Distribution of Clay Minerals and Benthic Foraminifera along the Inter-tidal Sediments of Terekhol Estuary

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DECLARATION BY STUDENT

I hereby declare that the data presented in this Dissertation report entitled "Distribution of Clay Minerals and Benthic Foraminifera Along the Inter-tidal Sediments of Terekhol Estuary" is based on the results of investigations carried out by me in the Discipline of Marine Sciences at the School of Earth, Ocean and Atmospheric Sciences, Goa University under the Supervision of Ms. Manjusha Madkaikar and the same has not been submitted elsewhere for the award of a degree or diploma by me. Further, I understand that Goa University or its authorities will not be responsible for the correctness of observations / experimental or other findings given in the dissertation.

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This is to certify that the dissertation report "Distribution of Clay Minerals and Benthic Foraminifera along the Inter-tidal Sediments of Terekhol Estuary" is a bonafide work carried out by Miss K. M. Dharani under my supervision in partial fulfilment of the requirements for the award of the degree of Master of Science in the Discipline of Marine Sciences at the School of Earth, Ocean and Atmospheric Sciences, Goa University.

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PREFACE

The Terekhol Estuary, nestled along the coastline is a dynamic ecosystem shaped by the intricate interplay of geological, hydrological, and anthropogenic influences. As one of the vital interfaces between freshwater rivers and the salty embrace of the ocean, the estuary serves as a crucial habitat for diverse flora and fauna while providing essential ecosystem services to surrounding communities.

This dissertation delves into a comprehensive analysis of the sediment characteristics within the Terekhol Estuary, spanning grain size distribution, total organic carbon content, clay mineralogy, and the distribution of benthic foraminifera. Through meticulous fieldwork and laboratory analyses, we aim to unravel the complex tapestry of sediment dynamics within this unique estuarine environment.

Each chapter of this dissertation offers valuable insights into different aspects of the sediment composition and its implications for the ecological health and functioning of the Terekhol Estuary. From the dominance of silt in the sediment matrix to the intricate interplay of clay mineralogy and organic carbon content, every facet contributes to our understanding of this dynamic ecosystem.

As we navigate through the findings and discussions presented herein, it becomes evident that the sediment characteristics of the Terekhol Estuary are not only a reflection of natural processes but also bear the imprint of human activities. Sand mining, deforestation, urbanization, and agricultural practices exert profound influences on sediment runoff, organic matter deposition, and habitat quality, underscoring the need for sustainable management strategies.

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CONTENTS

Chapter 1: Introduction

LIST OF ABBREVIATIONS

Entity	Abbreviation
Angstrom	Ȧ
Chlorite	Ch
Ferrous ammonium Sulphate	$(NH_4)_2Fe(SO_4)_2.6H_2O$
Illite	I
Iron	Fe
Kaolinite	K
Magnesium	Mg
Micrometres	µm
Millilitre	Ml
Millimetres	Mm
Orthophosphoric acid	(H_3PO_4)
Phi	Ø
Potassium dichromate	$(K_2Cr_2O_7)$
Sulphuric acid	(H_2SO_4)
Smectite	S
Total Organic Carbon	TOC
Square Kilometre	Sq. Km
X-ray Diffraction	XRD

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ABSTRACT

The Terekhol Estuary, situated along the coast represents a dynamic ecosystem influenced by various natural and anthropogenic factors. This study provides a comprehensive analysis of sediment characteristics within the estuary, focusing on grain size distribution, total organic carbon (TOC) content, clay mineralogy, and the distribution of benthic foraminifera. Sediment samples were collected from six locations spanning the mouth, middle, and head of the estuary. Grain size analysis revealed silt dominance across all locations, attributed to surrounding geology and human activities such as sand mining and deforestation. TOC content varied along the estuarine gradient, with higher concentrations observed in middle regions, indicating increased organic matter inputs and biological activity. Clay mineralogy analysis using X-ray diffraction identified kaolinite as dominant minerals, influenced by the geological composition of the area. Benthic foraminifera distribution showed higher abundance near the estuary mouth, correlating with nutrient-rich waters from upwelling and finer sediment composition enriched with clay minerals. These findings highlight the complex interactions between sediment dynamics, hydrological processes, and human activities within the Terekhol Estuary. Understanding these sediment characteristics is crucial for assessing estuarine health, informing management strategies, and promoting sustainable conservation efforts in this ecologically significant habitat.

KEYWORDS: Clay Mineral, Estuary, Grain Size, XRD

CHAPTER 1

INTRODUCTION

1.1BACKGROUND

Estuary is an inlet of the sea reaching into a river valley as far as the upper limit of tidal rise, usually being divisible into three sectors: a) a marine or lower estuary, in free connections with the open sea; b) a middle estuary subject to strong salt and freshwater mixing; and c) an upper or fluvial estuary, characterized by freshwater but subject to strong tidal action. The limits between these sectors are variable and subject to constant changes in the river discharge **(Fairbridge ,1980)**. The yearly discharge of river water into the ocean is roughly 37,400 cubic kilometres, constituting a mere 2.7 x 10^-3 percent of the total volume of seawater in the global ocean. This flow of river water transports around 15 x 10^15 grams of particulate matter and 4 x 10^15 grams of dissolved salts annually **(Martin and Whitfield, 1983)**. The prominent part of the fluvial materials transported by the rivers is deposited in estuarine and coastal areas90% **(Martin and Whitfield, 1983)**. The interference of marine-freshwater creates a complex and dynamic environment **(Morris et al. 1995)** with constant changes in physico-chemical parameters like temperature, salinity and pH. The runoff into the estuary may be from diverse sources that may impact the quality of water. The water transported from catchment areas may carry sediments/particulate matter containing metals that may eventually settle in the sediments **(Regnier and Wollast, 1993)**.

Sediments are a critical compartment of ecosystems where natural and anthropogenic chemicals accumulate. Current assessment methods include chemical extractions of “available” fractions, development of theoretical and empirical single chemical guidelines, laboratory toxicity testing of single species, field testing of single species, evaluations of populations and communities, and field exposures collecting chemical “available” fractions. Each approach has its own unique strengths and limitations, which has resulted in recommendations for use of multiple assessment methods. These methods provide unique information that aids the resulting decision making process of whether or not sediments are significantly contaminated from an ecological and human health viewpoint.

Sediments are influenced by various physical, chemical and biological post-depositional processes that render their use as a monitoring tool often difficult, especially in estuaries and coastal zones which are characterized by strong hydrodynamic and physico-chemical gradients (**Larsen et al. 1988; Eisma et al. 1989)**.

Marine sediments are the products of a limited number of physical, biological, and chemical processes. The nature of the resultant sediments is determined by the relative rates of input of material supplied by these processes. Physical processes dominate at ocean margins, where they transfer particles eroded from the land to the sea floor.

Biological processes dominate sediment formation in areas of high productivity that receives little terrigenous material. The equatorial Pacific and Southern Ocean are examples.

Several taxa of phytoplankton and zooplankton (the latter include benthic and upper water column representatives) secrete either $CaCO^3$ (coccolithophores and foraminifera's) or opal (hydrated SiO^2 - diatoms and radiolarians). If not masked by terrigenous material, the tests (shells) of these organisms can form carbonate or siliceous oozes.

Because the distribution and abundance of the various species are determined by the temperature, salinity, thermocline depth, carbonate chemistry, and productivity of the waters in which they live, most of what we know about paleoceanography is derived from fossil assemblages of these organisms.

In addition, the composition of the tests records the oxygen and carbon isotopic compositions and trace element contents of the waters in which they were secreted. These parameters in fossil tests provide insights to past ice volumes, temperature, productivity, and changes in biogeochemical cycles.

Benthic organisms also modify the historical record by actively mixing ("bioturbating") the most recently deposited sediments. Bioturbation, which is addressed later in the course, is effectively a low-pass filter that suppresses or eliminates records of events that create layers of sediment thinner than the depth of mixing. Rapidly deposited or anoxic sediments provide the only deep-sea records capable of resolving events shorter than about a millennium.

Chemical processes dominate sedimentation only in deep, low productivity areas shielded from terrigenous material. Precipitates from hydrothermal solutions emanating from mid-ocean ridges are prominent along the flanks of the East Pacific rise in the South Pacific.

Estuaries are highly biologically active zones lying between freshwater and marine systems. The classical view is that materials such as nitrates and phosphates which run into rivers as a result of man’s activity are used by the planktonic algae, or phytoplankton, for growth – in some cases causing nuisance blooms of these organisms. The management of the reduction of these blooms is based on the classical assumption that the materials stimulating them are brought into the estuary by the river, and that effective control of the blooms can be achieved by setting limits on the initial discharge of these materials into rivers.

In marine environments, particle transport is influenced by various factors such as currents, waves, and sediment characteristics. The two main types of particle transport in marine environments are bed load and suspended load. Bed load refers to the movement of sediment particles along the seabed or riverbed. This type of transport occurs when the force of the water (currents or waves) is sufficient to move particles along the bottom. Bed load transport typically involves larger and heavier particles such as sand and gravel. The movement of bed load particles is characterized by rolling, sliding, or saltating (bouncing) along the bed, often in the direction of the flow. Suspended load involves the transport of sediment particles within the water column. These particles remain suspended in the water due to the upward force exerted by turbulence or the buoyancy of fine particles. Suspended load can consist of a wide range of particle sizes, from clay and silt to sand and even coarser materials under certain conditions. The movement of suspended load is influenced by factors such as water turbulence, currents, and wave action. Suspended load transport is particularly important in areas with moderate to low flow velocities, where sediment remains suspended rather than settling on the bed **(Baskaran and Santschi, 1993)**. Grain size is the average size of the grains in a sediment sample. It is also known as the particle size. Grain size is the most fundamental physical property in sediment. The size and the shape of grain influence flow and compaction properties. Larger, more spherical particles flow more easily than smaller particles. Smaller particles dissolve more quickly and lead to higher suspension viscosities than larger ones. Geologists and sedimentologists use information on the sediment grain size to study trends in the surface processes related to the dynamic conditions of transportation and deposition. Various methods have been used to study the size parameters of the sediments like sieving sedimentation method etc. The main objective of a grain size analysis is to accurately measure individual particle size.

Silt consists of grains of particle size ranging from 0.008 to 0.0625 mm (0.0003–0.002 in.). It is intermediate in size between sand and clay. Silt size class ranges from 4.0 to 8.0 (phi).

Clay consists of grains of particle size between silt and colloid. These include any of the various hydrous aluminum silicate minerals that are plastic, are expansive, and have ion-exchange capacities. Clay size class ranges from 8 (phi) and onwards.

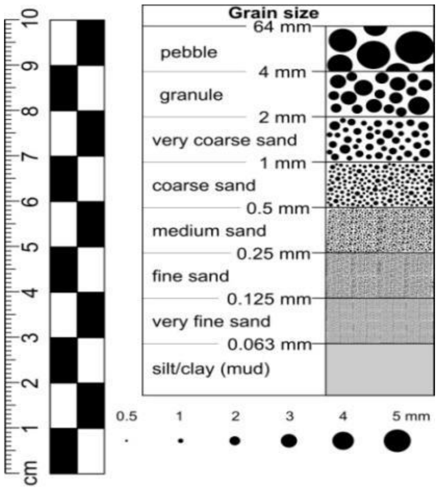


Fig 1.1: Particle grain size

Clay mineralogy, the scientific discipline concerned with all aspects of clay minerals, including their properties, composition, classification, crystal structure, and occurrence and distribution in nature. The methods of study include X-ray diffraction, infrared spectroscopic analysis, chemical analyses of bulk and monomineralic samples, determinations of cationic exchange capacities, electron-optical studies, thermal studies by differential thermal analysis, and thermo-gravimetric methods. The singular character of these hydrous silicate minerals and the nature of the problems surrounding them justify the status of clay mineralogy as a discipline distinct from mineralogy. A common body of knowledge is involved, however, particularly with regard to studies of internal structure.

Clay mineral particles aggregation and dispersion take place under changing conditions in naturals systems. Thus, the structure of clays particles is inherently influenced by the mineral matrix and the different fractions bound to it since properties of clays and clay-based minerals play an important role in the clay mineral assemblage, nature, structure, and ionic strength related to the interrelation between the surface of clay and the surrounding environment. The chemical nature of clay minerals' surface bound for example to organic matter compounds determines the oregano–clay interaction and influence of the sorption capacity at the solid aqueous interface **(Baldock and Skjemstad, 2000)**. Many mechanisms of biological protection in environment containing clay minerals and clay-based mineral particles operating from the smallest to the largest scale depend on the chemical properties and the dimensional arrangement of layers in the mineral. As a result, diverse mechanisms of protection can be attributed to clay minerals in some matrix-like soil for example. Due to firstly the physical nature of the mineral fraction, especially the presence of surfaces capable of adsorbing organic materials, and secondly the architecture of layers in the clay surface, there are multiple applications of clay minerals because of their versatile arrangements **(Baldock and Skjemstad, 2000)**. Surface reactive phases of clay minerals and clay-based minerals also play an important role in the regulation of contaminant fate and transport in surface and subsurface of the environment because these surfaces are the primary controllers of sorption processes in soils, thus acting as important regulators of contaminant transport. The modification of surface charge of clay minerals by organic constituents is responsible for dispersion/flocculation mechanisms of clay assemblage in the surface as well as the transport of mineral colloidal phases through soil. This surface charge is manifested by a significant retention of anions which assure that complex chemical properties have a number of important implications for solute and contaminant transport **(Bertsch and Seaman, 1999)**. Mutations and transformations of clays and clay-based minerals respond to their chemical and thermal environments, their properties and species change at each step from the origin, weathering, through their transportation, sedimentation, burial digenesis, and metamorphism Another transformation through the bounding mechanism between the organic cation and the charged clay layers is essentially electrostatic.

