Heavy mineral distribution studies along the Riverine sediments of Goa, India

A Dissertation Report for

GEO-651 Dissertation

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Submitted in partial fulfilment of Master's Degree

MSc in Applied Geology

by

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April 2024

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DECLARATION BY STUDENT

I hereby declare that the data presented in this Dissertation report entitled, "Heavy mineral distribution studies along Riverine sediments of Goa, India" is based on the results of investigations carried out by me in the Applied Geology at the school of Earth, Ocean and Atmospheric Sciences, Goa University under the Supervision of Dr. Pooja Ghadi 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 the dissertation.

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02/05/2024

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Date: 02/05/2024

Place: Goa University

COMPLETION CERTIFICATE

This is to certify that the dissertation report "Heavy mineral distribution studies along Riverine sediments of Goa, India" is a bonafide work carried out by Mr. Mohammad Kaif Jamkhandi under my supervision in partial fulfillment of the requirements for the award of the degree of Master of Science in the Discipline Applied Geology at the School of earth, ocean and Atmospheric Sciences, Goa University.

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Date: 2/5/2024

3/5/24

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School of Earth, Ocean & Atmospheric Sciences
Date:
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ABSTRACT

Heavy minerals are minerals with a density greater than about 2.9 grams per cubic centimetre. This is significantly denser than most common minerals found in sand. They help in understanding of depositional history and paleography. Rivers play an important role in the transport and concentration of heavy minerals. Rivers can transport and deposit valuable heavy minerals like titanium, zirconium, and gold. These minerals are often concentrated in placer deposits, which are accumulations of loose, sand- or gravel-sized particles. These deposits can be mined for their valuable minerals. However knowing the importance of Heavy mineral analysis and their distribution, Goa particularly lacks any published records with respect to this type of analysis. Hence this study is one such attempt to address the question. This study focuses on analyzing the heavy mineral components with special importance to the content of heavy minerals, to determine grain morphology and surface textures. For these two important rivers from Goa were chosen; River Sal and River Mandovi. From both the rivers and its tributaries total 39 Samples were collected. In the present study, heavy mineral assemblages were found to be dominated by Epidote, Tourmaline, Tremolite-Actinolite, Chlorite. Magnetic minerals such as Hematite, Goethite, Magnetite and Ilmenite was encountered as dominant mineral through X-ray Diffraction analysis. Scanning Electron Microscope (SEM) study of the grains of non-magnetic minerals such as Chlorite, Tourmaline, Epidote, Rutile and other minerals shows a variety of microtextures developed by mechanical, chemical and dissolution chemical processes operating in the river Sal and river Mandovi.

CHAPTER I

CHAPTER 1

1.1 Introduction

Sedimentation is the tendency of suspended particles to separate from the liquid in which they are trapped and come to rest on a barrier. This is because they move through the fluid depending on the forces acting on them. These forces can be due to gravity, centrifugal acceleration, or electromagnetism. In geology, deposition is often referred to as the opposite of erosion, the end point of sediment transport. In this sense, this also includes the cessation of transport by salted transport or true flatbed transport. Sedimentation is the settling of suspended particles in a liquid Sedimentation is the termination of the sedimentation process. In estuarine environments, establishment can be influenced by the presence or absence of vegetation. Trees such as mangroves are important in dampening waves and currents, thereby facilitating settlement of suspended particles. Sedimentation can affect objects of various sizes, from large rocks in running water, to individual molecules such as dust suspensions and pollen particles, to cell suspensions and solutions. such as proteins and peptides. Even small molecules generate forces strong enough to cause significant sedimentation. Along with the sediments Heavy Minerals end up in river sediments through a combination of erosion and transportation processes. Heavy minerals refer to minerals with a density greater than 2.9 g/cm^3. However, due to their diversity (more than 30 common translucent detrital species) and often characteristic parasitism, they have always played an important role in interpreting the origin of sediments. Although analysis of heavy minerals was most popular in the early part of this century, in the 1930s it was recognized that factors other than origin fundamentally controlled the distribution of heavy minerals. This, along with the development of new sedimentological and correlative techniques, led to a sharp decline in popularity, which essentially continues to this day. Nevertheless, heavy minerals remain very sensitive indicators of

