 ± 0.609	18.20
8th	21 - 24 (22.5)	19.94 ± 0.223	6.25
10th	27 - 30 (28.5)	20.27 ± 0.221	6.58
13th	36 - 39 (37.5)	25.38 ± 0.169	11.69
17th	48 - 51 (49.5)	16.31 ± 0.253	2.62
20th	57 - 60 (58.5)	14.27 ± 0.318	0.58
24th	69 - 72 (70.5)	13.79 ± 0.181	0.10
26th	75 - 78 (76.5)	13.02 ± 0.141	0.00

*Values in brackets indicate average depth.

Table 3.15 B Variation in ^{210}Pb activity with depth in selected fractions of core - 3.

Fraction	**Range of depth (cm)**	**^{210}Pb (total)**	**^{210}Pb(excess)**
1st	0 - 3 (1.5)	58.66 ± 0.271	48.57
3rd	6 - 9 (7.5)	49.44 ± 0.746	39.35
7th	18 - 21 (19.5)	17.23 ± 0.213	7.14
9th	24 - 27 (25.5)	14.65 ± 0.202	4.56
11th	30 - 33 (31.5)	15.66 ± 0.203	5.57
13th	36 - 39 (37.5)	12.51 ± 0.291	2.42
15th	42 - 45 (43.5)	9.47 ± 0.153	0.00
17th	48 - 51 (49.5)	14.90 ± 0.138	4.81
19th	54 - 57 (55.5)	10.57 ± 0.204	0.48
24th	60 - 63 (61.3)	10.36 ± 0.198	0.27
28th	81 - 84 (82.5)	10.18 ± 0.198	0.09
33rd	96-99 (97.5)	9.28 ± 0.125	0.00

* Values in brackets indicate average depth.

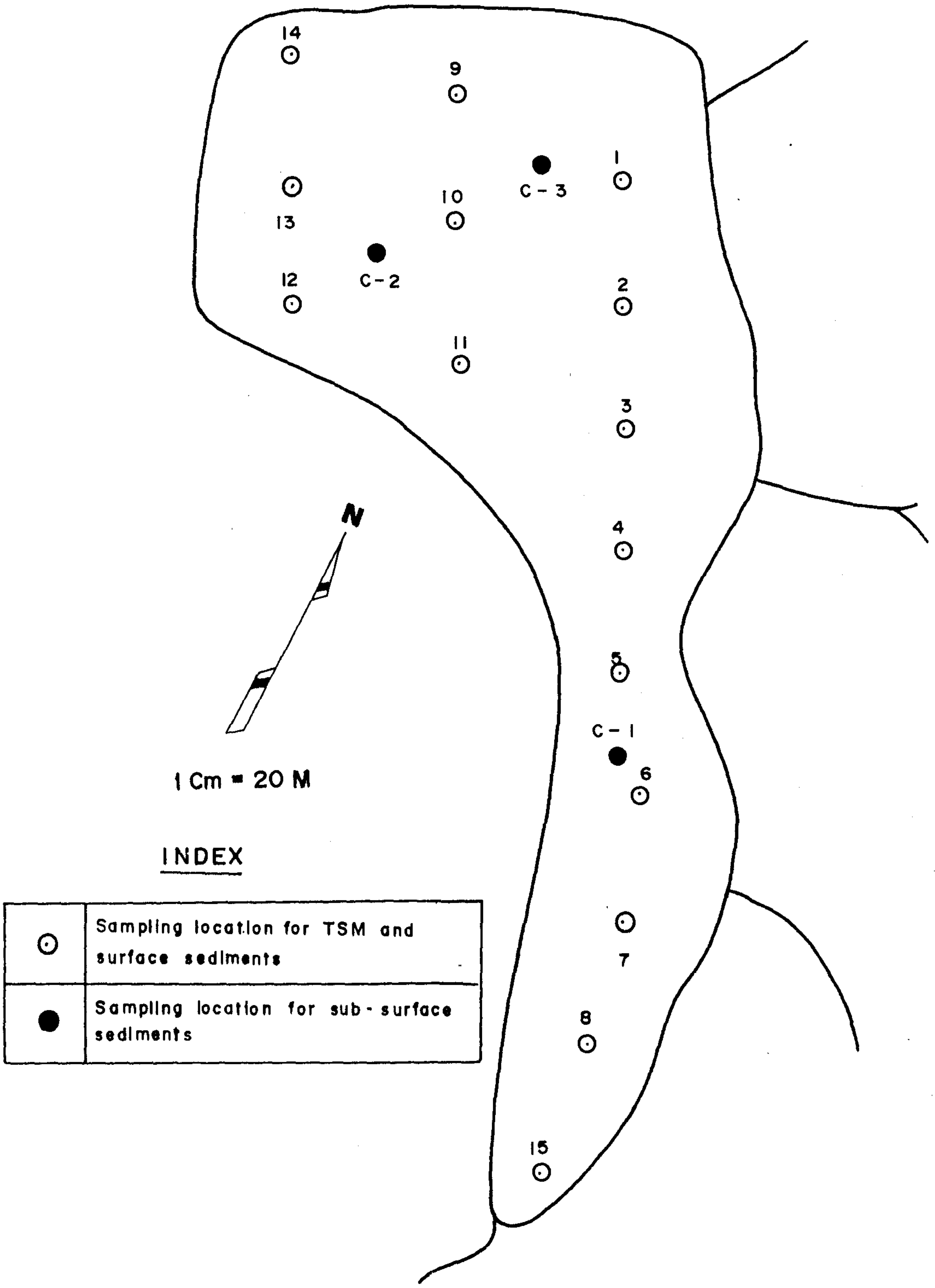


FIG. 3.1 LOCATIONS OF TOTAL SUSPENDED MATTER, SURFACE SEDIMENT AND SUB - SURFACE SEDIMENT SAMPLES WITHIN MAYEM LAKE

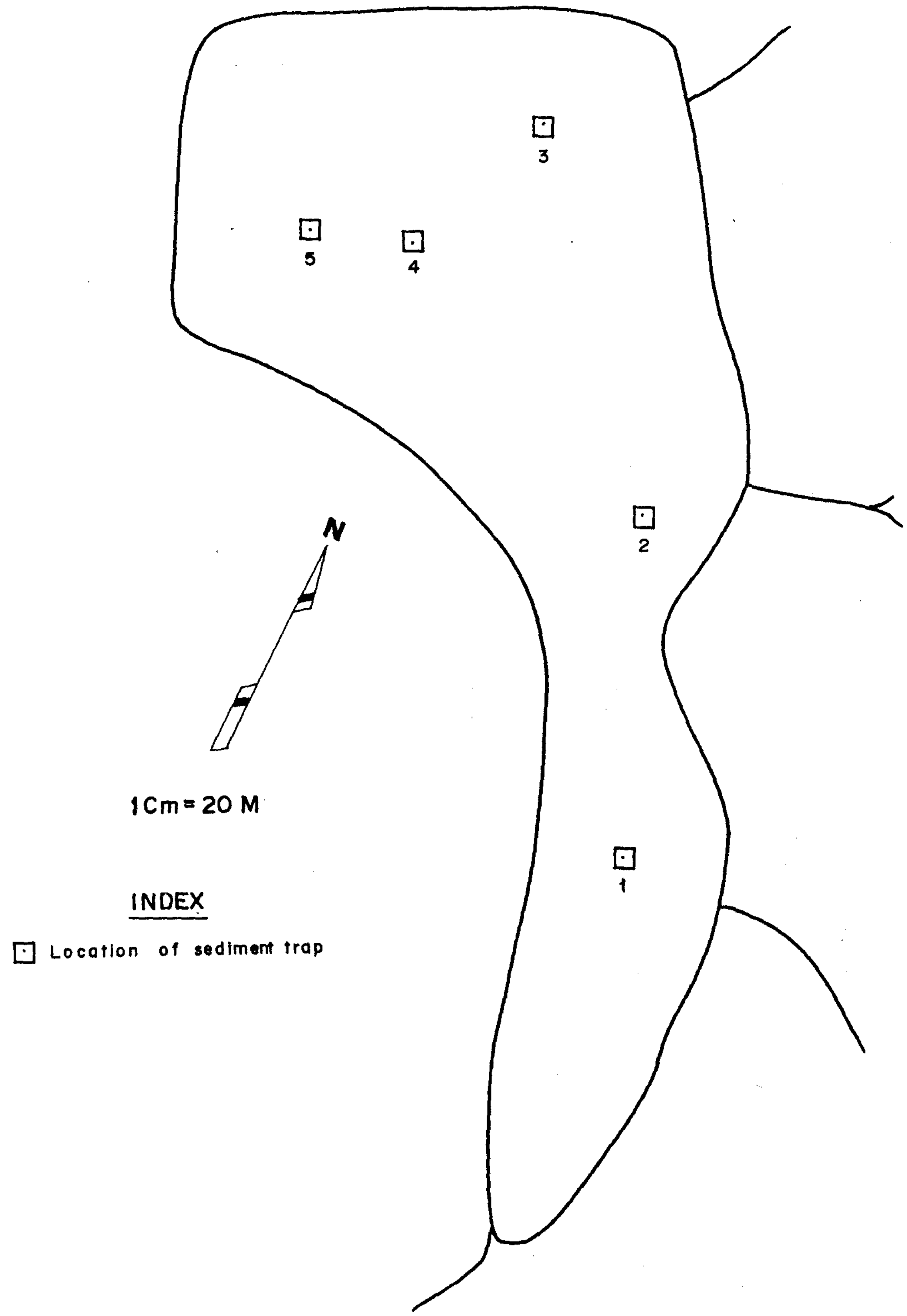


FIG. 3.2 LOCATION OF SEDIMENT TRAP WITHIN MAYEM LAKE

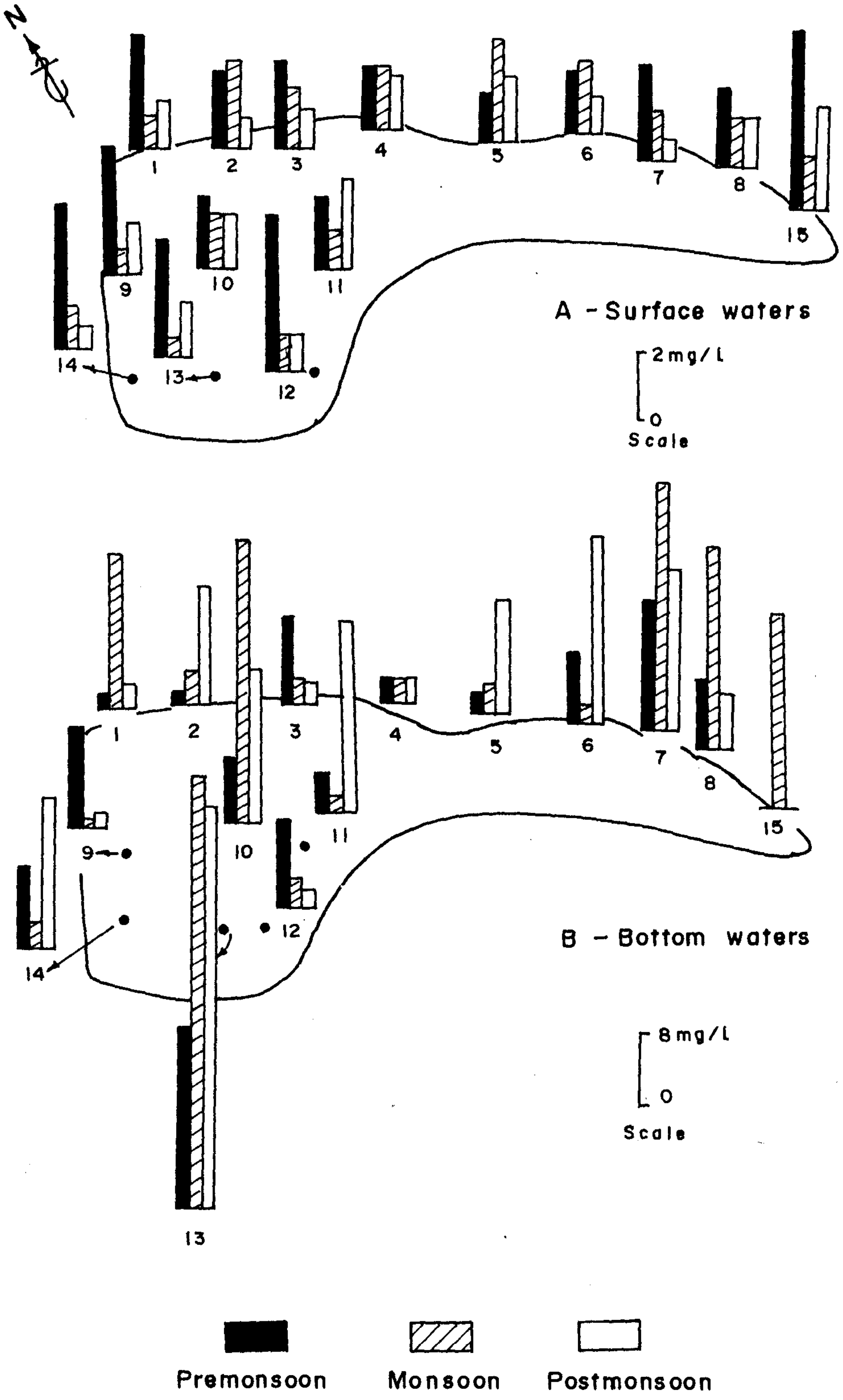


FIG. 3.3 SEASONAL VARIATION IN TOTAL SUSPENDED MATTER (TSM) IN MAYEM LAKE A) SURFACE WATERS B) BOTTOM WATERS.

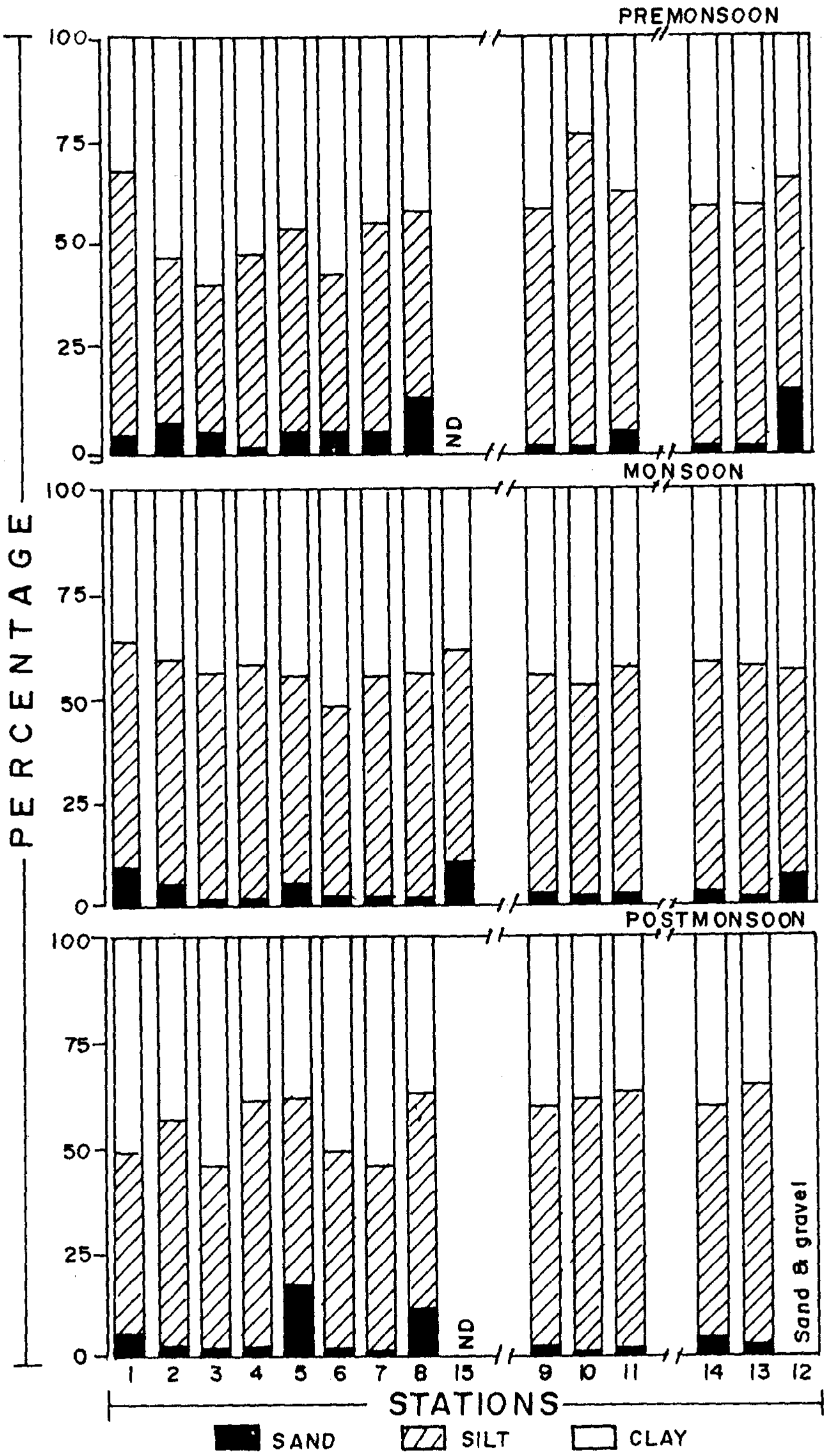
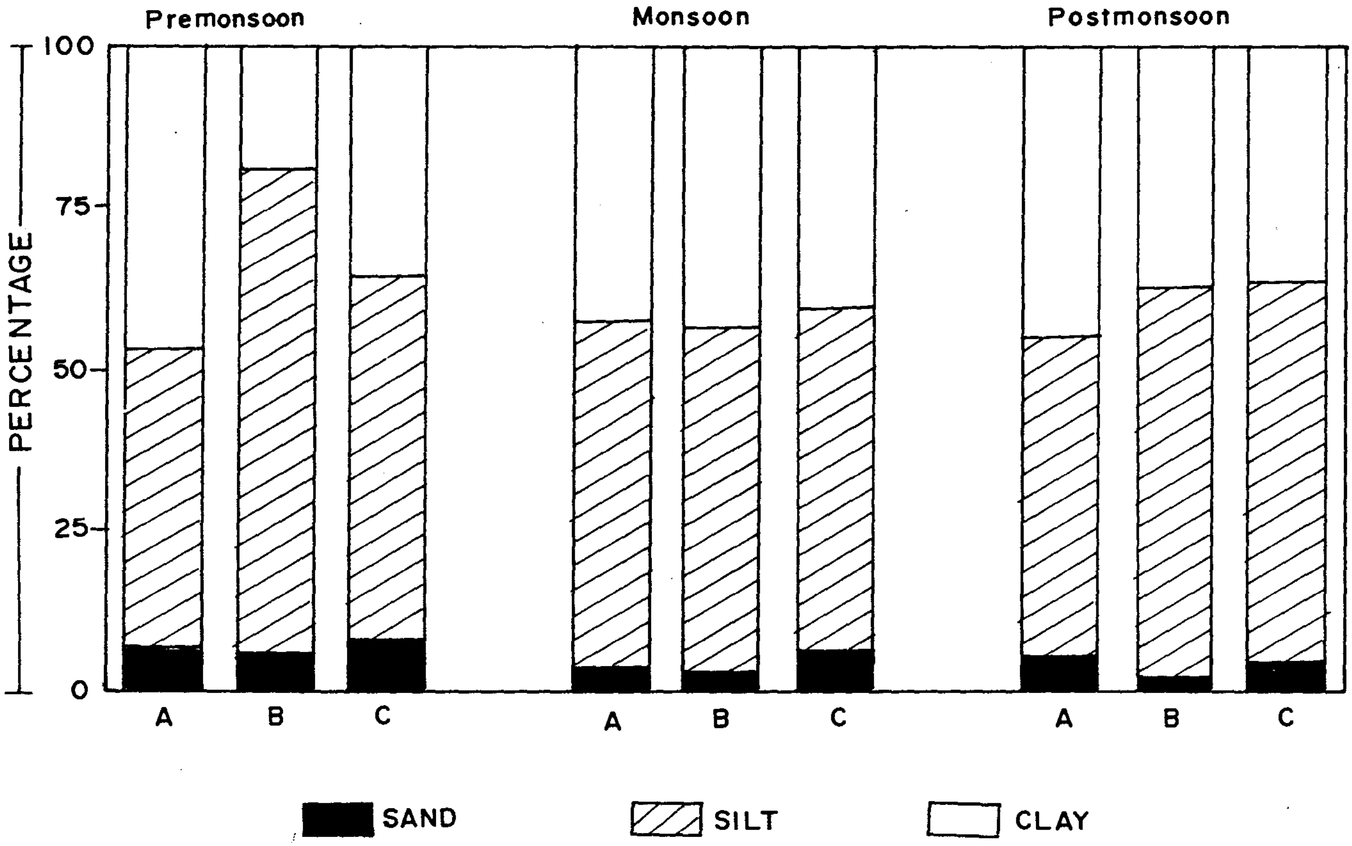