Clays are minerals that have unique physical and chemical characteristics. They are formed by small crystals, usually in the form of hexagonal platelets, which agglutinates to form conglomerates. These platelets are composed of alumino silicates organized, composed of the elements silicon, aluminum and oxygen, and others in smaller proportions, such as magnesium and iron. When hydrated, allows the separation of lamellar layers and intercalation of ions and molecules. The understanding of the properties of organized systems leads to interest in the study of systems consisting of the structured clays. For being generally of sedimentary origin, the clay can contain a large number of other minerals, represented by grains of varying diameters, soluble salts and organic matter. There are many different types of clay minerals, each with unique chemical and behavioural properties which arise from the structure of the clay minerals. But nearly all clays contain just two basic components which occur in different arrangements. These two basic building blocks of all clay minerals are the silica tetrahedron and the aluminum octahedron. When scientists talk about 1:1 or 2:1 clays, they refer to the ratio of silica tetrahedron sheets to aluminum octahedron sheets. 1:1 clay has one of each sheet; 2:1 clays have two tetrahedral sheets on either side of an aluminum octahedron sheet.

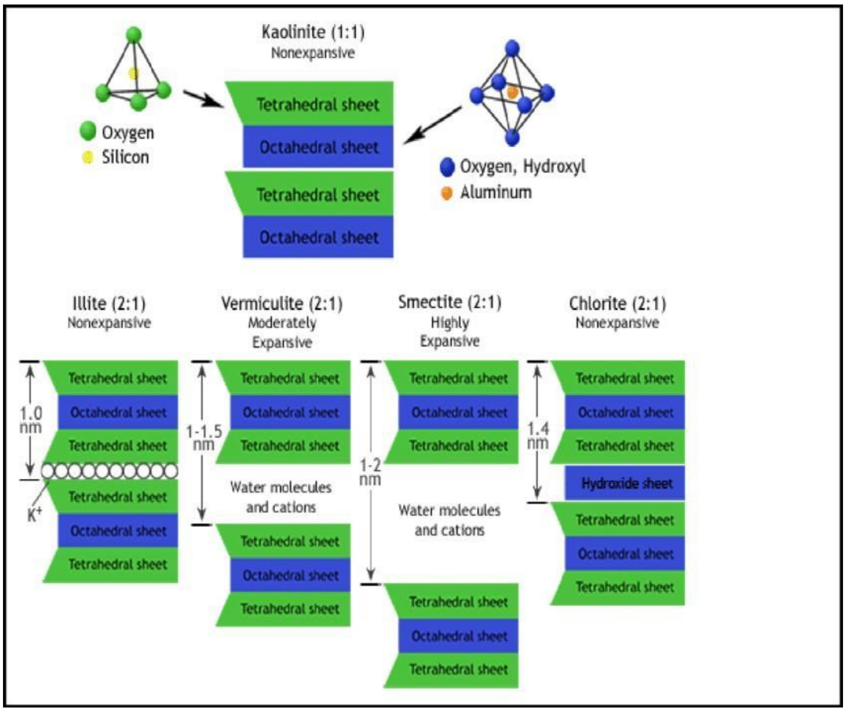


Fig 1.2: Structure of clay minerals.

Province of clay minerals found in India

The state of Gujarat is known for its significant reserves of clay minerals, particularly in regions such as Kachchh and Saurashtra. Kaolinite, montmorillonite, and illite are among the common clay minerals found in this area. These clay deposits are often associated with sedimentary formations and weathered volcanic rocks.

Rajasthan is another state in India with extensive deposits of clay minerals. Regions such as Bikaner, Jodhpur, and Jaipur are known for their clay deposits, which include kaolinite, bentonite, and other clay minerals. These deposits are associated with sedimentary rocks and alluvial plains.

West Bengal is rich in clay mineral resources, particularly in the Gangetic delta region. The Hooghly basin and other riverine plains in West Bengal contain significant deposits of kaolinite, montmorillonite, and other clay minerals. These deposits are often associated with fluvial and deltaic sedimentation.

Madhya Pradesh hosts clay mineral deposits in various parts of the state, including the Chhattisgarh Basin and the Vindhyan Basin. Clay minerals such as kaolinite, illite, and smectite are found in sedimentary formations and weathered rocks in these regions.

Assam, particularly the Brahmaputra valley, contains clay mineral deposits derived from the weathering of Himalayan rocks. Kaolinite, montmorillonite, and other clay minerals are found in alluvial deposits and sedimentary formations in this region.

In Kerala, clay mineral deposits are associated with laterite formations and tropical weathering processes. Kaolinite and other clay minerals are found in residual soils, bauxite deposits, and coastal sediments in Kerala.

KAOLINITE GROUP:

The kaolinite group includes the dioctahedral minerals kaolinite, dickite, nacrite, and halloysite, and the trioctahedral minerals antigorite, chamosite, chrysotile, and cronstedite. The primary structural unit of this group is a layer composed of one octahedral sheet condensed with one tetrahedral sheet. In the dioctahedral minerals the octahedral site are occupied by aluminum; in the trioctahedral minerals these sites are occupied by magnesium and iron. Kaolinite and halloysite are single-layer structures. Although dickite and nacrite have the same basic structure, the stacking sequence of layers is different in these minerals **(Dixon et al. 1989; Moore and Reynolds, 1997)**. Kaolinite, dickite, and nacrite occur as plates; halloysite, which can have a single layer of water between its sheets, occurs in a tubular form. All members of the kaolinite group form primarily during hydrothermal alteration or weathering of feldspars under acid conditions; but kaolinite and halloysite are probably the only members formed in soils **(Deer et al. 1975; Swindale, 1975)**. Kaolin minerals are used during the manufacture of ceramics, paper, and paint. In mono-mineralic samples the dioctahedral members of this group are readily identified because they become amorphous to X-rays after heating to 550 degrees C and their diffraction patterns disappear. Kaolinite, dickite, nacrite, and halloysite can be differentiated from chlorite by comparisons of the 3.58-angstrom kaolin peak with the 3.54-angstrom chlorite peak **(Biscaye et al. 1965)** and from chlorite and the trioctahedral members of this group by intercalation with potassium acetate **(Wada et al. 1965)**. Heating alone will not distinguish the dioctahedral kaolinite group minerals from chlorite because the 002, 003, and 004 chlorite peaks are also weakened by this heat treatment **(Moore and Reynolds, 1997)**. Intercalation complexes can also be used to differentiate individual dioctahedral kaolinite minerals. For example, dehydrated halloysite can be distinguished from kaolinite by intercalation with formamide **(Churchman et al.1984)**.

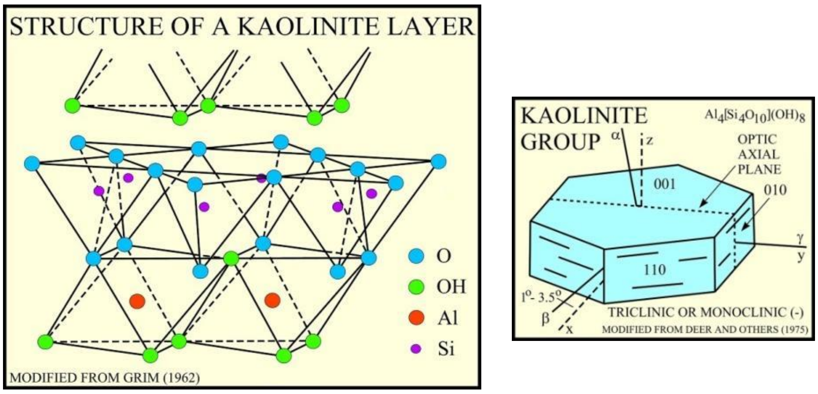


Fig. 1.3: Structure of kaolinite group.

CHLORITE GROUP :

The basic structure of chlorites consists of negatively charged mica-like (2:1) layers regularly alternating with positively charged brucite-like (octahedral) sheets **(Grim et al. 1962)**. Members of the chlorite group include: brunsvigite, chamosite, clinochlore, cookite, diabantite, nimite, pennantite, penninite, ripidolite, sheridanite, and thuringite. The various members are differentiated by the kind and amount of substitutions within the brucite-like layer and the tetrahedral and octahedral positions of the mica-like layer. The chlorite minerals are common components of low-grade greenschist facies metamorphic rocks, and of igneous rocks as hydrothermal alteration products of ferromanganese minerals **(Deer et al. 1975)**. Chlorites are also common constituents of argillaceous sedimentary rocks where these minerals occur in both detrital and anthropogenic.

Chlorites have their 001 peaks at 14 to 14.4 angstroms, depending on the individual species. Peak positions are unchanged by ion saturation, solvation with ethylene glycol, or heating. However, heat treatments above 500 C alter peak intensities **(Barnhisel and Bertsch, 1989; Moore and Reynolds, 1997)**. Typically, the 001 chlorite peak may increase dramatically and higher-order peaks may be conspicuously weakened. In poly-mineralic samples, chlorites can be distinguished from kaolinite by comparisons of the 3.58 angstrom kaolinite and 3.54 angstrom chlorite peaks, from smectites by the expansion and contraction of the 001 smectite peak after ethylene glycol solvation and heating to 400 C, and from vermiculite by the progressive collapse of the 001 vermiculite peak during heat treatments.

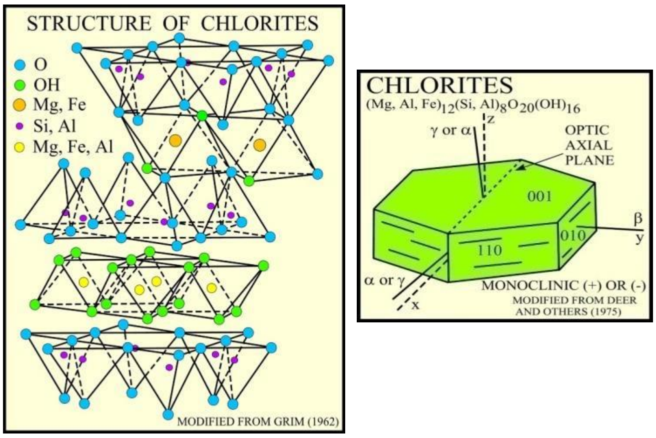


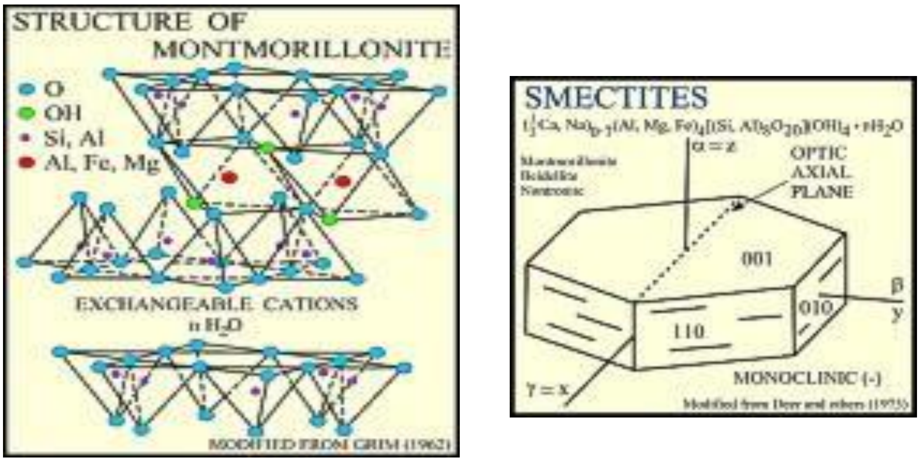
Fig. 1.4: Structure of chlorite group

SMECTITE GROUP :

Members of the smectite group include the dioctahedral minerals montmorillonite, beidellite, and nontronite, and the trioctahedral minerals hectorite (Li-rich), saponite (Mg-rich), and sauconite (Zn-rich). The basic structural unit is a layer consisting of two inward-pointing tetrahedral sheets with a central alumina octahedral sheet. The layers are continuous in the a and b directions, but the bonds between layers are weak and have excellent cleavage, allowing water and other molecules to enter between the layers causing expansion in the c direction **(Grim, 1962)**.

Smectites commonly result from the weathering of basic rocks. Smectite formation is favored by level to gently sloping terranes that are poorly drained, mildly alkaline (such as in marine environments), and have the high Si and Mg potentials **(Borchardt et al. 1977)**. Other factors that favour the formation of smectites include the availability of Ca and the paucity of K **(Deer et al. 1975)**. Poor drainage is necessary because smectites otherwise water can leach away ions (e.g. Mg) freed in the alteration reactions. Smectites are used in industry as fillers, carriers, absorbents, and a component in drilling fluids **(Grim et al. 1962).**

Smectites yield X-ray diffraction patterns characterized by basal reflections that vary with humidity, exposure to certain organic molecules, heat treatment, and exchangeable cation **(Wilson, 1987)**. When saturated with ethylene glycol, the 001 reflection of most smectites will swell to about 17 angstroms (about 17.8 angstroms with glycerol); when heated to 400 C, the 001 reflection will collapse to about 10 angstroms (the exact amount of collapse is often related to the exchange cation present and to the smectite itself). Individual smectites can sometimes be differentiated by their higher-order peaks or by cation saturation. For example, dioctahedral smectites have 060 reflections at 1.50-1.52 angstroms, whereas trioctahedral smectites have 060 reflections at 1.53-1.54 angstroms; and Li saturation can be used to differentiate some montmorillonites from beidellite **(Schultz et al. 1969)**.