FIG. 3.4A SEASONAL VARIATION IN SEDIMENT COMPONENTS OF SURFACE SEDIMENTS



A - Eastern zone B - Central zone C - Western zone

FIG. 3.4B ZONAL DISTRIBUTION OF SEDIMENT COMPONENTS OF SURFACE SEDIMENTS

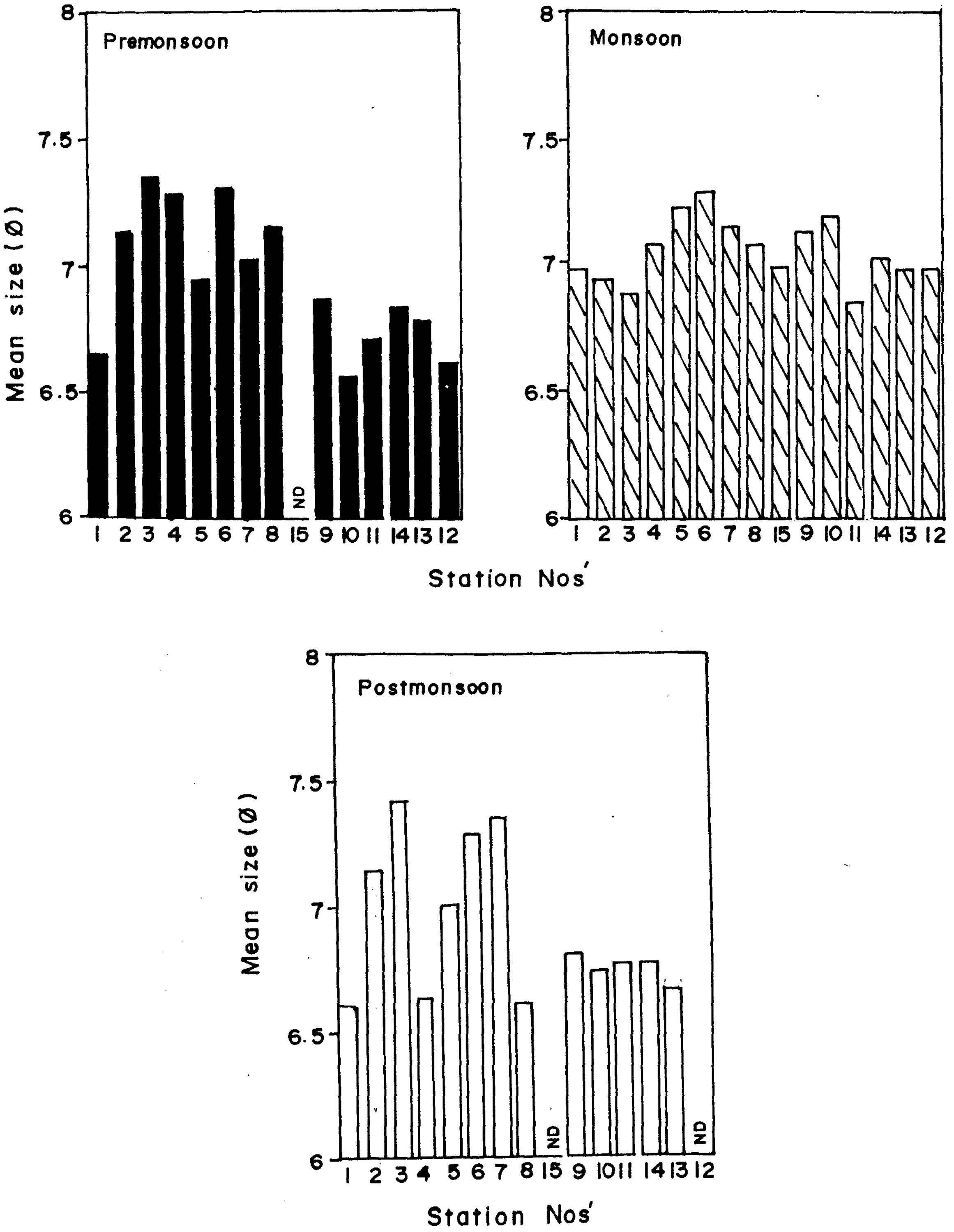


FIG. 3.5A(I) SEASONAL VARIATION IN MEAN SIZE OF SURFACE SEDIMENTS

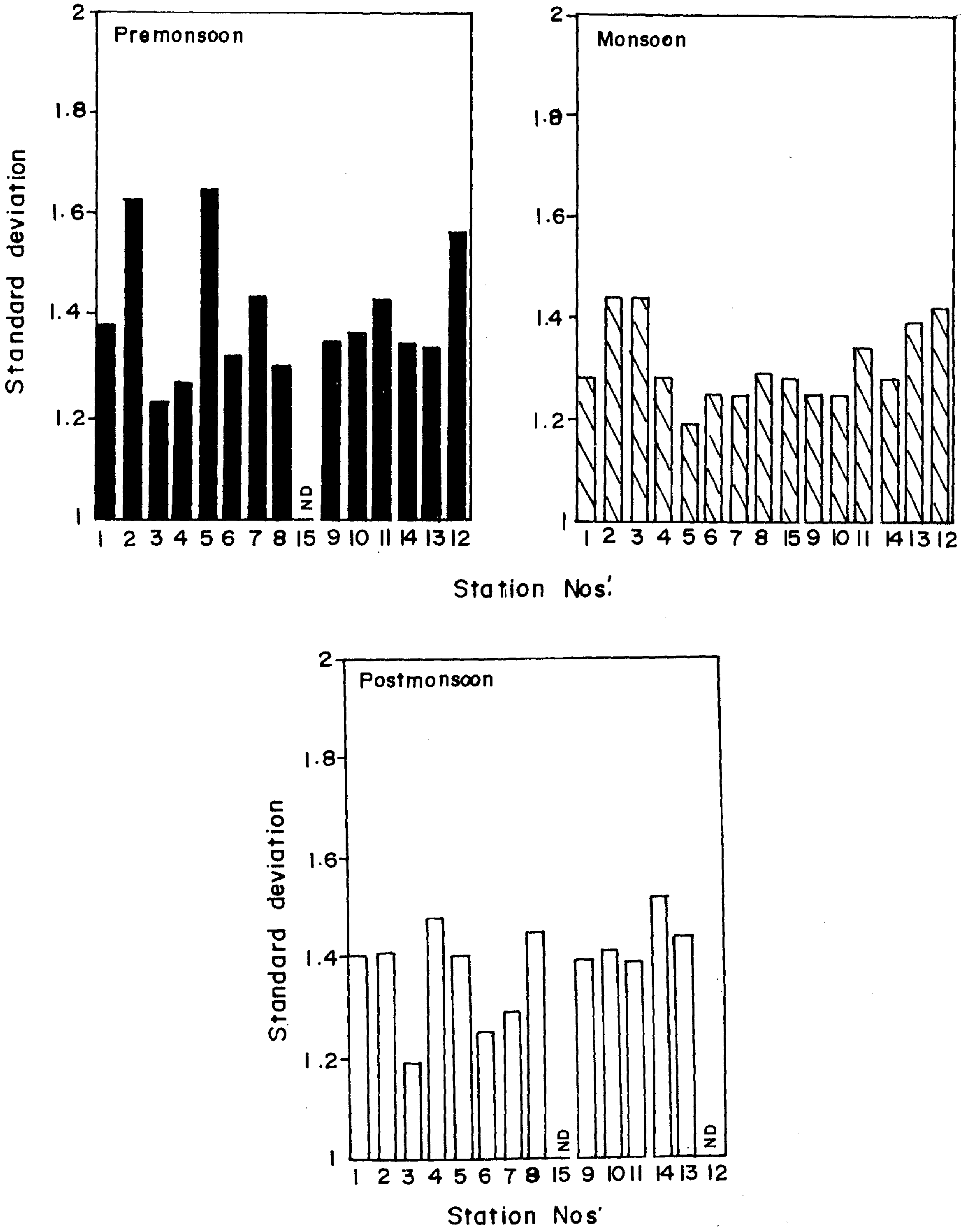


FIG. 3. 5A(ii) SEASONAL VARIATION IN STANDARD DEVIATION IN SURFACE SEDIMENTS

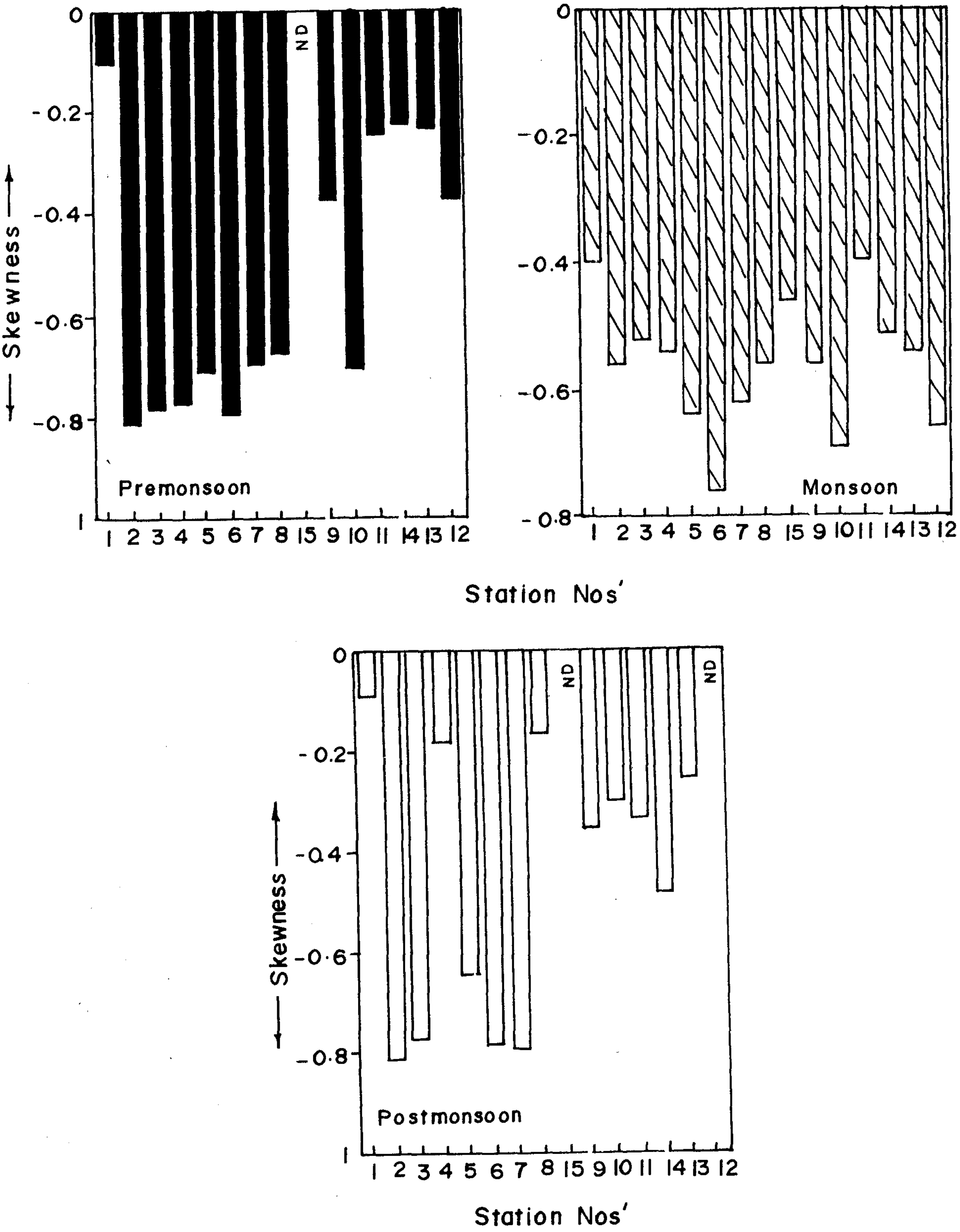


FIG. 3.5A(iii) SEASONAL VARIATION IN SKEWNESS IN SURFACE SEDIMENTS

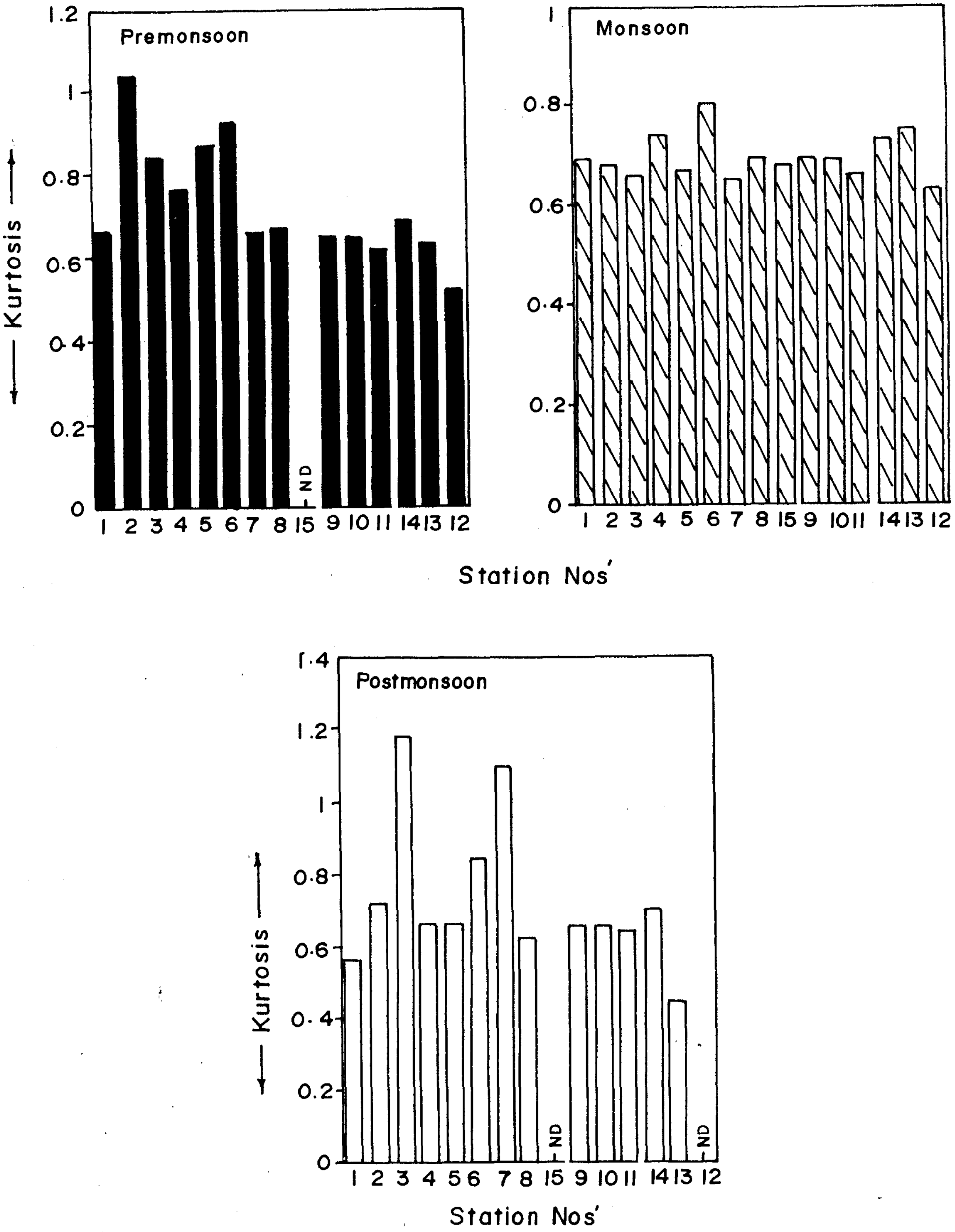


FIG. 3.5A(iv) SEASONAL VARIATION IN KURTOSIS IN SURFACE SEDIMENTS

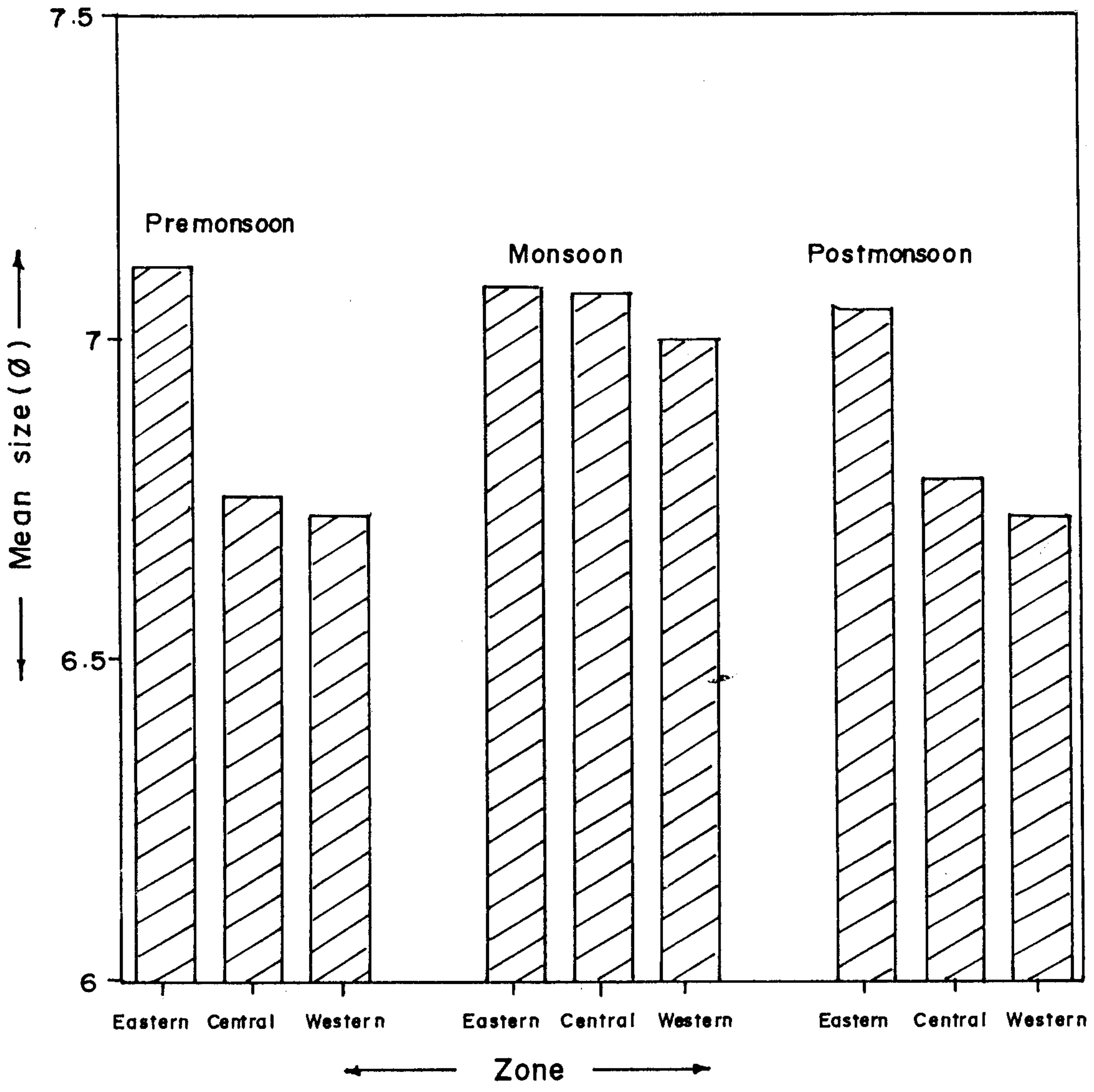


FIG. 3.5 B(i) ZONAL DISTRIBUTION OF MEAN SIZE OF SURFACE SEDIMENTS

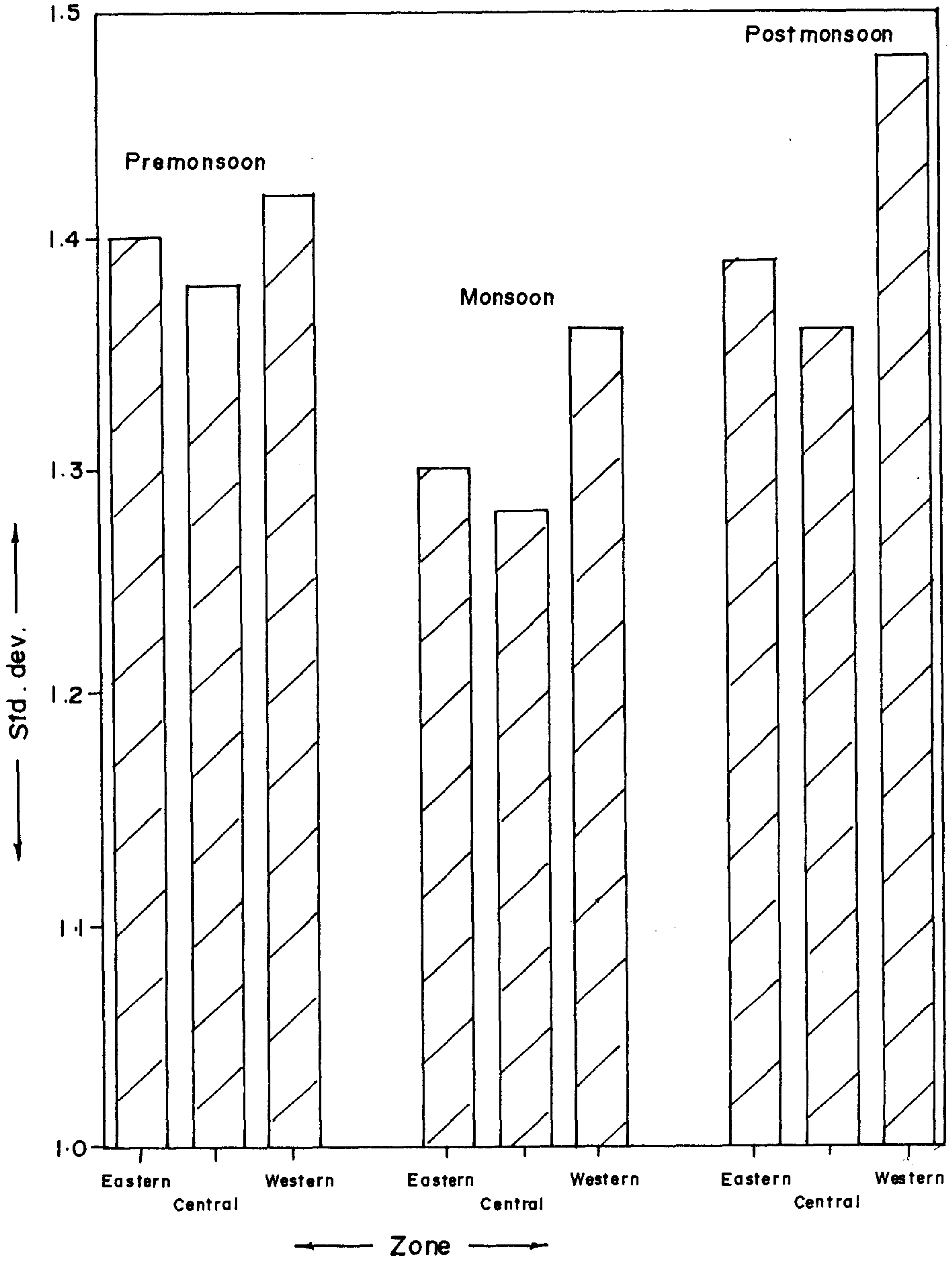


FIG.3.5 B (ii) ZONAL DISTRIBUTION OF STANDARD DEVIATION OF SURFACE SEDIMENTS

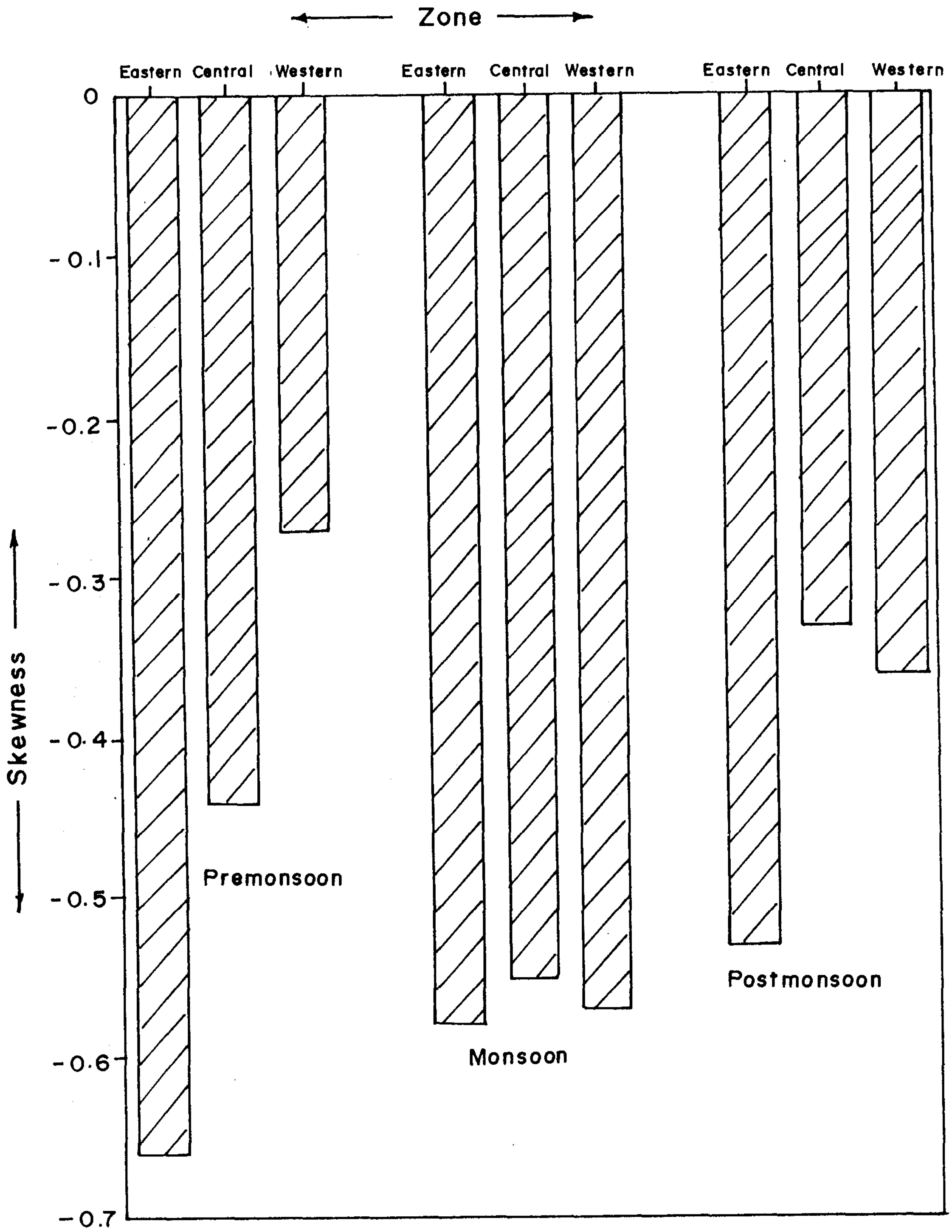


FIG. 3.5B(iii) ZONAL DISTRIBUTION OF SKEWNESS OF SURFACE SEDIMENTS

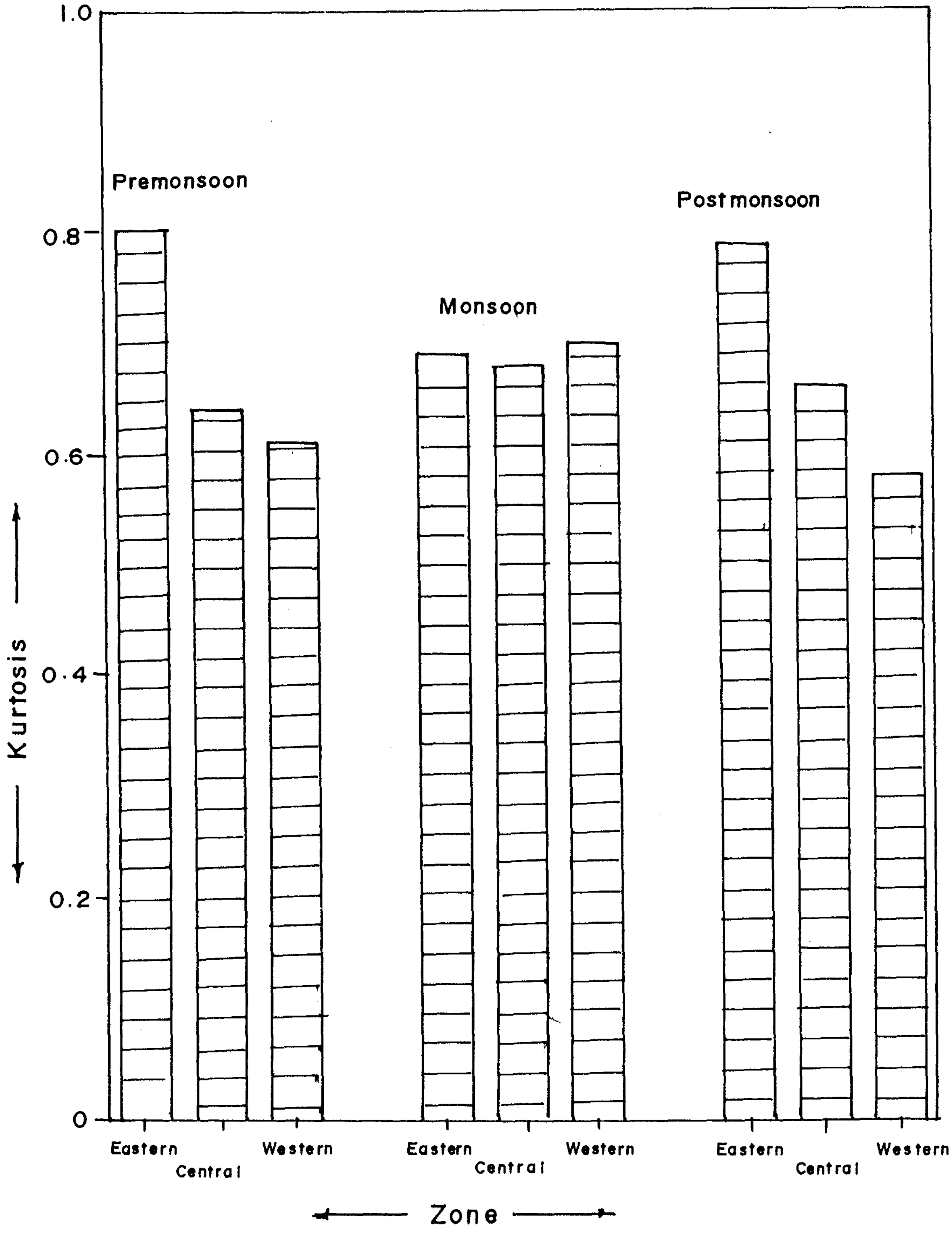
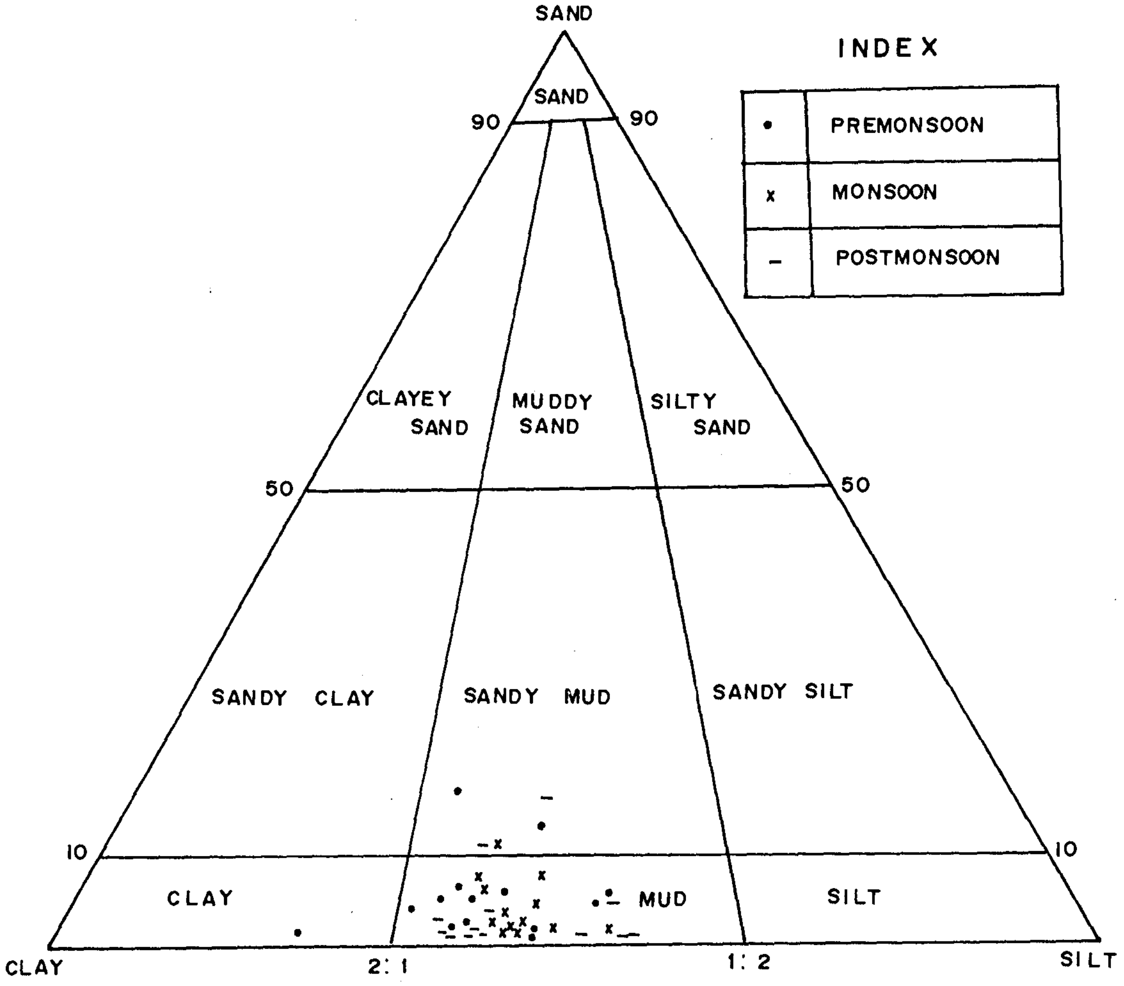


FIG. 3.5 B(iv) ZONAL DISTRIBUTION OF KURTOSIS OF SURFACE SEDIMENTS



MODIFIED FROM LINDHOLM, 1987

FIG. 3.6 TRIANGULAR PLOT (SAND - SILT - CLAY) FOR SURFACE SEDIMENTS

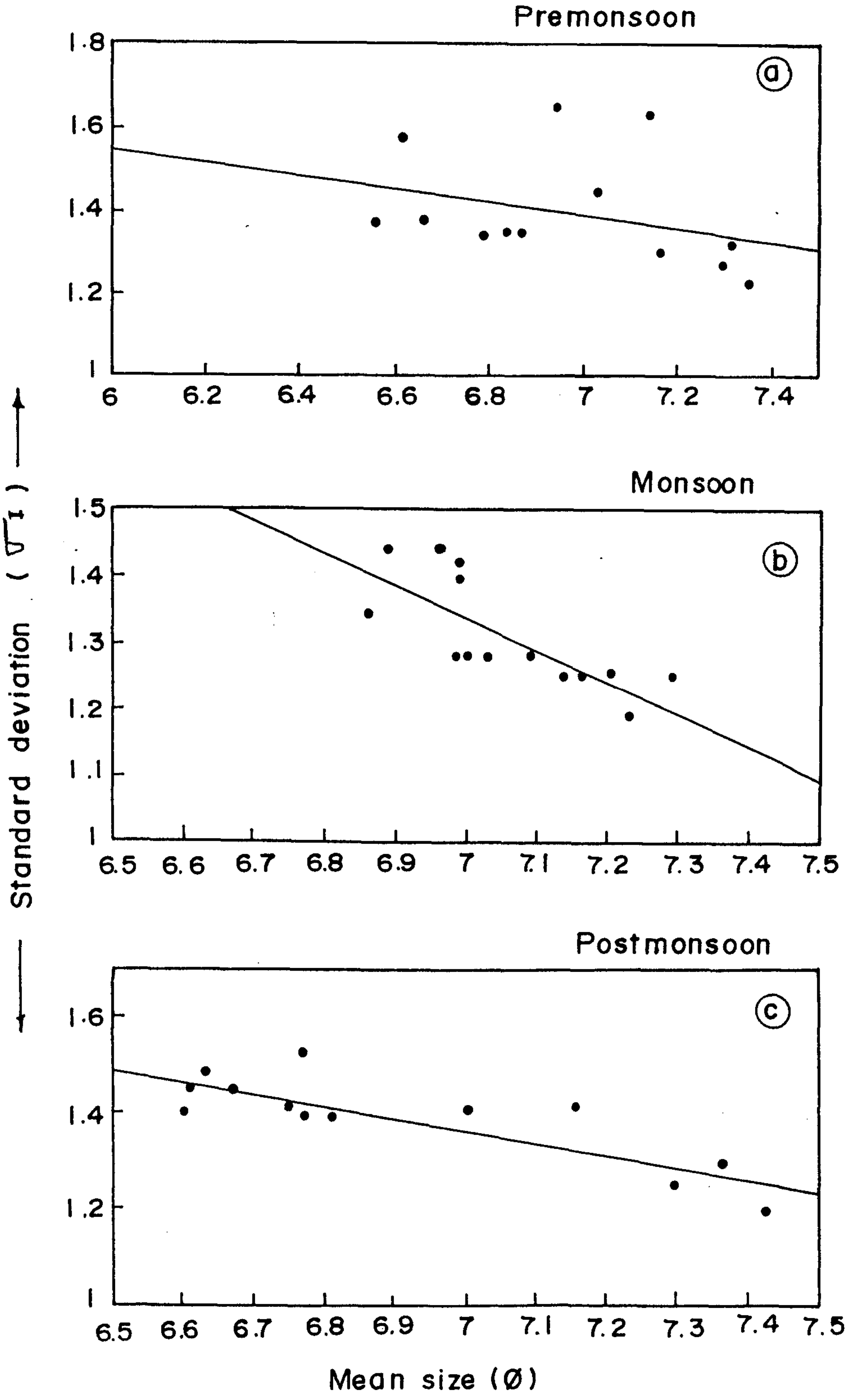


FIG. 3.7A BIVARIANT PLOT OF MEAN SIZE (Ø) V/S STANDARD DEVIATION (σ_I)

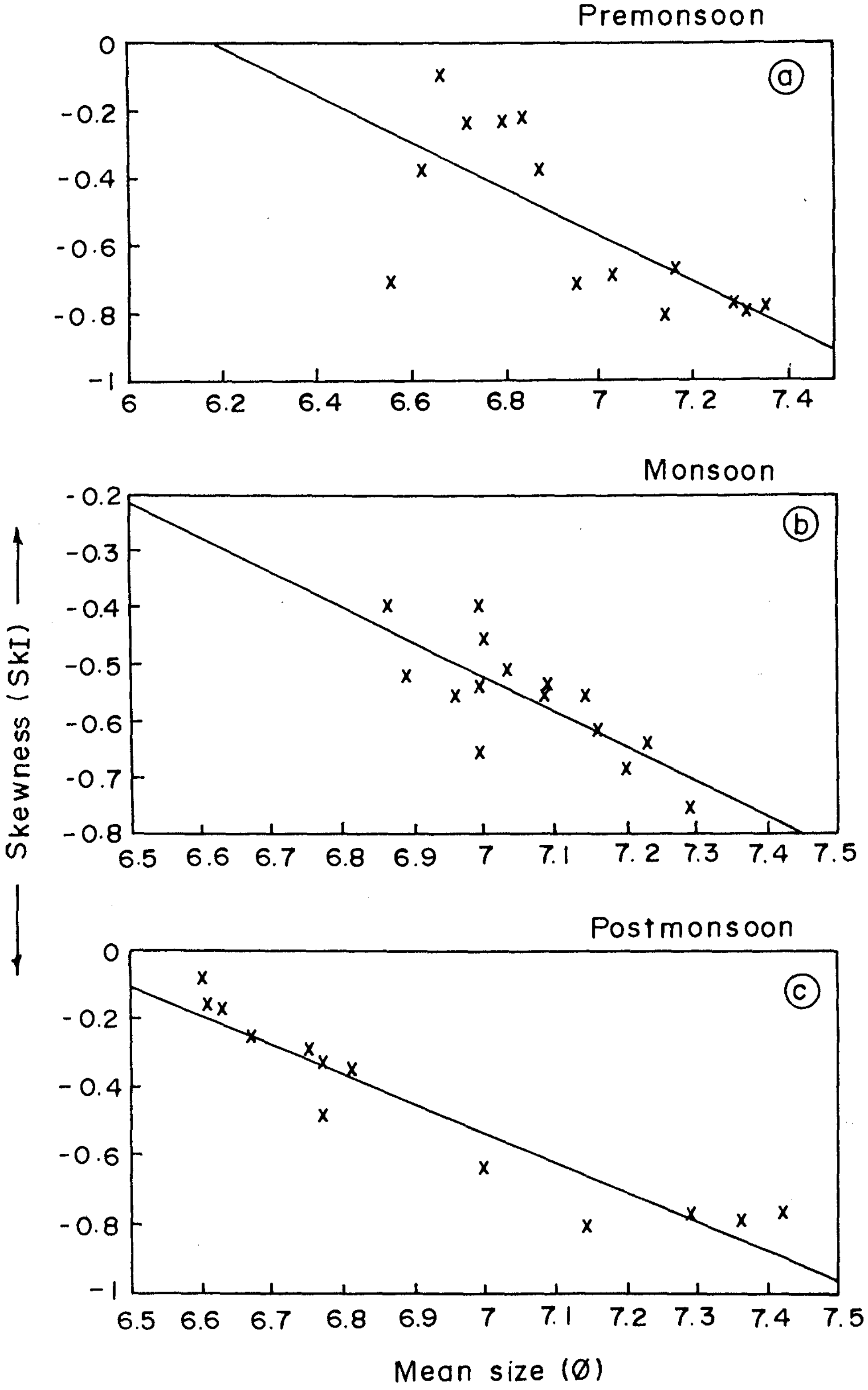


FIG. 3.7B BIVARIANT PLOT OF MEAN SIZE (Ø) V/S SKEWNESS (SKI)

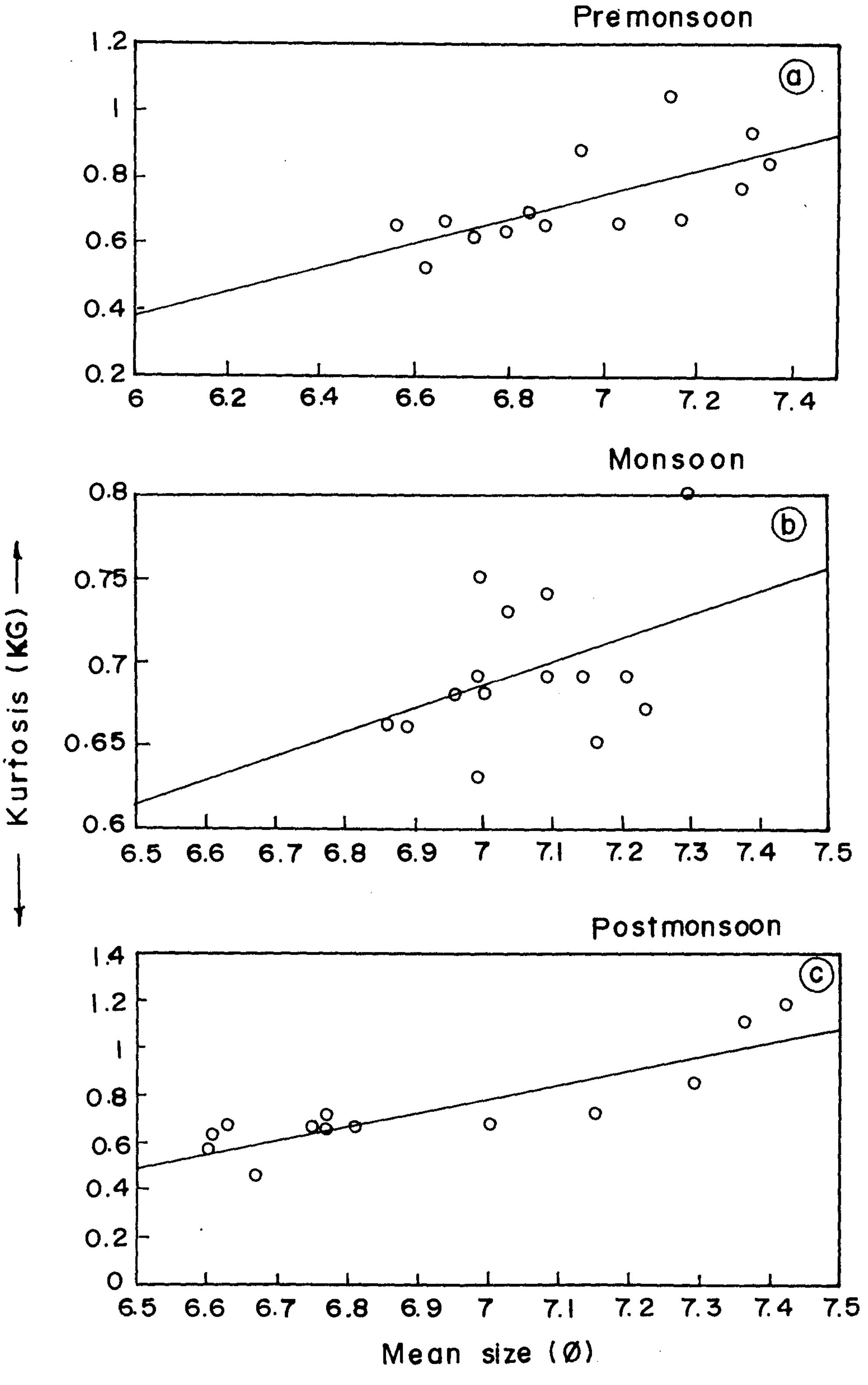


FIG. 3.7C BIVARIANT PLOT OF MEAN SIZE(Ø) V/S KURTOSIS(KG)

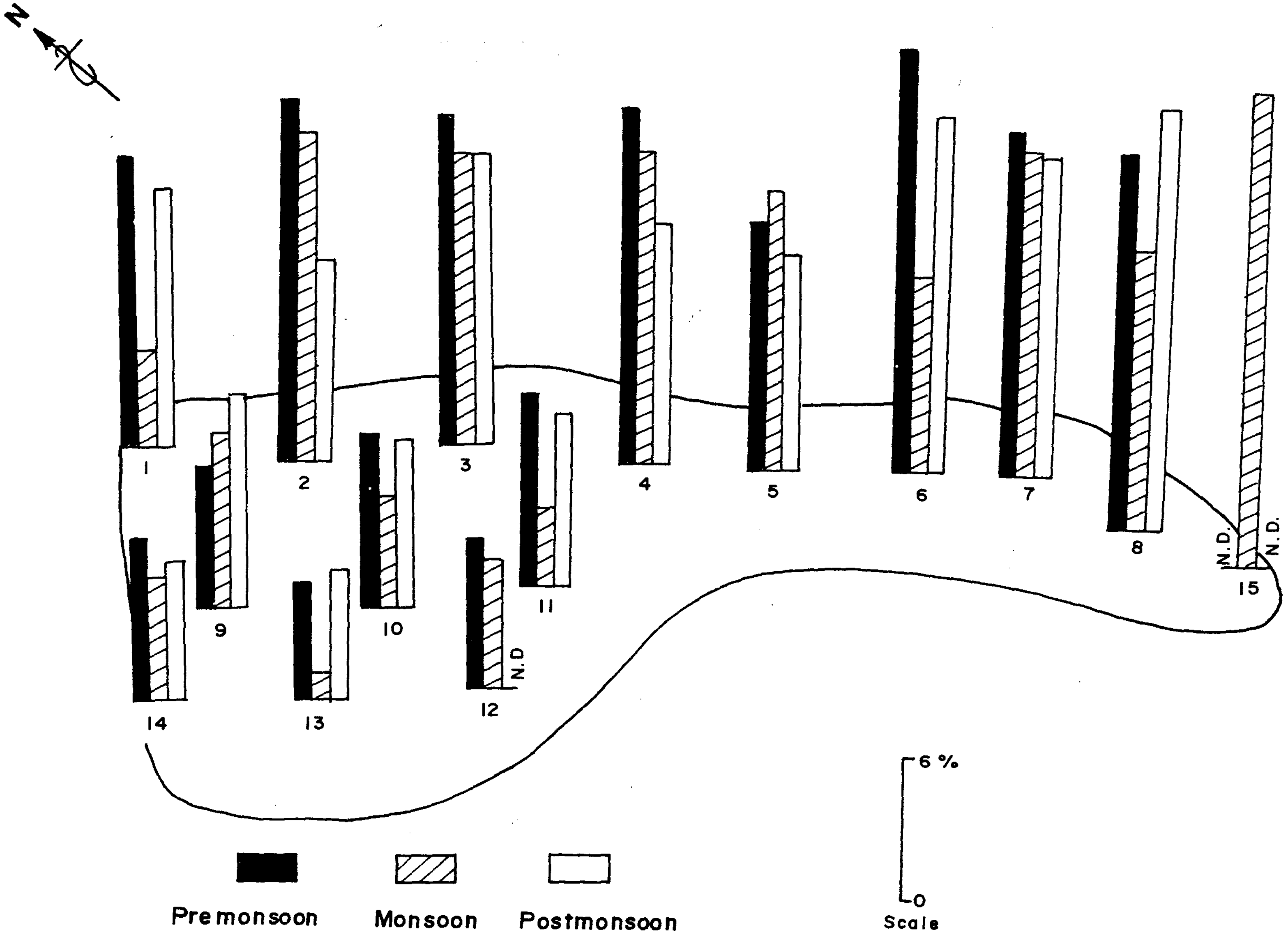


FIG. 3.8A SEASONAL VARIATION IN TOTAL ORGANIC CARBON CONTENT IN SURFACE SEDIMENTS

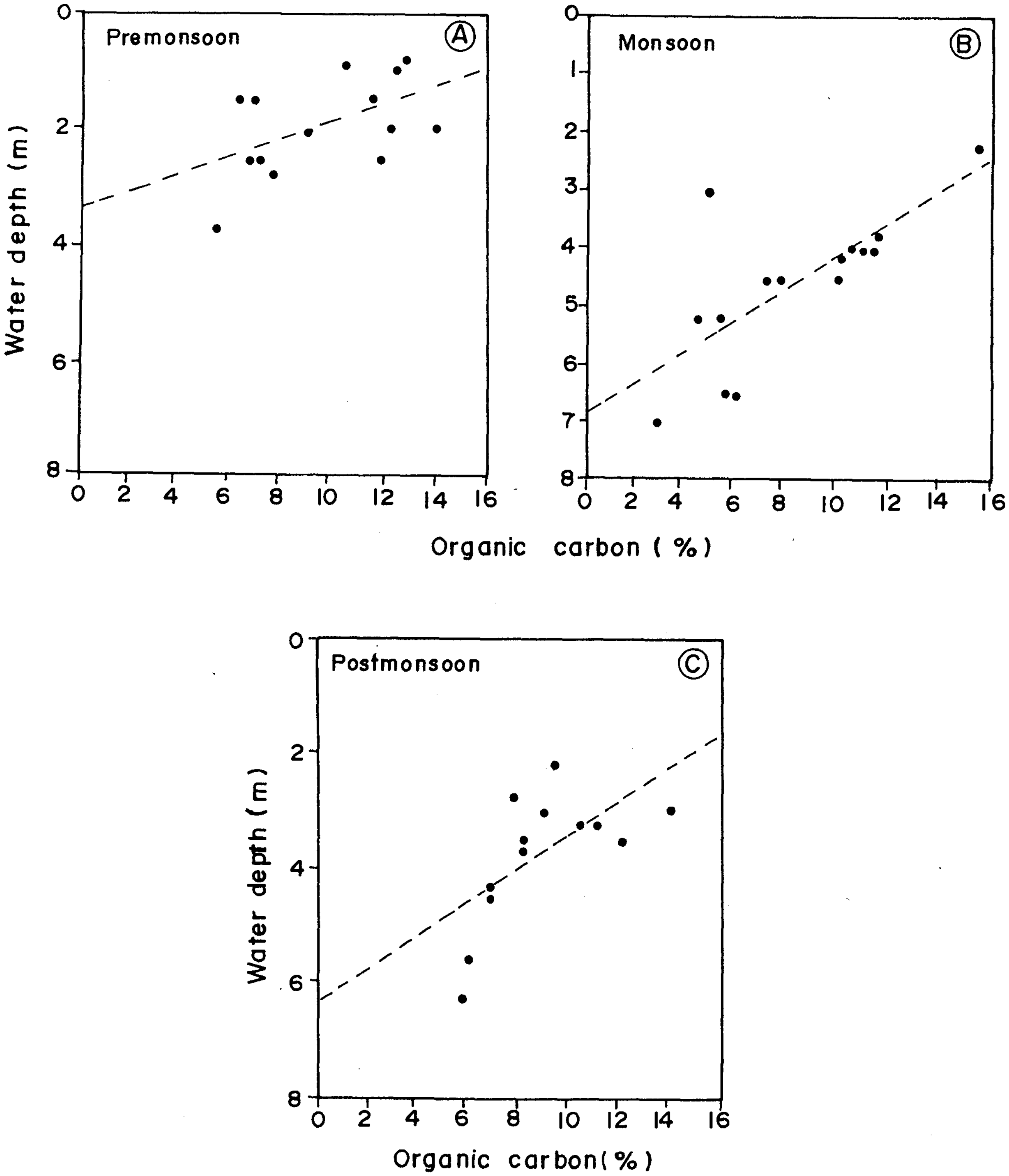


FIG. 3.9 VARIATION OF TOTAL ORGANIC CARBON IN SURFACE SEDIMENTS WITH DEPTH OF WATER COLUMN

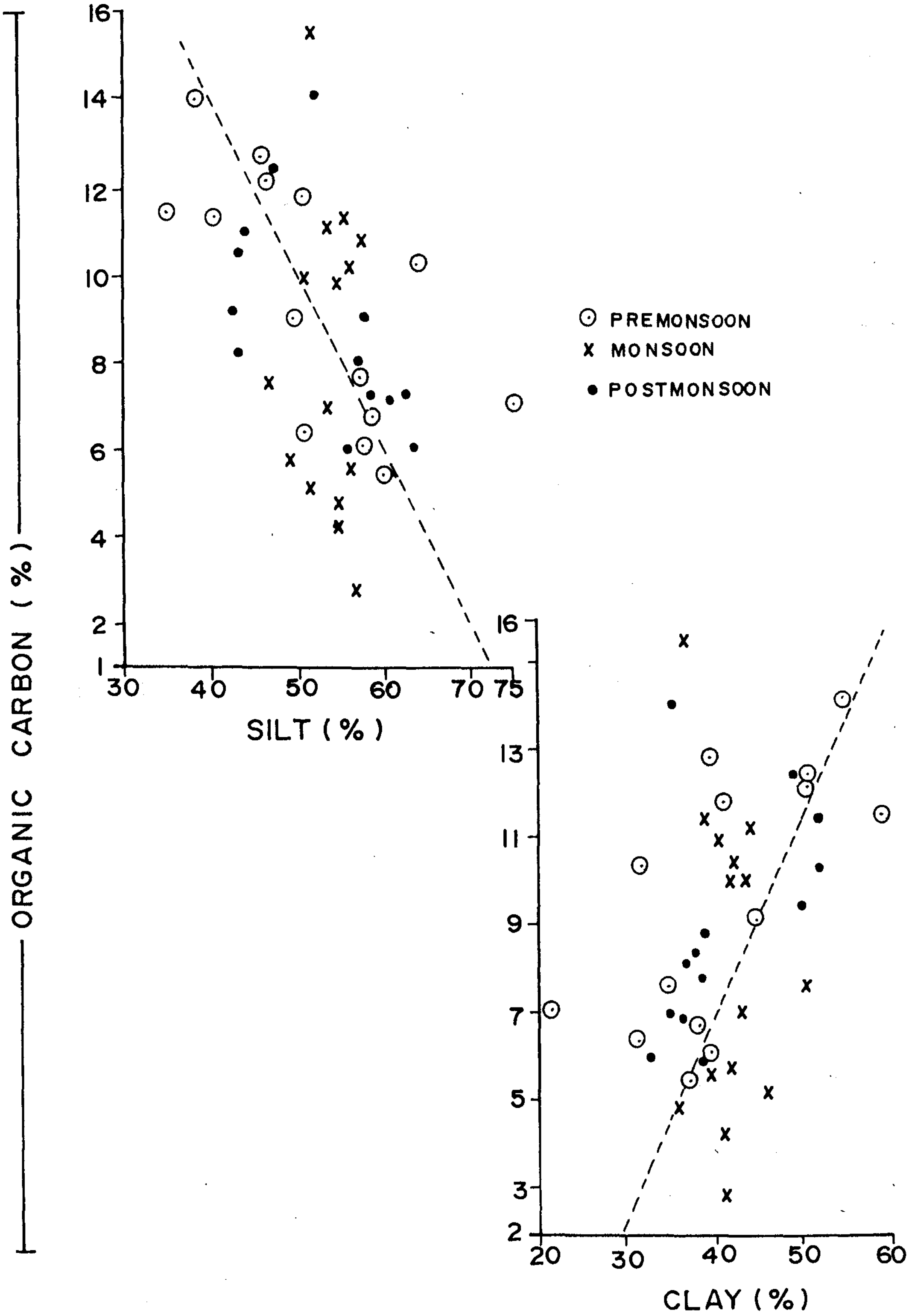


FIG. 3.10 RELATIONSHIP BETWEEN TOTAL ORGANIC CARBON AND SILT AND CLAY FRACTIONS OF SURFACE SEDIMENTS

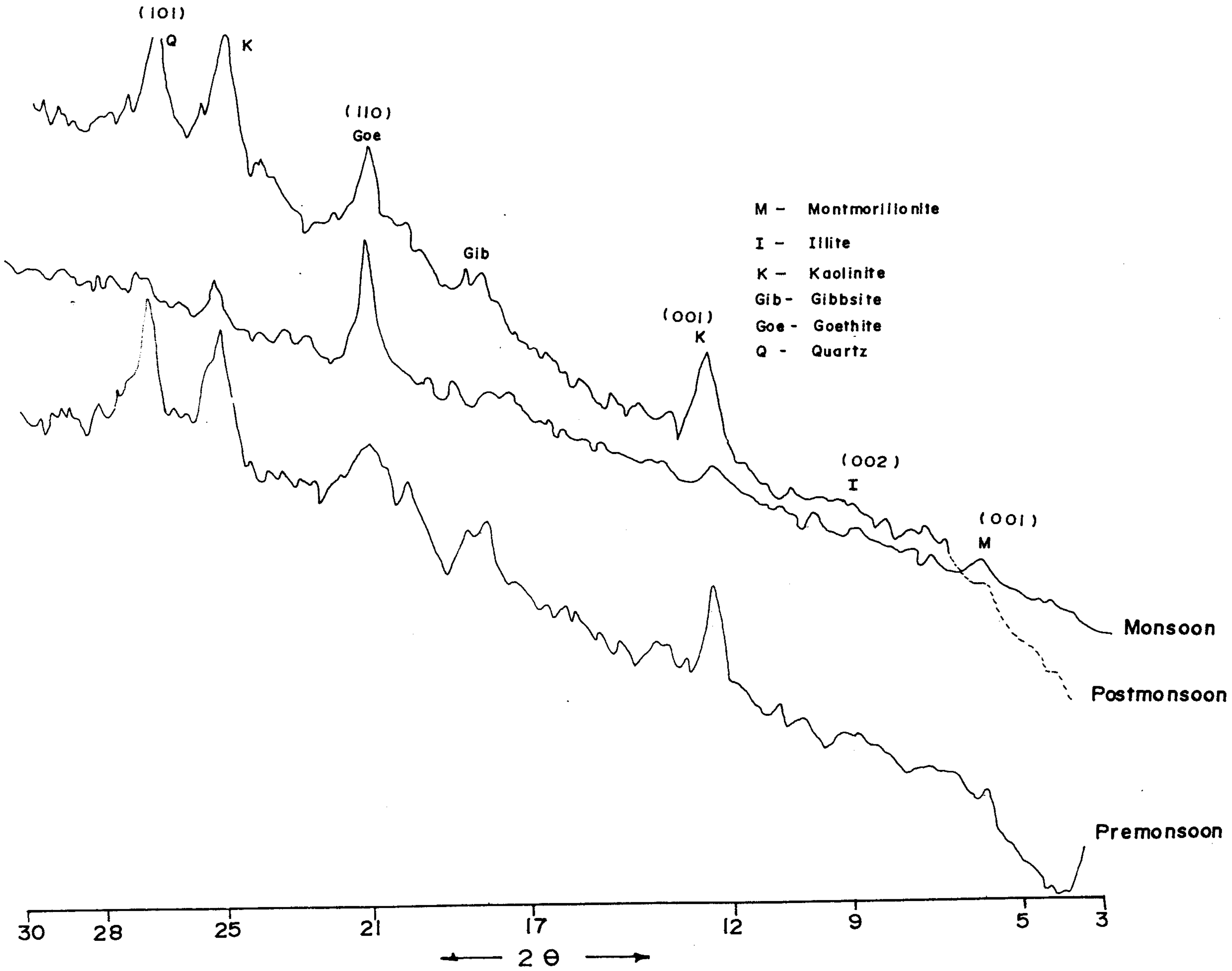


FIG.3.11A X-RAY DIFFRACTOGRAMS OBTAINED FOR < 2 µm FRACTION OF SURFACE SEDIMENTS AT ST. NO. 1

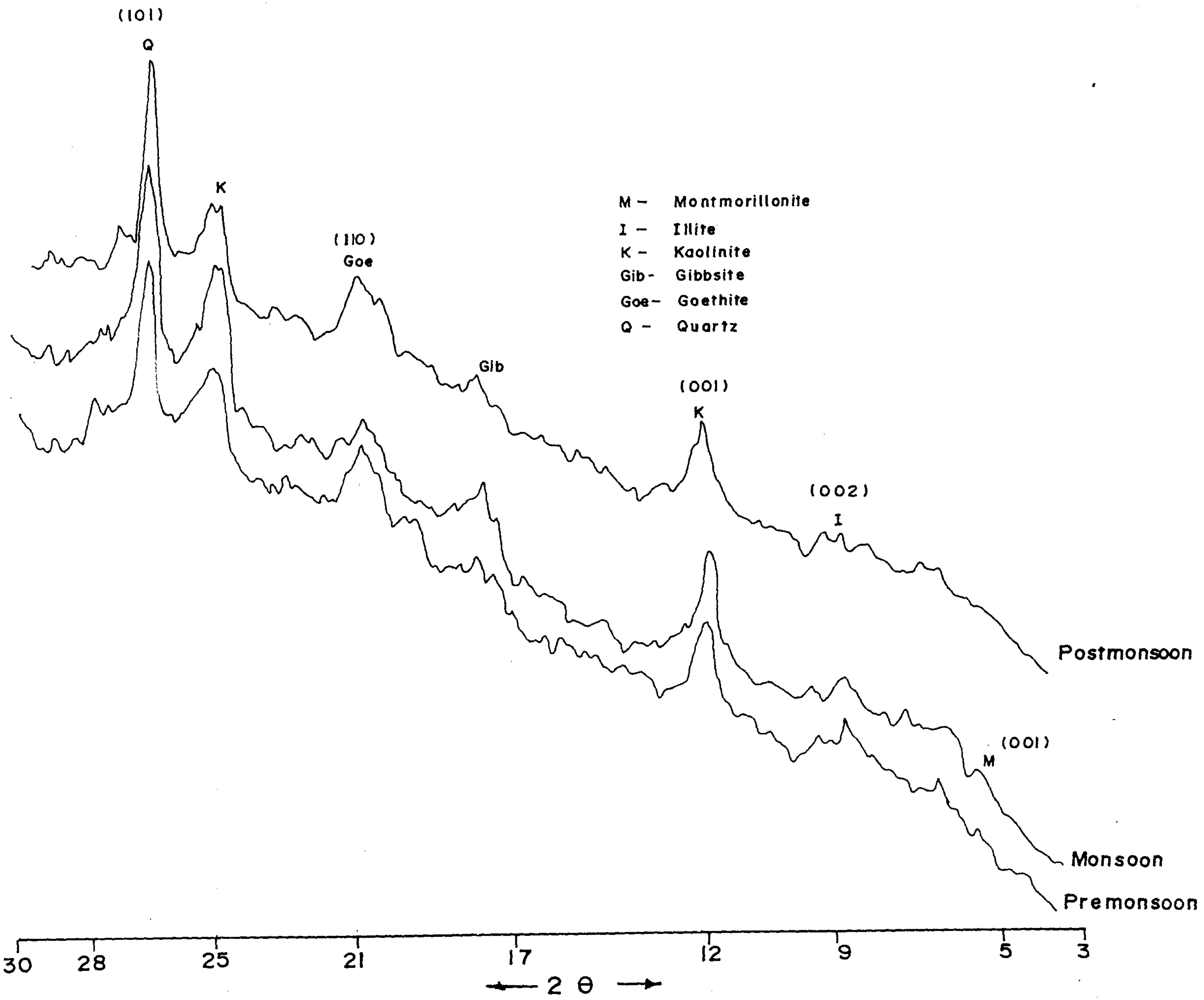


FIG. 3.11B X-RAY DIFFRACTOGRAMS OBTAINED FOR < 2µm FRACTION OF SURFACE SEDIMENTS AT ST. NO. 7

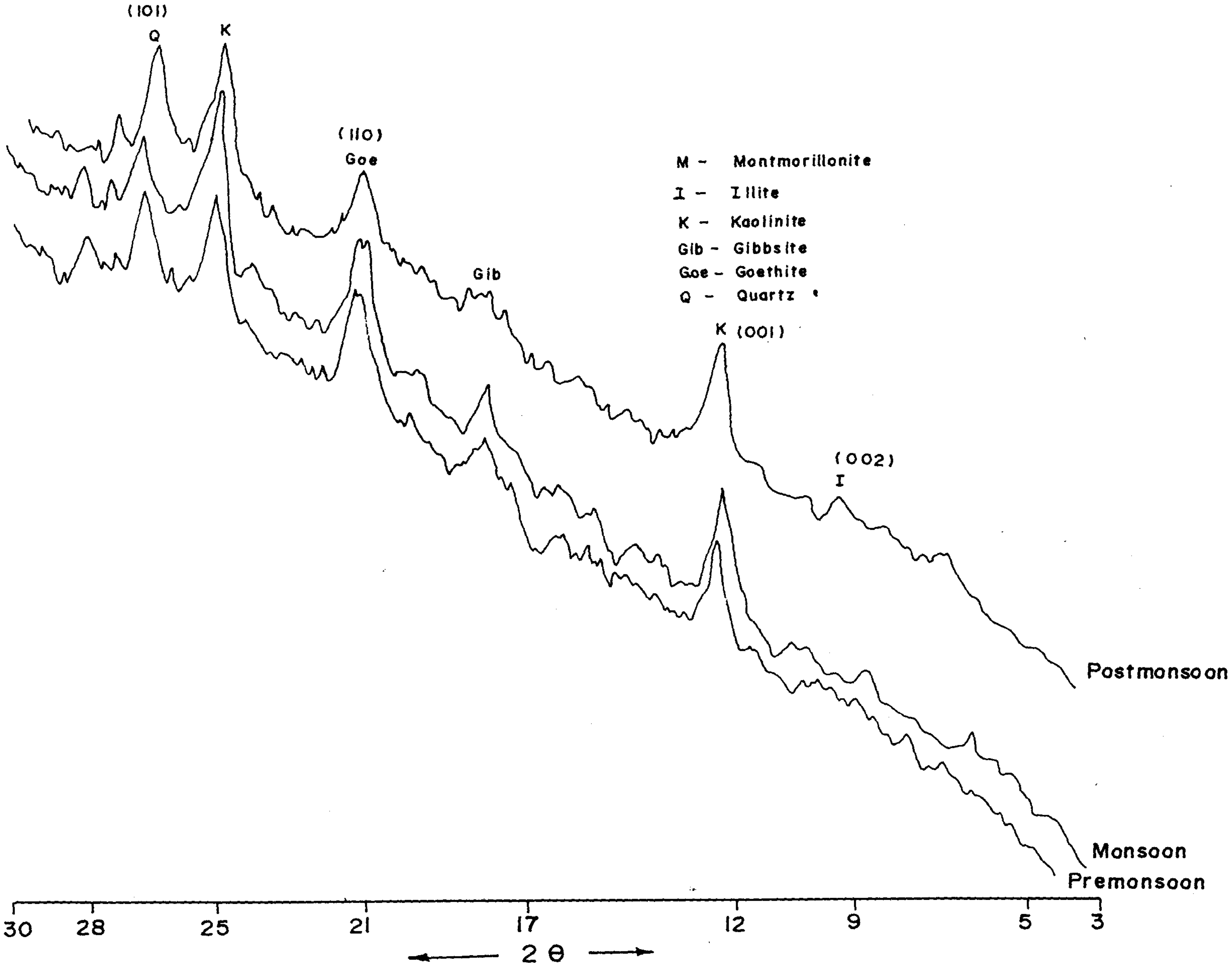


FIG. 3.11C X-RAY DIFFRACTOGRAMS OBTAINED FOR <2 μm FRACTION OF SURFACE SEDIMENTS AT ST. NO. 9

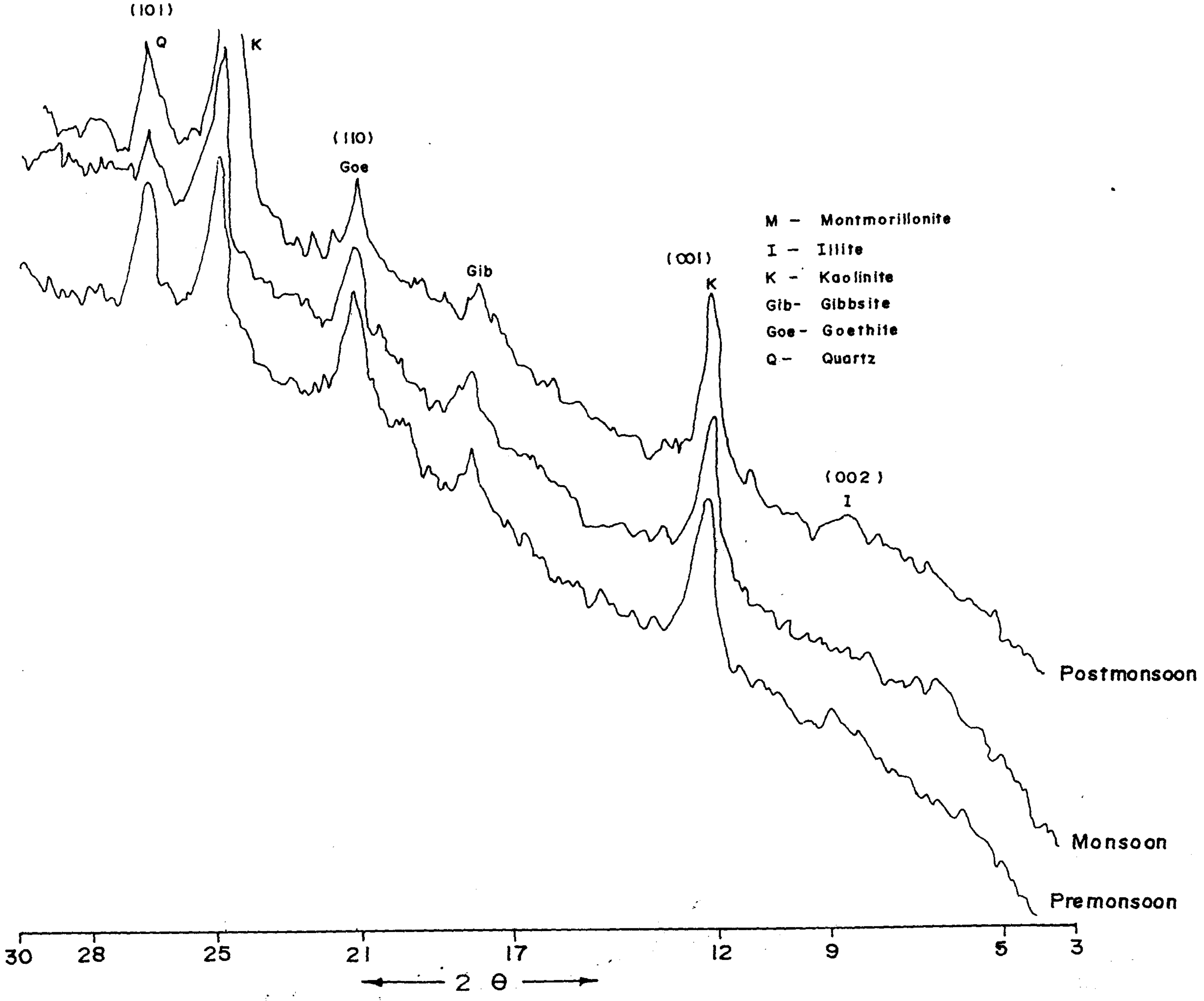


FIG. 3.11D X-RAY DIFFRACTOGRAMS OBTAINED FOR 2µm FRACTION OF SURFACE SEDIMENTS AT ST. NO. 13

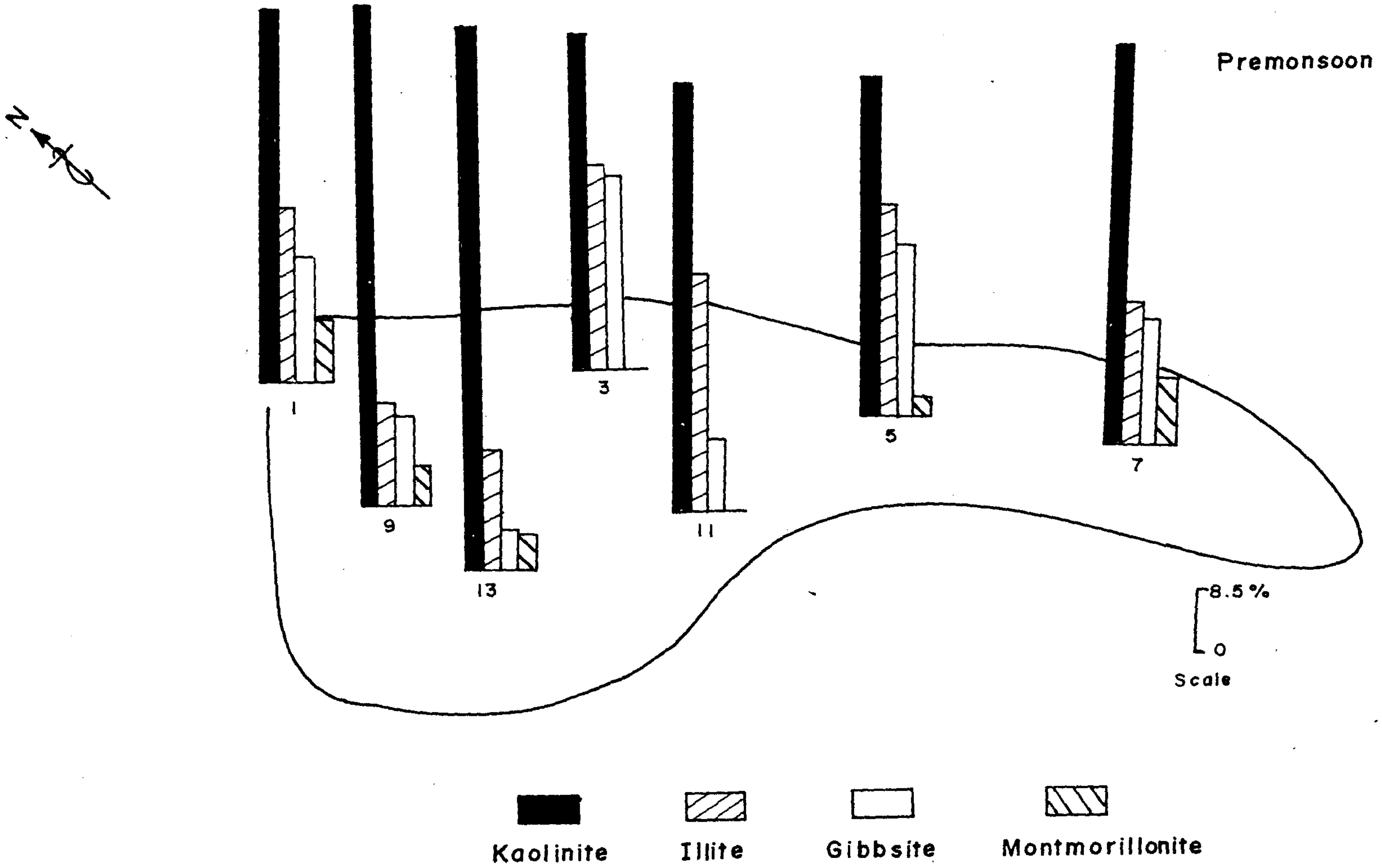


FIG. 3. 12A SPATIAL DISTRIBUTION OF RELATIVE ABUNDANCE OF CLAY MINERALS IN SURFACE SEDIMENTS

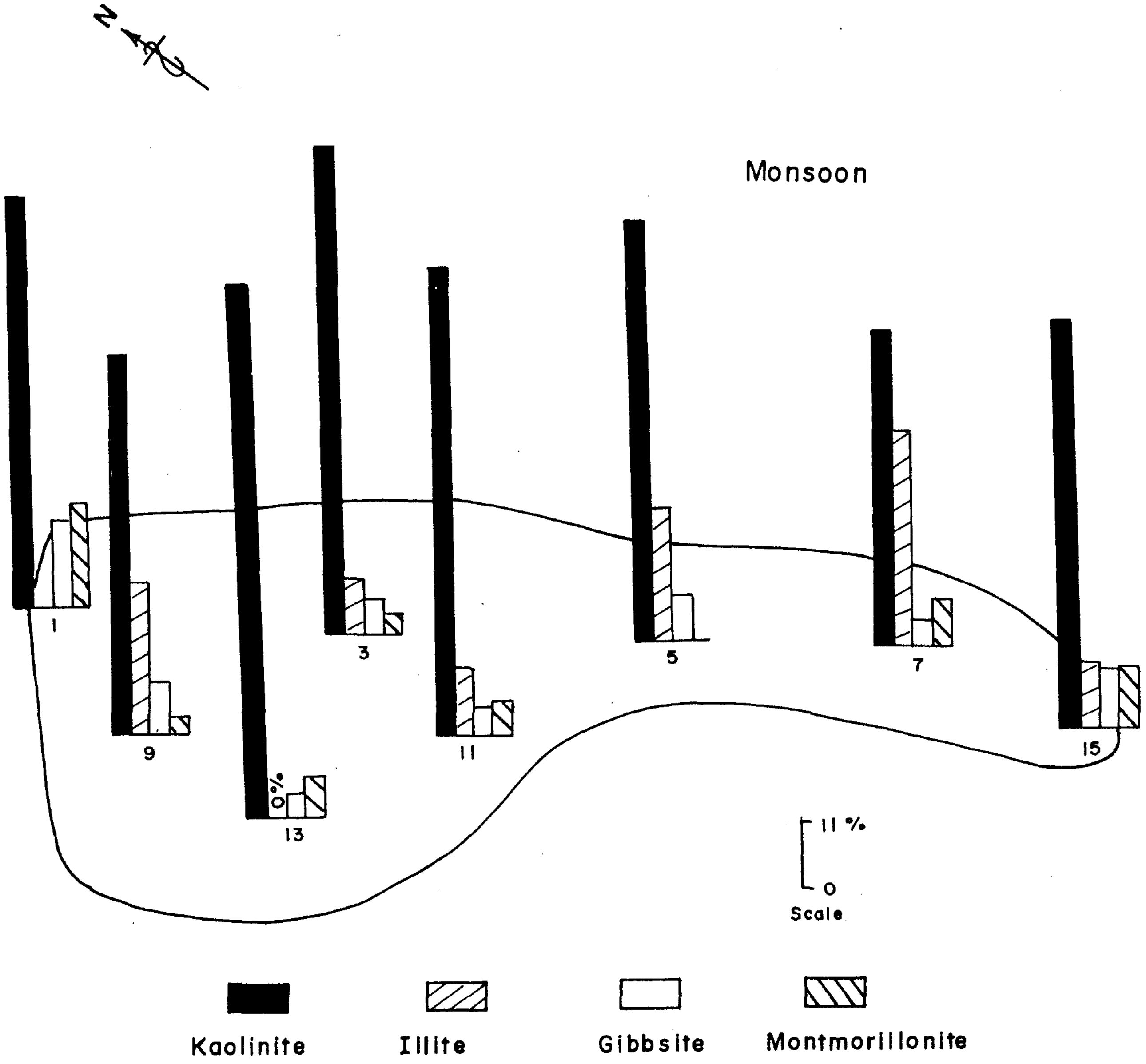


FIG. 3.12B SPATIAL DISTRIBUTION OF RELATIVE ABUNDANCE OF CLAY MINERALS IN SURFACE SEDIMENTS

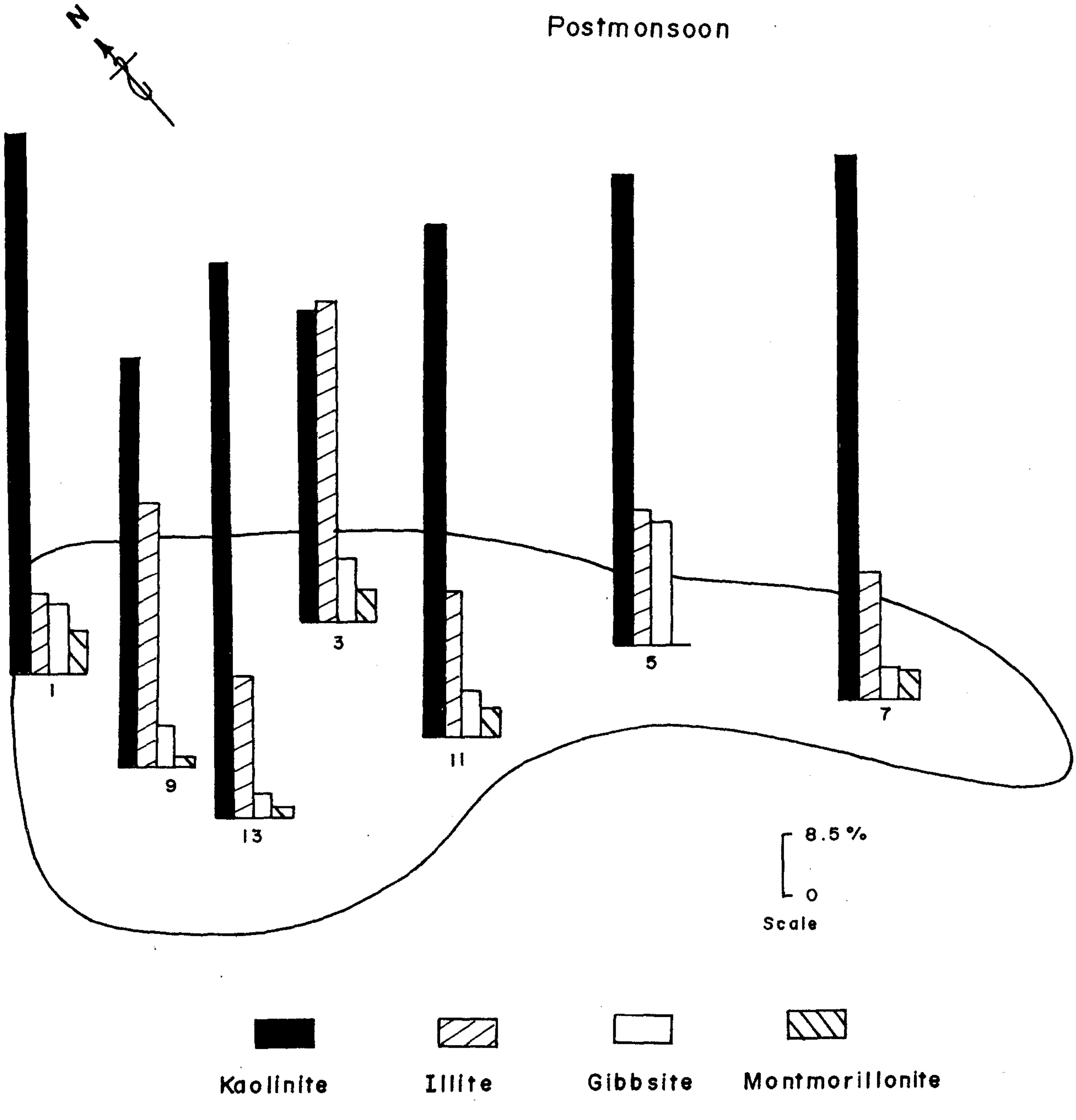


FIG. 3.12C SPATIAL DISTRIBUTION OF RELATIVE ABUNDANCE OF CLAY MINERALS IN SURFACE SEDIMENTS

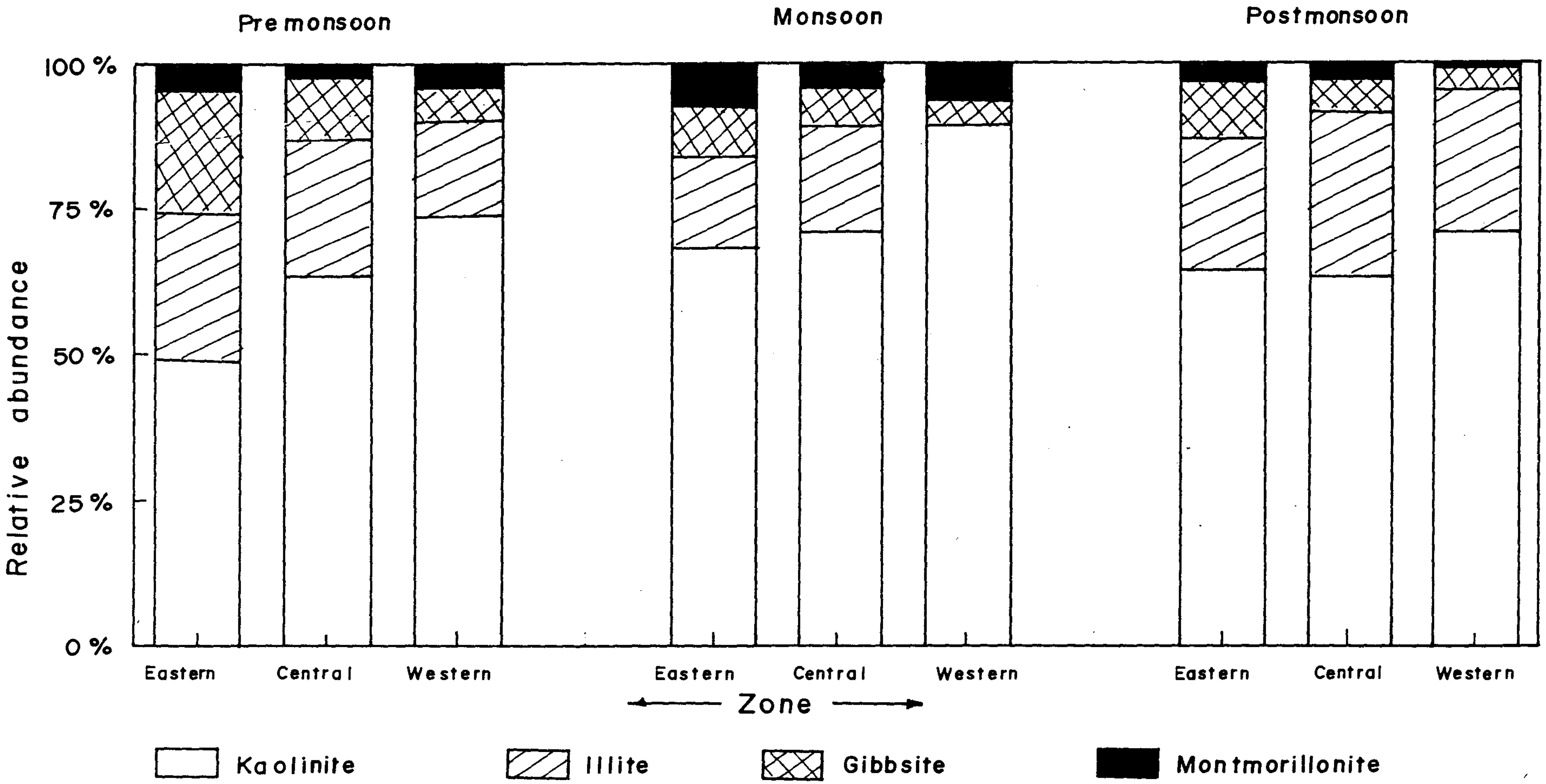


FIG. 3.13 ZONAL DISTRIBUTION OF RELATIVE ABUNDANCE OF CLAY MINERALS IN SURFACE SEDIMENTS

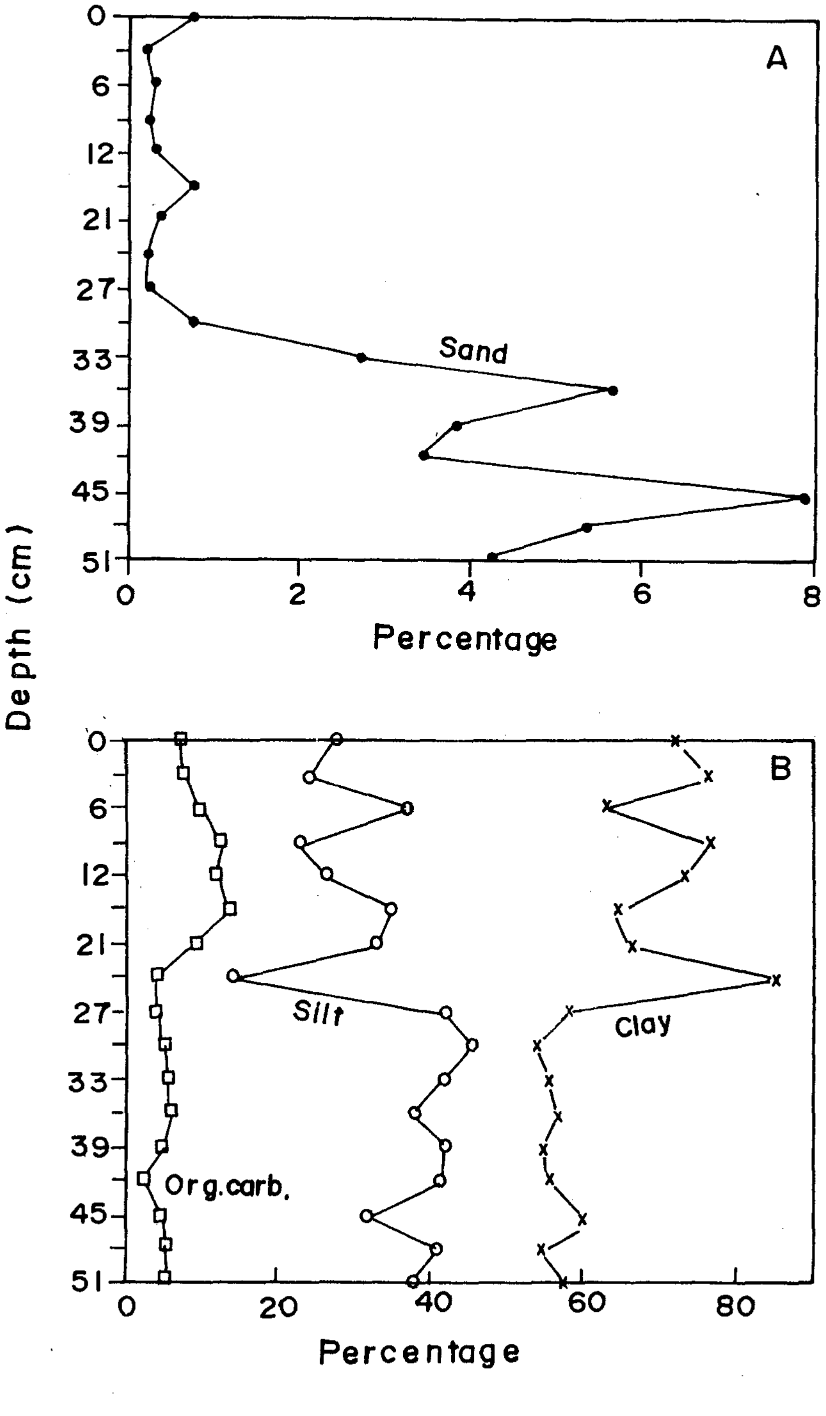


FIG. 3.14 DEPTHWISE VARIATION IN SEDIMENT COMPONENTS (SAND, SILT, CLAY) AND ORGANIC CARBON CONTENT IN CORE – 1

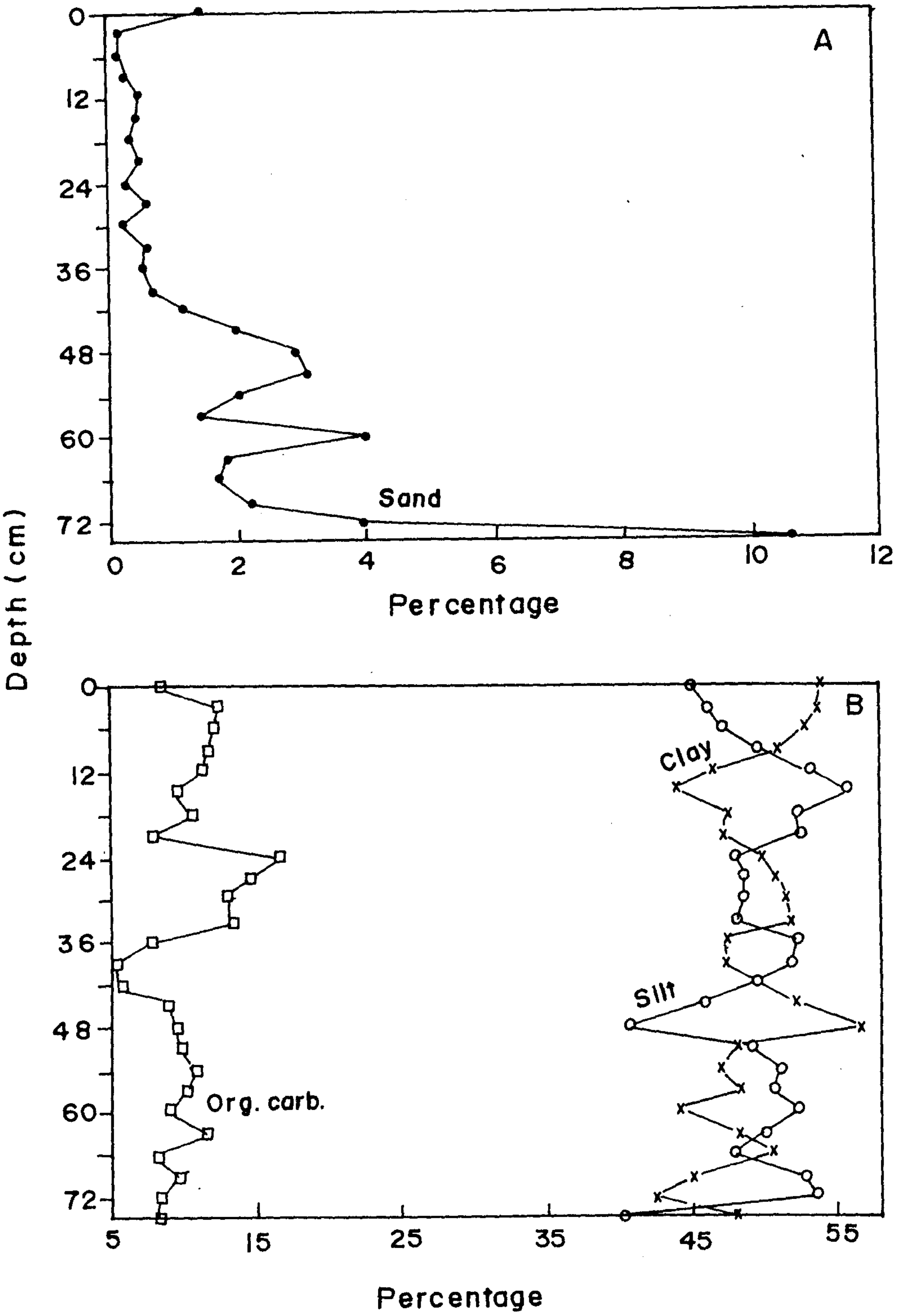


FIG. 3.15 DEPTHWISE VARIATION IN SEDIMENT COMPONENTS (SAND, SILT, CLAY) AND ORGANIC CARBON CONTENT IN CORE - 2

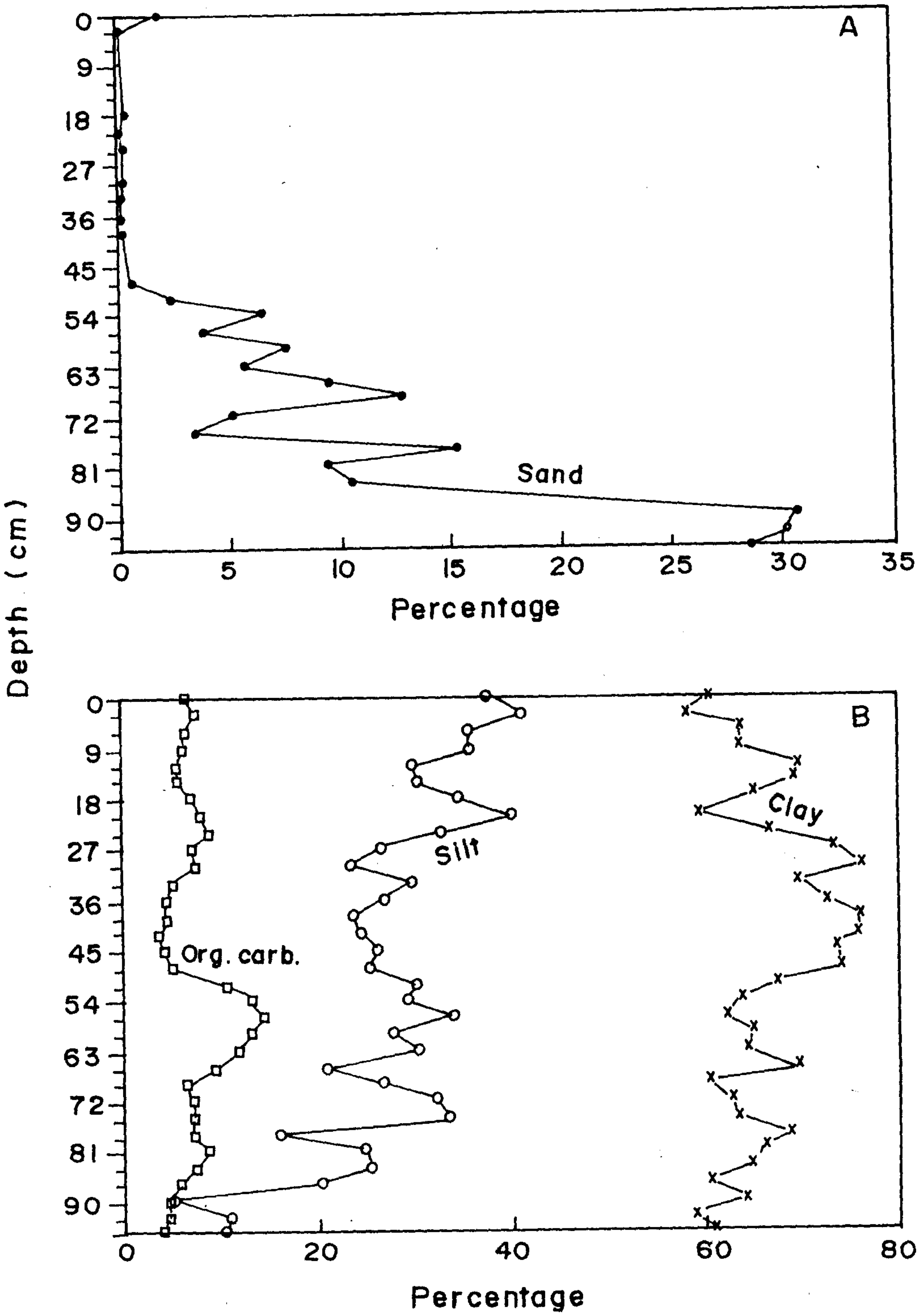


FIG. 3.16 DEPTHWISE VARIATION IN SEDIMENT COMPONENTS (SAND, SILT, CLAY) AND ORGANIC CARBON CONTENT IN CORE - 3

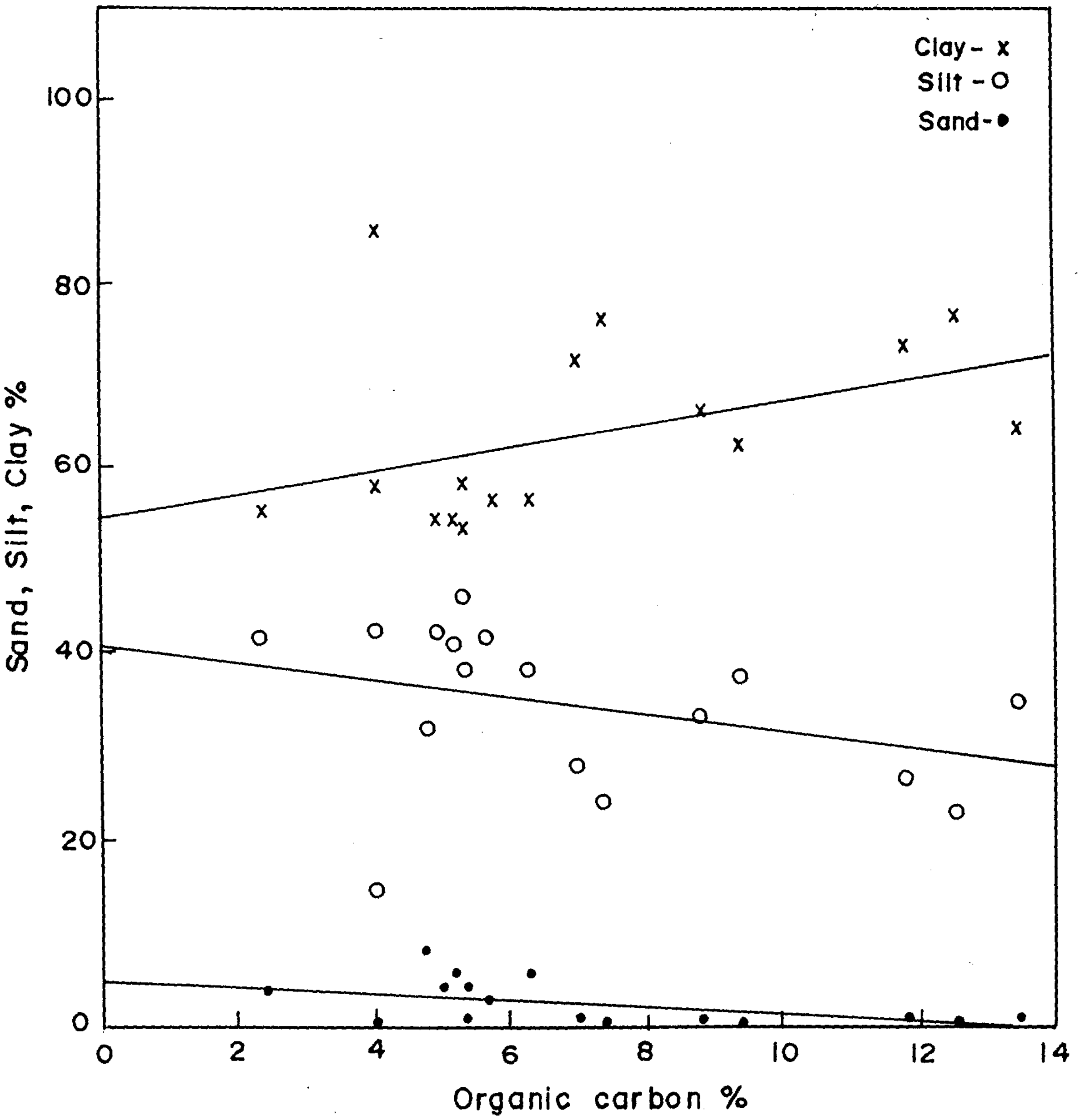


FIG. 3.17A RELATIONSHIP BETWEEN SAND, SILT, CLAY AND ORGANIC CARBON CONTENT IN CORE - I

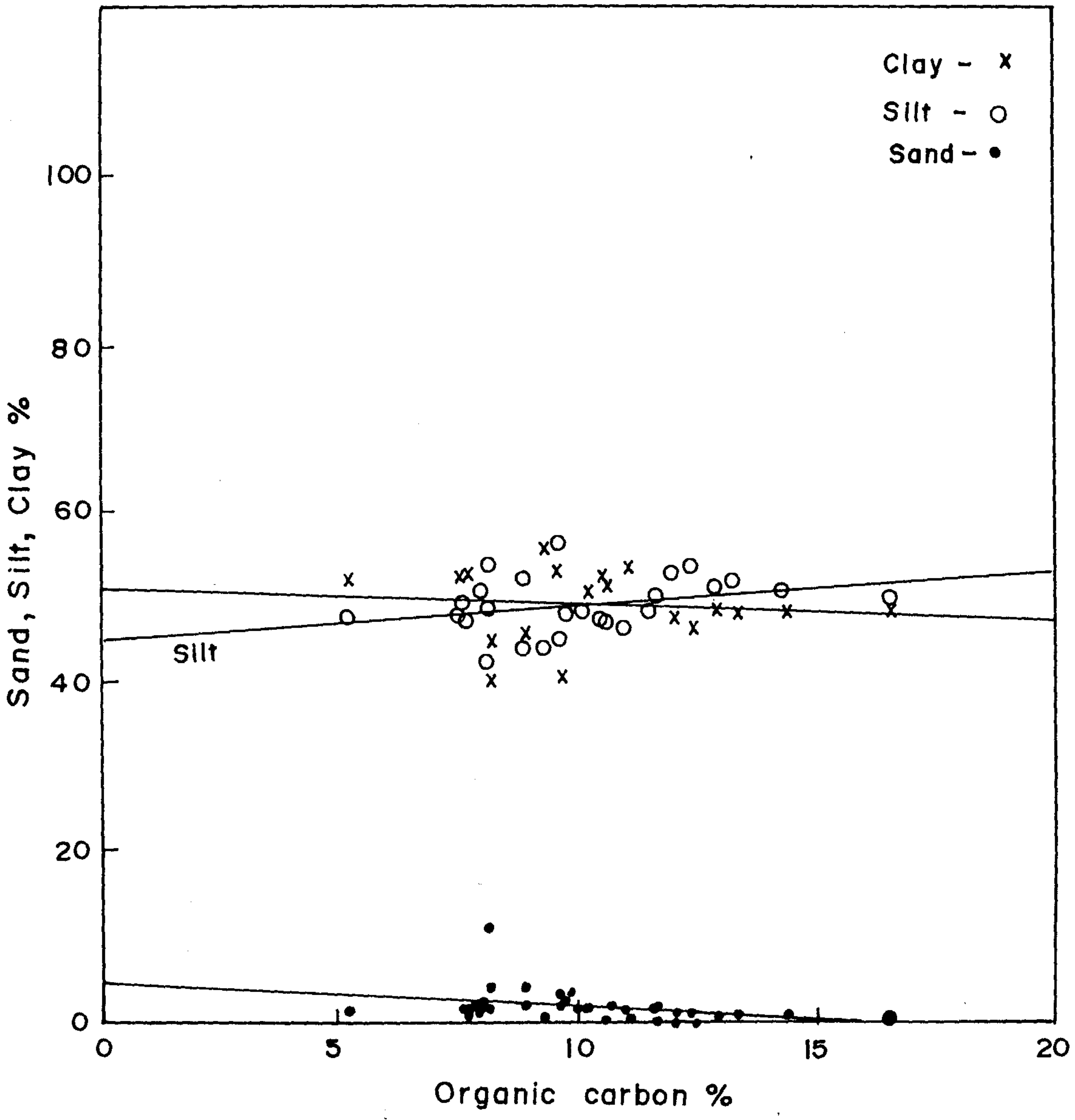


FIG. 3.17B RELATIONSHIP BETWEEN SAND, SILT, CLAY AND ORGANIC CARBON CONTENT IN CORE-2

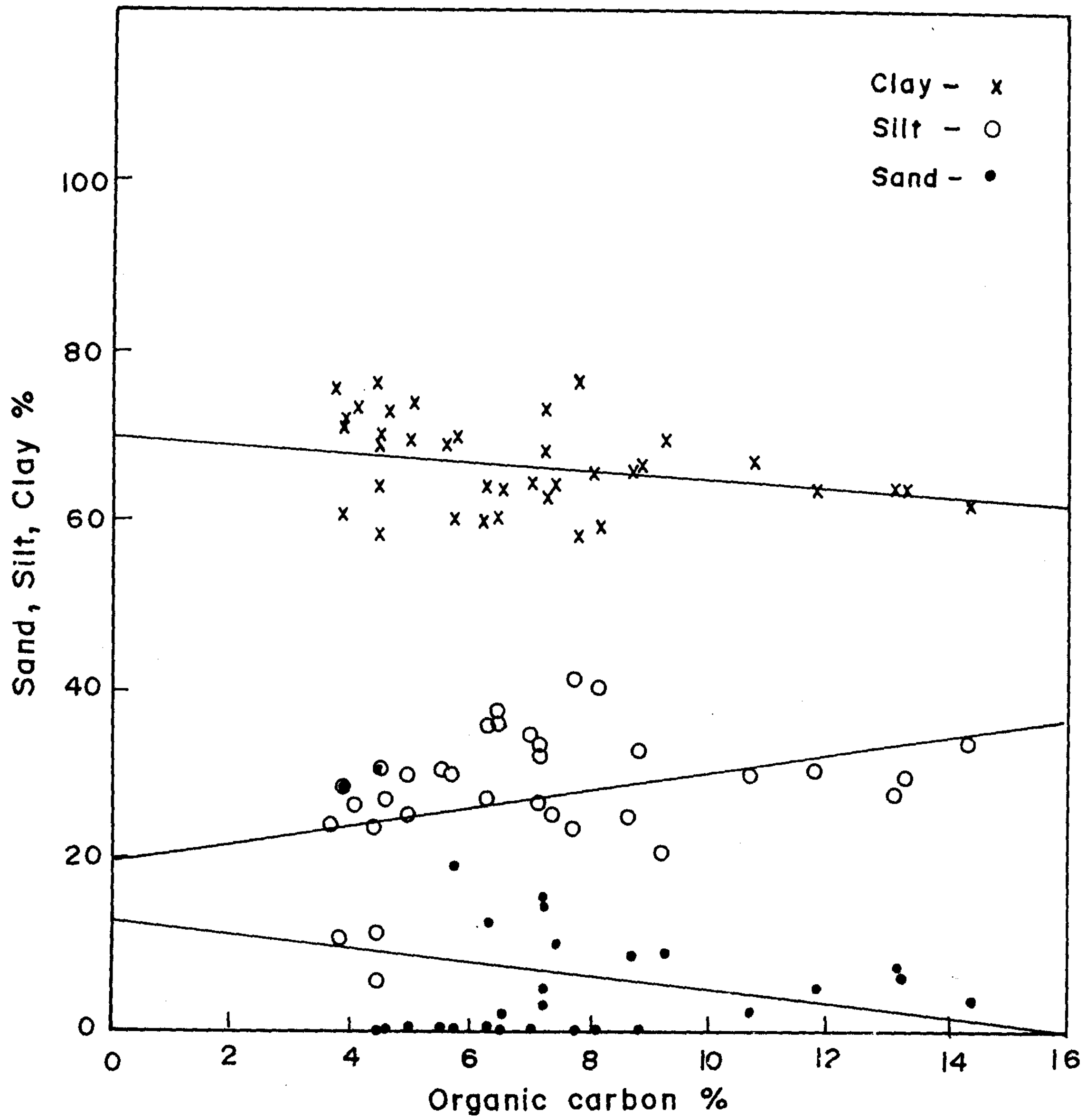


FIG. 3.17C RELATIONSHIP BETWEEN SAND, SILT, CLAY AND ORGANIC CARBON CONTENT IN CORE - 3

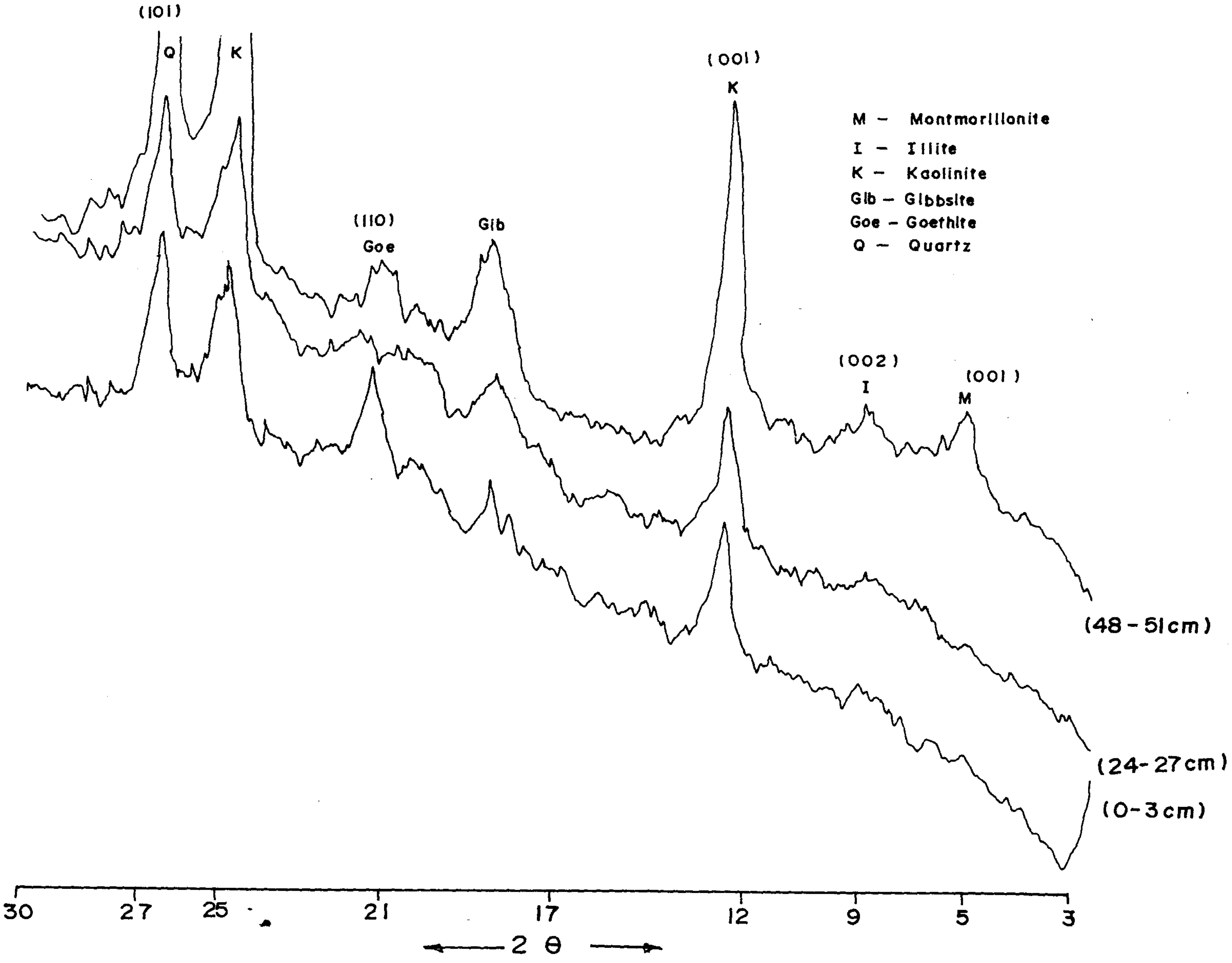


FIG. 3.18A X-RAY DIFFRACTOGRAMS OBTAINED FOR SELECTED FRACTIONS OF CORE-I

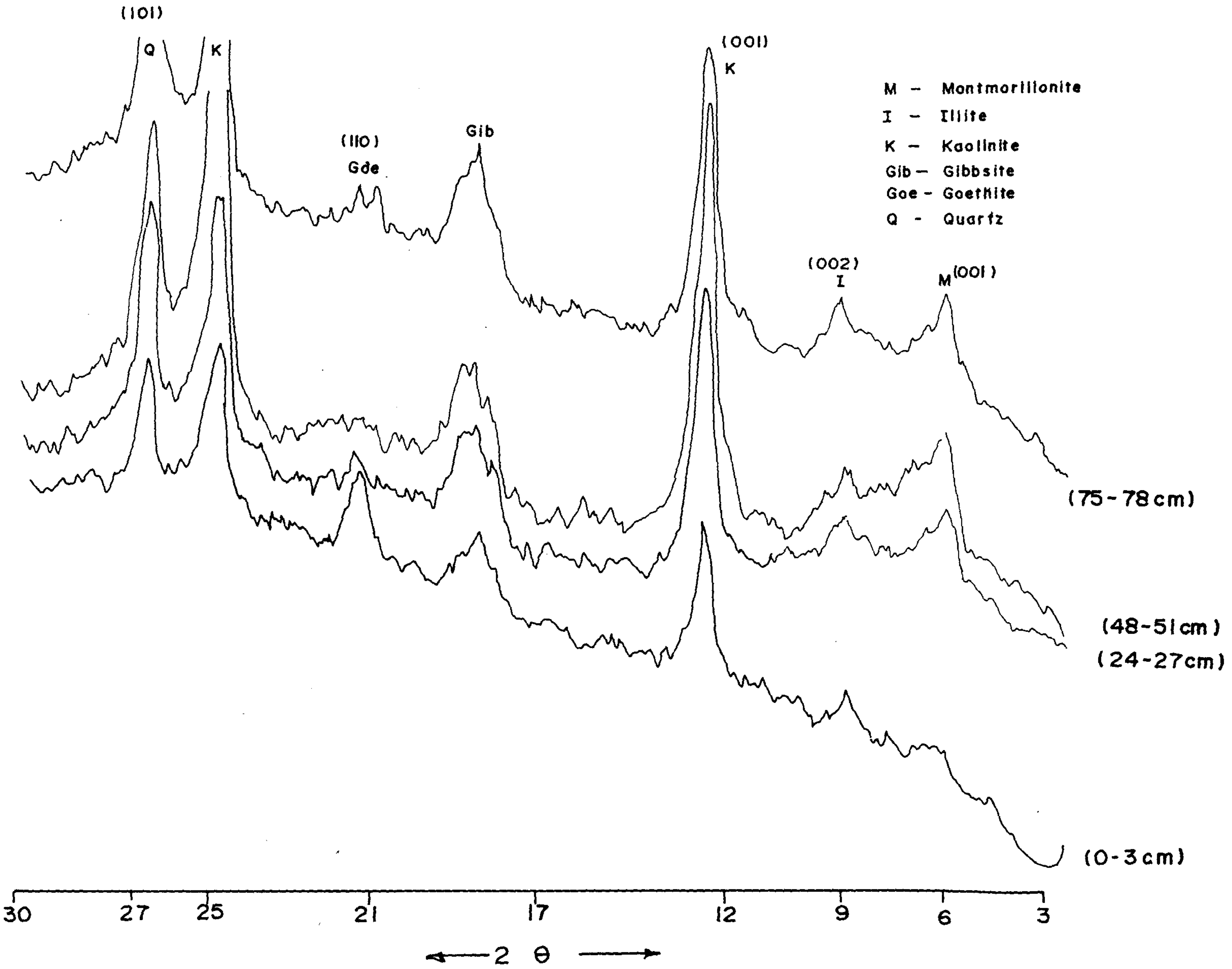


FIG. 3.18B X-RAY DIFFRACTOGRAMS OBTAINED FOR SELECTED FRACTIONS OF CORE-2

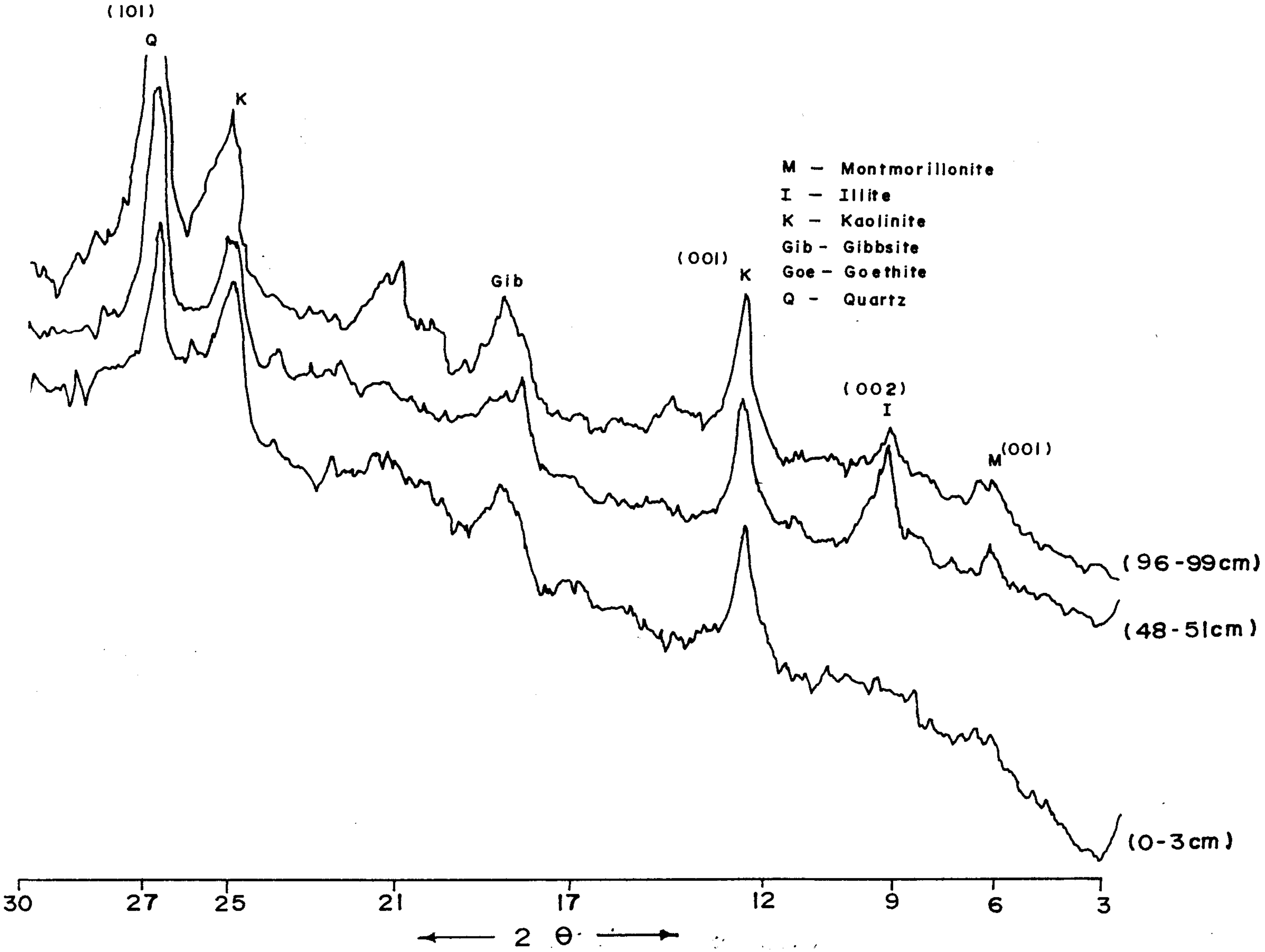


FIG. 3.18C X-RAY DIFFRACTOGRAMS OBTAINED FOR SELECTED FRACTIONS OF CORE-3

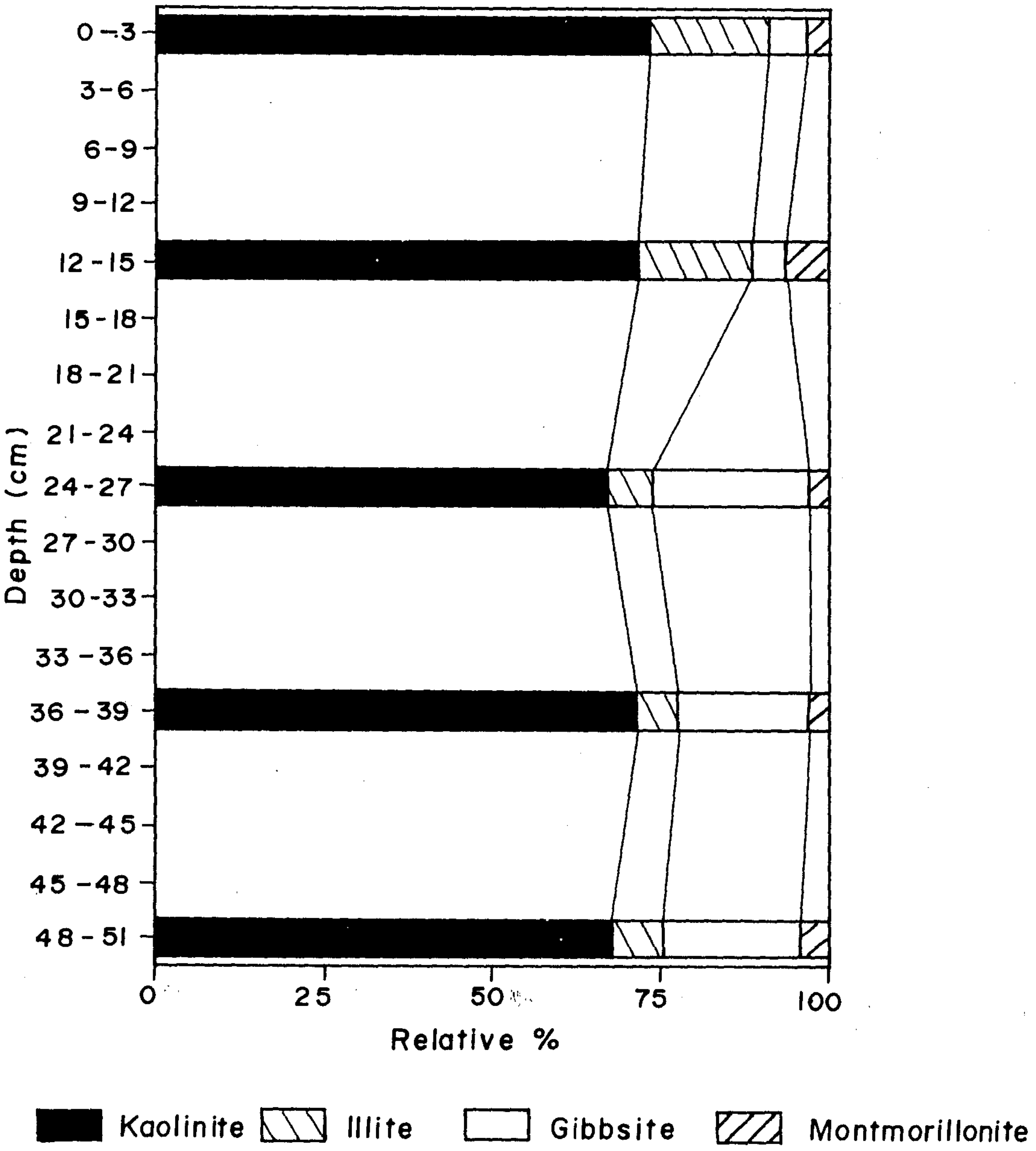


FIG.3.19A DEPTHWISE VARIATION IN RELATIVE ABUNDANCE OF CLAY MINERALS IN CORE - I

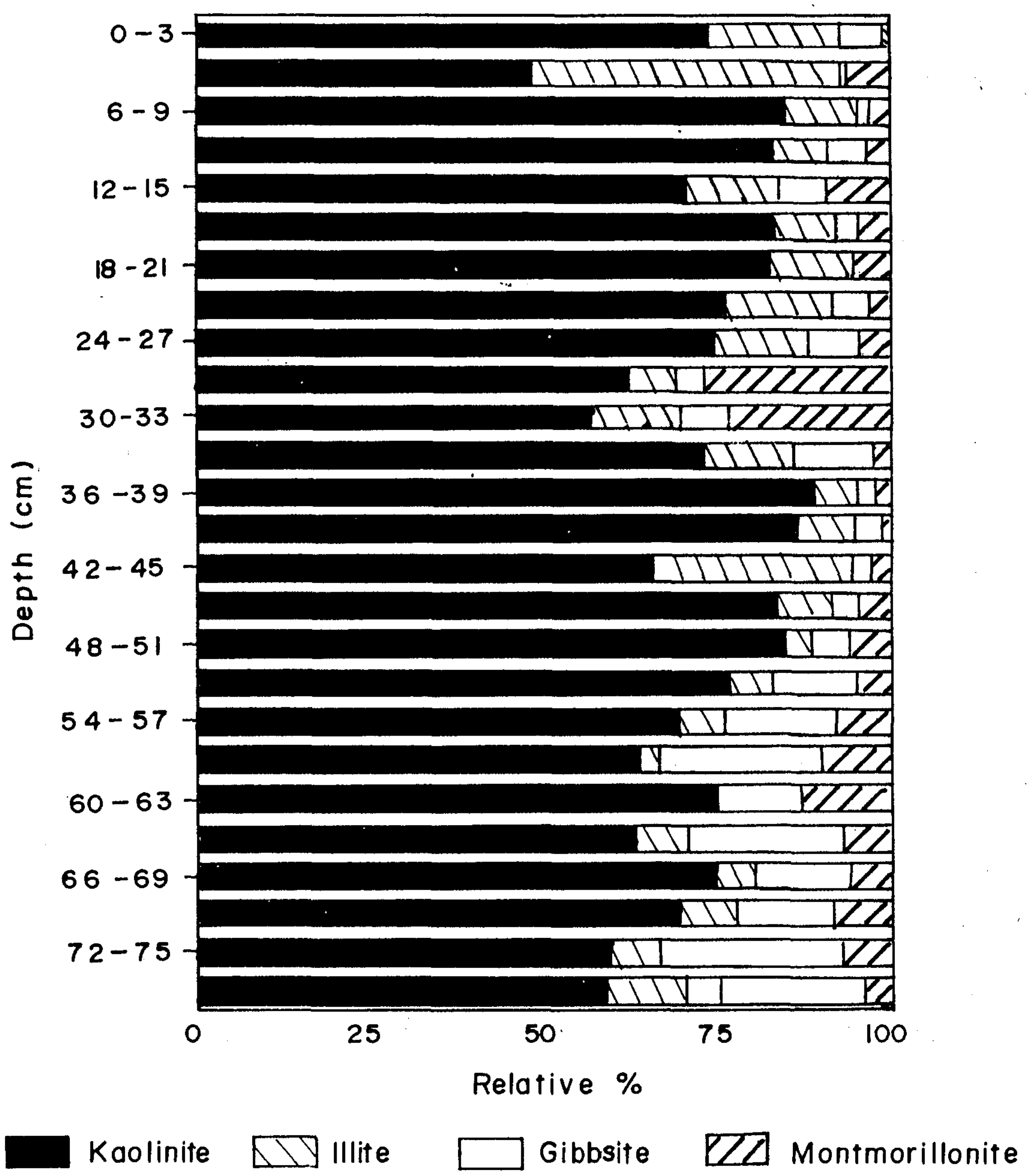


FIG. 3.19 B DEPTHWISE VARIATION IN RELATIVE ABUNDANCE OF CLAY MINERALS IN CORE-2

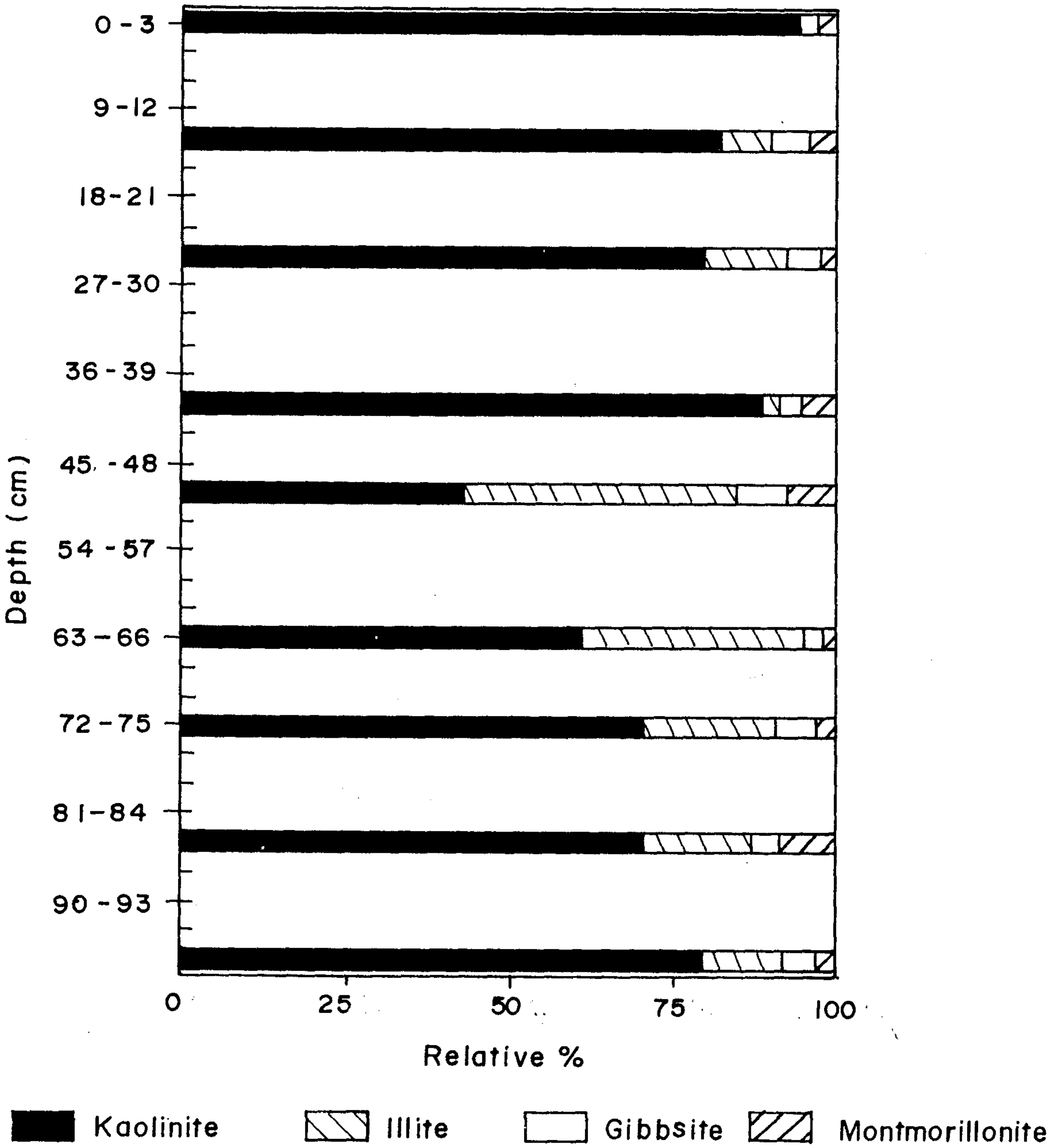


FIG. 3.19C DEPTHWISE VARIATION IN RELATIVE ABUNDANCE OF CLAY MINERALS IN CORE - 3

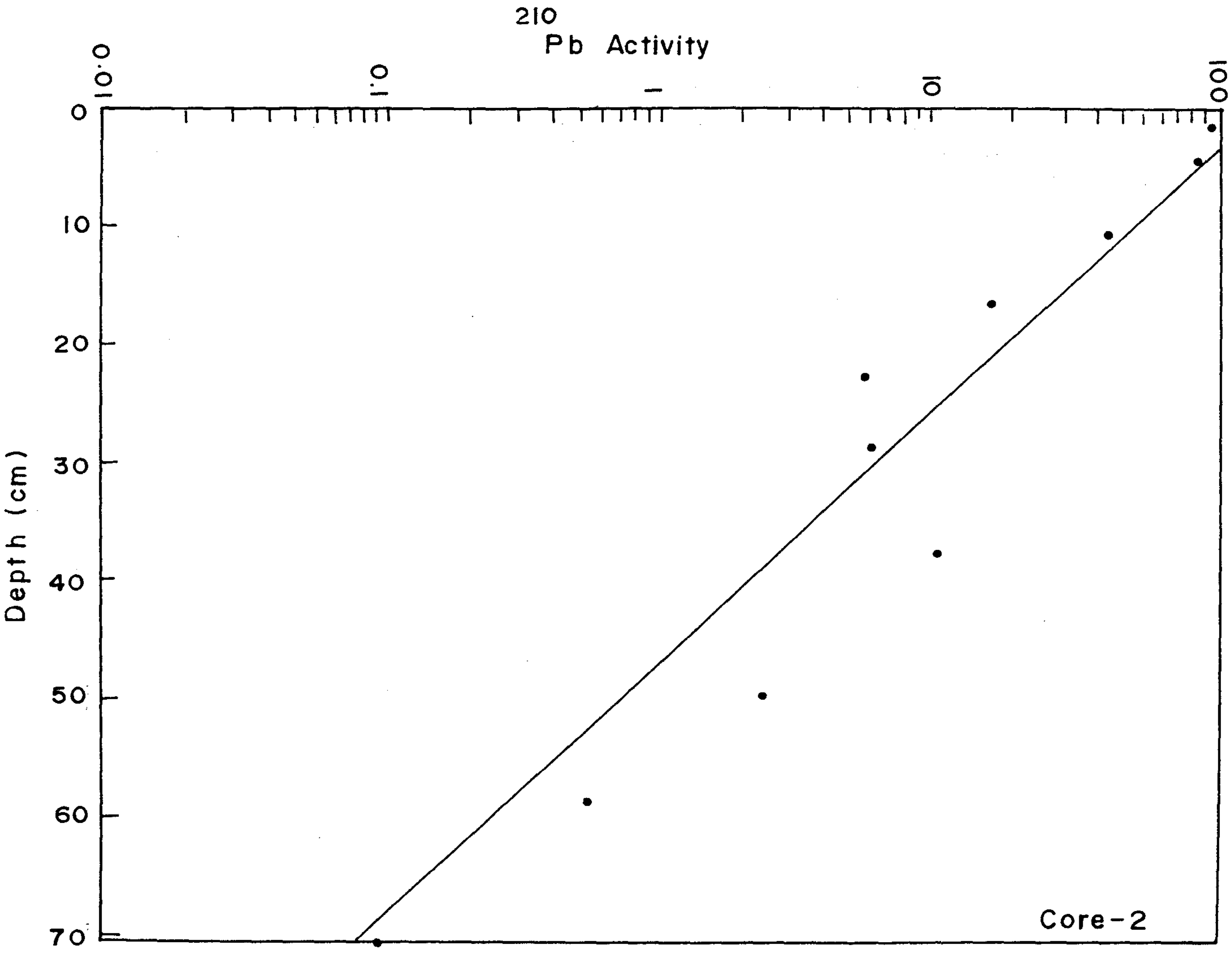


FIG. 3.20A EXPONENTIAL DECAY IN ^{210}Pb ACTIVITY (EXCESS) V/S DEPTH IN CORE-2

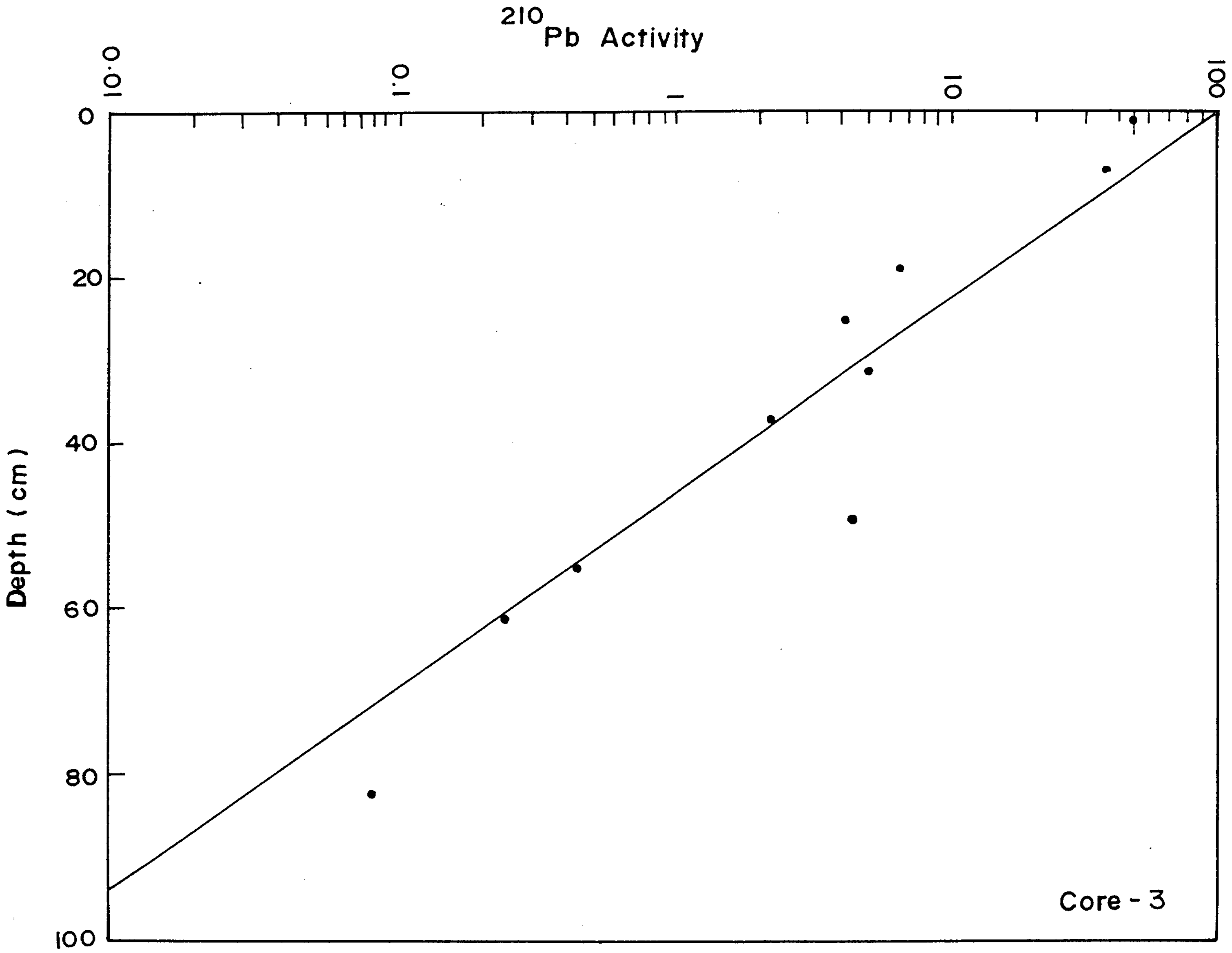


FIG.3.20B EXPONENTIAL DECAY IN ^{210}Pb ACTIVITY (EXCESS) V/S DEPTH IN CORE - 3

CHAPTER 4

GEOCHEMISTRY

Geochemistry is defined as the science concerned with chemistry of the earth as a whole and its component parts. It deals with distribution and migration of chemical elements within the earth, in space and time.

Geochemistry of lacustrine sediments was reported to be a potential tool to reconstruct palaeo-environment (Sekar *et al.,* 1994), to trace the source, to delineate zones of elemental concentration leading to pollution and to understand anthropogenic influence. Berner (1981) has classified lacustrine sediments on the basis of their geochemical behaviour. Roberts *et al.,* (1982) have stated that chemistry of lake sediments is the function of characteristics of catchment area and lake water. In the present study, an attempt is made to understand the distribution and association of elements within the surface and subsurface sediments of Mayem lake. An effort is also made to understand the source of sediments using elemental distribution and processes involved in such a distribution.

Methodology

0.3 gm of finely powdered samples were digested in a teflon beaker using a mixture of standard acids: HF, $HClO_4$ and HCl. The solution obtained is analysed by Inductively Coupled Plasma Emission Spectrometry (ICP) using ISA Jobin Keun JY 70 plus JCP spectrometer equipped with simultaneous polychromator for major elements and with a high resolution sequential monochromator for trace elements (Cotten *et al.,* 1995).

Elements analysed are :

A) Major elements - (In percentage)

a) Non - metals - Si, P

b) Metals - Al, Mg, Ca, Na, K

c) Transition metals - Fe, Mn, Ti

B) Trace elements - (In ppm)

a) Metals - Sr, Ba

b) Transition metals - Sc, V, Cr, Co, Ni, Cu, Zn, Zr, Nb, Y

c) Lanthanides (REE) - Light REE - La and Heavy REE - Yb

In addition, another parameter - loss on ignition was also analysed.

Loss on ignition (LOI)

LOI has been detected by calcination at 1000°C. However, an attempt was also made to calculate the loss on ignition at 100°C for comparative purpose. At this temperature, the moisture content, allophane and colloidal matter undergo destruction. With further increase in temperature, vegetal organic matter is lost at around 260°C. With subsequent rise, weight loss is due to dehydration and destruction of clay minerals. Loss on ignition is frequently used as a measure of organic carbon content of lake sediments. It is considered to be twice as that of the organic carbon content, especially when it is more than 10% (Hakanson and Jansson, 1983). It is also a fact that LOI is strongly correlated with the grain size of the sediments. Finer the size, relatively higher is the content of LOI.

A brief general information on major and trace elements which are analysed and used in the present study are given below :

Major Elements

a) Silicon (Si) :

Silicon is a major element in the Earth's crust. After oxygen, it is the most abundant of all the elements amounting to 28% of rocks of the lithosphere (Goldschmidt, 1954). It is predominantly present in sediments as oxide (i.e. silicates).

b) Aluminium (Al) :

Aluminium along with silicon is the most important constituent of the rock forming minerals. In tropical climate, especially during weathering processes, most of the aluminium from an original mineral is leached out to form clay mineral, while only small amount gets into solution.

c) Iron (Fe) :

Iron is one of the common elements occurring to an extent of about 5% by weight of the earth's crust and fourth in the list of abundance after oxygen, silicon and aluminium. It is an important element in lateritic terrain. Behaviour of Fe in sediments is largely dependent upon the stages of oxidation during weathering cycle. The increased concentration of this element may signify an anthropogenic input from the catchment area. Coey *et al.,* (1974) have argued that most of the Fe in lake sediments exists as amorphous ferric hydroxide.

d) Manganese (Mn) :

Manganese along with Fe are two important mobile elements in any aquatic environment. These elements play important role in binding of nutrients and toxic elements by virtue of their high specific area in the oxide form (Kango *et al.,* 1987).

In soils and particulate materials of the aquatic environment, Fe and Mn oxide commonly occur as coatings on minerals. They can be present in amorphous or micro - crystalline forms. Fe and Mn ions enter the aquatic system from both ground and surface waters. In groundwater, these ions generally occur in reduced oxidation states such as Mn^{+2} and Fe^{+3}. But, in the presence of dissolved oxygen in overlying waters, these get oxidized to Fe_2O_3 and MnO (Stumm and Lee, 1960). These elements are more associated with finer sediments. Subramanian and Gibbs (1972) have found that smaller the grain size of mineral, more Fe-oxide become bonded to clay minerals as coatings.

Mn, especially is a very reactive redox metal and in shallow areas of lakes, there is little or no reduction throughout the year. Similarly Mn - cycle is strongly coupled with carbon cycle and has a significant role in the oxidation of organic carbon in the lake (Aguilar and Nealson, 1993). Relatively higher concentration of manganese is determined by magnitude of source (i.e. catchment area input) relative to the size of a lake. (Urban *et al.,* 1990).

e) Magnesium (Mg) :

Magnesium is supposed to be the most scarce of alkaline earth elements of upper lithosphere, as it is susceptible to weathering. It is released mainly as chlorides and insoluble sulphates. It may also get transported as chemically undecomposed fine grained mineral particle forming one of the constituents of clay minerals.

f) Calcium (Ca) :

Calcium is also one of the major constituents of the Earth's crust. Calcium mineral acts as hosts to certain trace metals as well as rare earth elements (REE), such as Lanthanum and Yitterbium. These elements are more susceptible to weathering that results in their leaching, which causes their elimination from silicates. In general, they are closely associated with magnesium.

g) Sodium (Na) :

Sodium is one of the chief alkaline earth metals. It is present both in lithosphere as well as hydrosphere. It is also an essential rock forming element. It is susceptible to weathering and forms soluble salts. The distribution and in turn, the variation of Na content is a function of climate, topography and rock types of the catchment area.

h) Potassium (K) :

Potassium is an alkali element and an essential constituent of feldspars, felspathoids and micas. It is more readily fixed in clay minerals through cation exchange. This element commonly gets concentrated in finer sediments by virtue of adsorption through percolating solutions. Potassium has comparatively less degree of solubility in water than sodium.

All these alkali and alkaline earth elements namely Na, Ca, K and Mg are preferentially removed in solution relative to Si, Fe, Al from soils (weathered crust). This is due to their high mobility during weathering (Zhang, 1995).

i) Titanium (Ti) :

Titanium is a lithophile element. It has a strong affinity for non - metals except oxygen and sulphur. It is generally incorporated into sediments as an insoluble heavy mineral assemblage owing to its high specific gravity.

j) Phosphorous (P) :

Phosphorous is a constituent of lithosphere and an important element of a mineral apatite as well as granite and pegmatite rocks, wherein it occurs as phosphates. It generally emanates from igneous rocks and gets liberated during weathering cycle. A considerable enrichment of phosphate is observed in oxygenated sediments derived from limonite.

Trace Elements