$(\frac{1}{2}Ca, Na)_{0.7}(Al, Mg, Fe)_4[(Si, Al)_8O_{20}](OH)_4 \cdot nH_2O$

Fig. 1.5: Structure of smectite group

ILLITE GROUP:

Illite is essentially a group name for non-expanding, clay-sized, dioctahedral, micaceous minerals. It is structurally similar to muscovite in that its basic unit is a layer composed of two inward-pointing silica tetragonal sheets with a central octahedral sheet. However, illite has on average slightly more Si, Mg, Fe, and water and slightly less tetrahedral Al and interlayer K than muscovite **(Baileye et al. 1980**) The weaker interlayer forces caused by fewer interlayer cations in illite also allow for more variability in the manner of stacking **(Grim et al .1962).** Glauconite is the green iron-rich member of this group.

Illites, which are the dominant clay minerals in argillaceous rocks, form by the weathering of silicates (primarily feldspar), through the alteration of other clay minerals, and during the degradation of muscovite (**Deer et al.1975**) Formation of illite is generally favoured by alkaline conditions and by high concentrations of Al and K. Glauconite forms authigenically in marine environments and occurs primarily in pelletal form.

Members of the illite group are characterized by intense 10-angstrom 001 and a 3.3-angstrom 003 peaks that remain unaltered by ethylene glycol or glycerol solvation, potassium saturation, and heating to 550 degrees C (**Fanning et al .1989**). Glauconite can be differentiated from illite by a 1.5- to 1.52-angstrom 060 peak (illite's 060 peak occurs at 1.50 angstroms), and by the presence of only a very weak 5-angstrom 002 peak.

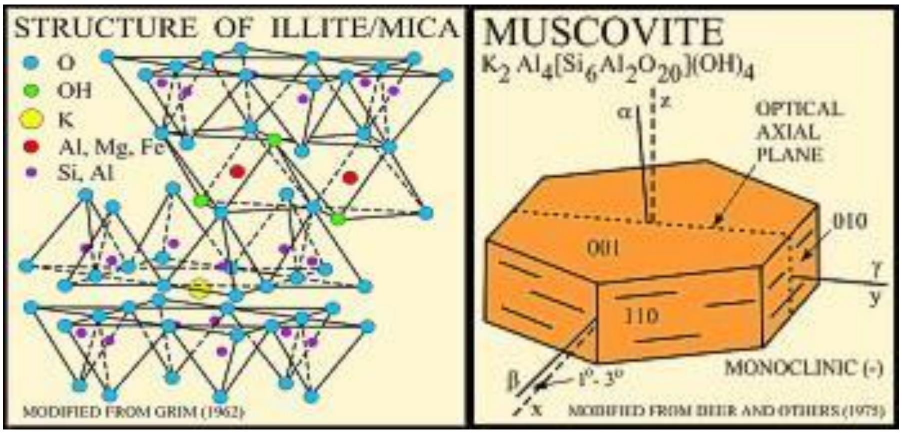


Fig 1.6: Structure of illite group

What are foraminifera?

Foraminifera are a large group of amoeboid protists with reticulating pseudo pods fine strands of cytoplasm that branch and merge to form a dynamic net. They typically produce a test or a shell, which can have either one or multiple chambers, some becoming quiet elaborate in structures. These shells are made up of calcium carbonate (CaCO3) or agglutinated sediment particles. About 275000 species are recognized, both living and fossil. They are usually less than 1 mm in size, but largest recorded specimen is about 19 cm. Foraminifera have typically been included in the group Protozoa. The form and the composition of test is the primary means by which foraminifera are identified and classified. Foraminifera are abundant all over the ocean and found in all marine environments. They either live on the sea bottom (benthic) or float in the upper water column (planktonic). A few benthic species have been recorded from terrestrial environments including ground water. Vertical distributions of live benthic foraminifera vary geographically and seasonally depending on biotic factors (competition, predation, bioturbation) or abiotic factors (oxygen, availability and quality of food, redox conditions, substrate characteristics, near-bottom currents, etc.) as an expression of a dynamic adaptation to optimize food acquisition.

Benthic foraminifera are single-celled eukaryotic organisms that live in marine sediments, from shallow coastal to deepest marine waters. They are a large group of amoeboid protests with a life cycle that alternates between two generations: sexually reproducing in the gamont generation, and asexually reproducing in the agamont generation. The life cycle of foraminifera can be completed within a year in tropical latitudes.

Fig 1.7 Examples of benthic foraminifera

1.2 Aim: To find the distribution of clay minerals and benthic foraminifera in intertidal sediments in Terekhol estuary.

1.3 Objectives :

- To study the regional distribution of clay mineralogy and to find provinces of the same in sediment along the Terekol Estuary
- To determine the textural parameters of the sediments.
- To fine distribution of Benthic foraminifera in the sediments.

1.4 Scopes:

Academic Research: Many researchers focus their careers on studying these microorganisms and minerals in academic institutions. They contribute to advancing scientific knowledge through publications, conferences, and collaborations with other scientists.

Environmental Consulting: Understanding clay minerals and benthic foraminifera can be valuable in environmental consulting firms. These professionals assess environmental impacts, conduct site investigations, and provide recommendations for sustainable land use and resource management.

Paleoclimatology and Paleoceanography: Researchers specializing in reconstructing past climates and oceanic conditions use data from clay minerals and benthic foraminifera to understand Earth's climate history. They contribute to climate change studies, ocean circulation modeling, and predicting future climate scenarios.

Oil and Gas Industry: Clay minerals are essential in petroleum geology for understanding reservoir properties and sedimentary basin evolution. Benthic foraminifer’s studies contribute to paleoenvironmental reconstructions, assisting in petroleum exploration and production.

Mining and Mineral Exploration: Knowledge of clay minerals is valuable in mining and mineral exploration companies for identifying economic deposits and understanding ore-forming processes. Benthic foraminifer’s studies can also provide insights into the depositional history of sedimentary basins, aiding in resource exploration.

Museum and Cultural Heritage Institutions: Museums and cultural heritage institutions may employ experts in clay mineralogy and micropaleontology to curate collections, conduct research on historical artifacts, and contribute to public education and outreach efforts.

CHAPTER 2

LITERATURE REVIEW

Jeshma et al. (2016) Studied about the benthic foraminiferal diversity and environmental characteristics of the Puravadaiyanar and Vettar estuaries based on 24 sediment samples. The Puravadaiyanar estuary hosts 47 foraminiferal species, while the Vettar estuary contains 26 species, with common species including *Ammonia beccarii*, *A. tepida, A. dentata, Nonionoides elongatum, Elphidium advenum, E. discoidale, Cribrononion simplex, Trochammina inflata, and Quinqueloculina seminulum*.

Kessarkar et al . (2009) The study examined about the seasonal variations of suspended particulate matter (SPM) in the Mandovi estuary. SPM concentrations follow a gradient, being low at river-end stations and increasing seaward, peaking at sea-end stations. Two periods, June–September and February–May, coincide with an estuarine turbidity maximum (ETM) at sea-end stations. These times correspond to high and low river discharge, associated with the southwest monsoon and persistent sea breeze, respectively. Salinity vs. SPM plots show a seaward deposit, skewed landward. SPM is composed of floccules, fecal pellets, and aggregates containing clay and biogenic particles, with diatoms most common—marine type at sea-end and freshwater-dominated at river-end stations. Clay mineral composition varies, with kaolinite- and smectite-rich suites at river- and sea-end stations. Smectite concentrations increase seaward with SPM content and are unaffected by salinity. Wind-driven waves and currents, along with biogeochemical processes at the estuary mouth, likely influence ETM formation and SPM transformation. Overall, the study highlights complex interactions shaping SPM dynamics in the Mandovi estuary across seasons.

Kessarkar et al. (2003) Reported about the mineralogy and isotopic composition of sediments collected along the western margin of India from both the Holocene and late Pleistocene periods. The analysis reveals distinct clay mineral associations in Holocene sediments, indicating contributions from various sources including the Indus River, Deccan Traps, and gneissic rocks. Sr isotopes are found to be sensitive to weathering, while Nd isotopes reflect source rock composition or sediment mixing. The fluctuation of 87Sr/86Sr ratios in Holocene sediments suggests intense chemical weathering in the hinterland, particularly in areas enriched with kaolinite. The influence of sediment transported by the Bay of Bengal waters on the southwestern margin of India during monsoon seasons is deemed insignificant. Late Pleistocene sediments exhibit decreased hydrolytic processes and a decrease in smectite content and Sr isotopic ratio. Overall, the study suggests consistent provenance and transport pathways for sediments in both Holocene and late Pleistocene periods along the western margin of India, with distinct mineralogical and isotopic signatures reflecting geological and environmental processes over time.

N.T. Rane and V.M. Matta (2019) Studied the long-term contamination history of pollutants resulting from intense mining activities in northern Goa, focusing on sediment core samples collected from three rivers: Bicholim (BR), Mandovi (MR), and Terekhol (TR). Analysis of sediment samples includes texture, Organic Carbon (OC), major elements (Fe, Al, Ca, Mg), and trace metals (Mn, Cu, Zn, Pb, Ni, Cr). The depositional environment of the cores is evaluated based on color and OC distribution. Environmental parameters such as contamination factor, geoaccumulation, enrichment factor, and pollution load index are utilized to assess pollution extent. Correlation coefficients aid in understanding relationships among major elements, trace metals, and their sources. The findings reveal strong pollution in the Bicholim River, particularly with Fe and Mn, and moderate pollution with Pb and Cr. The Mandovi River exhibits moderate pollution with Mn and Pb. In contrast, the Terekhol River, previously unpolluted, now shows pollution with Cu and Cr due to recent human interference. Overall, the study underscores the significant impact of mining activities on river sediments, particularly in the Bicholim and Mandovi rivers, with potential ecological implications for bottom-dwelling organisms.

Fernandes et al. (2018) The study done was on the seasonal distribution and dynamics of suspended particulate matter (SPM) in six river estuaries of Goa, India, with implications for estuarine management. The estuaries studied encompass both meso- and micro-tidal systems. Salinity stratification near estuary mouths is observed during the wet season, with well-mixed water columns in the dry season. SPM concentrations are found to be twice as high during the wet season compared to the dry season, with the Estuarine Turbidity Maximum (ETM) being a consistent feature in both seasons except in the Sal River estuary. The study elucidates the mechanisms behind ETM formation, highlighting gravitational circulation and flocculation at the salt-freshwater interface during the wet season, and the influence of tidal and wind-induced currents at river mouths during the dry season. The in situ vertical distribution of SPM volume concentration and mean particle size provides valuable insights into ETM formation and distribution patterns. Overall, these findings contribute to a better understanding of estuarine dynamics and are essential for effective estuarine management strategies such as conservation, shoreline protection, navigation, dredging, and embanking.

Kamble et al. (2024) The study was about a thorough taxonomic study utilizing high-resolution microscopy to examine benthic foraminifera from Neogene sections in western Kachchh, India. A total of 25 species belonging to 3 classes (*Globothalamea, Tubothalamea, Nodosariata*) and 4 orders (*Rotaliida, Textulariida, Miliolida, Polytmorphinida*) was identified from limestone and silty-claystone deposits of the Murachbann section, which whih where attributed to the lower Miocene period. The study provides valuable insights into the distribution of benthic foraminifera species in the Murachbann section and attempts to interpret the depositional paleoenvironment based on this distribution.

Maheshwar R. Nasnodkar and Ganapati N. Nayak. (2019) studied about the clay minerals in mudflat core sediments from the lower and middle regions of the tropical estuaries Sharavathi and Gurupur on the west coast of India, focusing on understanding their sources and the role of estuarine processes in their distribution. Kaolinite is found to be abundant in both estuaries, reflecting chemical weathering of source rocks, while smectite concentrations are slightly higher in the lower Sharavathi estuary compared to the middle region. Illite and chlorite concentrations are relatively higher in the lower region of both estuaries. The distribution of clay minerals is regulated by salinity within the estuaries. Metal concentrations in the clay fraction are higher in the middle region compared to the lower region, attributed to mixing processes enhancing metal adsorption onto suspended clay particles. Major elements such as Al, Fe, and Mn in the lower Sharavathi estuary are associated with kaolinite, while metals in the middle Sharavathi and Gurupur estuaries are associated with smectite and illite.

Nagendra et al. (2014) Studied about the subsurface lithosection NYKT of the Cauvery Basin, five planktic foraminiferal biozones were identified: Abathomphalus mayaroensis zone, Pseudotextularia deformis zone, Parvularugoglobigerina eugubina zone, Globoconusa daubjergensis zone, and Praemurica inconstans–Subbotina triloculinoides zone. The succession of planktic zones Pseudotextularia deformis of the terminal Maastrichtian (zones CF1–CF2) and Parvularugoglobigerina eugubina (zone Pα of Caron, 1985, which equals P1a of Keller, 1993) of early Danian indicates a relatively discontinuous Cretaceous–Tertiary transition without major hiatuses. The presence of ecological index benthic foraminifera Nuttallides truempyi and Bulimina trinitatensis in part of the Abathomphalus mayaroensis (=CF2) and Praemurica inconstans–Subbotina triloculinoides (=P2) zones suggests a paleodepth exceeding 500 meters, while their absence during biozones CF1, Pα, and P1 indicates a drop in sea level below 500 meters. This observation aligns with the regional paleobathymetric trends across the Cretaceous-Tertiary Boundary in the Cauvery Basin.