Adsorbing capacity of trace elements to get adhered to the particulate matter, is dependent upon their sequence of residence times. Mitchell (1964) has established following sequence for affinity of heavy metals towards clay minerals.

$$Pb > Ni > Cu > Zn$$

a) Strontium (Sr) :

Strontium can replace both K and Ca in the mineral lattice.

b) Barium (Ba) :

Barium also substitutes for K in rock forming minerals, although their covariation is not so strong as between K and Rb.

c) Scandium (Sc) :

Scandium is one of the transitional elements belonging to group IIIb.

d) Vanadium (V) :

Vanadium concentration is strongly enriched in basic rocks and sediments resulting from their weathering products. It is also a transitional element.

e) Chromium (Cr) :

Chromium (Cr^{+3}) can substitute for Mg^{+2} and Fe^{+3}. However, the distribution of this element in rock forming minerals is complicated by its ability to form independent chromium minerals (Rankama and Sahama, 1950). It is also a transitional element belonging to group VIb.

f) Cobalt (Co) :

Cobalt is of transitional element belonging to group VIII

g) Nickel (Ni) :

Nickel belongs to a transitional element in group VIII, but differs from cobalt in atomic number. The distribution of Ni in sediments, in general, is closely related to the distribution of Fe and Mg. The ability of Ni ions to substitute for Mg results in a close association of these two metals. Unskov and Lodochnikova, (1961) stressed the relation of cobalt and nickel to silica content.

h) Copper (Cu) :

Copper is a principal chalcophile element. Although Cu^{+2} may replace Fe^{+2} and Mg^{+2} in mineral structures, it occurs as sulphides in rocks (Rankama and Sahama, 1950). These sulphides get oxidized during weathering and cu^{+2} is released into solution. Therefore, small quantity is expected to be present in lithogenic detrital materials. Shales and argillites contain upto 40-50 ppm.

i) Zinc (Zn) :

Zinc is principally a chalcophile element. However, its affinity to sulphur is less prominent than that of other transitional elements. Because of similarity in ionic size, Zn^{+2} can also substitute for Fe^{+2} and Mg^{+2}.

j) Zirconium (Zr) :

Zirconium is an important element of mineral Zircon. It belongs to group IV b and is a member of transitional element.

k) Neobium (Nb) :

Neobium is a member of transitional element belonging to group Vb.

l) Yttrium (Y) :

Yttrium is a member of transitional element belonging to IIIb.

m) Rare earth elements (REE) :

a) Lanthanum series

Rare earth elements form a coherent series of elements with decrease in ionic radii from the lightest element (Lanthanum - La) to the heaviest element (Lutecium - Lu). Because of the "Lanthanide Contraction", relative abundance of REE in different types of rocks, sediments and waters have characteristic signatures which are used to study aquatic and solid - phase geochemistry. REE, in spite of their names, are more naturally abundant in sediments than many of the trace metals. Hence, they can also be used as pollution indicators (Olmez *et al.,* 1991).

Two elements from this series are studied i.e. ***Lanthanum (La)*** and ***Yitterbium (Yb)***.

Geostatistical parameters

In the present study, elemental concentration obtained was subjected to geostatistical analysis, namely simple correlation analysis, chemical index of alteration (CIA) and chemical maturity (Chm), factor analysis to understand the mutual association, effect of weathering and to delineate the sources. Further, the data was also processed to obtain enrichment factor (E.F.), index of geoaccumulation (Igeo), pollution load index (PLI) and degree of contamination (Cd) to understand and assess environmental impact and also to quantify anthropogenic influence, if any.

The background of the above mentioned parameters are given below.

I Simple Correlation Analysis

To understand the interrelationship and mutual association, among sedimentological characters (sand - silt - clay - organic carbon) and the geochemical elements, bulk geochemical data was subjected to "**Simple correlation analysis**" after normalising the data following Sahu (1982).

II Chemical/Statistical parameters

Lake sediments are formed mainly from material supplied from its terrestrial surroundings with minor quantity of material synthesised in water column. Terrestrial supply becomes important when terrain contains a weathered topographic profile. Mayem lake, being an example to such a case, an attempt is made to understand the intensity of weathering and status of maturity of sediments in relation to geochemical variations in elemental concentrations. In this regard, two parameters are computed namely a) Chemical index of alteration (Nesbit and Young, 1982) - CIA b) Chemical maturity (Konta, 1988) - Chm.

A) Chemical Index of Alteration (CIA) : It indicates the intensity of weathering.

$$\mathrm{CIA} = \frac{[Al_2\,O_3]}{[Al_2\,O_3 + CaO + Na_2O + K_2O]} \times 100$$

B) Chemical maturity - (Chm) : It signifies the degree of leaching of the rock material. It is defined as the ratio of percentage of Al to total percent of Na, Mg, and Ca taken together.

$$\frac{\text{Al }\%}{(\text{Na} + \text{Mg} + \text{Ca})\%}$$

III Factor Analysis

Factor analysis is just a data reduction technique. It is a set of procedures for removing the redundancy from a set of correlated variable or "factors". Thus, it summarizes the data and identifies relationships among variables.

Factor analysis can be divided into two broad types called R - mode and Q - mode techniques. The former is concerned with interrelations between variables, and operates by extracting eigen values and eigenvectors from a covariance or correlation matrix. While, the later is concerned with relationships between objects, often as an attempt to discern patterns or groupings within their arrangement in multivariate space. Q - mode method focusses on the similarities between individuals in the data set and hence, they are not usually amenable to statistical analysis (Davis, 1986). Therefore, in the present study, elemental data of only surface sediments was subjected to R - mode factor analysis with varimax criterion (Kaiser's varimax scheme) that involves maximisation of the variance of the loadings on the factor using Fortran programme.

IV Environmental impact factors

As stated earlier, Mayem lake is situated within an active iron ore open-cast mining zone in Bicholim taluka, Goa. Although, no excavation is operative within its catchment area, mine rejects are being dumped and therefore, environmental effects are anticipated. Hence, in the present study, an attempt is made to quantify the impacts of anthropogenic activities using two geostatistical parameters : namely

i) Enrichment factor (Borole *et al.,* 1982) (E.F.)

ii) Index of geoaccumulation (Muller, 1979) (I_{geo})

***i) Enrichment factor (E.F.)*:**

"Enrichment factor", a term generally used to denote the excess concentration of particular element relative to its background value. This factor is defined in different ways by various authors (Kemp *et al.,* 1976; Borole *et al.*, 1982; Hakanson and Jansson, 1983; Zhang, 1995 and Mohan, 1995). For the present analysis the formula given by Borole *et al.,* (1982) is used.

$$\text{E.F.} = \frac{[\text{Metal/Al}]_{\text{sediment}}}{[\text{Metal/Al}]_{\text{Background}}\ (\text{PAAS})}$$

This ratio is capable of indicating pollution impact as the concentration of Al in weathering products and their parent material are generally comparable (Martin and Meybeck, 1979). It is commonly expressed as a ratio with respect to standard. In the present study, Global shale - PASS (Taylor and Mclenan, 1985) is used as a standard.

ii) Index of Geoaccumulation (I_{geo}) :

The "Geoaccumulation Index" proposed by Muller (1979) was computed for those elements that show higher enrichment factor to assess the impact and extent of pollution. It is defined as

$$I_{geo} = \frac{\log_2 (Cn)}{1.5 \times Bn}$$

Where, Cn = measured concentration of an element 'n'

Bn = Background value (PAAS) of element 'n'

The factor 1.5 is used for possible variations in background data due to lithogenic effects. The index of geoaccumulation consists of seven grades, with Igeo of 6 indicating 100 fold enrichment above background values ($2^6 \times 1.5 = 96$).

The pollution intensity is deciphered from Igeo sediment accumulation factor as follows :-

Pollution Intensity	**Sediment accumulation factor**	Igeo class
Very strongly polluted	>5	6
Strongly to very strongly polluted	4 - 5	5
Strongly polluted	3 - 4	4
Moderately to strongly polluted	2 - 3	3
Moderately polluted	1 - 2	2
Unpolluted to moderately polluted	0 - 1	1
Practically unpolluted	0	0

In addition, in the present study, two more parameters were used to confirm and support the findings, namely i) Pollution load index (PLI) and ii) Degree of contamination (C_d).

i) Pollution Load Index (PLI)

Tomlinson *et al.,* (1980) employed a simple method based on Pollution load Index (PLI) to assess the extent of pollution by metals in sediments of estuarine environment. An attempt is also made, in the present study to evaluate metal pollution using PLI. It was calculated using an equation (Tomlinson *et al.,* 1980).

$$\text{PLI} = \sqrt[n]{\text{Product of n number of C.F. values}}$$

Where,

C.F. = Contamination factor

N = Number of metals

Contamination factor can be obtained from a formula

$$\text{C.F.} = \frac{\text{Metal concentration of polluted sediment}}{\text{Background value of that metal}}$$

ii) Degree of contamination (Cd) is defined as the sum of all contamination factors larger than one (Hakanson and Jansson, 1983).

$Cd < n$ = Low degree of contamination

$n < Cd < 2n$ = Moderate degree of contamination

$2n < Cd < 4n$ = Considerable degree of contamination

$Cd > 4n$ = Very high degree of contamination.

where, n = number of elements considered to calculate the factor/degree.

In addition, ***'Anthropogenic factor'*** (Szefer *et al.,* 1995) was computed only for the data of core - 2 to confirm the results obtained from enrichment factor, index of geoaccumulation and pollution load index.

It is given by a formula

$$A.F. = M_s/M_d$$

Where,

A.F = Anthropogenic factor

M_s = Mean concentration of element in the top layer of sediment

M_d = Mean concentration of element in the deepest layer of the sediment.

Results and discussion

Part I Surface sediments

Loss on Ignition (LOI)

The data obtained on loss on ignition on selected surface sediment samples is presented below and graphically represented in figure (Fig. 4.1B).

Sampling St. Nos.	Premonsoon		Monsoon		Postmonsoon	
	LOI	L-100	LOI	L-100	LOI	L-100
1	28.63	3.37	18.15	1.56	27.08	3.11
4	31.15	4.34	29.91	3.31	27.54	3.41
7	31.29	3.79	31.50	3.66	29.18	3.68
13	18.75	3.20	20.21	2.32	20.33	2.86

Note : All values are in percentage.

From the table, it is seen that LOI value ranges from 18.75% to 31.29% during premonsoon, from 18.15% to 31.50% during monsoon and from 20.33 to 29.18% during postmonsoon. L-100 value ranges from 3.20% to 4.34 during premonsoon, from 1.56% to 3.66% during monsoon and from 2.86% to 3.68% during postmonsoon. It is clear from the data that LOI and L-100 (loss on drying at 100°C) values are relatively higher for st.no. 7, except L-100 value for premonsoon. It may be noted here that st. no.7 is from inner valley portion. Least values of LOI and L-100 are obtained for st. no.13, during premonsoon and postmonsoon which is the deepest and from outer reservoir segment.

Lower values of LOI and L-100 during monsoon are recorded at st. no.1.

Major elements

Elemental concentration of surface sediments in Mayem lake is presented in table (Table 4.1) and graphically represented in figures (Fig. 4.1A and B).

Concentration of major elements shows following trend

$$P < Na < Mn < Ca < K < Ti < Mg < Fe < Al < Si$$

a) Silicon (Si) : Si is a predominant element in surface sediments of Mayem lake. In premonsoon, it ranges from 16.5% to 17.9%, In monsoon, from 7.99% to 18.1% and during postmonsoon, it ranges from 16.2% to 17.5%. It is seen that Si concentration is the least at st. no.1 irrespective of seasons and highest at st. no.13 during premonsoon and postmonsoon and st.no.7 during monsoon. It is also clear from the data that Si concentration, on an average, is relatively less in eastern shallower portion than western deeper portion irrespective of seasons.

b) Aluminium (Al) : In premonsoon, Al concentration ranges from 7.94% to 9.10%. During monsoon, it ranges from 5.93% to 8.71% while during postmonsoon, it ranges from 7.41% to 9.53%. Al concentration is the least at st. no.7 during premonsoon and postmonsoon whereas during monsoon, it is least at st. no.1. Highest Al concentration is recorded at st. no. 4 irrespective of the seasons.

c) Iron (Fe) : In the present study, total iron is determined as Fe_2O_3 as sample was pre-ignited to 700°C before analysis. At this temperature, FeO becomes oxidised to Fe_2O_3.

In premonsoon, Fe concentration ranges from 8.46% to 16.1%; during monsoon, it is from 7.59% to 35% while during postmonsoon, it ranges from 10.2% to 15.6%. From the data, it is seen that Fe concentration is the least of st.no.4 and the highest at st.no.13 except during monsoon. During monsoon, the least Fe concentration is recorded at st.no.7 and highest at st.no.1. Fe concentration is relatively less in eastern shallower portion compared to western deeper portion except during monsoon.

d) Magnesium (Mg) : Mg concentration during premonsoon ranges from 0.57% to 0.89%; during monsoon, it is from 0.40% to 0.86%, while during postmonsoon, it ranges from 0.58% to 0.84%. It is seen that Mg concentration is the least at st. no. 13 except during monsoon, wherein the least concentration is at st.no.1. The highest concentration is at st. no. 7, except during postmonsoon, wherein highest concentration is at st.no.1.

e) Titanium (Ti) : In premonsoon, Ti concentration ranges from 0.49% to 0.67%; during monsoon, it is from 0.38% to 0.58%, while during postmonsoon, it ranges from 0.49% to 0.66%. The data shows the highest Ti concentration at st. no. 4 irrespective of seasons, while Ti concentration is the least at st.no. 7 during premonsoon and postmonsoon whereas during monsoon the least value is obtained for st. no.1.

f) Manganese (Mn) : In premonsoon, Mn concentration hardly changes and remains almost uniform (av. 0.14%). During monsoon, it shows considerable variation and ranges from 0.10% to 0.60%. While during postmonsoon, its concentration ranges from 0.11% to 0.27%. The highest Mn concentration is recorded at st.no.13 during premonsoon and postmonsoon and st. no.1 during monsoon. Mn concentration is the least at st.no.1 during premonsoon and postmonsoon and st.no.7 during monsoon.

g) Calcium (Ca) : Ca concentration during premonsoon ranges from 0.24% to 0.37%; during monsoon, it is from 0.19% to 0.33%, while during postmonsoon, it ranges from 0.29% to 0.36%. Data shows relatively less Ca concentration during monsoon. Ca concentration is the highest at st.no.4 during premonsoon and monsoon and st.no.7 during postmonsoon. The concentration is the least at st.no.13 during premonsoon and postmonsoon and at st.no.1 during monsoon.

h) Sodium (Na) : In premonsoon, Na concentration ranges from 0.10% to 0.16%; during monsoon, it is from 0.07% to 0.15% while during postmonsoon, it ranges from 0.10% to 0.16%. The data shows relatively less concentration during monsoon. Na concentration is the highest at st.no.1 during premonsoon and postmonsoon and st.no.4 during monsoon. Its concentration is the least at st.no.13 during premonsoon and postmonsoon and at st.no. 1 during monsoon.

i) Potassium (K) : K concentration during premonsoon ranges from 0.76% to 0.84%; during monsoon, it is from 0.34% to 0.83%, while during postmonsoon, it ranges from 0.72% to 0.84%. K shows relatively less concentration during monsoon but with a wider range. K concentration is the highest at st.no.4 during premonsoon and postmonsoon and at st.no.7 during monsoon. Its concentration is the least at st.no.13 during premonsoon and postmonsoon and at st.no.1 during monsoon.

Thus, it is clear from seasonal variation in Mg, Ca, Na, and K that concentration of all these elements is considerably less at st.no.1 during monsoon.

j) Phosphorous (P) : In premonsoon, P concentration ranges from 0.08% to 0.10%; during monsoon, it is from 0.07% to 0.17%, while during postmonsoon, it ranges from 0.09 to 0.11%. It is seen from the data that range of variation is relatively wider during monsoon. St. no. 1 has the highest P concentration irrespective of seasons. Least P concentration is recorded at st. no. 7 during premonsoon and monsoon and at st.no.4 during postmonsoon.

Trace elements

Elemental concentration of trace elements in surface sediments of Mayem lake are presented in table (Table 4.1) and graphically represented in figures (Fig. 4.1C and D).

Concentration of trace elements show the following trend.

Yb<Nb<Sc<Y<Co<La<Sr<Cu<Zr<Zn<Ni<V<Cr<Ba

a) Strontium (Sr) : Sr concentration during premonsoon ranges from 32 ppm to 42 ppm; during monsoon, it is from 22 ppm to 41 ppm, while during postmonsoon, it ranges from 32 ppm to 42 ppm. Sr concentration is the least at st. no.13 during premonsoon and postmonsoon and at st.no.1 during monsoon. Its concentration is the highest at st.no.1 during premonsoon and postmonsoon and at st.no.4 during monsoon. It is also seen that eastern portion of the lake has relatively higher Sr concentration than western portion.

b) Barium (Ba) : In premonsoon, Ba concentration ranges from 230 ppm to 260 ppm; during monsoon, it is from 107 ppm to 267 ppm, while during postmonsoon, it ranges from 226 ppm to 250 ppm. The Ba concentration is the least at st. no. 13, except during monsoon, wherein st. no. 1 shows the least concentration. It is also seen that range of variation of Ba concentration is wider during monsoon. Its concentration is the highest at st.no.4 during premonsoon and postmonsoon and at st.no.7 during monsoon.

c) Scandium (Sc) : Sc concentration during premonsoon ranges from 18 ppm to 22 ppm; during monsoon, it is from 18 ppm to 26 ppm, while during postmonsoon, it ranges from 17 ppm to 23 ppm. It is seen that Sc concentration is the highest at st. no. 1 irrespective of seasons. The Sc concentration is almost constant at all other stations in all seasons with the least concentration at st.no.7.

d) Vanadium (V) : In premonsoon, V concentration ranges from 162 ppm to 213 ppm; during monsoon, it is from 144 ppm to 188 ppm, while during postmonsoon, it ranges from 145 ppm to 218 ppm. It is seen from the data that V concentration is relatively less during monsoon except at st.no.7. Highest V concentration is recorded at st.no.1 during premonsoon and postmonsoon and at st.no.13 during monsoon. V concentration is the least at st.no.7 during premonsoon and postmonsoon and at st.no.1 during monsoon.

e) Chromium (Cr) : Cr concentration during premonsoon ranges from 158 ppm to 292 ppm; during monsoon, it is from 157 ppm to 234 ppm, while during postmonsoon, it ranges from 150 ppm to 282 ppm. Cr concentration is the highest at st.no.1 during premonsoon and postmonsoon and st.no.13 during monsoon. St. no.7 shows the least concentration irrespective of seasons.

g) Cobalt (Co) : In premonsoon, Co concentration ranges from 26 ppm to 40 ppm; during monsoon, it is from 24 ppm to 38 ppm, while during postmonsoon, it ranges from 23 ppm to 31 ppm. St. no. 1 shows the least and st. no. 7 shows the highest Co concentration irrespective of seasons.

h) Nickel (Ni) : Ni concentration during premonsoon ranges from 108 ppm to 132 ppm; during monsoon, it is from 82 ppm to 136 ppm, while during postmonsoon, it ranges from 104 ppm to 126 ppm. It is clear from the data that the least Ni concentration is at st.no.13 during premonsoon and postmonsoon and st.no.1 during monsoon. The highest Ni concentration is recorded at st. no. 7 during premonsoon and monsoon and at st. no.1 during postmonsoon.

i) Copper (Cu) : In premonsoon, Cu concentration ranges from 67 ppm to 89 ppm; during monsoon, it is from 53 ppm to 60 ppm, while during postmonsoon, it ranges from 48 ppm to 78 ppm. Cu concentration is the least at st.no. 13 during premonsoon and at st.no.7 during monsoon and postmonsoon. Its concentration is the highest at st.no.4 during premonsoon, st. no.13 during monsoon and st.no. 1 during postmonsoon.

J) Zinc (Zn) : Zn concentration during premonsoon ranges from 140 ppm to 218 ppm;, during monsoon, it is from 115 ppm to 139 ppm, while during postmonsoon, it ranges from 107 ppm to 128 ppm. It is seen from the data that, in general, Zn concentration decreases from premonsoon through monsoon to postmonsoon except st. no. 7. St. no. 4 shows the least concentration irrespective of seasons.

K) Zirconium (Zr) : In premonsoon, Zr concentration ranges from 103 ppm to 152 ppm; during monsoon, it is from 105 ppm to 118 ppm, while during postmonsoon, it ranges from 108 ppm 136 ppm. The range of Zr concentration is narrow during monsoon. Zr concentration is the least at st.no.7 during premonsoon and postmonsoon and at st.no.1 during monsoon. Its concentration is the highest at st.no.1 during premonsoon, st.no.7 during monsoon and st.no.4 during postmonsoon.

l) Neobium (Nb) : Nb concentration during premonsoon ranges from 14 ppm to 19 ppm; during monsoon, it is from 10 ppm to 16 ppm, while during postmonsoon, it ranges from 14.5 ppm to 18 ppm. The range of variation in Nb concentration is more during monsoon. It is clear from the data that the highest Nb concentration is at st. no.4 irrespective of seasons and the least at st. no.7, except during monsoon. It is also clear that st. no. 1 shows relatively low Nb concentration during monsoon compared to premonsoon and postmonsoon.

m) Yttrium (Y) : In premonsoon, Y concentration ranges from 20 ppm to 31 ppm; during monsoon, it is from 20 ppm to 26 ppm, while during postmonsoon, it ranges from 20 ppm to 30 ppm. The range of variation in Y concentration is the least during monsoon. The highest Y concentration is at st.no.4 and the least at st.no.13 irrespective of seasons.