Diz et al. (2004) Studied about the distribution and dynamics of live benthic foraminifera in coarse sediments of the Ria de Vigo on the north western Iberian margin. It reveals that the distribution of live benthic foraminifera, particularly small forms ranging from 63 to 125 micrometers, is primarily influenced by food availability and bottom current range. The findings suggest that microalgae or bacterial biofilms colonizing shell surfaces serve as the primary food resource for these organisms. During upwelling events, which enhance bottom food supply, opportunistic species colonize the environment, facilitated by moderate-to-low velocity bottom currents. The study also highlights the role of bottom current regimes in shaping the vertical distribution of live benthic foraminifera, with attached forms thriving under high-velocity currents and free-living forms favoring moderate-to-low velocity currents. Moreover, the research demonstrates that in coarse sediments, attached forms typically considered epifaunal may function as 'pseudoepifauna' above disturbance depths, while a 'true' infaunal community exists below, unaffected by currents. Overall, the findings shed light on the complex interactions between food availability, bottom currents, and benthic foraminiferal ecology in coastal marine environments.

Saravanan et al. (2019) Studied about 6100-year record of benthic and planktonic foraminifera from inner neritic sediments off the Goa coast, eastern Arabian Sea, to discern the response of benthic foraminifera to shallow-marine processes. The dominant benthic foraminifera assemblage includes species like *Nonion cf. asterizans, Ammonia beccarii, A. gaimardii,* and *Virgulinella fragilis.* Planktonic foraminifera, mainly represented by Globigerinoides ruber, appear sporadically. Combining foraminiferal proxies with total organic carbon content and isotopic values suggests fluctuations in productivity and salinity in the shallow eastern Arabian Sea. The study reveals warmer and less saline coastal waters from 6100 to 4600 cal yr BP, corresponding to a stronger monsoon, followed by a cooler period until 2600 cal yr BP, coinciding with lower sea surface temperatures and aridity in the Indian subcontinent. Additionally, short-term cold events from 2900 to 2600 cal yr BP, similar to those observed off Pakistan, are evident. During the Little Ice Age, the shallow sea off Goa experienced decreased productivity. Overall, the paper provides insights into long-term environmental changes in the eastern Arabian Sea and their linkages to regional and global climate dynamics.

Venkatramanan et al. (2011) Studied about the abundance and distribution of clay minerals, sand, silt, clay, and organic matter in the surface sediments of the Tirumalairajanar Estuary across two different seasons. Ten selected stations along the estuary, including the mouth and freshwater zone, were studied. Clay and silt were observed along the estuary region, with some stations also examined in the upstream end. Organic matter was found to be a significant factor influencing the distribution of clay minerals, with higher clay mineral concentrations observed during the postmonsoon season compared to the premonsoon season. The predominant clay minerals identified include chlorite, kaolinite, montmorillonite, illite, and scarce gibbsite. X-ray diffraction analysis was used to identify minerals in the sediment samples. Sediment texture was highlighted as a key factor influencing the distribution of organic matter.

Purnima Bejugam and G. N. Nayak (2019) They studied about the sediment cores from the Mahanadi, Godavari, and Krishna rivers to understand spatial and temporal variations in grain size, clay minerals, organic elements, and metals. Different mineral compositions indicated varied sediment sources. High metal content in shallow areas suggested input from specific geological formations. The ratio of organic carbon to nitrogen indicated terrestrial organic matter supply. Sediment characteristics reflected rainfall intensity and runoff, affecting biological productivity. Changes in sediment composition revealed shifts in oxygen levels and biological activity. The study highlights the influence of monsoons and dissolved oxygen on sediment provenance and preservation of organic elements and metals.

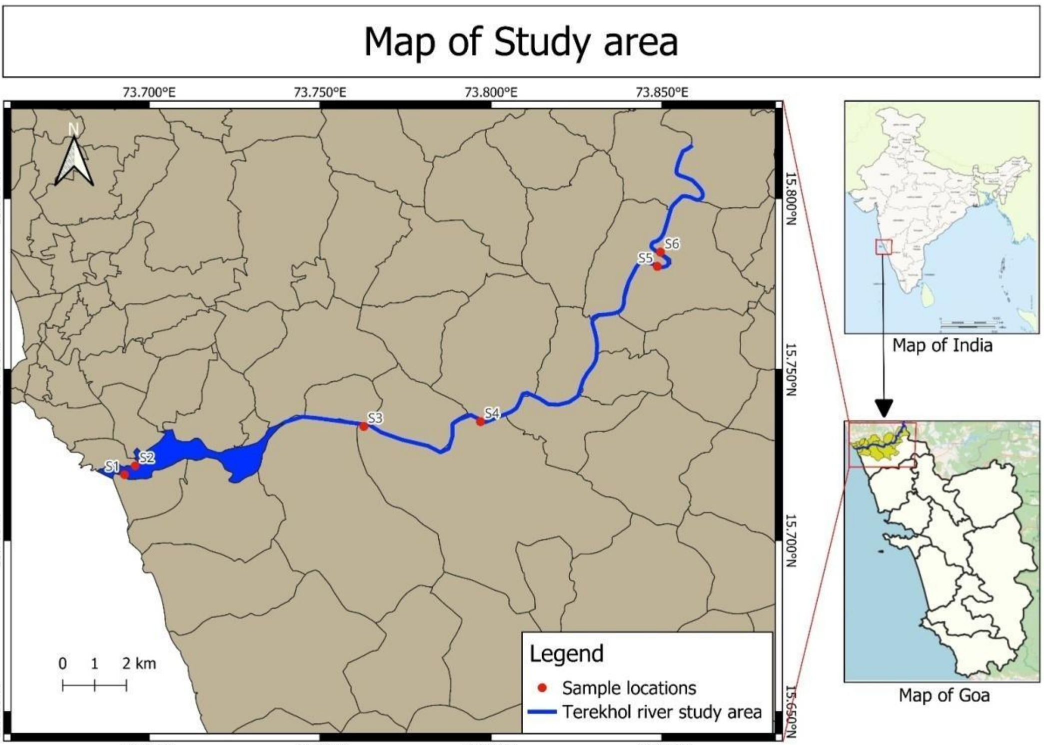
CHAPTER 3

METHODOLOGY

Methodology

3.1Study area

3.1 Base map



3.2 sampling location

Terekhol river originates in the Manohargad in the Sahyadris, located in the northwestern area. It flows along the border of Goa in a southwest direction. This river enters the Arabian Sea. The length of this river is 27.5 km. It enters the state of Goa near Patradevi. Terekhol is an important river for the people of Pernem as it fulfils the requirement of water and nourishes the ecosystem of the Pedne. Aronde is another name for this river.

The sampling was done along the estuary. Total samples collected were 6. The first 2 samples were from either side of the mouth from the estuary. Next third and fourth samples from the middle of the estuary, fifth and sixth were from the head of the estuary.

3.1 Table showing sampling locations co-ordinate

Sampling location	Latitude	Longitude
Location 1	15°43'14"N	73°41'39"E
Location 2	15°43'18"N	73°42'00"E
Location 3	15°44'00"N	73°45'46"E
Location 4	15°44'04"N	73°47'50"E
Location 5	15°46'50"N	73°50'48"E
Location 6	15°47'03"N	73°50'57"E

3.2 Preparation of base map, study area map.

Graphs were prepared using the app called OriginLab. OriginLab is a data analysis and graphing software for engineering and science that has a point-and-click interface and batch operations tools The study area was selected after the available literature survey and survey of India toposheet number 48E/10 and a Google Earth image was used for preparing the base map (figure 3.1).The study area map (Figure 3.2) showing the sampling locations were prepared using QGIS version 3.8.2.The location pins were identified using the Google Earth Pro software. A total of 6 locations pins were marked along the Terekhol Estuary, sequentially labelled from location 1 to location 6, tracing the course from its mouth to its source further inland .The coordinates of the location markers were recorded in Table1.The Terekhol Estuary is an important ecosystem where freshwater and marine ecosystems interact dynamically. This surface sediment sampling expedition, which took place in June 2023, had the goal of evaluating the sediment surface in order to investigate the distribution of clay minerals and benthic foraminifera.

3.3 Field work

Sediment samples collected on 15th and16th June 2023 along the transect stations of estuary were investigated. For study of clay minerals and benthic foraminifera total of 6 samples were collected from 6 locations starting from Terekhol to Banda (i.e. from mouth to head of the estuary). From every station 2 samples were collected. The samples were collected during the low tides using plastic scoop. The samples were placed in zip-lock bag and then stored ice box. Later the sample was shifted to laboratory and placed in refrigerator till further analysis.

3.4 Laboratory Analysis

Upon reaching to the laboratory samples were oven dried at 60˚C. Part of dried sediment was for the analysis of sediment components (sand, silt, clay) and Clay mineralogy. Portion of the dried sample was finely powdered using a gate mortar and pestle. The powdered sediment samples were used for the estimation of Total organic carbon (TOC).

3.5 Sediment component

The surface samples are collected using a plastic scoop and transferred to a pre-labelled polythene bags and stored in an ace box. Later , the samples were kept for drying in an oven at 60℃ until the sediments are completely dried.

The size of the sediment particles vary depending on the hydrodynamics and the environment in which it get deposited. The pipette method involving the settling velocity principle based on Stroke's law is used to determine the sand:silt:clay ratio.

10 g of oven dried sediment samples were weight and then added to 1000ml glass beaker, distilled water was added allowing the sediments to settled overnight, the water from the beaker is decanted using a decanting pipe without disturbing the sediment, repeat this step 3to 4 times until the salinity is low. Salinity is checked by adding $AgNO_3$ in the decanted water after the 4th day. Upon the removal of the salinity, add 10ml of 10% sodium hexametaphosphate to dissociate clay particles and was kept overnight. On the next day add 5ml of 30 % hydrogen peroxide solution to oxidize organic matter completely and is kept undisturbed foe a day. The treated samples are then sieved through a 63 micron sieve and the filter is collected in a 1000ml measuring cylinder. The beaker as well as the sediment on the sieve is washed thoroughly until the solution becomes clear. The solution from the cylinder is made up to 1000ml using distilled water and homogenised for about 2 minutes with the help of a stirrer. The stirring timer is noted down and the solution is allowed to settle. The room temperature was determined using a thermometer and the extraction time is calculated at the size 8 ϕ following the table below.

3.2 Pipette analysis table.

Size ϕ	Depth at which pipette is to be inserted (cm)	Time at which water is to be pipette out Hours:Minutes: seconds				
		28°C	29°C	30°C	31°C	32°C
4	20	00:00:48	00:00:46	00:00:46	00:00:44	00:00:44
5	10	00:01:36	00:01:34	00:01:32	00:01:29	00:01:28
6	10	00:06:25	Oo:06:15	00:06:06	00:06:57	00:05:52
7	10	00:25:40	00:25:02	00:24:25	00:24:49	00:23:27
8	10	01:42:45	01:40:13	01:37:42	01:37:15	01:33:51
9	10	06:30:00	06:40:40	06:32:50	06:32:10	06:11:30
10	10	27:06:00	26:30:00	-	-	-

The sand particles remaining on the sieve are transferred into a 100ml pre-weighed beaker and are oven dried at 60 °C. After pipetting 25 ml of the clay solution by inserting the pipette at 10 cm depth, at a calculated time according to the room temperature. The samples are transferred into 100 ml pre-weighed beaker and then it is oven dried at 60°C. The dried samples are weighed to calculated the percentage of sand, silt and clay using the formulae:

$$\%Sand = \left(\frac{Weight\ of\ sand}{Total\ weight\ of\ the\ sediment}\right) \times 100$$

$$x = \left(weight\ of\ clay \times \frac{1000}{25}\right) - 1$$

$$\%\ of\ clay = \left(\frac{X}{Total\ weight\ of\ sediment}\right) \times 100$$

$$\%Silt = 100 - (\%\ of\ sand + \%\ of\ clay)$$

3.6 Clay minerals analysis

X-ray diffraction is used to ascertain a material's crystal structure. This is an experimental technique where a sample of the substance under test is exposed to an X-ray beam. In crystals, the atoms are arranged in a given order, which causes the beam to diffract at specific angles and intensities.

The following procedure is followed:

Clay mineral analysis of dried sub sampled was carried out. It involves same procedure as followed for pipette analysis up to studying the sample in a 1000ml cylinders. However, the pipetting time for the clay mineral analysis was calculated for 9ϕ. After 6 hours 30 minutes, 25ml of sample is pipette out from 10 cm depth. Add 10ml acetic acid to remove calcareous material and 10ml hydrogen peroxide to remove organic carbon. The content from the beaker was then allowed to settle for overnight. Later, the supernatant was Decanted using decanting pipe and distilled water was added to the beaker and content was allowed to settle overnight. This procedure was repeated 4-5 times to free clay from access reagents. Pipette out 1ml of slurry and spread uniformly over a pre numbered clean glass slide. This slides was air dried completely to obtain uniformly distributed thin layer of clay.