Rare Earth Elements

n) Lanthanum (La) : La concentration during premonsoon ranges from 29 ppm to 43 ppm; during monsoon, it is from 22.5 ppm to 36 ppm, while during postmonsoon, it ranges from 28 ppm to 41 ppm. The highest La concentration is at st. no. 4 irrespective of seasons. The least concentration is at st. no.13, except during monsoon, wherein st. no. 1 shows the least concentration.

o) Yitterbium (Yb) : In premonsoon, Yb concentration ranges from 2 ppm to 2.8 ppm; during monsoon, it is from 2 ppm to 2.25 ppm, while during postmonsoon, it ranges from 1.95 ppm to 2.65 ppm. It is seen that the range of variation in Yb concentration is the least during monsoon. The highest Yb concentration is at st. no. 4 irrespective of seasons. The least Yb concentration is recorded at st. no. 13 during premonsoon and monsoon and st. no. 7 during postmonsoon.

From above individual elemental description, it is seen that some of the elements are highly concentrated at a given location irrespective of seasons. For e.g. P, Sc at st.no.1, Co at st.no.7 and Al, Ti, Nb, La, Y, Yb at st.no.4. Very strong correlation between these elements which are high at st.no. 4 is recorded (Table 4.2). From chapter 3, it is clear that higher clay and organic matter content were recorded at st. nos. 4 and 7. Therefore, higher concentration of these elements at st.nos. 4 and 7 is attributed to the presence of higher concentration of clay and organic carbon.

Some elements are found to be high at a given location during fairweather seasons (premonsoon and postmonsoon). For e.g. Si, Fe, Mn, at st.no.13, Ba and K at st.no.4, Na, Sr, V and Cr at st.no.1. High elemental concentration at st. no. 13 can be attributed to association of Si, Fe and Mn with sand and silt, whereas, enrichment of V, Cr, Sr, at st.no.1 during premonsoon and postmonsoon can be related to high organic carbon content and finer sediments (silt + clay) at these stations as compared to monsoon. Similarly, at st.no.4 enrichment of K and Ba can be related to high clay and organic carbon.

Elemental concentration of Ca at st.no.4, Zn at st.no.1 Mg and Ni at st.no.7 are higher during premonsoon and monsoon compared to postmonsoon. In addition, at st.no.1, Zr is found to higher during premonsoon, Fe and Mn during monsoon and Mg and Cu during postmonsoon. Similarly, at st.no. 4, Cu is found to be higher during premonsoon, Sr and Na during monsoon and Zr during postmonsoon. At st.no.7, Si, K, Ba and Zr are found to be higher during monsoon and Ca during postmonsoon. At the deepest point of the lake i.e. at st. no.13, higher concentration of V, Cr and Cu was recorded during monsoon and Zn during postmonsoon. When elemental concentration is observed closely with the concentration of sand, silt, clay and organic carbon, it is observed that distribution of most of the trace elements and some major elements are controlled by organic carbon and clay content. In addition, distribution can also be directly related to influx of material.

The concentration of Si and Co at st.no.1, Zn at st.no.4, Sc and Cr at st.no.7 and Y at st.no.13 is the least irrespective of seasons. In fairweather seasons, i.e. in premonsoon and postmonsoon, concentration of Mn at st.no.1, Fe at st.no.4, Al, Ti, V, Nb and Zr at st.no.7, Ca, Mg, Na, Sr, Ba, Ni and La at st.no.13 is the least. Similarly, some elements like P at st.no.7, Yb at st.no.13 are the least during premonsoon and monsoon compared to postmonsoon. Elemental concentration of Cu is the least at st.no.13 during premonsoon, and st.no.7 during monsoon and postmonsoon. In addition, concentration of Fe and Mn is the least at st.no.7 during monsoon and Yb during postmonsoon. During monsoon, elemental concentration of most elements namely Al, Mg, Ti, Ca, Na, K, Ba, Sr, V, La, Nb, Ni and Zr is the least at st.no.1. During this season, the highest Fe and Mn concentration and least concentration of above listed elements at st.no.1 is directly controlled by influx of sediments from the catchment area.

Among the four stations considered for elemental distribution, st.no.7 represents inner valley portion and st. nos. 1, 4 and 13 represent outer reservoir segment. An attempt is made to compare the elemental concentrations between inner valley portion and outer reservoir segment. The results obtained show that sediments in the inner valley portion contain higher concentration of Mg, Na, K, Co and Ni and lower concentration of Si, Fe, Mn, Al, Ti, P, Sc, V, Cr, Cu. From the sediment distribution study presented in chapter 3, it was clear that inner valley portion receives relatively small quantity of sediment input than outer reservoir segment. The elemental concentration mentioned above helps in delineating elemental input. It can be said that Si, Al, Ti, Fe, Mn, P, Cr, Cu, Sc and V are being added from the catchment area to the outer reservoir segment of Mayem lake during monsoon.

When the average elemental concentrations of st. nos. 1, 4 and 7 which represent shallow, eastern zone is compared with st. no. 13, which represents deeper, western zone, it is found that most of the elements are concentrated in shallow eastern zone irrespective of seasons, except few elements like Si, Zn. During fairweather seasons (premonsoon and postmonsoon), Fe and Mn concentrations are less in shallow eastern zone.

Seasonal geochemical data of surface sediments is grouped together to have general representation of the lake in simple correlation analysis (Table 4.3). Significant seasonal interrelations are also used in the interpretation. The data presented in table 4.3 reveals the following association :

a) Si, Al, Ti, K, Na show positive correlation with each other as well as with majority of trace elements.

b) Fe, Mn, P and sand are very strongly correlated with each other and negatively correlated with majority of the elements except Zn, Sc and Cr.

c) Alkalis and alkaline earth elements show good correlation with trace elements specially Sr, Ba, Ni, La, Nb and Cu.

d) Organic carbon is well correlated with Mg, Ca, Na and certain trace elements such as Sr, Ni, La, Y. Although, its concentration increases with decrease in grain size, it shows weak positive correlation with clay fraction (r=0.4906). Organic carbon also has weak correlation with Al, Si and Ti.

In addition, when individual elements are considered, Fe shows positive correlation with sand (r=0.6283) which is very significant during monsoon (r=0.9426). Fe shows significant negative correlation with Mg (r=- 0.9247). Mn shows strong positive correlation with sand, especially during monsoon (r=0.9037) and Fe (r=0.8844). Close association of Fe and Mn indicates that they are released from same source from the catchment area. Such association has also been reported by Padmalal and Seralathan (1993) in Vembanad lake. In Mayem lake, high concentration of Fe and Mn recorded at st.no.1 during monsoon indicates input of these elements from the catchment area through the stream which runs across rocky terrain. Results also reveal association of Fe and Mn with sand. This is specially true in deeper zone i.e. at st.no.13 during fairweather seasons (premonsoon and postmonsoon). Study on sediment characteristics has revealed that during monsoon, sediment input to the lake is a mixture of sand - silt - clay, out of which coarser material like silt and sand reaches and settles faster in deeper portion of the lake. Material containing Fe and Mn being generally denser, must also be settling along with coarser material in deeper zone. Phosphorous shows good positive correlation with Fe (r=0.9325) and Mn (r=0.7986). Association of Fe, Mn and P due to scavenging behaviour has been explained earlier by Seralathan (1987). Close association of Fe, Mn and P is also reported by Bortleson and Lee (1972). The present study shows good correlation between Zn and Fe (r=0.8686) as well as Zn and Mn (r=0.8534). Sc and Cr also show positive correlation with Fe, though value obtained is not significant.

Mg show good positive correlation with trace elements like Sr (r=0.9549), Ba (r=0.8144), Ni (r=0.9670), Y (r=0.6795), rare earth elements La (r=0.7647) and also organic carbon (r=0.8373). Ca shows good correlation with Mg (r=0.7907) and trace elements like Sr (r=0.8613), Ba (r=0.7190), Ni (r=0.7703), rare earth elements. La (r=0.7768) and also with organic carbon (r=0.8075). Both Ca and Mg show positive correlation with clay, though not significant. Na shows good correlation with Ca (r=0.7969), Mg (r=0.9744), Sr (r=0.9699), Ba (0.8140), Ni (r=0.9211), La (r=0.7734) and organic carbon (r=0.7607). Similarly, K shows very good positive correlation with Na (r=0.7955), Mg (r=0.7914), Ca (r=0.6984), Sr (r=0.8709), Ba (r=0.9944), Ni (r=0.8573) and La (r=0.7278).

Distribution and concentration of Ca, Mg, Na, K and associated trace elements (Sr, Ba, Ni, La and Y) after entering the Mayem lake from its catchment area through the streams seems to be controlled by organic carbon and clay content.

Al shows good positive correlation with clay, especially during monsoon (r=0.8468), Ti (r=0.9490) and V (r=0.8402). Ti, similarly shows good correlation with V (r=0.8882), Zr (r=0.8170), Y (r=0.6938) and Yb (r=0.6688). V shows significant positive correlation with Cr, Cu and Zr. Similarly, Zr shows good correlation with Cr, La, Nb, Y, Yb. Y shows good correlation with organic carbon (r=0.7251). From this, it is clear that all these elemental distribution seems to be controlled by finer sediments (clay) and organic carbon.

Higher LOI values obtained are related to higher organic carbon within Mayem lake sediments. Also LOI values show good correlation with organic carbon. The direct relation between LOI and organic carbon content has been studied earlier by Duck (1986) in Loch Tummel, Scotland. Lower value of LOI at st.no.1 may be attributed to the least supply of organic detritus during monsoon at this station, as observed earlier from sedimentological studies.

The data obtained on **chemical index of alteration (CIA)** is presented in table (Table 4.3). It is seen that CIA values vary in a small range with slightly higher values during monsoon. Thus, on an average, it varies from 91.32 (premonsoon), 91.91 (monsoon) to 91.43 (postmonsoon). High values obtained for Mayem lake surface sediments indicate highly altered nature and finer size of sediments. Relatively higher CIA value obtained for monsoon can be related to supply of more altered material during this season. The data obtained on **chemical maturity (Chm)** of surface sediments is presented in table (Table 4.3). It is seen from this data that during premonsoon, it ranges from 5.97 to 9.42, during monsoon, it is from 6.65 to 8.99, while during postmonsoon, it ranges form 5.79 to 9.09. Thus, the range of variation in Chm is narrow during monsoon which indicates relative uniformity in leaching nature of sediments. It is also very interesting to note that st.no.13 which represents the deepest portion of lake, shows the highest Chm value indicating strong leaching, in turn, more maturity of sediments relative to other stations. St.no.7 shows the least Chm value indicating less maturity.

Elemental data of surface sediments for each season was separately subjected to R - mode factor analysis and various isolated factor loadings for first three factors (Eigenvalues >1) are considered for interpretation.

Premonsoon : The first three factors account for 100% of total variations (Table 4.4A).

Factor 1 - This factor is associated with 50.69% of total variations. It shows the highest positive loadings on Fe followed by P, Zn and shows the highest negative loadings on K, Ba and Ca. As most of the major elements with majority of the trace elements are negatively loaded, the factor indicates coarse detrital fraction.

Factor 2 - This accounts for 32.09% of total variations. It shows the highest positive loadings Al, Ti, Sc, V, Cr, Zr, Nb, Yb and strong negative loadings on Co. This suggests fine detrital source, i.e. clay fraction.

Factor 3 - This factor is associated with 16.95% of total variations. It shows positive loadings on Si, Mn followed by Fe and shows higher negative loadings on Na, Mg, Sr, Ni followed by Zn and Cu. This can be attributed to anthropogenic factor.

Monsoon : The first three factors account for 100% of total variations (Table 4.4B)

Factor 1 : This factor is associated with 78.82% of total variations. It shows the highest positive loadings Si, Ti, K, Zr, Ba, Nb, Ni, Co and Mg, but shows strong negative loadings on Fe, Mn, P, Sc followed by Zn. Thus, it can be interpreted as finer detrital fraction since most of the elements are positively loaded. Very high negative loadings on Fe, Mn, represent dominance of material released from mine rejects. Factor 1 accounts for the highest variations (78.82%) of all the seasons, which suggests dominance of finer detrital influx relatively enriched in Fe and Mn during this season.

Factor 2 : This accounts for 15.74% of total variations. It shows positive loadings on Zn, Fe, Mn, Cu and has negative loadings on majority of other elements. This suggests coarse detrital material with heavy minerals.

Factor 3 : This factor accounts for 5.44% of total variations. It has positive loadings on Cu followed by Cr and V. It also shows positive loadings on Ti, Ca, Al. Thus, it can be interpreted as material dominant in heavy minerals.

Postmonsoon : The first three factors accounts for 100% of total variation (Table 4.4C).

Factor 1 : This factor is associated with 60.91% of total variations. It shows strong positive loadings on Si followed by Fe, Mn and the highest negative loadings on Mg, Na, Sr, followed by Ni, Ca, Y. Thus, it indicates coarse detrital material with the influence of mining rejects.

Factor 2 : It exhibits 22.52% of total variations. It shows strong positive loadings on Cr, Cu, V, Sc followed by Ti. It has negative loadings on Co followed by Ca, Mn. This suggests heavy mineral suite within the finer fraction.

Factor 3: This factor accounts for 16.56% of total variations. It shows positive loadings on Zn and P followed by Fe and Mn and the highest negative loadings on K, Ba followed by Zr and Al. This suggests anthropogenic factor. Negative loadings on K also indicate coarse detrital fraction.

Thus, based on factor loadings of three different seasons, it could be concluded that four distinct sources can be pointed out for sediments of Mayem lake.

I) Coarse detrital

ii) Fine detrital

iii) Heavy minerals

iv) Anthropogenic factor (mining rejects).

Enrichment factor computed for selected elements of surface sediments are presented in table (Table 4.5). The factor is high (1<) for Fe, Mn, Co, Cr, Cu, Ni, Zn. The data also reveals many fold enrichment in Fe and Mn during monsoon followed by Co, Cr and Zn at st.no.1. This clearly supports the influx of material rich in these elements at this station stated earlier. Koyama *et al.,* (1989) have reported high concentration of Fe, Co and Cr in surface sediments of lake Taupo, New Zealand.

The data computed on **Igeo index** for surface sediments is presented in table (Table 4.6). It is seen from this table that Igeo values for Fe and Mn are more significant as compared to other elements, especially during monsoon. On an average, these values range from 0.2723 to 2.3209 for Fe and from - 0.0544 to 2.1520 for Mn. Thus, it can be said that Mayem lake sediments fall within a class range of 0 - 3, thereby indicating moderately to strongly polluted with respect to Fe and Mn (twelve fold enrichment). Negative values obtained for other elements like Co and Zn indicate practically unpolluted nature with respect to these elements.

To confirm above findings, in the present study, an attempt is made to compute **pollution land index (PLI)**. For this purpose, seasonal average value has been used. The data obtained is presented in table (Table 4.7). From this table, it is seen that pollution load index for the Mayem lake is 1.69. As the value is well over 1, the index shows that Mayem lake is polluted. **Contamination factor** computed as a prerequisite to compute PLI is found to be very high for Fe, Mn, Cr, Co and Zn indicating anthropogenic influence on the catchment area.

Further, PLI was used to delineate inner valley portion from outer reservoir segment. Higher PLI value is obtained for outer reservoir segment (1.80 - av. of st. nos.14 and 13) as compared to inner valley portion (1.58 - st. no. 7), which indicates higher influence on outer reservoir segment. An attempt was also made to compute **Degree of contamination** in the present study. Degree of contamination estimated for the whole Mayem lake, taking sum of averages of selected elements is 14.71 (n=8). The elements selected are Fe, Mn Cu, Co, Ni, Zn, Cr and Ti. As the value lies between n and 2n, the Mayem lake sediments can be classified as moderate in degree of contamination.

Part II Subsurface Sediments

In lacustrine environment, core study helps to reconstruct the palaeo-environment and thereby assess the pattern of sedimentation through past. In recent times, especially heavy metal distribution (Pb, Hg, Cd, Zn and Cr) with depth is regarded as tracers to delineate the zone of contamination (Premazzi *et al.,* 1986; Provini and Gaggino, 1986). Such studies are helpful to comment on the impact due to point source (Jones *et al.,* 1991). Geochemical studies have also been used to interpret the palaeo-weathering processes as well as extent of biological activity (Sekar *et al.,* 1992).

For the study of elemental distribution with depth within Mayem lake, every alternate sub - sampled fraction of core - 2 (at an interval of 6 cm) and selected sub - sampled fraction of core - 1 (3 no's) and core - 3 (4 no's) are considered.

Depthwise variation in elemental concentration (major and trace) of core - 2, core - 1 and core - 3 are presented in tables (Table 4.8 and 4.9) and graphically represented in figures (Fig. 4.2 A,B,C) and (Fig. 4.3 A,B,C,D) respectively.

The data obtained on LOI and L-100 for alternate sub - sampled fractions of core - 2 is shown below.

Range of depth (cm)	LOI	L-100
0-3	29.13	3.76
6-9	27.52	3.56
12-15	28.87	1.94
18-21	28.95	5.19
24-27	34.31	5.25
30-33	35.29	5.36
36-39	22.71	3.49
42-45	22.97	4.45
48-51	26.18	4.56
54-57	26.45	4.87
60-63	24.66	4.20
66-69	24.19	4.22
72-75	24.78	3.75

Note : All values are in percentage.

It is seen from the table that LOI values range from 22.71% to 35.29% (av. 26.98%). LOI does not show any definite trend with depth, but it is clear from data that in general, LOI values are higher in top layers from surface to a depth of 45 cm (av. 28.72%) than bottom layers (av. 25.25%). Significant higher values are noticed in top layer between 0 - 33 cm depth. L-100 values range from 1.94% to 5.36% (av. 4.22%). L-100 also does not show any definite depthwise trend. However, higher L-100 values are observed between 18 - 33 cm depth.

The data obtained on LOI and L-100 for selected sub-sampled fractions of core - 1 and core - 3 is given below.

	core - 1			core - 3			
Range of depth in cm	0 - 3	24 - 27	48 - 51	0 - 3	48 - 55	72 -75	96 - 99
L -100	4.14	3.40	3.00	4.60	4.35	3.47	2.48
LOI	25.24	19.08	18.45	19.19	21.44	19.67	20.70

It is seen from the table that in core - 1, LOI ranges from 18.45% to 25.24 % and L-100 ranges form 3% to 4.14%. While in core-3, LOI ranges form 19.19% to 21.44% and L-100 ranges from 2.48% to 4.60%. The data reveals that, both LOI and L-100 show gradually decreasing trend with depth, except LOI of core-3.

Depthwise variation in elemental concentration (major and trace) of all cores (core -2, core -1 and core -3) analysed is presented in tables (Table 4. 8 and 4.9) and graphically represented in figures (Fig. 4. 2 A,B,C and Fig. 4. 3 A,B,C,D).

Major elements : It is seen from figures (Fig. 4.2 A and B) that concentration of Si, Al, Ti, Mg, Na and K increases while that of Fe, Mn, Ca, and P gradually decreases with depth. It is also seen that depthwise variation in concentration of Fe and Mn is identical to each other with a prominent peak at 45 cm depth. Mn concentration almost remains constant below 63 cm depth. P concentration remains almost constant throughout the depth.

It is observed that top portion (from surface to depth of around 50 cm) shows a wide fluctuation in elemental concentration relative to lower portion.

Trace elements : It is seen from figure (Fig. 4.2 C) that, in general, concentration of majority of trace elements increases with depth except Co and Zn. While that of Yb does not show any peculiar trend with depth. Relative concentration of trace elements also shows wide fluctuation within top layer (i.e. from surface to depth of 50 cm) as compared to bottom layer wherein the concentration almost remains constant.

Three fractions namely - i) top (0 - 3 cm) ii) middle (24 - 27 cm) and iii) bottom (48 - 51 cm) of core - 1 (collected from inner valley portion) analysed show that concentration of Si, Al, Ti, Na and K gradually increases, while Fe, Mn, Ca and P decreases with depth (Fig. 4.3 A and B). Concentration of all the trace elements, in general, shows gradually increasing trend with depth except Co, which shows a decreasing trend. Ba and Zn do not show any peculiar trend with depth (Fig. 4.3 C and D).

Four fractions, namely i) top (0 - 3 cm) ii) middle (48 - 51 cm) iii) intermediate (72 - 75 cm) and iv) bottom (96 - 99 cm) of core - 3 collected from NE corner of outer reservoir segment show different trends with depth (Fig. 4.3A,B,C and D). Mg concentration decreases gradually, while Ca and Na concentrations virtually remain constant at 0.3% and 0.1% respectively. Si, Al, Ti and K show two high peaks - one at surface and another at 75 cm depth. While, Fe concentration shows exactly opposite trend to that of Si, Al, Ti and K. Mn concentration decreases with depth upto 75 cm. Concentration of majority of trace elements (Sr, Ba, Sc, Ni, Cu, La, Nb, Y, Yb and Zr) show similar distribution trend with two higher values - one at surface and other at 75 cm depth. Co and Zn gradually decrease till 75 cm, whereas V and Cr show decreasing trend till 51 cm and further these elements increase.

The elemental concentration were used to compute simple correlation coefficient only for core - 2 (Table 4.10). For other cores, namely core - 1 and core - 3 as the number of fractions analysed were less, such a computation has not been attempted.

Based on similarity matrix obtained, elemental associations are delineated as follows.

i) The major elements like Si, Al, Ti show fairly good correlation among themselves and also with trace elements like Sr, Ba, Sc, V, Cr, Ni, La, Cu, Nb, Y, Yb and Zr. It is also interesting to note that Si is strongly negatively correlated with Fe, Mn, Ca, P and Co while, Al and Ti show negative correlation with P and Co.

ii) Fe, Mn, Ca, P, Co and Zn are strongly positively correlated among themselves.

When these elemental groups are compared with sediment components, it is noticed that elements in the first group along with Na are strongly positively correlated with sand and most of these elements are strongly negatively correlated with organic carbon. Mn and Co are strongly negatively correlated with sand. Fe and Mn are positively correlated with silt and clay, though values are not significant. Similarly, Ca, P and Zn with silt, Co with silt, clay with organic carbon and P with organic carbon show positive correlation, although values are not significant.

Core - 2 was collected from the deepest portion of the lake as mentioned earlier. The study on zonal distribution of surface sediments detailed in chapter 3, revealed that relatively coarser sediments are deposited in deeper portion of Mayem lake compared to shallower portion, wherein finer sediments along with organic carbon are deposited. When elemental distribution within surface sediments are considered, concentration of Si along with elements like V, Cr and Cu are higher at deeper portion.

Sedimentological studies of core - 2 described in chapter 3 has revealed that sand fraction increases with depth with near uniformity and less concentration upto 40 cm from top. Silt and clay variation is within smaller ranges compared to other cores. Silt and organic carbon content decreases with depth.

Distribution of elements namely Si, Al, Ti, Mg, Na and K with majority of trace elements can be related to the distribution of sand fraction. Good positive correlation obtained between these elements and sand strongly supports this. This means, distribution of these elements is controlled by sand fraction. Strong negative correlation obtained between these elements and organic carbon, in addition to reverse trend suggests that distribution of these elements is independent of organic carbon concentration. Uniformity in elemental concentration below 50 cm depth must be due to sediments with less number of minerals (i.e. monolithic components).

Negative correlation obtained between sand fraction and elements like Fe, Mn, Cu and Zn clearly shows that concentration of these elements is independent of sand fraction. Elemental concentration of these elements decreases with depth and show positive correlation with organic carbon, which itself decreases with depth. Therefore, it may be stated that concentration of these elements in Mayem lake is controlled by organic carbon and clay content. LOI and L-100 directly agree with the trend of organic carbon within the core.

Relatively high values of elemental concentrations of Fe and Mn obtained at 45 cm depth must be directly reflecting large input of these elements from old mine dumps which stabilised later. Higher elemental concentration of Fe, Mn, Ca, P, Co and Zn in the top layer indicates increase of input of these elements in recent years. Among these elements, addition of Fe, Mn with Co and Zn to sediments can be from new mine dumps. P concentration may be due to scavenging affinity between Mn and P while Ca concentration is due to the same behaviour between Ca and P. P input, from soil of the catchment area, although to a lesser extent, can not be ruled out.

Elemental distribution when compared from one core to another, show similarity between core - 1 and core - 2. It may be important to note here that both core - 1 and core - 2 were collected from central portion of the basin with different water depths. However, between the two, core - 1 being the representative of inner valley portion (i.e. which receives lesser input from catchment area), very close and direct relation between clay and organic carbon was observed. In addition, as core - 1 is from relatively shallow basin compared to core - 2, both clay and organic carbon obtained was higher. In core - 1, trend of elemental concentration of Mn, Mg, Ca, P. etc. is closely related to clay content variation. Such relation is not significant in core - 2. Another important observation is that the trend of variation of most elements in core -1 is gradual as compared to core - 2, which indicates deposition of material in quiet environment at core - 1 site.

Core - 3 was collected from the shallow portion of outer reservoir segment, closer to NE corner of the basin. Elemental distribution described earlier shows two higher concentrations in Si, Al, Ti, K along with most of the trace elements, one at the surface and other at 75 cm depth. Mn, Co and Zn show decrease in their concentration till 75 cm depth. V and Cr decrease till 51 cm and Mg decreases gradually till bottom. Fe concentration is less at 75 cm depth. In this core, clay content is very high between 30 and 51 cm depth, as well as both silt and clay decrease with depth. Relatively higher percentage of sand is also recorded in deeper portion. High elemental concentration of Si, Al, Ti and K along with majority of trace elements at 75 cm depth therefore, can be related to higher sand content at deeper zones. Decrease of Fe, Mn, Co and Zn concentration agrees with decrease in clay content with depth. Distribution trend of V and Cr seems to agree with distribution trend of silt content within this core.

From this account, it is clear that distribution of sediment components and elemental concentration in core - 3 is different from that of core - 1 and core - 2. This must be due to shallow depositional environment, large influx of sediment material and faster rate of sedimentation at this location.

Quantification of anthropogenic influence

To understand the anthropogenic influence with time, geochemical data of cores was subjected to **Enrichment factor** analysis and **Index of Geoaccumulation**.

Enrichment factor computed for core - 2 is presented in table (Table 4.11). It is clearly seen from this table that enrichment factor of Fe and Mn typically shows two peaks - one near the surface and another at 45 cm depth. This relative enrichment of Fe and Mn at 45 cm depth is due to supply of material from old mine dumps (Fig. 2.1) within the catchment area as stated earlier. While, gradual increase in Fe, Mn concentration till surface may be related to subsequent release of material to the lake from the partially stabilised old dumps. Enrichment of these elements near the surface is attributed to additional release of material from new mine dumps (Girap and Nayak, 1996). The general increase in enrichment factor of Cr with depth can be related to its association with coarse quartzo-feldspathic sediments (sand), which itself is higher in concentration at depth. Varma *et al.,* 1993 have related higher Cr content to coarser nature of sediments elsewhere.

The data on enrichment factor obtained for core -1 and core - 3 is presented in table (Table 4.12). It is seen that enrichment factor for core - 1 shows typical decreasing trend in elements Fe, Mn, Co, Ni and Zn, whereas Cr shows increasing trend. In core - 3, Cr shows gradual increasing trend while Ni shows decreasing trend with depth. Other elements do not show any particular trend with depth. This confirms association of Fe, Mn, Co, Ni, Zn with clay and Cr with sand content.

The data computed on **Index of geoaccumulation (I_{geo})** for core - 2 is presented in table (Table 4.13). It is clear from the data that all elements, in general show decreasing trend except Cr and Ni. Higher accumulation index obtained for top sediments confirms the release of material from mine dumps i.e. anthropogenic influence on Mayem lake, especially with reference to enrichment of Fe, Mn, Co, Zn.

Data obtained on Igeo values for core - 1 and core - 3 is presented in table (Table 4.14). From the table, it is seen that Igeo values for Fe and Mn show decreasing trend with depth in core -1, while no definite trend is seen in core - 3.

To confirm the results obtained on enrichment factor and Igeo, geochemical data on cores was subjected to **pollution load index (PLI).**

The data on PLI for core - 2 is presented in table (Table 4.15). It is clear from the data that PLI values gradually decrease with depth with two peaks, one near the surface (0 - 3 cm) and another at 39 - 45 cm depth. The values obtained confirm an input of material from old and new mine dumps.

The data on PLI for core - 1 and core - 3 are presented in table (Table 4.16). From this table, it is clear that PLI values decrease gradually from 1.90 to 1.26 in core - 1. But in core - 3, it decreases from 2.08 to 1.31 till 75 cm depth and then increases to 1.96 till bottom. The values confirm the statement made earlier.

It is also seen from above two tables (Table 4.15 and 4.16) that Pollution load index obtained for top sediments of core - 3 is the highest (2.08) as compared to that of core - 1 (1.90) and core - 2 (2.05). This confirms relatively higher anthropogenic influence through influx of mine dump material into outer reservoir segment with the highest at NE corner (core - 3).

Further the geochemical data was subjected to obtain **anthropogenic factor.** The data obtained on anthropogenic factor for core - 2 is presented in table (Table 4.17). From this table, it is clear that Fe, Mn, Zn, Co and Cr in general, show decreasing trend with depth, with two higher peaks, one near the surface and other at 39 - 45 cm depth. This clearly supports the findings stated earlier. i.e. impact on the lake sediments due to release of material from old and new mine dumps.

Table 4.1 Elemental concentrations of major (%) and trace (ppm) elements in surface sediments .

Sampling St. No's	Major elements (%)									
	Si	Al	Ti	Fe	Mn	Mg	Ca	Na	K	P
Premonsoon										
1	16.50	8.79	0.63	10.90	0.12	0.88	0.29	0.16	0.76	0.10
4	16.70	9.10	0.67	8.46	0.15	0.76	0.37	0.13	0.84	0.09
7	17.10	7.94	0.49	9.23	0.15	0.89	0.30	0.14	0.79	0.08
13	17.90	8.57	0.55	16.10	0.15	0.57	0.24	0.10	0.76	0.10
Monsoon										
1	7.99	5.93	0.38	35.00	0.60	0.40	0.19	0.07	0.34	0.17
4	17.30	8.71	0.58	8.79	0.15	0.82	0.33	0.15	0.81	0.09
7	18.10	8.26	0.52	7.59	0.10	0.86	0.27	0.13	0.83	0.07
13	17.40	8.00	0.53	16.20	0.26	0.58	0.25	0.10	0.71	0.10
Postmonsoon										
1	16.20	9.00	0.65	11.70	0.11	0.84	0.29	0.16	0.74	0.11
4	16.70	9.53	0.66	10.20	0.13	0.76	0.30	0.13	0.84	0.09
7	16.50	7.41	0.49	12.40	0.22	0.78	0.36	0.14	0.72	0.10
13	17.50	8.36	0.55	15.60	0.27	0.58	0.24	0.10	0.73	0.10

contd /-

	Trace elements (ppm)													
Sampling St. No's	**Sr**	**Ba**	**Sc**	**V**	**Cr**	**Co**	**Ni**	**Cu**	**La**	**Nb**	**Y**	**Yb**	**Zn**	**Zr**
Premonsoon														
1	42.0	233.0	22.0	213.0	292.0	26.0	130.0	84.0	36.0	18.0	29.0	2.5	218.0	152.0
4	41.0	260.0	22.0	200.0	222.0	29.0	130.0	89.0	43.0	19.0	31.0	2.8	140.0	140.0
7	39.0	250.0	18.0	162.0	158.0	40.0	132.0	77.0	30.0	14.0	23.0	2.0	148.0	103.0
13	32.0	230.0	21.0	192.0	232.0	26.0	108.0	67.0	29.0	15.5	20.0	2.0	141.0	117.0
Monsoon														
1	22.0	107.0	26.0	144.0	206.0	24.0	82.0	54.0	22.5	10.0	21.0	2.2	139.0	105.0
4	41.0	265.0	20.0	182.0	195.0	36.0	130.0	59.0	36.0	16.0	26.0	2.25	115.0	116.0
7	39.0	267.0	18.0	165.0	157.0	38.0	136.0	53.0	34.0	15.0	26.0	2.2	120.0	118.0
13	32.0	221.0	20.5	188.0	234.0	29.0	105.0	60.0	27.0	14.5	20.0	2.0	137.0	113.0
Postmonsoon														
1	42.0	231.0	23.0	218.0	282.0	23.0	126.0	78.0	38.0	18.0	28.0	2.55	118.0	127.0
4	42.0	250.0	22.0	200.0	217.0	29.0	123.0	60.0	41.0	18.0	30.0	2.65	107.0	136.0
7	40.0	230.0	17.0	145.0	150.0	31.0	115.0	48.0	31.0	14.5	23.0	1.95	124.0	108.0
13	32.0	226.0	20.0	186.0	226.0	29.0	104.0	56.0	28.0	14.6	20.0	2.00	128.0	115.0

Table 4.2 Simple correlation between elements (major and trace) and sediment components in surface sediments.

	Si	Al	Ti	Fe	Mn	Mg	Ca
Al	0.8155						
Ti	0.6562	0.9490					
Fe	-0.7996	-0.7462	-0.6650				
Mn	-0.7481	-0.8008	-0.7389	0.8884			
Mg	0.6736	0.6297	0.5987	-0.9247	-0.8816		
Ca	0.5539	0.5330	0.5874	-0.8030	-0.5966	0.7907	
Na	0.6978	0.6806	0.6732	-0.8755	-0.8646	0.9744	0.7969
K	0.9599	0.8816	0.7613	-0.9124	-0.8492	0.7914	0.6984
P	-0.8252	-0.6826	-0.5029	0.9325	0.7986	-0.7834	-0.6166
Sr	0.7475	0.7781	0.7720	-0.9273	-0.8846	0.9549	0.8613
Ba	0.9579	0.8477	0.7228	-0.9321	-0.8470	0.8144	0.7190
Sc	-0.1689	-0.3908	-0.3380	0.2413	0.2409	-0.1896	-0.1921
V	0.4799	0.8402	0.8882	-0.3672	-0.5664	0.3336	0.1957
Cr	-0.0252	0.3839	0.5222	0.2003	-0.0695	-0.1389	-0.2232
Co	0.4385	0.0936	-0.1185	-0.6062	-0.3102	0.4877	0.4011
Ni	0.7319	0.7229	0.6681	-0.9761	-0.9321	0.9670	0.7703
Cu	0.2039	0.4857	0.5777	-0.3345	-0.4570	0.3789	0.2997
La	0.5314	0.8067	0.8809	-0.8079	-0.8098	0.7647	0.7768
Nb	0.7221	0.9400	0.9803	-0.7612	-0.8214	0.7099	0.6845
Y	0.1928	0.5524	0.6938	-0.6391	-0.6578	0.6795	0.6562
Yb	-0.0419	0.4789	0.6688	-0.3285	-0.4163	0.3303	0.3736
Zn	-0.0871	-0.0931	-0.0222	0.1138	0.0307	0.0260	-0.0952
Zr	0.2800	0.6759	0.8170	-0.4070	-0.5395	0.4049	0.3669
Sand	-0.7474	-0.5974	-0.5219	0.6283	0.4842	-0.4462	-0.6026
Silt	0.0340	0.0967	-0.0018	0.2101	0.1386	-0.2764	-0.4694
Clay	0.2026	0.1029	0.1763	-0.3902	-0.2815	0.3941	0.6283
Org.carb.	0.3209	0.3015	0.3506	-0.7778	-0.6533	0.8373	0.8075

	Na	K	P	Sr	Ba	Sc	V
K	0.7955						
P	-0.7020	-0.8940					
Sr	0.9699	0.8709	-0.7700				
Ba	0.8140	0.9944	-0.9112	0.8762			
Sc	-0.1877	-0.2976	0.3315	-0.3129	-0.2416		
V	0.4253	0.5229	-0.2339	0.4805	0.4722	-0.1676	
Cr	-0.0118	-0.0376	0.3559	-0.0134	-0.0926	0.0731	0.8149
Co	0.3557	0.4627	-0.7582	0.3581	0.5211	-0.1002	-0.3726
Ni	0.9211	0.8573	-0.8678	0.9394	0.8763	-0.1859	0.4166
Cu	0.3712	0.3126	-0.1448	0.3894	0.2818	0.1626	0.6717
La	0.7734	0.7278	-0.6211	0.8747	0.7119	-0.4060	0.6242
Nb	0.7672	0.8309	-0.5919	0.8578	0.7993	-0.3062	0.8170
Y	0.6553	0.4354	-0.4132	0.7260	0.4243	-0.3672	0.4830
Yb	0.3274	0.1881	-0.1115	0.4289	0.1531	-0.3273	0.6015
Zn	0.0147	-0.1183	0.2231	-0.0615	-0.1344	0.4231	0.1714
Zr	0.4457	0.4176	-0.2072	0.5339	0.3664	-0.2726	0.7927
Sand	-0.4955	-0.7335	0.6347	-0.5971	-0.7461	0.2608	-0.2177
Silt	-0.2492	-0.0489	0.0634	-0.2593	-0.0808	-0.1601	0.2242
Clay	0.3881	0.2752	-0.2509	0.4310	0.3084	0.0670	-0.1306
Org.carb.	0.7607	0.5122	-0.6042	0.7635	0.5481	-0.0864	0.0110

	Cr	Co	Ni	Cu	La	Nb	Y
Co	-0.7713						
Ni	-0.1077	0.5233					
Cu	0.5501	-0.2018	0.4484				
La	0.1910	0.1114	0.8180	0.4994			
Nb	0.4046	-0.0170	0.7686	0.5798	0.9114		
Y	0.1977	0.0217	0.7002	0.5047	0.9111	0.7211	
Yb	0.4791	-0.3104	0.3924	0.5746	0.7774	0.6241	0.8979
Zn	0.3772	-0.2067	0.0059	0.5285	-0.1364	0.0235	0.0049
Zr	0.6469	-0.3423	0.4641	0.5975	0.7526	0.7984	0.7688
Sand	0.1812	-0.3469	-0.4982	0.2256	-0.5113	-0.5755	-0.2330
Silt	0.3419	-0.0643	-0.2181	-0.1012	-0.2427	-0.0764	-0.2482
Clay	-0.3616	0.1518	0.3562	0.0176	0.3945	0.2614	0.3123
Org.carb.	-0.3646	0.5016	0.8131	0.3193	0.6961	0.4761	0.7251

	Yb	Zn	Zr	Sand	Silt	Clay
Zn	0.0234					
Zr	0.8201	0.3372				
Sand	-0.0267	0.3611	-0.2541			
Silt	-0.1438	0.3574	0.2015	0.0506		
Clay	0.1534	-0.4478	-0.0915	-0.3755	-0.9442	
Org.carb.	0.4055	0.0030	0.2913	-0.2603	-0.4439	0.4906

N = 12
Significance level 0.7079 - 99%
0.6581 - 98%

Table 4.3 Chemical Index of alteration (CIA) and Chemical maturity (Chm) for surface sediments.

Sampling St.nos.	Chm	CIA	Av.
(Premonsoon)			
1	6.6090	91.561	91.32
4	7.2222	91.005	
7	5.9699	90.580	
13	9.4176	92.150	
(Monsoon)			
1	8.9848	93.567	91.91
4	6.7000	90.989	
7	6.5556	90.909	
13	8.9892	92.182	
(Postmonsoon)			
1	6.9767	91.892	91.43
4	8.0084	91.790	
7	5.7891	89.974	
13	9.0870	92.075	

Table 4.4A Varimax rotated R - mode factor analysis for surface sediments during premonsoon.

Elements	**Factor 1**	**Factor 2**	**Factor 3**
Si	0.3859	- 0.3226	0.8643
Al	- 0.3297	0.9415	0.0696
Ti	- 0.4057	0.8978	- 0.1714
Fe	0.7270	0.1476	0.6706
Mn	- 0.4877	- 0.4980	0.7171
Mg	- 0.1633	- 0.2646	- 0.9504
Ca	- 0.9258	0.1709	- 0.3373
Na	- 0.0283	- 0.0638	- 0.9976
K	- 0.9992	0.0345	0.0217
P	0.5629	0.7995	0.2097
Sr	- 0.4336	0.1979	- 0.8791
Ba	- 0.9687	- 0.2092	- 0.1340
Sc	- 0.0463	0.9978	0.0475
V	0.1256	0.9813	- 0.1461
Cr	0.4057	0.8852	- 0.2277
Co	- 0.2930	- 0.9237	- 0.2467
Ni	- 0.4978	- 0.1531	- 0.8537
Cu	- 0.6607	0.3931	- 0.6395
La	- 0.7308	0.6220	- 0.2811
Nb	- 0.4040	0.8887	- 0.2166
Y	- 0.5748	0.5779	- 0.5793
Yb	- 0.6151	0.7139	- 0.3347
Zn	0.5028	0.4143	- 0.7586
Zr	- 0.0620	0.9035	- 0.4241
% variance	50.96	32.09	16.95
Eigenvalue	12.23	7.70	4.07

Table 4.4B Varimax rotated R-mode factor analysis for surface sediments during monsoon.

Elements	Factor 1	Factor 2	Factor 3
Si	0.9719	- 0.0598	0.2278
Al	0.9028	- 0.1762	0.3924
Ti	0.8324	- 0.2972	0.4677
Fe	- 0.9456	0.3060	- 0.1103
Mn	- 0.9607	0.2673	- 0.0752
Mg	0.8524	- 0.5152	- 0.0894
Ca	0.6813	- 0.6151	0.3969
Na	0.7500	- 0.6373	0.1771
K	0.9570	- 0.2468	0.1522
P	- 0.9862	0.1632	- 0.0274
Sr	0.8614	- 0.4896	0.1354
Ba	0.9413	- 0.3060	0.1424
Sc	- 0.9915	0.1292	0.0122
V	0.6944	0.0753	0.7157
Cr	- 0.3776	0.5266	0.7617
Co	0.8516	- 0.5038	- 0.1447
Ni	0.8763	- 0.4742	- 0.0851
Cu	0.2000	0.1019	0.9745
La	0.7640	- 0.6429	0.0546
Nb	0.8961	- 0.2940	0.3325
Y	0.5242	- 0.8035	- 0.2821
Yb	- 0.1383	- 0.9659	- 0.2189
Zn	- 0.6110	0.7907	0.0387
Zr	0.9594	- 0.2821	0.0030
% Variance	78.82	15.74	5.44
Eigenvalue	18.92	3.78	1.31

Table 4.4C Varimax rotated R-mode factor analysis for surface sediments during postmonsoon.

Elements	Factor 1	Factor 2	Factor 3
Si	0.9645	0.2162	0.1518
Al	0.0121	0.6879	- 0.7257
Ti	- 0.1777	0.7736	- 0.6082
Fe	0.7824	- 0.0829	0.6172
Mn	0.7027	- 0.5615	0.4370
Mg	- 0.9801	0.1899	- 0.0568
Ca	- 0.7977	- 0.6015	0.0428
Na	- 0.9447	0.3049	0.1211
K	- 0.0722	0.1112	- 0.9912
P	- 0.2455	0.5216	0.8171
Sr	- 0.9223	0.1338	- 0.3625
Ba	- 0.2658	- 0.0021	- 0.9640
Sc	- 0.0516	0.9114	- 0.4084
V	0.0227	0.9504	- 0.3103
Cr	0.0608	0.9980	- 0.0185
Co	0.2842	- 0.9419	- 0.1787
Ni	- 0.8296	0.4217	- 0.3660
Cu	- 0.2842	0.9587	0.0114
La	- 0.5696	0.4350	- 0.6974
Nb	- 0.4489	0.6859	- 0.5727
Y	- 0.6254	0.4067	- 0.6660
Yb	- 0.3328	0.6662	- 0.6674
Zn	0.4289	- 0.2265	0.8745
Zr	- 0.1651	0.5922	- 0.7887
% Variance	60.91	22.52	16.56
Eigenvalues	14.62	5.41	3.97

Table 4.5 Enrichment factor for surface sediments.

Season	Sampling St. No's.	Fe	Mn	Ba	Co	Cr	Cu	Ni	Zn	Zr
Premonsoon	1	2.1243	1.2135	0.3656	1.2454	2.6576	1.6989	1.7399	2.0885	0.6917
	4	1.5926	1.4652	0.3941	1.3418	1.9516	1.7387	1.6807	1.2955	0.6154
	7	1.9914	1.6793	0.4343	2.1212	1.5919	1.7240	1.9558	1.5697	0.5189
	13	3.2182	1.5558	0.3702	1.2774	2.1657	1.3899	1.4826	1.3855	0.5461
Monsoon	1	10.111	8.9938	0.2489	1.7041	2.7791	1.6189	1.6268	1.9739	0.7083
	4	1.7288	1.5308	0.4197	1.7403	1.7910	1.2042	1.7559	1.1118	0.5327
	7	1.5741	1.0761	0.4459	1.9370	1.5206	1.1407	1.9370	1.2234	0.5714
	13	3.3196	2.7645	0.3646	1.4606	2.2392	1.2759	1.4776	1.3800	0.5407
Postmonsoon	1	2.2270	1.0864	0.3540	1.0760	1.6178	1.5407	1.6471	1.1041	0.5644
	4	1.8335	1.2125	0.3618	1.2813	1.8216	1.1193	1.5184	0.9455	0.5708
	7	2.8667	2.6391	0.4281	1.7615	1.6194	1.1516	1.8258	1.4092	0.5830
	13	3.1966	2.8708	0.3729	1.4606	2.1627	1.1696	1.4636	1.2893	0.5502

Table 4.6 Index of geoaccumualtion ($I_{ge}o$) for surface sediments.

Seasons	Sampling St. No's	Fe	Mn	Co	Cr	Ni	Zn
Premonsoon	1	0.6379	- 0.1699	- 0.1325	0.9610	0.3499	0.6134
	4	0.2723	0.1520	0.0251	0.5656	0.3499	- 0.0255
	7	0.3979	0.1520	0.4890	0.0750	0.3720	0.0546
	13	1.2006	0.1520	- 0.1325	0.6292	0.0825	- 0.0153
Monsoon	1	2.3209	2.1520	- 0.2479	0.4577	- 0.3149	- 0.0359
	4	0.3275	0.1520	0.3370	0.3785	0.3499	- 0.3093
	7	0.1157	- 0.4330	0.4150	0.0658	0.4150	- 0.2479
	13	1.2095	0.9456	0.0251	0.6415	0.0418	- 0.0568
Postmonsoon	1	0.7401	- 0.2955	- 0.3093	0.9107	0.3049	- 0.2722
	4	0.5421	- 0.0544	0.0251	0.5327	0.2701	- 0.4134
	7	0.8239	0.7045	0.1213	0	0.1731	- 0.2006
	13	1.1551	1.0000	0.0251	0.5914	0.0280	- 0.1548

Table 4.7 Pollution load index (PLI) for surface sediments.

Sampling St. No.	Fe		Mn		Cu		Co		Ni		Zn		Cr		Ti		PLI	Zonal Index	Lake Index
	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B			
1	19.2	4.11	0.28	3.07	72	1.6	24.33	1.28	112.67	1.66	158.33	1.67	260	2.6	0.55	1.23	1.97	1.80	1.69
4	9.15	1.96	0.14	1.59	69.33	1.54	31.33	1.65	127.67	1.88	120.67	1.27	211.33	2.11	0.64	1.41	1.65		
13	15.97	3.42	0.23	2.52	61	1.36	28	1.47	105.67	1.56	135.33	1.42	230.67	2.31	0.54	1.21	1.79		
7	9.74	2.09	0.16	1.74	59.33	1.32	36.33	1.91	127.67	1.88	130.67	1.37	155	1.55	0.5	1.11	1.58	1.58	
Av.C.F.		2.89		2.23		1.46		1.58		1.74		1.43		2.14		1.24			

A = Average concentration of three seasons of Fe, Mn and Ti is in %, while others elements are in ppm.

B = Contamination factor (C.F.)

Table 4.8 Elemental concentrations of major (%) and trace (ppm) elements in core - 2

No	**Fraction**	**Major elements (%)**										
		Range of depth (cm)	**Si**	**Al**	**Ti**	**Fe**	**Mn**	**Mg**	**Ca**	**Na**	**K**	**P**
1	1st	0-3	16.10	7.62	0.50	12.60	0.21	0.75	0.42	0.13	0.75	0.11
2	3rd	6-9	16.00	7.94	0.50	13.30	0.22	0.81	0.34	0.14	0.76	0.11
3	5th	12-15	16.50	8.34	0.55	11.00	0.18	0.91	0.38	0.15	0.82	0.10
4	7th	18-21	17.50	8.63	0.57	9.23	0.09	0.93	0.31	0.15	0.83	0.11
5	9th	24-27	18.70	7.52	0.46	5.74	0.06	0.86	0.27	0.11	0.67	0.08
6	11th	30-33	18.20	7.83	0.47	5.00	0.05	0.86	0.24	0.10	0.73	0.07
7	13th	36-39	18.60	10.8	0.65	8.46	0.21	0.81	0.29	0.12	1.12	0.07
8	15th	42-45	17.40	9.37	0.62	11.90	0.43	0.73	0.34	0.13	0.91	0.07
9	17th	48-51	19.90	9.90	0.70	6.02	0.04	0.82	0.29	0.16	0.60	0.07
10	19th	54-57	19.30	9.90	0.68	6.33	0.04	0.82	0.29	0.16	0.83	0.08
11	21st	60-63	19.30	10.30	0.76	6.89	0.03	0.81	0.27	0.16	0.88	0.07
12	23rd	66-69	20.00	10.30	0.75	6.17	0.03	0.89	0.28	0.18	0.91	0.07
13	25th	72-75	19.30	10.30	0.75	7.27	0.03	0.78	0.27	0.16	0.88	0.07

contd /-

No	Fraction	Range of depth (cm)	Trace elements (ppm)													
			Sr	Ba	Sc	V	Cr	Co	Ni	Cu	La	Nb	Y	Yb	Zn	Zr
1	1st	0-3	40.0	233.0	17.0	153.0	163.0	30.0	117.0	52.0	31.0	14.0	22.0	3.1	240.0	103.0
2	3rd	6-9	39.0	237.0	18.5	165.0	174.0	35.0	122.0	56.0	31.0	14.0	22.0	1.9	146.0	108.0
3	5th	12-15	43.0	260.0	18.5	170.0	168.0	37.0	132.0	54.0	33.0	16.0	24.0	2.1	142.0	110.0
4	7th	18-21	43.0	258.0	19.0	172.0	168.0	31.0	139.0	52.0	34.0	16.5	26.0	2.2	127.0	112.0
5	9th	24-27	37.0	234.0	16.0	148.0	146.0	29.0	137.0	46.0	28.0	13.5	21.0	2.0	120.0	110.0
6	11th	30-33	36.0	238.0	17.0	154.0	149.0	27.0	136.0	48.0	30.0	13.5	23.0	2.1	118.0	125.0
7	13th	36-39	43.0	310.0	24.0	208.0	200.0	35.0	155.0	58.0	38.0	20.0	30.0	2.8	130.0	165.0
8	15th	42-45	42.0	260.0	21.0	185.0	212.0	26.0	145.0	53.0	42.0	17.0	32.0	2.6	130.0	130.0
9	17th	48-51	49.0	260.0	22.0	205.0	260.0	17.0	149.0	58.0	49.0	19.0	40.0	3.1	148.0	135.0
10	19th	54-57	48.0	250.0	23.0	225.0	305.0	16.0	152.0	64.0	49.0	19.0	39.0	3.0	132.0	138.0
11	21st	60-63	49.0	255.0	23.0	230.0	310.0	15.0	151.0	60.0	52.0	20.5	40.0	3.1	135.0	160.0
12	23rd	66-69	51.0	260.0	24.0	230.0	280.0	15.0	155.0	68.0	55.0	21.0	42.0	3.7	132.0	153.0
13	25th	72-75	48.0	252.0	24.0	235.0	310.0	15.0	149.0	62.0	54.0	20.5	41.0	3.1	125.0	143.0

Table 4.9 Elemental concentrations of major (%) and trace (ppm) elements in core - 1 and core - 3.

No	Fraction	Range of depth (cm)	Major elements (%)									
core-1												
			Si	Al	Ti	Fe	Mn	Mg	Ca	Na	K	P
1	1st	0 - 3	16.90	9.22	0.59	11.70	0.21	0.88	0.28	0.14	0.92	0.09
2	9th	24 - 27	17.40	10.70	0.67	12.70	0.04	0.77	0.22	0.23	0.97	0.06
3	17th	48 - 51	22.10	10.80	0.82	6.09	0.04	0.78	0.23	0.23	0.98	0.06
core - 3												
1	1st	0 - 3	18.10	10.80	0.69	11.70	0.27	0.78	0.30	0.12	1.05	0.10
2	17th	48 - 51	17.80	8.12	0.52	14.80	0.26	0.61	0.33	0.11	0.71	0.10
3	25th	72 - 75	22.00	10.00	0.89	6.71	0.05	0.60	0.32	0.11	0.89	0.03
4	33rd	96 - 99	14.80	7.36	0.64	21.00	0.12	0.41	0.34	0.12	0.64	0.06

contd /-

No	Fraction	Range ofdepth (cm)	Trace elements (ppm)													
			Sr	Ba	Sc	V	Cr	Co	Ni	Cu	La	Nb	Y	Yb	Zn	Zr
core - 1																
1	1st	0 - 3	42.0	282.0	20.0	185.0	170.0	35.0	131.0	56.0	34.0	17.0	26.0	2.30	128.0	133.0
2	9th	24 - 27	42.0	308.0	23.0	205.0	210.0	27.0	146.0	59.0	40.0	19.5	30.0	2.70	125.0	149.0
3	17th	48 - 51	48.0	276.0	25.0	236.0	300.0	14.0	145.0	61.0	57.0	22.0	43.0	3.35	138.0	160.0
core - 3																
1	1st	0 - 3	42.0	287.0	24.0	220.0	230.0	31.0	150.0	61.0	43.0	19.5	32.0	3.40	125.0	165.0
2	17th	48 - 51	34.0	213.0	20.0	165.0	190.0	28.0	105.0	57.0	28.0	14.0	21.0	1.95	130.0	106.0
3	25th	72 - 75	43.0	244.0	27.0	290.0	380.0	17.0	125.0	60.0	54.0	22.5	39.0	3.35	97.0	153.0
4	33rd	96 - 99	29.0	182.0	21.0	285.0	475.0	21.0	93.0	50.0	32.0	16.0	21.0	1.95	1.28.0	113.0

Table 4.10 Simple correlation between elements (major and trace) and sediment components and elements in core-2

	Si	Al	Ti	Fe	Mn	Mg	Ca
Al	0.6896						
Ti	0.6919	0.9470					
Fe	-0.8491	-0.2664	-0.2604				
Mn	-0.8058	-0.3432	-0.4738	0.8506			
Mg	0.1243	-0.1453	-0.1463	-0.3513	-0.3281		
Ca	-0.7909	-0.3527	-0.3011	0.8824	0.7420	-0.2810	
Na	0.3247	0.5362	0.7276	0.0040	-0.4127	0.1228	0.0945
K	0.3476	0.8697	0.7179	0.0625	0.0925	-0.1607	-0.0780
P	-0.7951	-0.6861	-0.5924	0.6167	0.4265	0.2238	0.7078
Sr	0.6252	0.8431	0.9508	-0.2195	-0.5039	-0.0025	-0.1559
Ba	0.2941	0.7306	0.5164	0.0093	0.1576	0.0634	-0.1010
Sc	0.6349	0.9831	0.9580	-0.1959	-0.3364	-0.1852	-0.2956
V	0.7057	0.9496	0.9809	-0.3029	-0.5042	-0.1352	-0.3635
Cr	0.6886	0.8511	0.9490	-0.3064	-0.5617	-0.2531	-0.3175
Co	-0.8026	-0.6317	-0.7903	0.5785	0.7970	0.1543	0.5048
Ni	0.8736	0.8775	0.8029	-0.5969	-0.5128	0.0912	-0.6536
Cu	0.4998	0.8113	0.8746	-0.1162	-0.4004	-0.0848	-0.1283
La	0.7211	0.8843	0.9766	-0.3222	-0.5445	-0.1992	-0.3280
Nb	0.6929	0.9762	0.9802	-0.2646	-0.4248	-0.0627	-0.3093
Y	0.7769	0.9045	0.9735	-0.3929	-0.5684	-0.1673	-0.3913
Yb	0.5920	0.7238	0.8003	-0.2402	-0.4205	-0.3423	-0.1043
Zn	-0.4985	-0.2921	-0.1961	0.5407	0.3470	-0.4073	0.7696
Zr	0.7664	0.9215	0.8281	-0.4666	-0.4363	-0.1339	-0.5732
Sand	0.5721	0.6206	0.7827	-0.2771	-0.5825	-0.3847	-0.2430
Silt	-0.1994	-0.3978	-0.4014	0.0704	0.2058	-0.0902	0.2567
Clay	-0.0190	0.2517	0.1970	0.0741	0.0143	0.2097	-0.1472
Org.carb.	-0.1136	-0.6837	-0.6824	-0.3110	-0.1382	0.4611	-0.2559
Depth	0.8768	0.8184	0.8656	-0.5970	-0.6781	-0.1236	-0.6469

	Na	K	P	Sr	Ba	Sc	V
K	0.2877						
P	0.0427	-0.5147					
Sr	0.8833	0.5907	-0.3815				
Ba	0.1044	0.9331	-0.4399	0.4087			
Sc	0.6151	0.8366	-0.6135	0.8668	0.6583		
V	0.6912	0.7062	-0.6093	0.9163	0.5114	0.9728	
Cr	0.7382	0.5214	-0.5554	0.9113	0.2801	0.8908	0.9586
Co	-0.6282	-0.1962	0.5762	-0.7766	0.0372	-0.6577	-0.7856
Ni	0.3306	0.6800	-0.8244	0.6852	0.6333	0.8171	0.8155
Cu	0.8192	0.6069	-0.3343	0.8905	0.3905	0.8882	0.9088
La	0.7413	0.5913	-0.6014	0.9373	0.3551	0.9114	0.9593
Nb	0.6662	0.8066	-0.6056	0.9235	0.6549	0.9705	0.9699
Y	0.6997	0.6102	-0.6460	0.9261	0.3995	0.9157	0.9570
Yb	0.5916	0.5332	-0.4802	0.7947	0.2972	0.7368	0.7618
Zn	0.1304	-0.1696	0.5401	-0.0513	-0.2632	-0.2453	-0.2555
Zr	0.2855	0.7779	-0.8579	0.6645	0.6626	0.8791	0.8595
Sand	0.5892	0.2814	-0.4685	0.7500	0.0416	0.6392	0.7489
Silt	-0.1425	-0.3223	0.2709	-0.2953	-0.2844	-0.3969	-0.4586
Clay	-0.0063	0.3115	-0.1036	0.0945	0.3335	0.2530	0.2672
Org.carb.	-0.4520	-0.7791	0.2528	-0.6173	-0.5505	-0.7111	-0.6222
Depth	0.4659	0.4890	-0.8176	0.7524	0.3061	0.8168	0.8807

	Cr	Co	Ni	Cu	La	Nb	Y
Co	-0.8904						
Ni	0.7159	-0.6411					
Cu	0.8789	-0.6858	0.5854				
La	0.9759	-0.8839	0.7692	0.8705			
Nb	0.8874	-0.6931	0.8460	0.8556	0.9241		
Y	0.9642	-0.8813	0.8243	0.8403	0.9924	0.9303	
Yb	0.7854	-0.7589	0.5365	0.7499	0.8248	0.7665	0.8105
Zn	-0.1492	0.1726	-0.6192	-0.0290	-0.1806	-0.2395	-0.2360
Zr	0.7531	-0.6236	0.8873	0.6799	0.7802	0.8647	0.8104
Sand	0.8559	-0.8476	0.4657	0.6014	0.8210	0.6874	0.7985
Silt	-0.3735	0.2119	-0.4122	-0.2704	-0.3245	-0.4458	-0.3034
Clay	0.1310	0.0680	0.2760	0.1387	0.0972	0.2751	0.0797
Org.carb.	-0.5595	0.3174	-0.3380	-0.6315	-0.6283	-0.6810	-0.5961
Depth	0.8786	-0.8878	0.8747	0.6934	0.9063	0.8300	0.9208

	Yb	Zn	Zr	Sand	Silt	Clay	Org.carb.
Zn	0.2652						
Zr	0.6689	-0.3990					
Sand	0.7340	0.0663	0.5550				
Silt	-0.0501	0.4483	-0.3900	-0.3325			
Clay	-0.1628	-0.4639	0.2490	0.0171	-0.9390		
Org.carb.	-0.7438	-0.3151	-0.5364	-0.4801	0.1540	-0.0939	
Depth	0.6859	-0.4751	0.8401	0.7376	-0.4191	0.1909	-0.3902

N = 13

Significance level 0.6340 - 98%

0.8010 - 99.99%

Table 4.11 Enrichment factor for core - 2.

Sr. No	Fraction	Range of depth (cm)	Fe	Mn	Co	Cr	Ni	Zn
1	1st	0 - 3	2.8326	2.4497	1.6577	1.7113	1.8064	2.6523
2	3rd	6 - 9	2.8695	2.4629	1.8560	1.7531	1.8077	1.5485
3	5th	12 - 15	2.2594	1.9185	1.8680	1.6115	1.8620	1.4338
4	7th	18 - 21	1.8322	0.9270	1.5125	1.5574	1.8949	1.2393
5	9th	24 - 27	1.3076	0.7092	1.6237	1.5532	2.1433	1.3438
6	11th	30 - 33	1.0939	0.5676	1.4519	1.5223	2.0434	1.2691
7	13th	36 - 39	1.3419	1.7284	1.3645	1.4815	1.6885	1.0136
8	15th	42 - 45	2.1756	4.0792	1.1683	1.8100	1.8206	1.1683
9	17th	48 - 51	1.0417	0.3591	0.7230	2.1010	1.7706	1.2589
10	19th	54 - 57	1.0953	0.3591	0.6805	2.4646	1.8063	1.1228
11	21st	60 - 63	1.1459	0.2589	0.6132	2.4078	1.7247	1.1037
12	23rd	66 - 69	1.0262	0.2589	0.6132	2.1748	1.7704	1.0792
13	25th	72 - 75	1.2210	0.2614	0.6192	2.4314	1.7186	1.0320

Table 4.12 Enrichment factor for core - 1 and core - 3.

core - 1

Sr. No.	Fraction	Range of depth (cm)	Fe	Mn	Co	Cr	Ni	Zn	Cu
1	1st	0 - 3	2.1738	2.0246	1.5984	1.4751	1.6716	1.1691	1.080
2	9th	24 - 27	2.0333	0.3323	1.0625	1.5701	1.6053	0.9838	0.980
3	17th	48 - 51	0.9660	0.3292	0.5458	2.2222	1.5795	0.0760	1.004

core - 3

Sr. No.	Fraction	Range of depth (cm)	Fe	Mn	Co	Cr	Ni	Zn	Cu
1	1st	0 - 3	1.8558	2.2222	1.2086	1.7037	1.6340	0.9747	1.004
2	17th	48 - 51	3.1223	2.8462	1.4519	1.8719	1.5213	1.3482	1.247
3	25th	72 - 75	1.1495	0.4444	0.7158	3.0400	1.4706	0.8168	1.06
4	33rd	96 - 99	4.8878	1.4493	1.2014	5.1630	1.4566	1.4645	1.20

Table 4.13 Index of geoaccumulation (I_{geo}) for core - 2.

Sr. No.	Fraction	Range of depth (cm)	Fe	Mn	Co	Cr	Ni	Zn
1	1st	0 - 3	0.8377	0.6374	0.0740	0.1199	0.1979	0.7521
2	3rd	6 - 9	0.9157	0.7045	0.2964	0.2141	0.2583	0.0350
3	5th	12 - 15	0.6418	0.4150	0.3766	0.1635	0.3720	- 0.0051
4	7th	18 - 21	0.3887	- 0.5850	0.1213	0.1635	0.4465	- 0.1661
5	9th	24 - 27	- 0.2966	-1.1699	0.0251	-0.0390	0.4256	- 0.2479
6	11th	30 - 33	- 0.4957	-1.4330	- 0.0780	- 0.0097	0.4150	- 0.2722
7	13th	36 - 39	0.2630	0.6374	0.2964	0.4150	0.6037	- 0.1325
8	15th	42 - 45	0.7553	1.6714	- 0.1325	0.4991	0.5075	- 0.1325
9	17th	48 - 51	- 0.2279	- 1.7549	- 0.7454	0.7935	0.5467	0.0546
10	19th	54 - 57	- 0.1554	- 1.7549	- 0.8329	1.0238	0.5755	- 0.1104
11	21st	60 - 63	- 0.0331	- 2.1699	- 0.9260	1.0473	0.5660	- 0.0780
12	23rd	66 - 69	- 0.1924	- 2.1699	- 0.9260	0.9005	0.6037	- 0.1104
13	25th	72 - 75	0.0443	- 2.1699	- 0.9260	1.0473	0.5467	- 0.1890

Table 4.14 Index of geoaccumualtion (I_{geo}) for core - 1 and core - 3.

core - 1

Sr. No.	Fraction	Range of depth(cm)	Fe	Mn	Co	Cr	Ni	Zn
1	1st	0 - 3	0.7401	0.6374	0.2964	0.1806	0.3610	- 0.1548
2	9th	24 - 27	0.8584	-1.7549	- 0.0780	0.4854	0.5174	- 0.1890
3	17th	48 - 51	- 0.2019	-1.7549	-1.0255	1.0000	0.5075	- 0.0463

core - 3

Sr. No.	Fraction	Range of depth(cm)	Fe	Mn	Co	Cr	Ni	Zn
1	1st	0 - 3	0.7401	1.0000	0.1213	0.6167	0.5564	- 0.1890
2	17th	48 - 51	1.0791	0.9456	- 0.0255	0.3410	0.0418	- 0.1325
3	25th	72 - 75	- 0.0621	- 1.4330	- 0.7454	1.3410	0.2934	- 0.5549
4	33rd	96 - 99	1.5839	- 0.1699	- 0.4406	1.6630	- 0.1333	- 0.1548

Table 4.15 Pollution load index (PLI) for core - 2

Sr. No	Fraction	Range of depth (cm)	Contamination factor						
			Fe	Mn	Co	Cr	Ni	Zn	PLI
1	1st	0 - 3	2.6981	2.3333	1.5789	1.63	1.7206	2.6253	2.05
2	3rd	6 - 9	2.8480	2.4444	1.8421	1.74	1.7941	1.5368	1.99
3	5th	12 - 15	2.3555	2.0000	1.9474	1.68	1.9412	1.4947	1.88
4	7th	18 - 21	1.9764	1.0000	1.6316	1.68	2.0441	1.3368	1.57
5	9th	24 - 27	1.2291	0.6607	1.5263	1.46	2.0147	1.2632	1.29
6	11th	30 - 33	1.0707	0.5556	1.4211	1.49	2.0000	1.2421	1.21
7	13th	36 - 39	1.8116	2.3333	1.8947	2.00	2.2794	1.3684	1.92
8	15th	42 - 45	2.5482	4.7778	1.3684	2.12	2.1324	1.3684	2.17
9	17th	48 - 51	1.2891	0.4444	0.8947	2.60	2.1912	1.5579	1.28
10	19th	54 - 57	1.3555	0.4444	0.8421	3.05	2.2353	1.3895	1.29
11	21st	60 - 63	1.4754	0.3333	0.7895	3.10	2.2206	1.4211	1.25
12	23rd	66 - 69	1.3212	0.3333	0.7895	2.80	2.2794	1.3895	1.21
13	25th	72 - 75	1.5567	0.3333	0.7895	3.10	2.2912	1.3158	1.25

Table 4.16 Pollution load Index for core - 1 and core - 3.

core - 1

Sr. No.	Fraction	Range of depth (cm)	Contamination factor						
			Fe	Mn	Co	Cr	Ni	Zn	PLI
1	1st	0 - 3	2.5054	2.3333	1.8421	1.7000	1.9265	1.3474	1.90
2	9th	24 - 27	2.7195	0.4444	1.4211	2.1000	2.1471	1.3158	1.47
3	17th	48 - 51	1.3041	0.4444	0.7368	3.0000	2.1324	1.4526	1.26

core - 3

Sr. No.	Fraction	Range of depth (cm)	Contamination factor						
			Fe	Mn	Co	Cr	Ni	Zn	PLI
1	1st	0 - 3	2.5054	3.0000	1.6316	2.300	2.2059	1.3158	2.08
2	17th	48 - 51	3.1692	2.8889	1.4737	1.900	1.5441	1.3684	1.95
3	25th	72 - 75	1.4368	0.5556	0.8947	3.800	1.8382	1.0211	1.31
4	33rd	96 - 99	4.4968	1.3333	1.1053	4.750	1.3672	1.3474	1.96

Table 4.17 Anthropogenic factor for core - 2.

Sr. No.	Fraction	Range of depth (cm)	Anthropogenic factor					
			Ca	Co	Fe	Mn	P	Zn
1	1st	0-3	1.56	2.00	1.86	7.00	1.57	1.92
2	3rd	6 - 9	1.26	2.33	1.98	7.33	1.57	1.17
3	5th	12 - 15	1.41	2.47	1.64	6.00	1.43	1.14
4	7th	18 - 21	1.15	2.07	1.37	3.00	1.57	1.02
5	9th	24 -2 7	1.00	1.93	0.85	2.00	1.14	0.96
6	11th	30 - 33	0.89	1.80	0.74	1.67	1.00	0.94
7	13th	36 - 39	1.07	2.33	1.26	7.00	1.00	1.04
8	15th	42 - 45	1.26	1.73	1.77	**14.3**	1.00	1.04
9	17th	48 - 51	1.07	1.13	0.89	1.33	1.00	1.18
10	19th	54 - 57	1.07	1.07	0.94	1.33	1.14	1.06
11	21st	60 - 63	1.00	1.00	1.02	1.00	1.00	1.08
12	23rd	66 - 69	1.03	1.00	0.92	1.00	1.00	1.06
13	25th	72 - 75	1.00	1.00	1.08	1.00	1.00	1.00

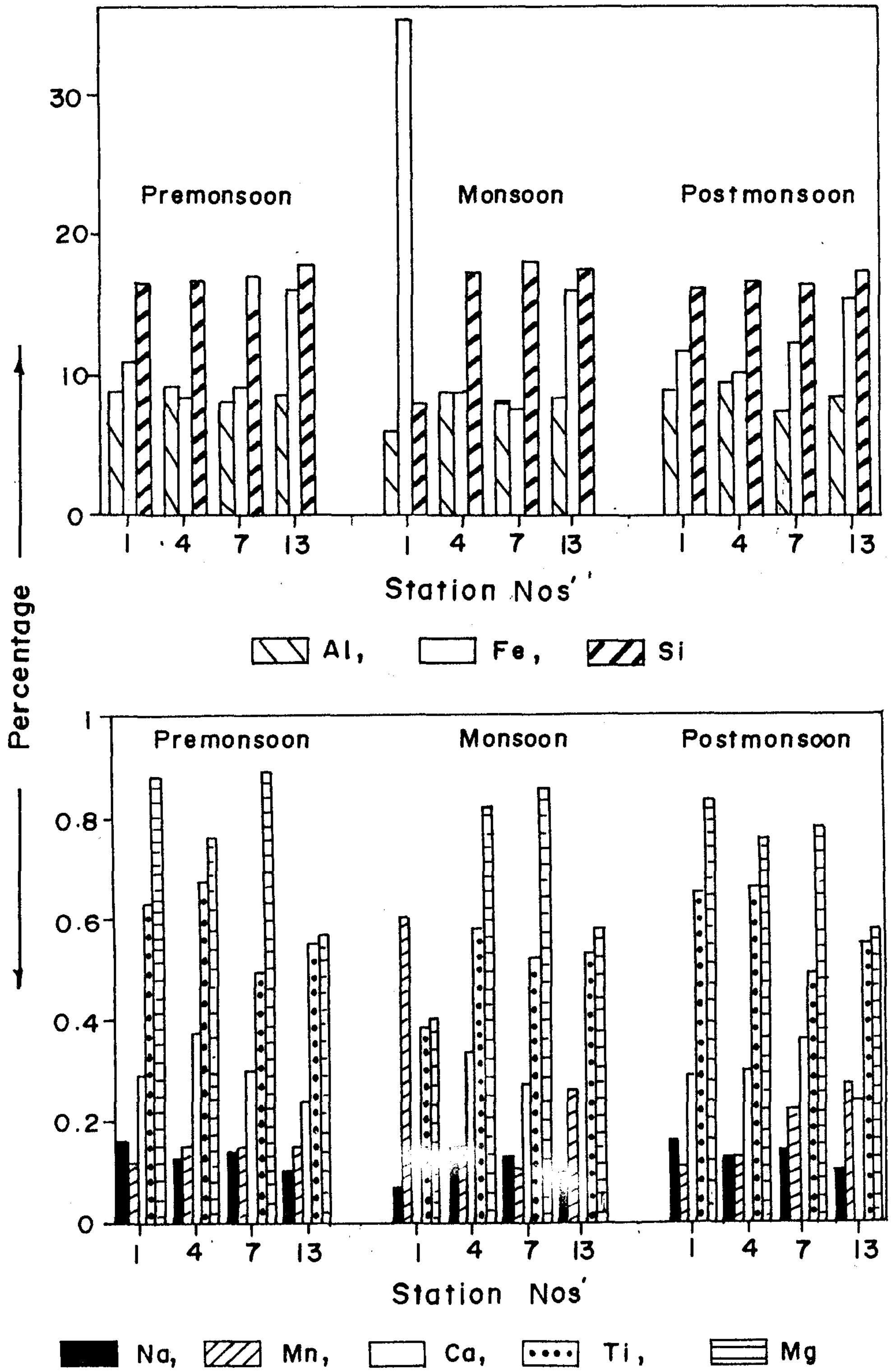


FIG. 4.1A SPATIAL AND SEASONAL VARIATION IN CONCENTRATIONS OF Al, Fe, Si, Na, Mn, Ca, Ti, Mg (%) IN SURFACE SEDIMENTS

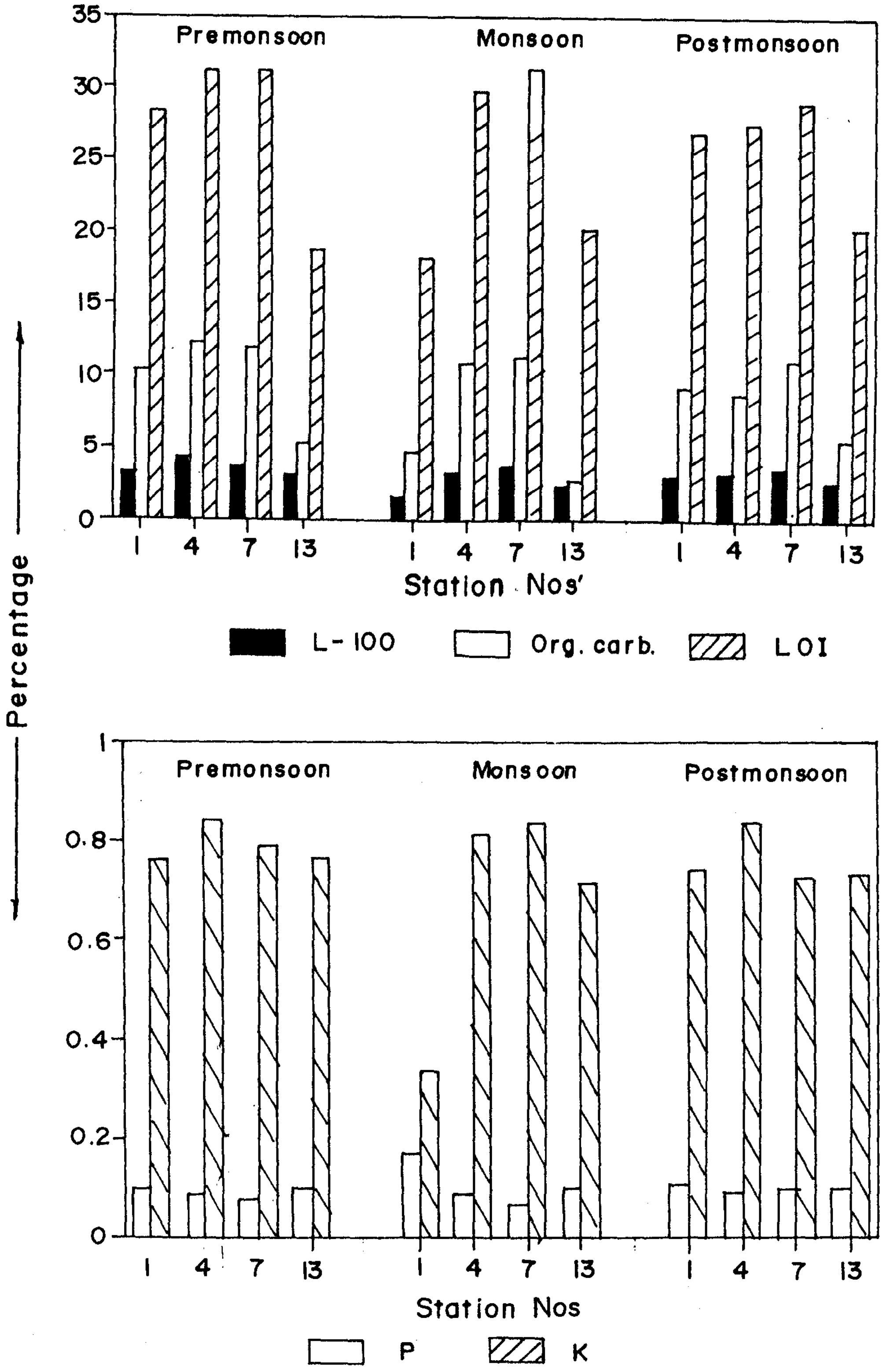


FIG. 4.1B SPATIAL AND SEASONAL VARIATION IN CONCENTRATION OF P, K, LOSS ON IGNITION (LOI), L-100 AND ORGANIC CARBON IN SURFACE SEDIMENTS