Later, the prepared slides were glycolated using ethylene glycol at 100°C for 1 hour 30 minutes. These slides were then scanned from 3° to 30° 2θ at 15mins on the X-ray diffractometer. Further, slide was scanned again in the range of 24° to 26° 2θ at 0.5° 2θ/min in order to distinguish between kaolinite and Chlorite peak. The percentage of clay mineral was calculated by weighting the integrated peak area of basal reflection in the glycolated X-ray diffractograms by following the semi-quantitative method given by **Biscaye (1965).**

Formula to calculate clay mineral percentage

1. Smectite: $S = S_o \times 1$
2. Illite: $I = I_o \times 4$
3. Kaolinte + Chlorite$(K+Ch)_o \times 2$

$$S\% = (\frac{So\times1}{S+I+(K+Ch})100$$

$$I\% = (\frac{Io\times4}{S+I+(K+Ch)})100$$

$$K+Ch\% = (\frac{(K+Ch)o\times2}{S+L+(K+Ch)})100$$

$$K\% = (\frac{Ko}{Ko+Cho \div (K+ch)})100) \times 100$$

The rapid technique has been demonstrated to be a reliable estimator of the octahedral composition of illite **(Hunziker et al. 1986**). Additionally, it can be valuable for identifying clay mineral origins and the transportation dynamics of clay minerals in marine sediments (**Moriarty 1987);Esquevin (1969**) states that alkali-rich (muscovitic) illites have hi values (> 0.40). The ratio falls when the octahedral aluminum is replaced with magnesium and iron. Biotitic (mg and Fe-rich) illites are limited to levels < 0.15 **(Esquevin 1969).**

Formula to calculate Illitechemistry is: $I_o = 5Å / 10Å$

3.7 Total organic matter

The total organic carbon is estimated to understand the role of organic components of the sediments in transport, deposition and mobility of trace metals. The TOC is determined by using the modified Walkley-Black Method (**Gaudette et al. 1974**)

The dried samples where powdered using motar and pestle. 0.5g of powered samples where weight and then taken into a 500 ml conical flask. The sediment is treated with 10ml of 1N standard potassium dichromate solution and 20ml of sulphuric acid and silver sulphate mixture. The conical flask was gently swirled for 1 min and was allowed to stand for 30mins. After 30 mins, 200ml of MilliQ water is added. to this 10ml of 85% orthophosphoric acid and 0.2g of sodium fluoride was added, and solution was gently mixed. Later few drops of diphenylamine indicator were added. The solution was titrated against 0.5N ferrous ammonium of chlorine ions is prevented by addition of silver sulphate. The standardization blank was performed using the same procedure.

The percentage of TOC is calculated using the following formula:

$$\% \, of \, TOC = 10(1 - \frac{T}{S}) \times F$$

Where,

S = Standardization blank titration, ml of ferrous solution

T = Sample titration, ml of ferrous solution

F = (1.0N) × 12/4000 × 100/sample weight = 0.6, when the sample weight is exactly 0.5g

Where, 12/4000= m.eq.wt.carbon

3.8 Benthic foraminifera

A stereo microscope is an optical microscope that provides a three-dimensional view of a specimen. It is also known by other names such as dissecting microscope and stereo zoom microscope. Dissecting microscope parts include separate objective lenses and eyepieces. As a result, you have two separate optical paths for each eye. The slightly different angling views to the left and right eyes produce a three-dimensional visual. Because it gives the three-dimensional view it is also called as the dissecting microscope

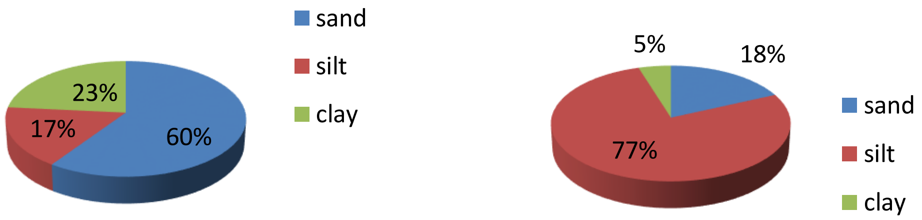
Take 10 grams of dry samples in 500ml beaker add little water for the sediment to soak and break the lumps. Add 5ml of hydrogen peroxide to remove organic matter. Add 10ml of 10% sodium hexametaphosphate used ad dispersant. Add 10 g of sodium hexametaphosphate dissolve in beaker adding little by little water. Transfer to volumetric flask and make the volume to 100ml. Keep for 3 hrs stirring every 15 minutes. Sieve through 63µm wet sieving keep the sieve under the running tap water. Slowly move the sediment with brush. Wash until clear water is seen passing through the sieve. Whatever remains on the sieve transfer into the 100ml breaker and dry at 60°C.dried samples to be sieved through 150µm sieve >150µm is used for the identification. Sample is spread on the petri dish and seen under stereo microscope and then benthic foraminifera were counted from 10 grams of sediment sample.

CHAPTER 4

ANALYSIS AND CONCLUSION

4.1 Sediment Analysis

The grain size analysis was carried out to all the 6 sample. The table below shows the percentage of sand, silt and clay.



Sample 1 (mouth)

Sample 2 (mouth)

Sample 3 (middle)

Sample 4 (middle)

sample 5 (head)

Sample 6 (head)

Figure 4.1 Graphical representation showing percentage of sand silt and clay in sample 1, 2, 3, 4, 5 and 6

The above table shows the concentrations of sand, silt and clay percentage in all 6 stations of the Terekhol estuary.

Grain size refers to the diameter or size of individual particles in a sediment or soil sample. It's commonly categorized into sand, silt, and clay based on their sizes. The percentage of sand varies from 0.83% to 59.51%, percentage of silt varies from 23.49% to 93.89% and percentage of clay varies from 2.9% to 17%. The percentages of sand, silt and clay for each sample are represented graphically in figure 4.1. Sample 1 has 59.51% of sand, 23.49% of silt and 17% of clay. Sample 2 consists 18.2% of sand, 77% of silt and 4.8% of clay. Sample 3 has 3.50% of sand, 93.89% of silt and 2.9% of clay present. Sample 4 has 12.65% of sand, 84.20% of silt and 3.14% of clay. Sample 5 has 0.50% of sand, 88.14% of silt and 11.34% of clay. Sample 6 has 0.83% of sand, 90.99% of silt and 8.18% of clay. Sediment sample from mouth region of the estuary i.e. sample 1 has higher percentage of sand followed by samples from 2,3,4,5 and 6 where silt percentage were more clay percentage were more in head of the estuary that is sample 5 and 6.

To understand the textural characteristics of sediments and hydrodynamic conditions of depositional environment a ternary diagram proposed by **Flemming (2002) and Pejrup (1988)** is used respectively

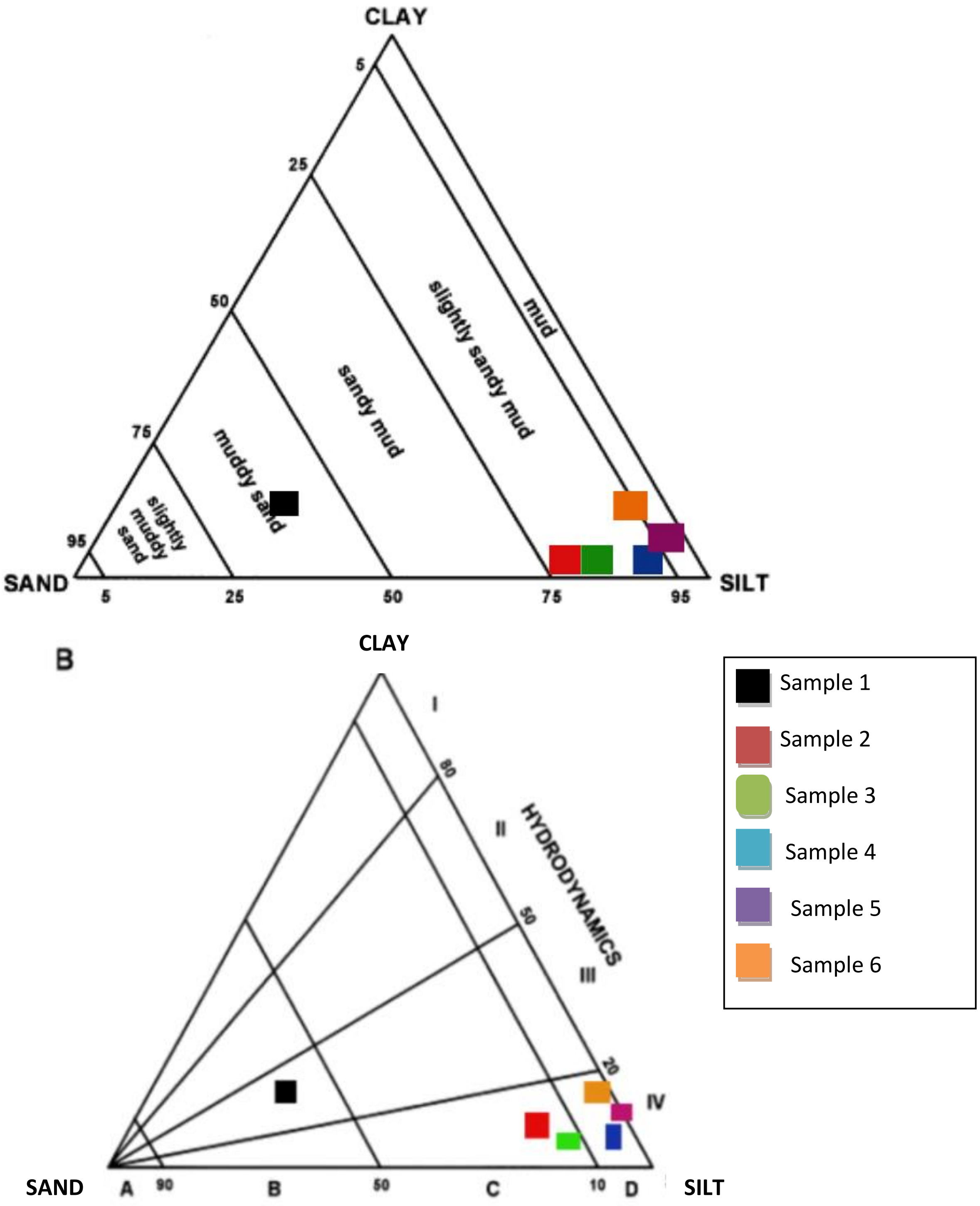


Fig 4.1 Ternary diagrams for the textural classification of sediments on the basis of sand/mud ratios. Diagram A**: Flemming (2002); B: Pejrup** (1988)

The data plotted in ternary diagram flemming (2002) witnesses highly variable grain size character that is

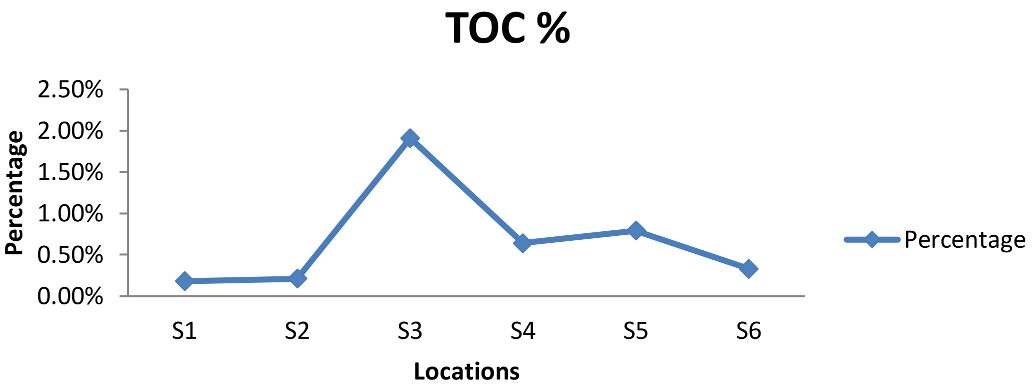
Sample 1 which is marked in black colour shows that the texture of sediment is muddy sand Sample 2, 3 and 4 which is marked in red, green and blue colour shows that the texture of the sediment in this area is slightly sandy mud. Sample 5 and 6 is marked in purple and orange in colour show mud texture.

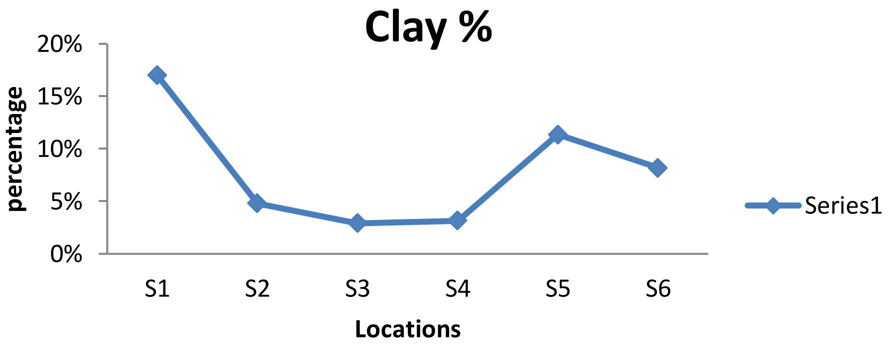
This highly variable grain size character reflects change in hydrodynamic condition of depositional environment which is inferred by plotting the data in ternary diagram pejrup (1988). Sample 1 falls in B-III which shows relatively violent hydrodynamic condition sample 2-6 falls in C-IV and D-IV which represents a very violent hydrodynamic conditions.