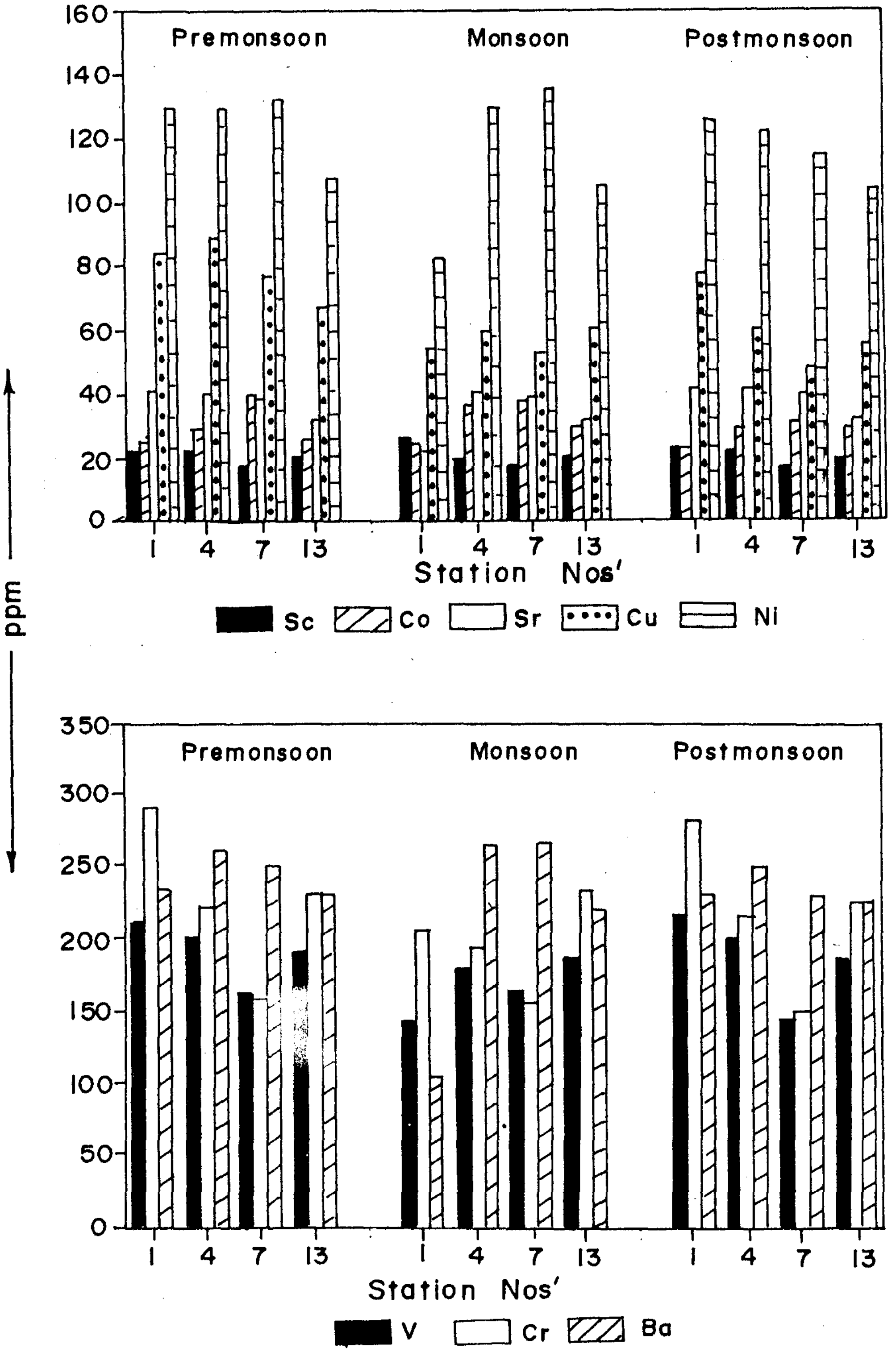


FIG. 4.1C SPATIAL AND SEASONAL VARIATION IN CONCENTRATIONS OF Sr, Sc, Co, Cu, Ni, V, Cr, Ba (ppm) IN SURFACE SEDIMENTS

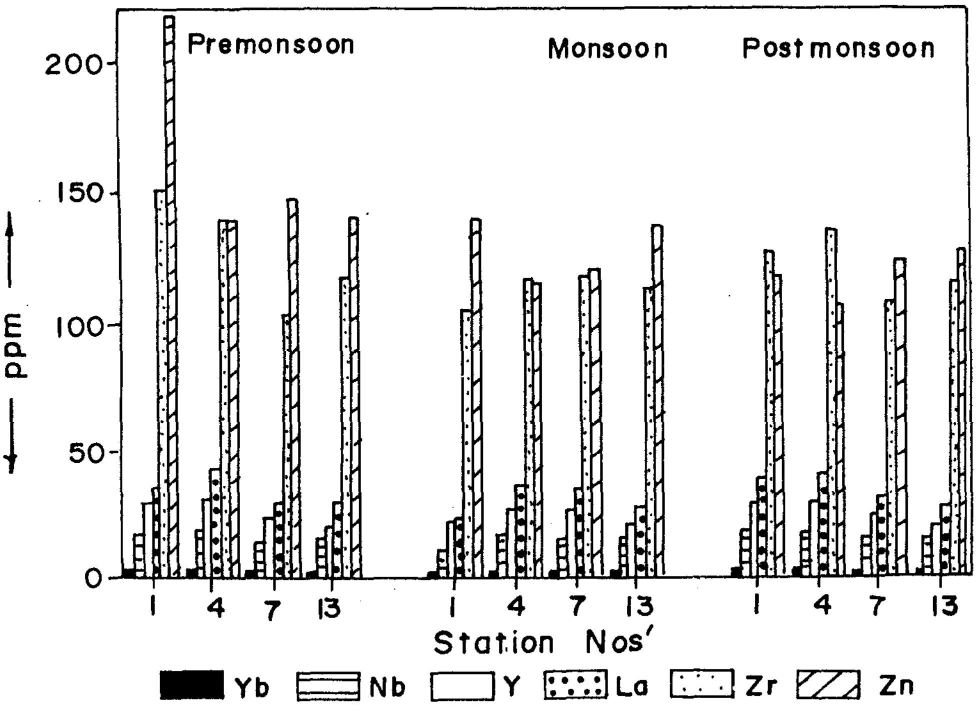


FIG. 4.1D SPATIAL AND SEASONAL VARIATION IN CONCENTRATIONS OF Yb, Nb, Y, La, Zr, Zn (ppm) IN SURFACE SEDIMENTS

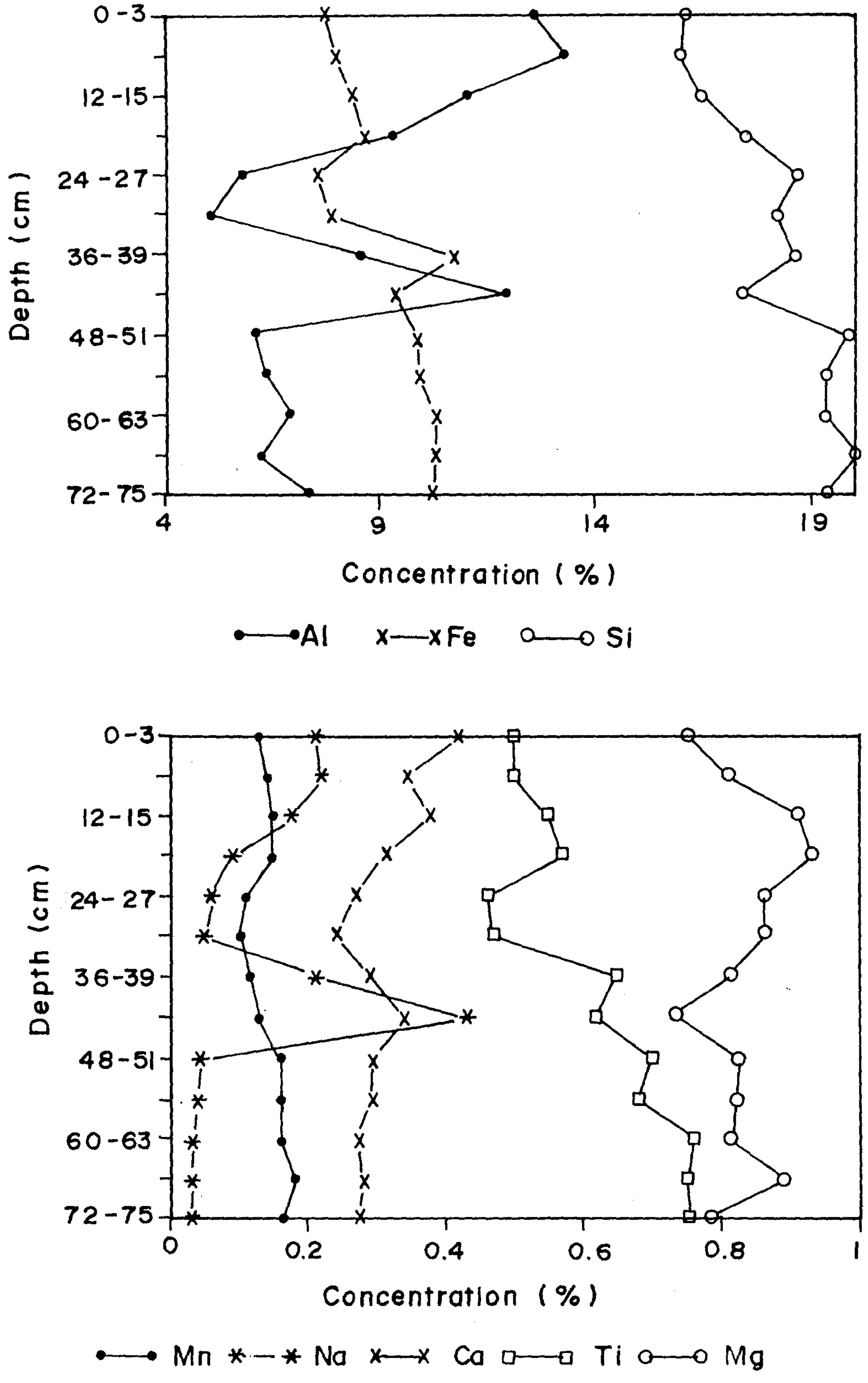


FIG.4.2A DEPTHWISE VARIATION IN THE CONCENTRATIONS OF Al, Fe, Si, Mn, Na, Ca, Ti, Mg (%) OF CORE-2

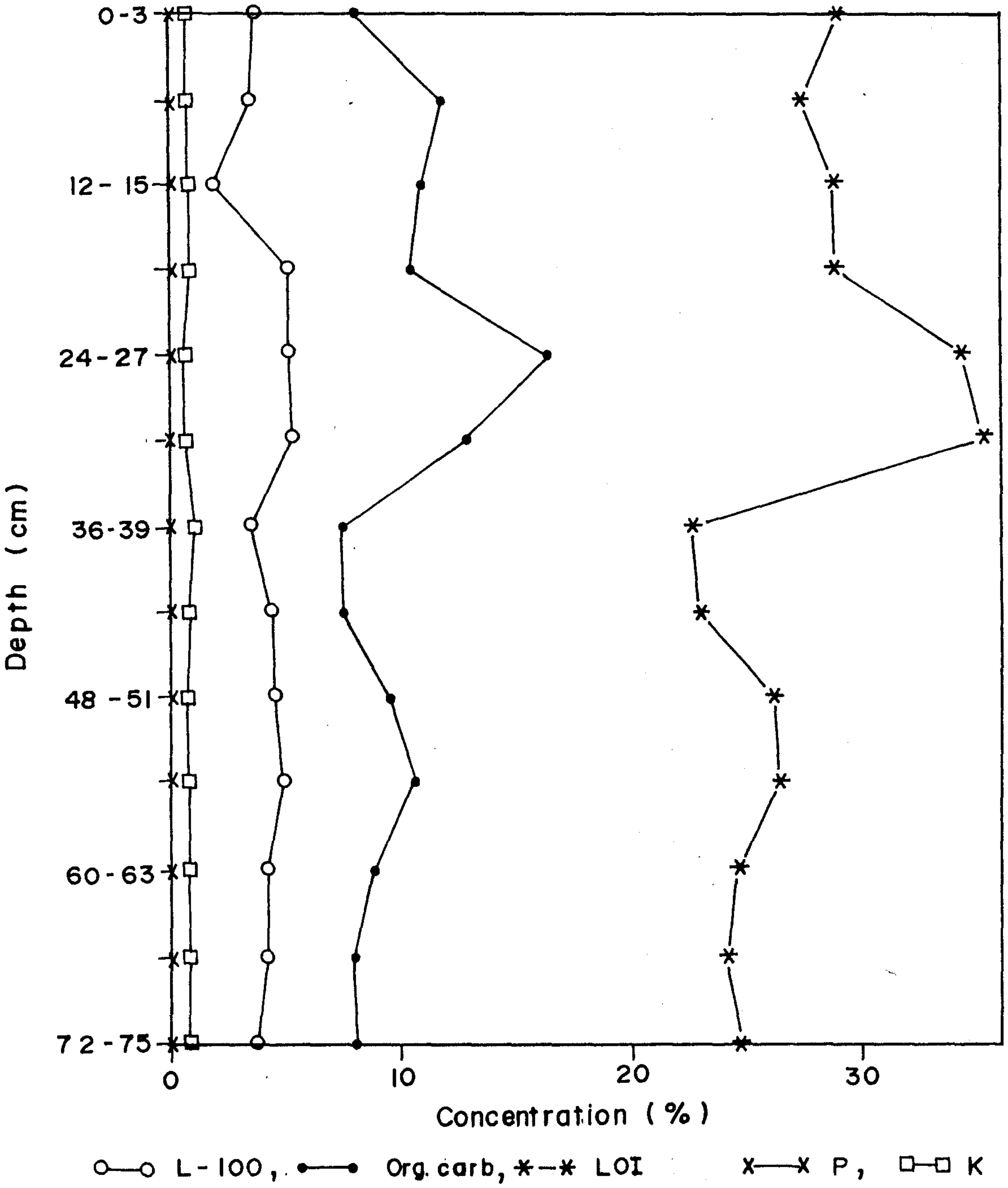


FIG. 4.2B DEPTHWISE VARIATION IN THE CONCENTRATIONS OF P, K, LOSS ON GNITION (LOI), LOSS ON IGNITION AT 100°C (L-100) AND ORGANIC CARBON OF CORE-2

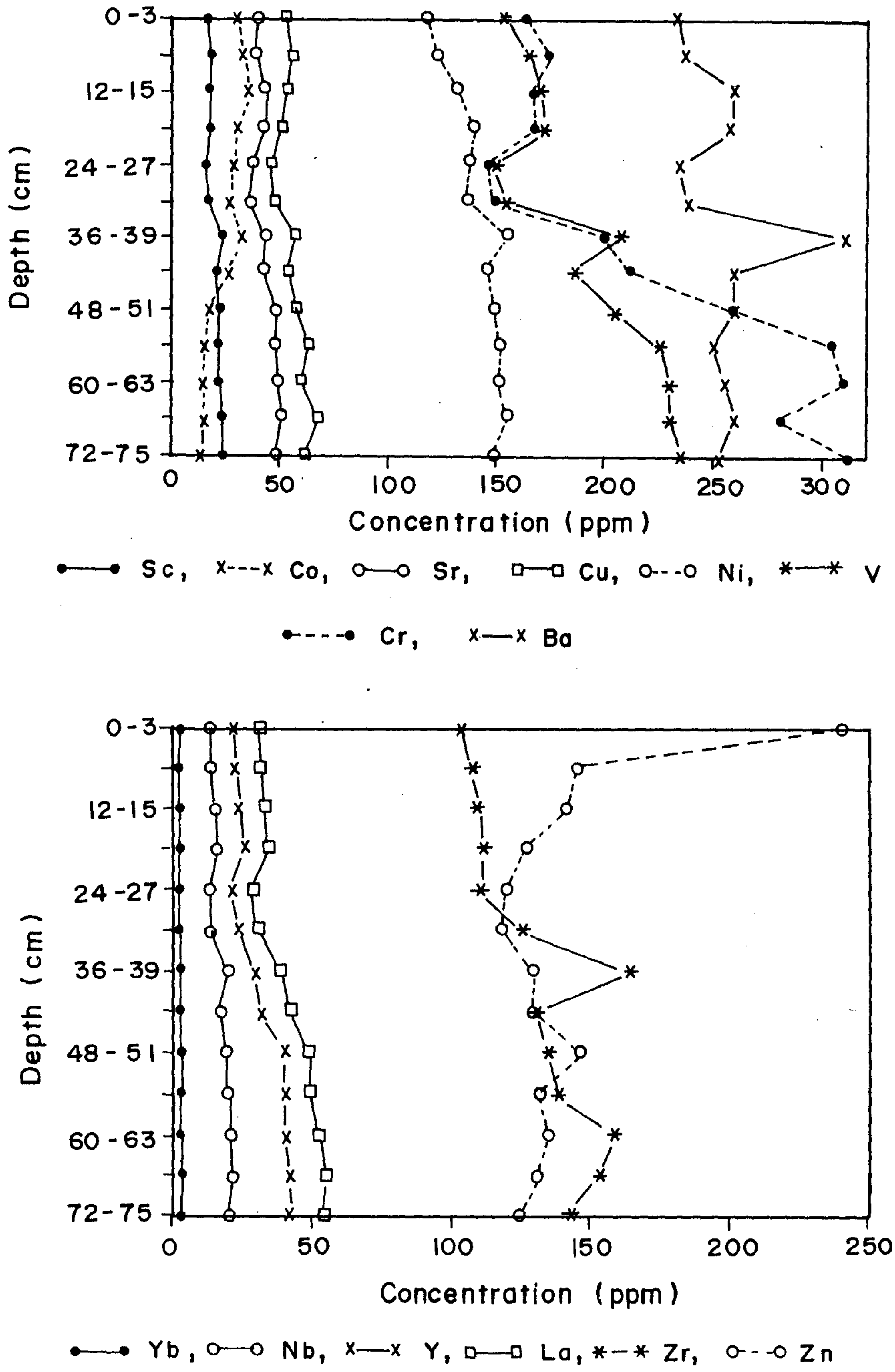


FIG. 4.2C DEPTHWISE VARIATION IN THE CONCENTRATIONS OF TRACE ELEMENTS (ppm) OF CORE - 2

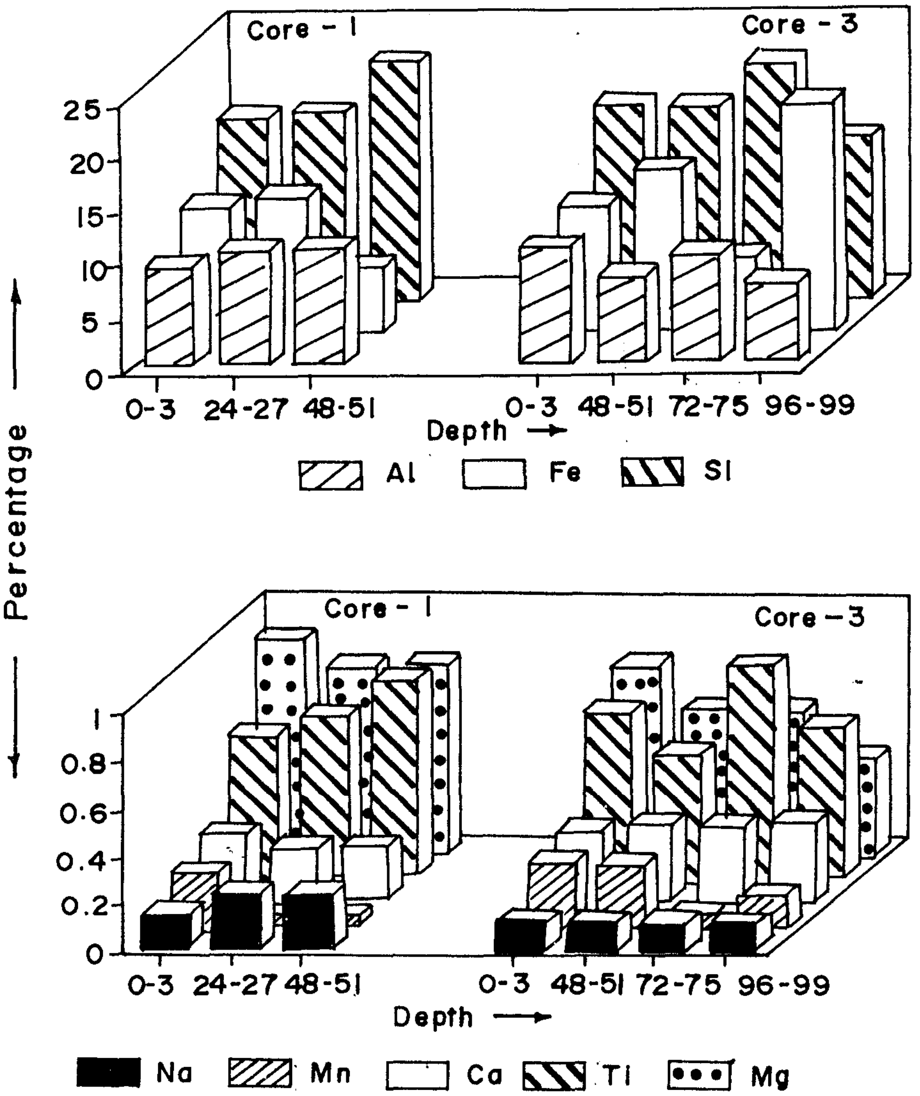


FIG. 4.3A DEPTHWISE VARIATION IN THE CONCENTRATIONS OF Al, Fe, Si, Na, Mn, Ca, Ti, Mg OF CORE-1 AND CORE-3

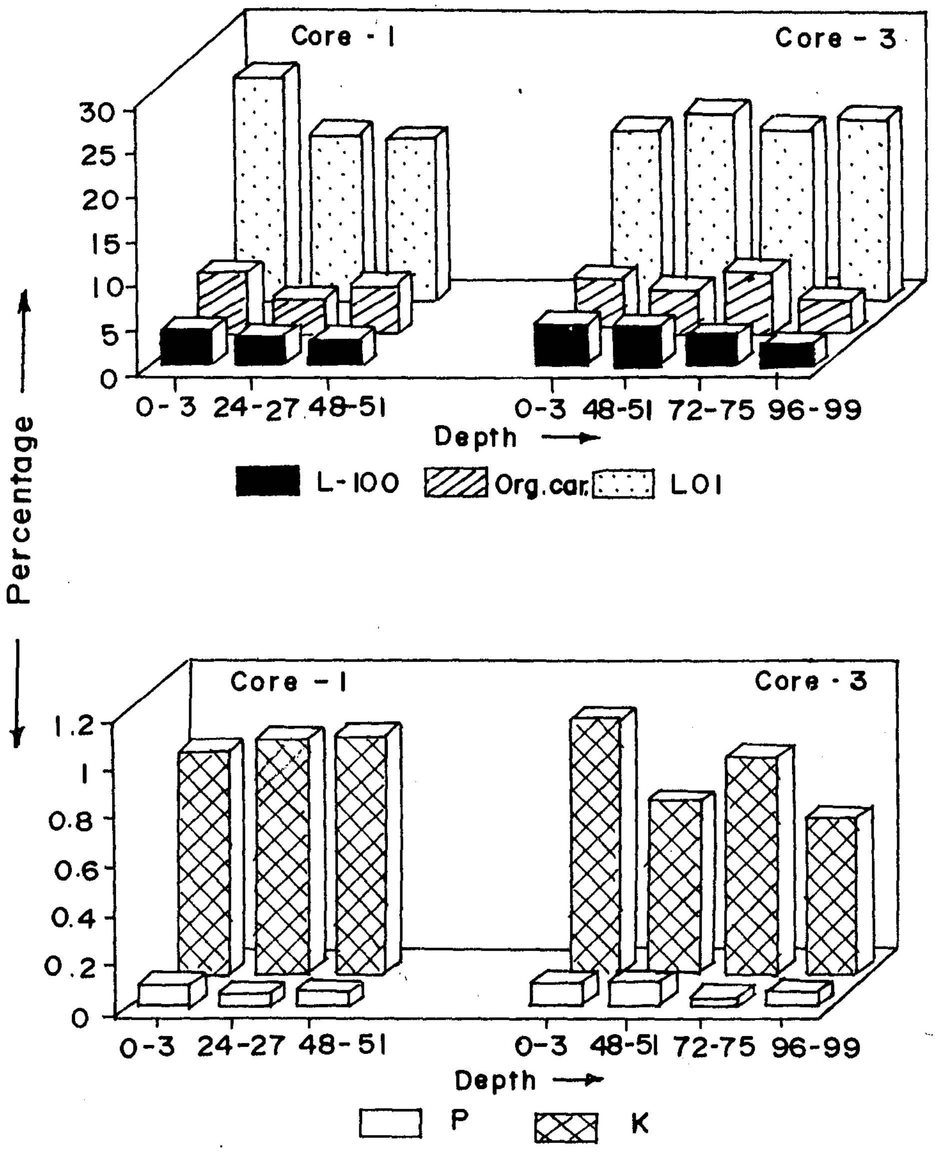


FIG. 4.3 B DEPTHWISE VARIATION IN THE CONCENTRATIONS OF P, K, LOSS ON IGNITION (LOI), LOSS ON IGNITION AT 100°C (L-100) AND ORGANIC CARBON OF CORE - I AND CORE-3

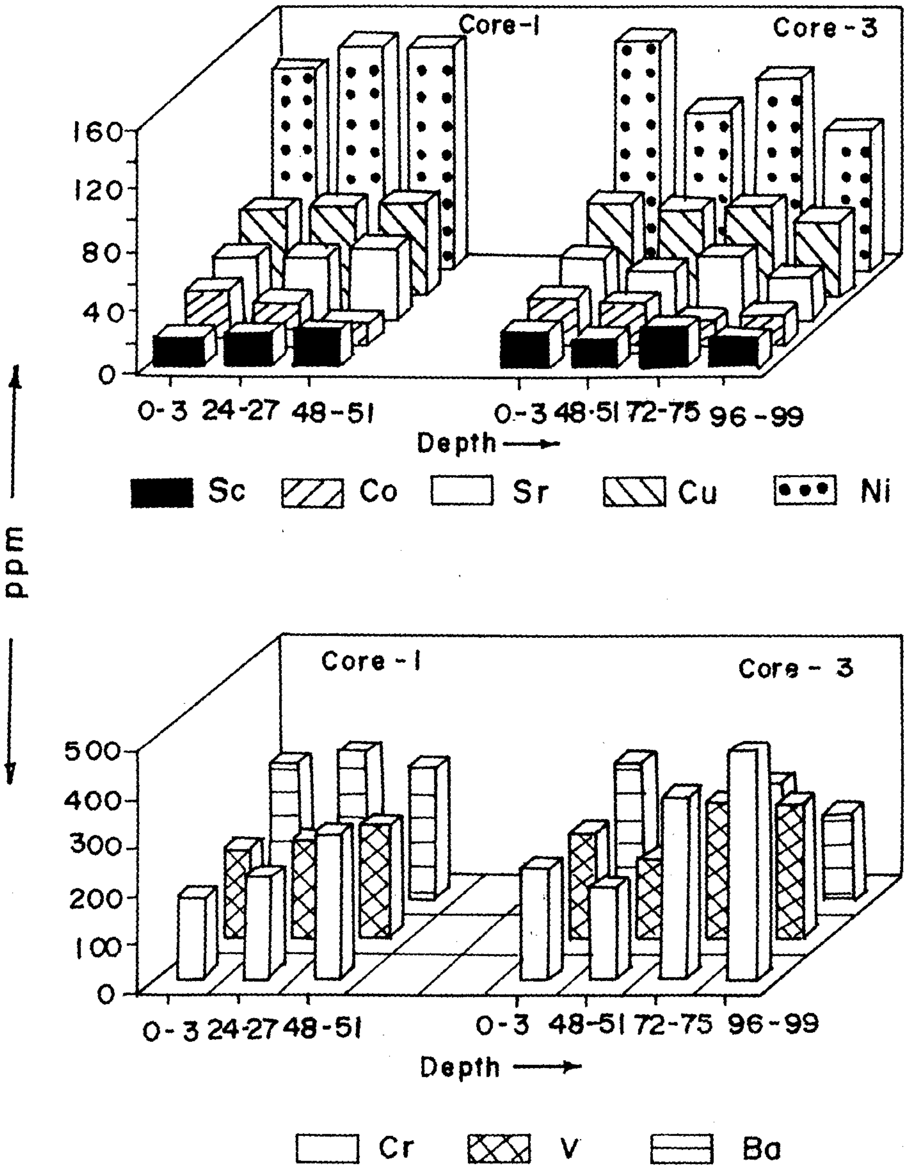


FIG.4.3C DEPTHWISE VARIATION IN CONCENTRATIONS OF Sc, Co, Sr, Cu, Ni, Cr, V, Ba (ppm) OF CORE - 1 AND CORE - 3

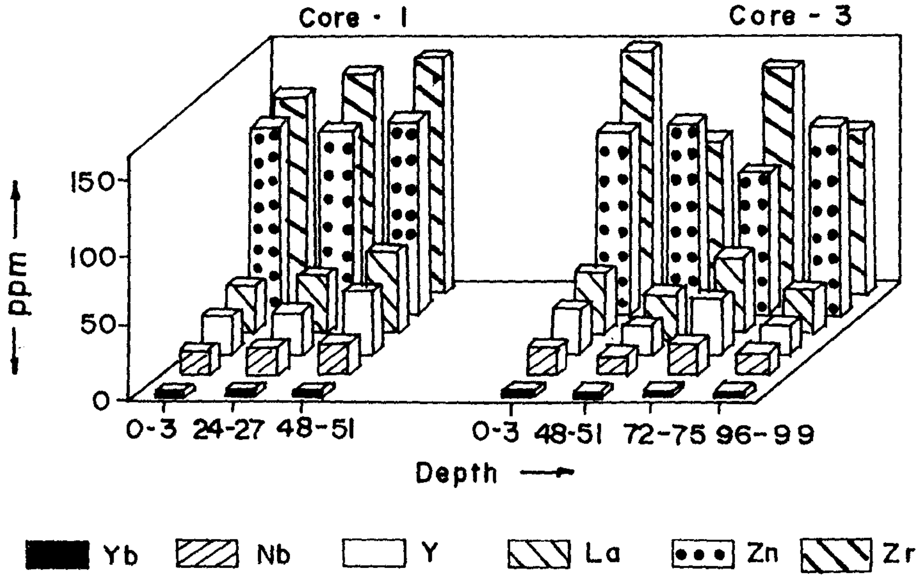


FIG. 4.3D DEPTHWISE VARIATION IN CONCENTRATIONS OF Yb, Nb, Y, La, Zn, Zr (ppm) OF CORE-1 AND CORE-3

CHAPTER 5

SUMMARY

The Mayem is a shallow, closed, freshwater lake with crescent shape. It occupies a low lying valley portion at the foothills of mountainous range of Western ghats and lies at an elevation of 15 m above mean sea level. Based on nutrient budget, earlier studies have classified this lake as more oligotrophic during monsoon and less eutrophic during fairweather seasons. In the present study, detailed investigation was undertaken on geomorphology of the catchment area, seasonal and spatial variation in total suspended matter, surface sediment constituents, depthwise variation in sediment constitutents along with elemental concentration and distribution in surface and sub-surface sediments. An attempt has also been made to understand the rate of sedimentation and extent of anthropogenic influence on sediments with time in this lake.

Geomorphological study carried out on the catchment area of Mayem lake has revealed the role of various topographic features like relief, gradient, nature and hardness of rocks, soil cover and vegetation, in release of sediment material through ephemeral streams. This study has helped to indirectly estimate the sediment yield. The study has also revealed the presence of homogenous lithology with hard and relatively resistant rock types within the catchment area which indicates old stage of erosion cycle. A detailed study on the bathymetry of lake basin using echosounder has revealed the presence of two sub-basins within the lake namely, inner valley portion and outer reservoir segment, separated by a geological feature that is found to control the sedimentary processes within the Mayem lake. Distribution of isobath gradients have revealed the presence of sediment pockets and the pattern of sediment movement. Presence of delta-like structure at the confluence of one of the major streams at north-eastern corner of the lake clearly suggested the large scale supply of water and sediments through this stream. Further, gentle slope towards south-western side from this structure reveals the gradual movement of sediments towards the deeper portion of the lake. The depth and penetration of acoustic waves have revealed the thick accumulation of fine grained unconsolidated material. Study has also shown that accumulation of finer material results in a gentle gradient relative to coarser material which indicates steep gradient. Thus, a combined study of catchment area and lake basin has shown that Mayem lake is an active site of fine sediment accumulation.

The study on TSM has revealed that its concentration is higher in bottom waters compared to that of surface waters. Within surface waters, higher TSM concentration is recorded during premonsoon which is attributed to the addition of material due to primary productivity. TSM concentration in bottom waters is higher during monsoon and postmonsoon compared to premonsoon. It is also seen that the range of variation in surface and bottom water, when taken together, is more during monsoon. Higher TSM concentration and the larger range obtained during monsoon and higher TSM concentration during postmonsoon is directly attributed to material input through the streams from the catchment area. Distribution of TSM with space within the lake, when considered, higher concentration is recorded in the western zone which indicates gradual movement of sediment material from eastern shallower zone to western deeper zone. This seems to be controlled by influx of water and sediment through streams.

Present study has helped to classify surface sediments of Mayem lake as clayey silt. Sand fraction is relatively higher in eastern and western zones that suggests the addition of coarser material, in addition to input through streams, from respective banks due to slumping, although to a less extent. Relatively higher proportion of silt in the deeper western portion than the shallower eastern portion has been recorded. The relatively higher porportion of clay along the eastern portion is attributed to the extensive growth of macrophytes which are responsible to retain fine grained sediments. Grainsize parameters show narrow range of variation during monsoon, wherein, surface sediments are finer, better sorted, very negatively skewed and relatively less platykurtic. Total organic carbon content obtained for Mayem lake is relatively higher than most of the tropical lakes in India. This is attributed to its shallow and closed nature as well as presence of large scale growth of macrophyte in lake and some traces of forest litter as a refractory matter in surface sediments. Present study has shown that the organic carbon content is less during monsoon. This is attributed to dilution of organic carbon due to input of large inorganic material from catchment area during this season. Further, the study has also shown that the organic carbon content is higher in sediments of shallow, eastern zone compared to deeper, western zone which is attributed to its strong association with finer sediments. Study on clay minerals within surface sediments has revealed that kaolinite is dominant and montmorillonite is the least abundant. Goethite is also found to be present as an iron-rich clay sized mineral. Study revealed that kaolinite and gibbsite have their origin from laterites, illite from ferrugenous phyllites, while montmorillonite from aeolian source. The presence of goethite is attributed to influx of material from iron-ore rejects. Elemental (major and trace) distribution within the surface sediments has revealed enrichment of a set of elements which includes Fe, Mn, P, Co, Zn. This is attributed to addition of material released from mine rejects through ephemeral streams. Studies on geostatistical parameters showed that sediments are highly weathered and well matured. The data when processed to obtain R-mode factors, revealed four different sources for Mayem lake sediments, namely coarse detrital, fine detrital, heavy minerals and anthropogenic. Igeo index computed showed that surface sediments are moderately polluted with respect to Fe, Mn, Co, Zn and pollution load index has pointed out that outer reservoir segment has polluted to a greater extent relative to inner valley portion.

Detailed study on sediment cores, with reference to sedimentological parameters revealed that sand content increases with depth with near constancy in the upper part of cores. It is also important to note the depth difference in the near constancy of sand content in different cores. i.e. 30 cm in core - 1, 40 cm in core - 2 and 50 cm in core - 3. This suggests variable rate of sediment influx and deposition in different parts of the lake. It can be generalised that rate of sediment is higher in outer reservoir segment (core - 2 and core - 3) than in inner valley portion (core - 1). Within the outer reservoir segment, rate of sedimentation is found to be higher at a place where major stream joins the lake than the central deeper portion. Relative proportion (ratio) of silt to clay is less in case of core - 1 and core- 3 compared to that of core - 2. Organic carbon content is relatively higher in upper layer of core - 1 and core - 2 than core - 3. Uniform decrease in clay with organic carbon in core - 1 is attributed to sediment deposition in calmer conditions. Higher percentage of clay and less content of organic carbon in upper layer of core - 3 revealed large input of inorganic material through the stream at this point. It also indicates trapping of fine sediments in shallow zones by macrophytes. Variation of sediment components with depth could also indicate the nature of parent rocks and their palaeo - weathering process then operative within the catchment area. The study on ^{210}Pb radiometric dating has helped to confirm the faster rate of sedimentation interpreted at the location of core -3 (0.404 cm/yr) compared to that of core - 2 (0.34 cm/yr). The data on the present rate of sedimentation available, when compared with the past rate obtained, showed considerable increase in the rate of influx of material and its deposition within Mayem lake in recent times. Elemental concentration analysed for selected core fractions has revealed an increase in the concentration of majority of elements with depth, which supported the interpretation made on the nature of parent material and palaeo-weathering process based on sediment components. The set of elements namely Fe, Mn, Co, Zn and P are found to enrich in top layer of cores which is directly attributed to anthropogenic interference i.e. addition of material from iron - ore rejects. Fe and Mn concentration at 45 cm depth is also similarly related to the impact of old mine dumps. The data when processed for geostatistical parameters, confirmed an anthropogenic influence in recent times.

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