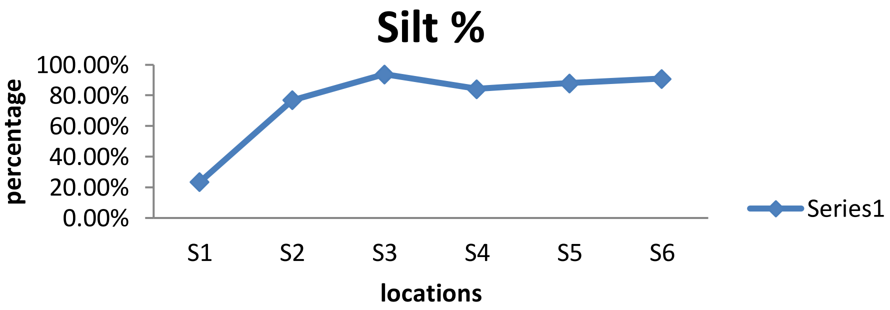
4.3 Total organic carbon

The below graph and table represents the percentage of total organic carbon in the sediments of Terekhol Estuary.

Total Organic Carbon (TOC) is a measure of the total amount of carbon in organic compounds in pure water and aqueous systems. TOC is a valued, analytical technique that is applied by organizations and labs to determine how suitable a solution is for their processes. The percentage of TOC for all samples is given in Table 4.3. The organic carbon content varies from minimum of 0.18% in location 1 to a maximum of 1.91% at location 3 .As seen in the graph the mid-region sample 3 exhibit higher content of organic matter compared to samples from the mouth and head locations (Figure 4.3).There is variation within each location, suggesting differences in organic matter content even within the same area







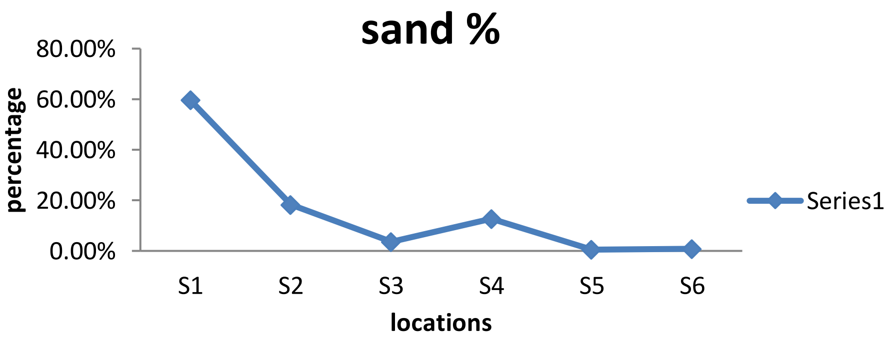


Fig 4.3 Graphs representing Sand , silt ,clay and TOC percentage in Terekhol estuary.

Table 4.3 Sand, silt ,clay and TOC percentage in sediment sample

Locations	Sand%	Clay%	Silt%	TOC%
S1	59.51%	17%	23.49%	0.18%
S2	18.2%	4.8%	77%	0.21%
S3	3.50%	2.9%	93.89%	1.91%
S4	12.65%	3.14%	84.20%	0.64%
S5	0.50%	11.34%	88.14%	0.79%
S6	0.83%	8.18%	90.99%	0.33%

These results suggest that organic carbon concentrations increase as you move from the mouth towards the middle of the estuary, with the highest concentrations found in the middle regions and then it decreases from middle region This pattern is likely influenced by factors such as the input of organic matter from surrounding land and biological activity within the estuarine ecosystem. High organic carbon levels can impact water quality, sediment dynamics, and ecosystem health within the estuary.

4.4 Percentage of clay minerals using XRD graph

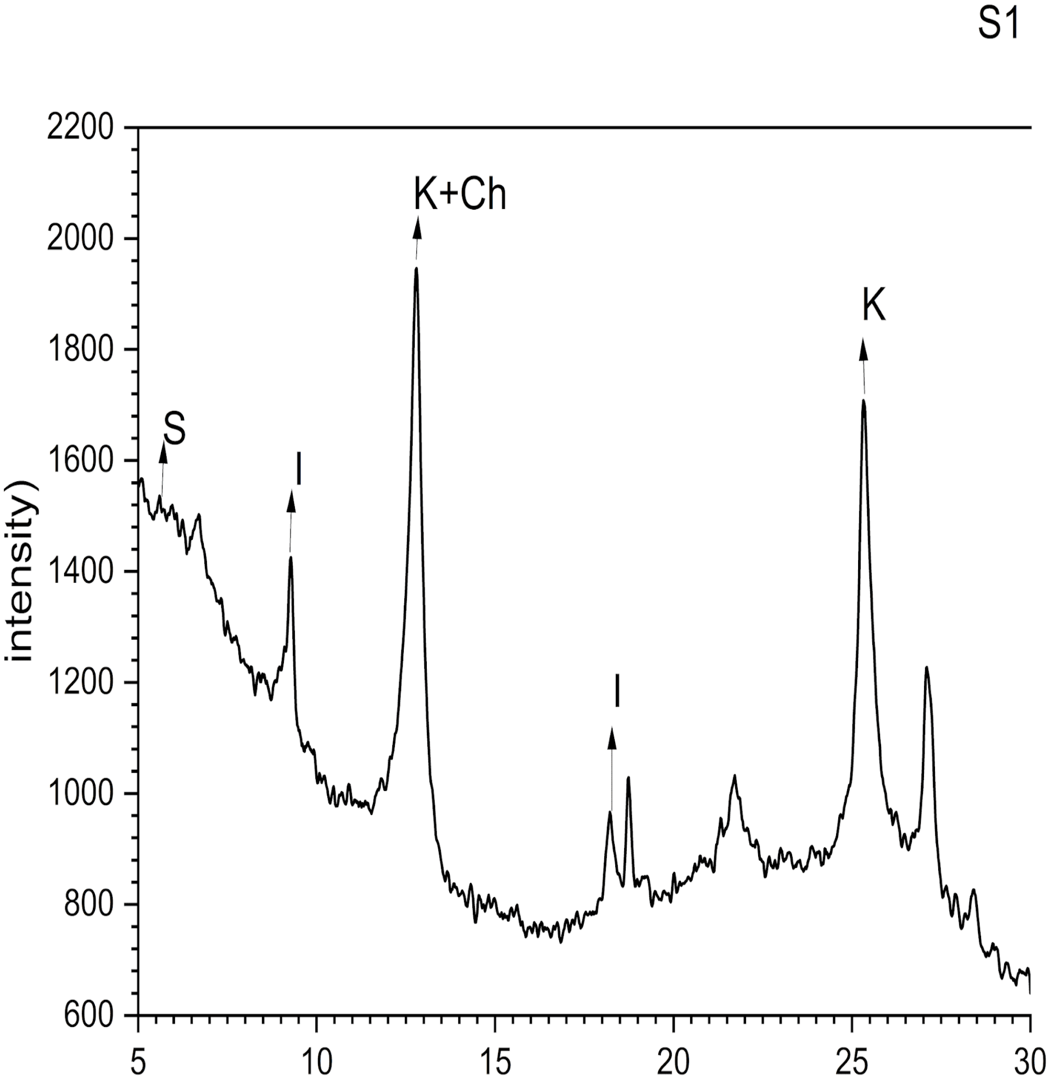
Sample	I%	S%	(K+Ch)%	K%
S1	21.02%	4.85%	74.12%	74.12%
S2	15.03%	3.75%	81.20%	81.20%
S3	14.81%	3.70%	81.48%	81.48%
S4	22.10%	0%	77.89%	67.79%
S5	0%	0%	100%	100%
S6	0%	0%	100%	100%

Table 4.3 showing percentage of Illite, Smectite and Kaolinite

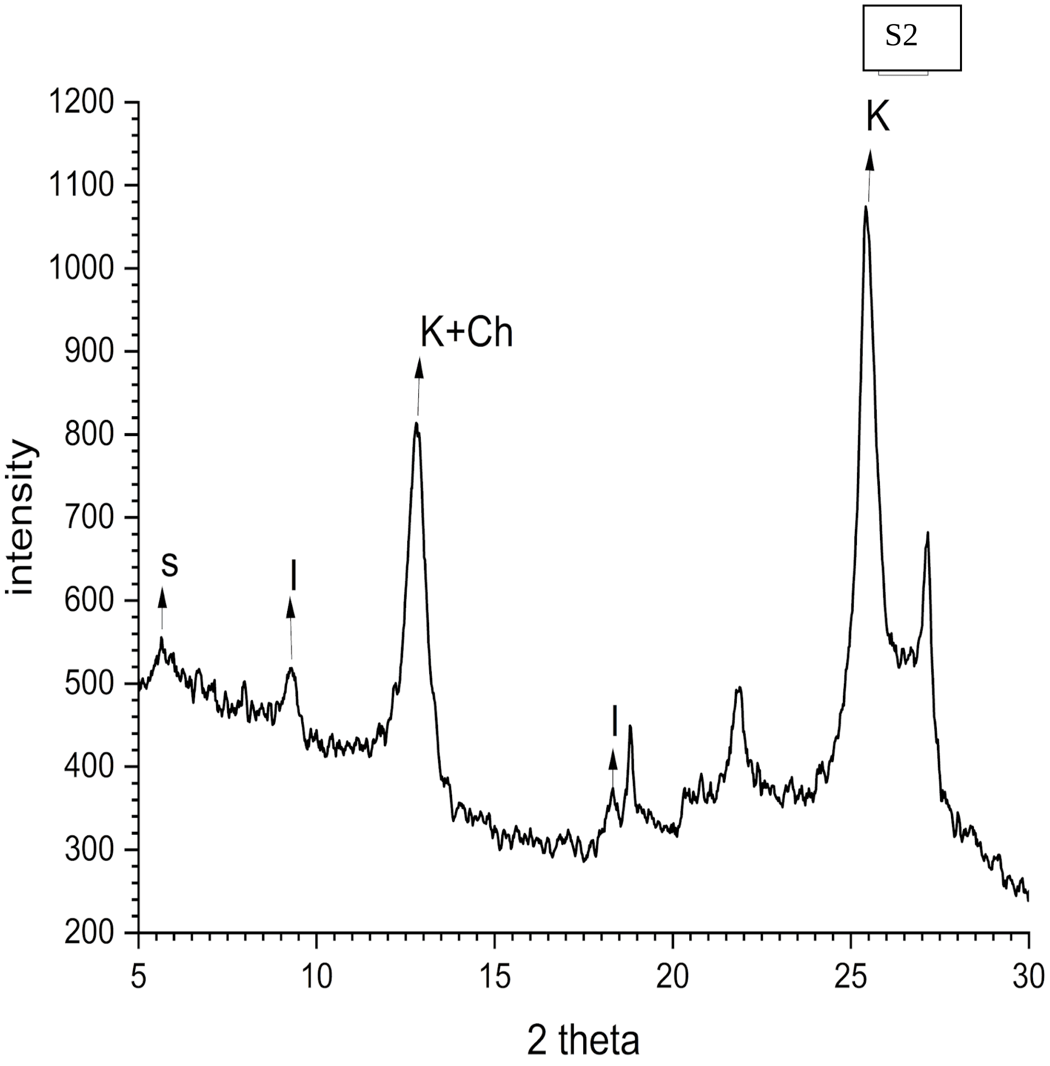
Further illite chemistry shows rich in Mn and Fe concentration in the sediments.

SAMPLE NUMBER	ILLITE CHEMISTRY
Sample 1	0.4
Sample 2	0.3

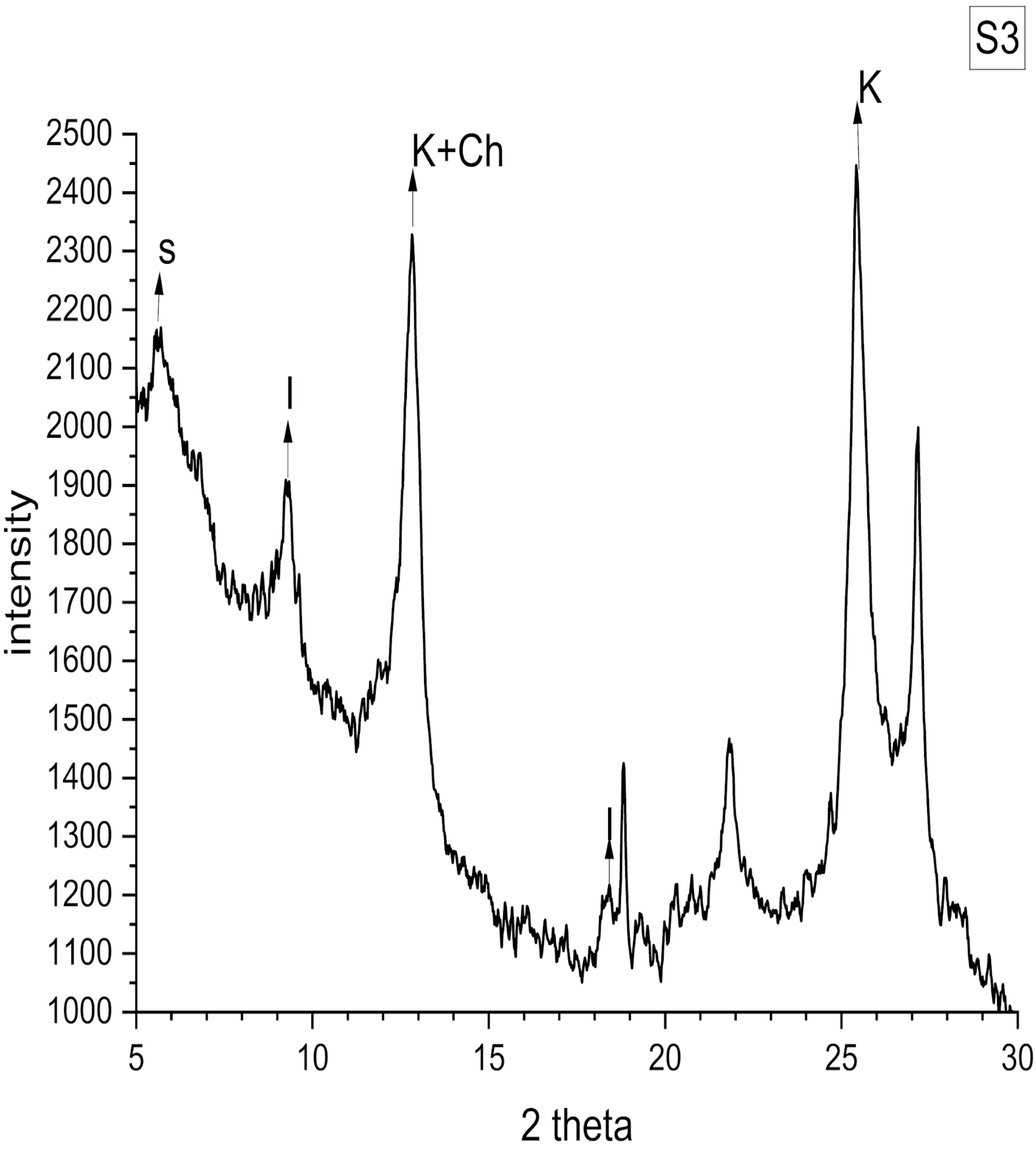
Table 4.4 showing Illite chemistry


S1
intensity)
2200
2000
1800
1600
1400
1200
1000
800
600
5
10
15
20
25
30
S
I
K+Ch
I
K

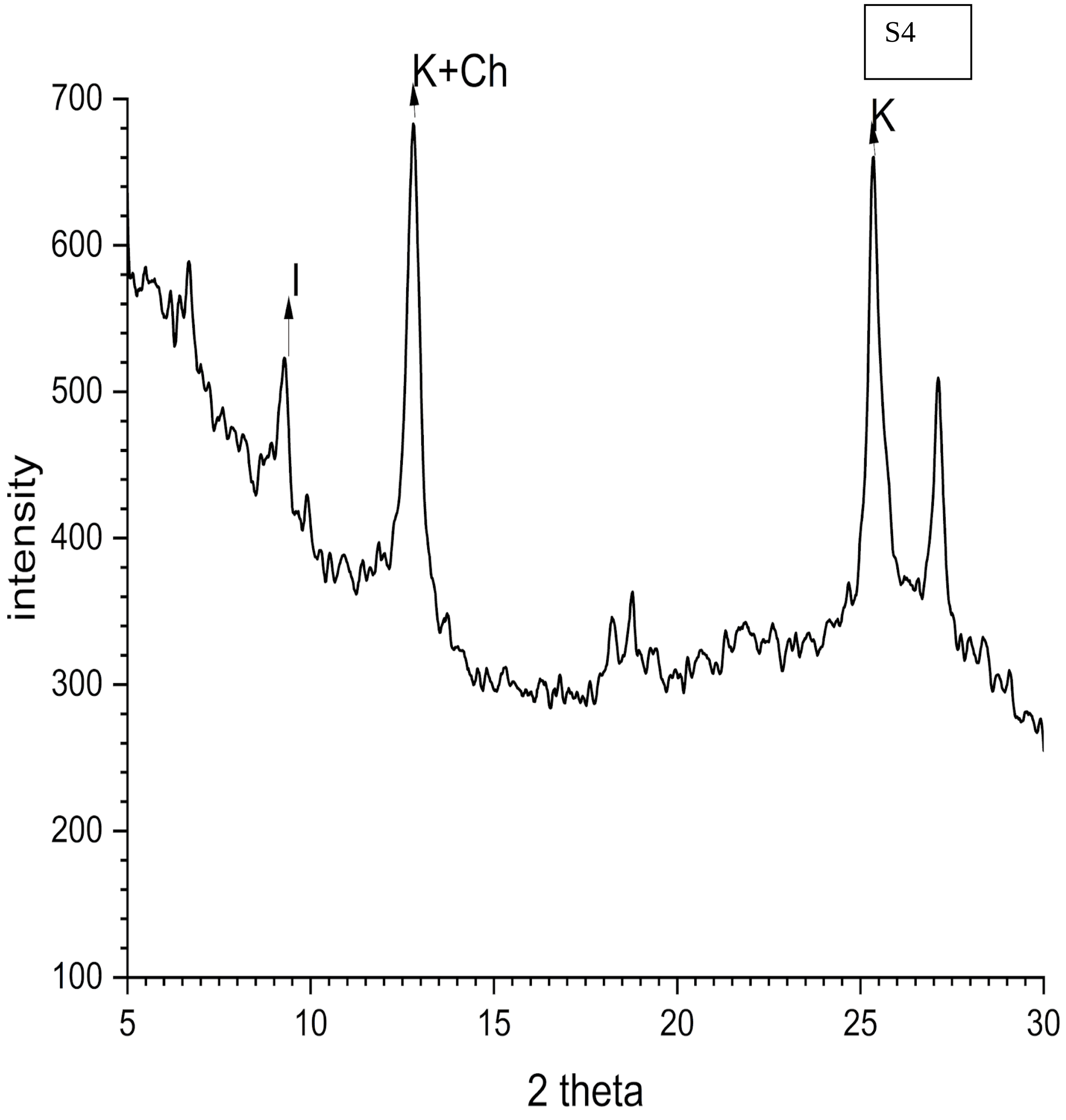
A:Location 1


S2
K
K+Ch
s
I
I
1200
1100
1000
900
800
700
600
500
400
300
200
intensity
5
10
15
20
25
30
2 theta

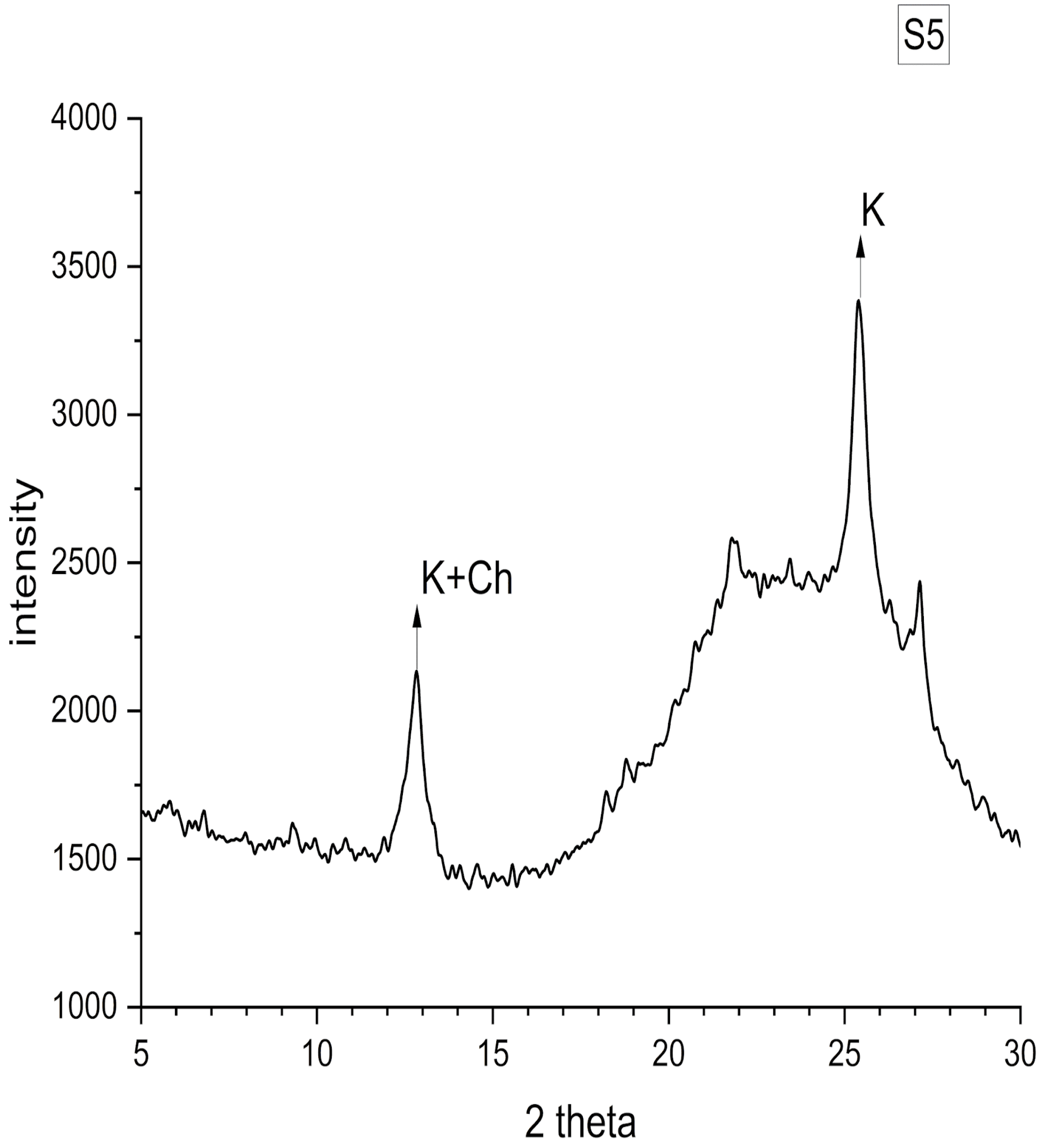
B:Location 2


S3
K
K+Ch
s
I
I
intensity
2500
2400
2300
2200
2100
2000
1900
1800
1700
1600
1500
1400
1300
1200
1100
1000
5
10
15
20
25
30
2 theta

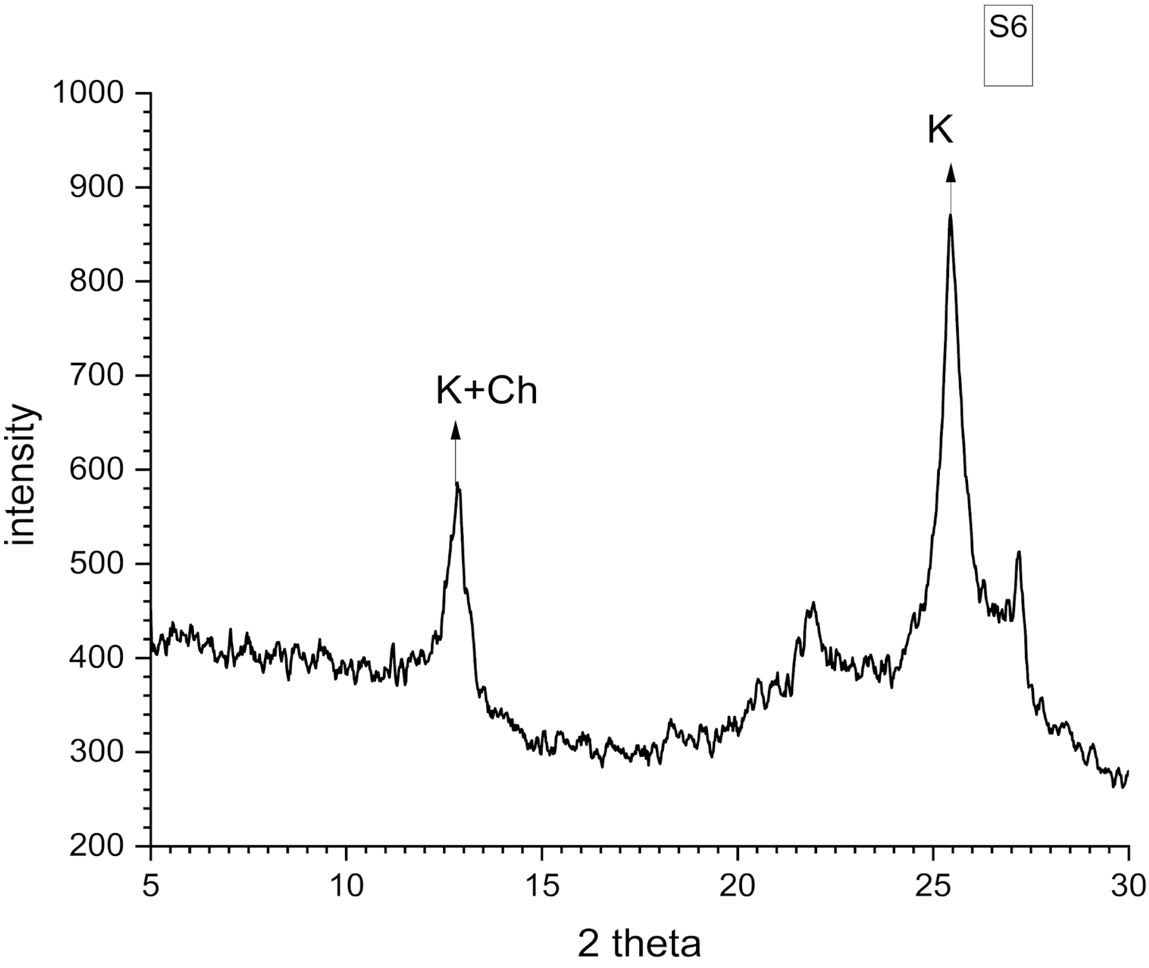
C: Location 3


S4
K+Ch
K
I
intensity
700
600
500
400
300
200
100
5
10
15
20
25
30
2 theta

D:Location 4


S5
K
K+Ch
intensity
4000
3500
3000
2500
2000
1500
1000
5
10
15
20
25
30
2 theta

E: Location 5



F:Location 6

Figure 4.4 A, B, C, D E and F showing XRD graph samples 1,2,3,4,5 and 6 respectively

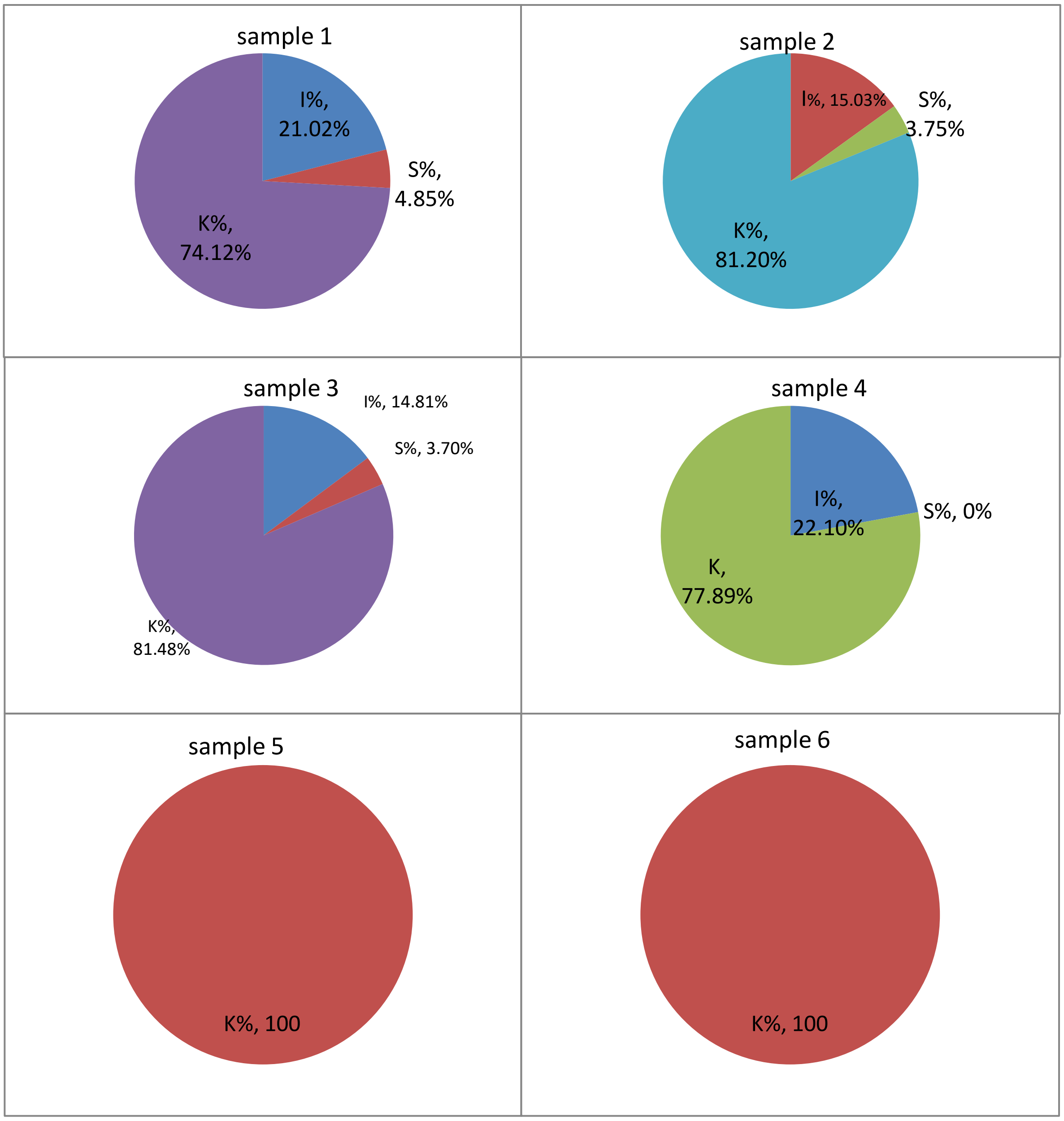


Fig 4.5 Graphical representation of Smectite,Illite and Kaolinite in sample 1,2,3,4,5and 6

XRD analysis was conducted on six sediment samples, revealing the presence of Illite, Smectite, Kaolinite, . The abundance of clay minerals follows the order of Kaolinite > Illite > Smectite. Smectite content ranges from3.70 % to 4.85%, with Illite ranging from 14.81% to 23.72%, and Kaolinite from 67% to 100%.

Smectite and Illite exhibit a decreasing trend from sample 1 to 4, becoming absent in subsequent samples, while Kaolinite decreases from sample 6 to sample 1, indicating a reverse trend from mouth to head region.

4.5 Benthic foraminifera found in the Terekhol estuary.

Sample	Total number of foraminifera in 10g of the sediment sample	Full shell foraminifera in 10g of sediment sample	Broken foraminifera in 10g of sediment sample
Location 1(mouth of the estuary)	476	387	89
Location 2(mouth of the estuary)	357	169	188
Location 3(middle of the estuary)	-nil-	-nil-	-nil-
Location 4(middle of the estuary)	-nil-	-nil-	-nil-
Location 5(head of the estuary)	-nil-	-nil-	-nil-
Location 6(head of the estuary)	-nil-	-nil-	-nil-

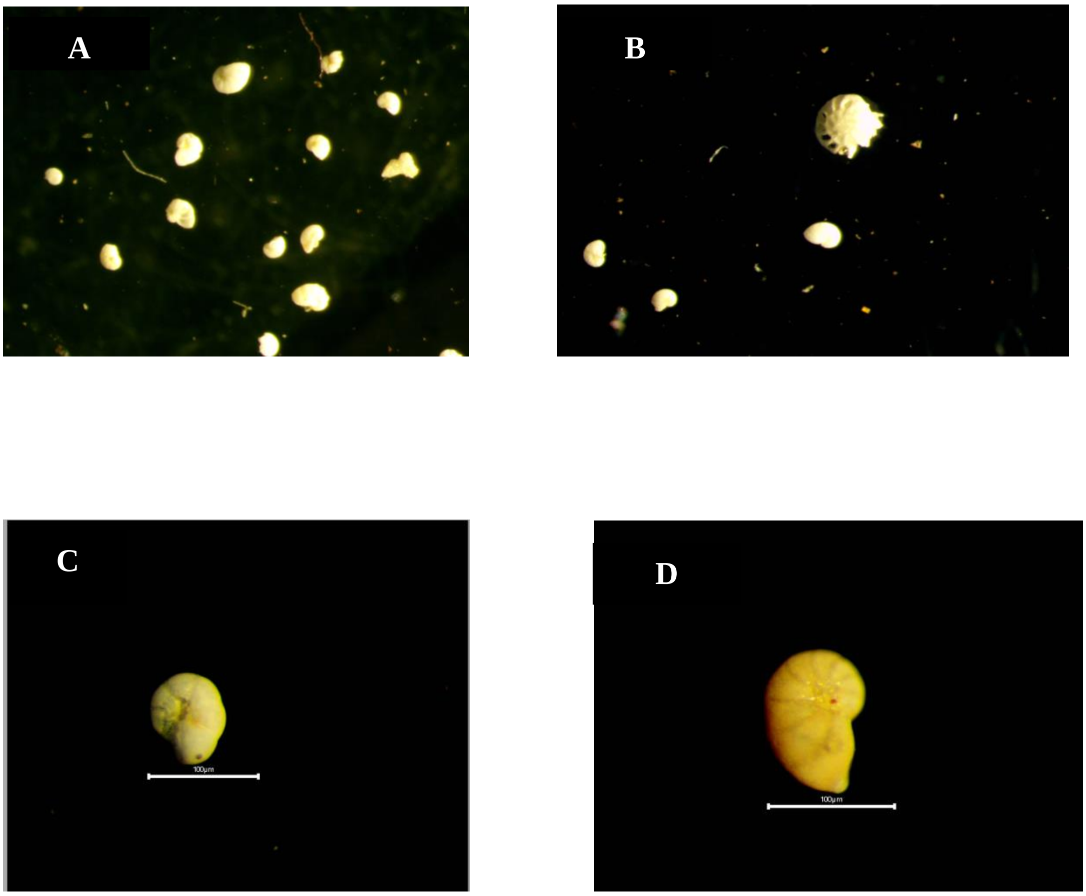


Fig 4.6 A,B,C and D represents benthic foraminifera found in location 1 and location 2

Distribution pattern of formanifera in surface sediment in this estuary shows gradual landward of formaniferal density along the estuary. In sample 1(mouth) shows total of 476 in sediment sample and in sample 2 (mouth) shows total formanifera of 357 in 10 g of sediment sample .

Higher number of formanifra are found in the mouth region of the estuary with more marine influence

DISCUSSION

Sediment analysis

The observed variations in sediment composition across the sampling locations within the estuary provide valuable insights into the mineralogy textural composition of sediments and hydrodynamics of environmental conditions within the Terekhol Estuary.

The sediment component and grain size variations along the estuary indicate change in energy gradient which reflects change in the process of sediment transport. Increase in sand fraction in the sediment of mouth region corresponds to high energy condition. Whereas increase in mud fraction in the sediment of corresponds to low energy conditions which is true for middle estuary region and head region. The dominance of sand and silt particles at the location could be attributed to the higher energy regime associated with tidal currents and wave action near the estuary mouth (**Nasnolkar et al. 1996**). These processes facilitate the transportation and deposition of coarser sediment particles, resulting in the observed composition. The head region is restricted by hence, the qualities outlined account for the presence of the smallest sediment particles located at the upstream end of the estuary, where water circulation is at its weakest (**Romano et al. 2013**).

In recent years in Terekhol estuary there are lots of human activities such as sand mining deforestation, construction, agriculture, and urbanization this accelerate soil erosion and sedimentation. If there is significant land disturbance in the Terekhol Estuary's watershed, it could lead to higher silt levels due to increased sediment runoff into the estuary.

Total Organic Carbon

Total organic content is highest in sample 3 (middle estuary) seems to be due to mud size particle. The grain size of sediments influences the distribution and concentration of TOC. Finer sediments, such as silts and clays, typically have higher surface areas and higher organic carbon contents due to their greater adsorption capacity. Coarser sediments, such as sands, generally have lower TOC content because they have less surface area available for organic matter adsorption. Clay minerals have a high affinity for organic matter. In estuarine environments like Terekhol, clay minerals can absorb organic matter, leading to higher TOC content in sediments. Organic matter can be derived from terrestrial sources (such as plant debris) or from aquatic sources (such as phytoplankton). The presence of clay minerals can influence the preservation and accumulation of organic matter in sediment.

Distribution of clay mineralogy in the sediments of Terekhol estuary using XRD graphs

It is observed that kaolinite is predominately present along the estuary. The peak indicating the presence of kaolinite could be seen as primarily representing kaolinite rather than chlorite, as kaolinite is more expected to be dominant under the typical conditions of the study area **(Bukhari and Nayak, 1996**). The abundance of kaolinite in the Terekhol Estuary reflects the ongoing chemical weathering of source rocks, specifically granites and granitic gneisses, in the region. The breakdown of feldspar minerals in these rocks due to water and acidic reactions leads to the formation of kaolinite (**Nasnodkar and Nayak, 2019**). Higher amount of Kaolinite and its decreasing trend from head to mouth region clearly reflects its derivation from catchment area and hinterland area which consists mainly of precambrian crystalline rock. Illite typically originated from the weathering of potassium-rich minerals, especially potassium feldspar (**Bejugam and Nayak ,2017)**. Presence of Illite in location 1, 2 and 3 indicates that it has derived from marine origin. Smectite often originates from the weathering of volcanic ash and tuff (**Kessarkar et al. 2012**). Decreasing trend of smectite from sample 1, 2, 3 and 4 complete absence of smectite in sample 5 and 6 indicates reflects its marine origin.

Benthic foraminifera

From the observed distribution pattern of foraminifera the surface sediment of this estuary it can be inferred that they are mainly restricted to lower estuary where sediment component are rich in sand fraction leading to formation of porous sediment texture which allows circulation of dissolved oxygen.

CONCLUSION

The sediment composition within the Terekhol Estuary varies across its spatial extent, influenced by several factors including its proximity to the estuary mouth, local hydrodynamics, the origin of sediments, and the specific conditions of where sediments settle.

The distribution of Total Organic Carbon (TOC) varies along the estuarine gradient. The mid-region samples of the Terekhol Estuary display higher levels of organic matter compared to those from the mouth and head locations. Additionally, there are variations within each location, indicating differences in organic matter content even within the same area. The Total Organic Carbon (TOC) percentages offer valuable insights into the organic richness or decomposition levels present in the soil or sediment samples collected from these diverse locations.

Analysis of clay mineralogy using XRD graphs reveals the presence of smectite, illite, kaolinite, and chlorite, with kaolinite being the dominant mineral.

The presence of smectite and illite at the mouth of the Terekhol Estuary is likely the result of a complex interplay of geological, hydrological, and sedimentological processes acting within the estuarine system and its surrounding watershed. It also indicates that it has come from marine origin.

The abundance of these clay minerals, particularly kaolinite is likely influenced by dominance of potassium-bearing minerals and kaolinite-rich sediments in the Terekhol Estuary. This could be influenced by the weathering of local bedrock or input from surrounding catchment areas.

The abundance of benthic foraminifera is more at the estuary mouth due to more of marine influx salinity and tidal energy are major influencing factor on foraminifera distribution **(Hayward and Hollis, 1994)**

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