provenance, and if limiting factors are properly addressed, their study may continue to provide important information for paleogeological reconstructions. They are classified into 3 types for the convenience of density of the Useable. They are Heavy heavy minerals with a density of 6.8-21g/cm³, Light light minerals with the density of 4.2-6.7g/cm³ and Gemstones with a density of 2.9-4.1g/cm³. Other heavy minerals such as garnet and rutile tell stories of past volcanic activity and the erosion of ancient rocks. Heavy mineral journeys are often concentrated journeys. This often results in concentration in certain locations, forming valuable placer deposits such as beach sands rich in titanium and zircon. Heavy minerals such as ilmenite, rutile, zircon, and garnet are important economic resources and serve many industrial applications, such as: It is used as a raw material in the nuclear energy production industry and in the production of metallurgical and industrial products (Grosz and Schruben, 1994). Economic heavy minerals in coastal zones in general are of great interest in exploration and exploitation in various locations around the world.

This study sought to analyze the heavy mineral components with special importance to the content of heavy minerals and to determine grain morphology and surface textures.

1.12 Factors Influencing Heavy mineral Suites

The composition of heavy mineral suites in sediments is influenced by various factors.1. Tectonic Settings of the source region: The geological processes occurring in the source region significantly impact the heavy mineral content. Different tectonic settings (such as mountain-building events, subduction zones, or rift valleys) yield distinct heavy mineral assemblages. 2. Transport systems and depositional environments: The method of transport of sediments (rivers, glaciers, wind, etc.) and

where they are ultimately deposited (river deltas, deep-sea fans, coastal plains) influence the distribution of heavy minerals. For example, river systems can selectively transport certain minerals downstream. 3. Relief and slope: Steep slopes can result in more efficient erosion and transport of heavy minerals. Conversely, gentle slopes allow for selective deposition. 4. Provenance: The specific rock types in the source region contribute different heavy minerals.

1.13 Rivers in Goa

Goa is the 25th state of the Indian Union and has an area of approximately 3,702 km. Eleven rivers flow through this small but beautiful state. These rivers have sustained the land of Goa since the earliest forms of human settlement. The discovery of a large number of rare Stone Age carvings proves this. Terakol, Mandovi, Baga, Zuari, Kolbar, Sal, Mandre, Harmar, Sal, Tarpora and Galjibag are the 11 rivers of Goa and are considered the lifeblood of the state. These 11 major rivers and 42 tributaries are not only important as sources of drinking water due to the size of their catchment areas and their attractiveness to people, but also support Goa's ecosystem. Most of Goa's major rivers originate in the dense forests of the Western Ghats, many of which are protected areas, and flow into the Arabian Sea. Goa's small-scale landscape is dominated by these rivers, which form a complex system of wetlands, tidal marshes, and cultivated rice fields, connected by canals, inland lakes, bays, lagoons, and streams. and is controlled by periodic tides. Therefore, Goa is more closely connected to the river and its livelihood also depends on it.

Figure 1.1 River basin map of Goa

1.14 Geology of Goa

The state of Goa is located towards western coast of India having area of 3702 km sq. The state is located between latitude 14°53'57''N and 15°47'59" E and between the longitudes 73°40'54" N and 74°20'11" E. It is surrounded by Maharashtra in the north and Karnataka in the south, Arabian sea towards west. Shimoga Goa supracrustal belt is situated in the NW part of western Dharwar craton. Shimoga Goa belt trends NNW-SSE and is approximately 250 km in length and 120 km in breadth at Dharwar. Eastern margin at Shimoga belt is faulted, the south is laden with shallow water deposits and western margin is marked with Chandranath Gneiss and Canacona Granite.

The supracrustals that constitute the Goa Group of Gokul et al. (1985) can be divided into two lithostratigraphic sequences namely the Barcem Group and the Ponda Group (Dessai 2011). The former comprises predominantly greenstones (metabasalts) and

rests on a basement of the 3300–3400 Ma Anmode Ghat Trondhjemite Gneiss with a crudely developed quartz-pebble conglomerate at the base, and shows lithological similarities with the lower part of the Bababudan Group. The younger sequence is dominated by clastics, and is assigned to a new stratigraphic group formally termed the Ponda Group which is equivalent to the Chitradurga Group of the Dharwar Supergroup. This group rests on a basement of the 2700–2900 Ma Chandranath granite gneiss with a distinct unconformity marked by a polymict, granite-clast metaconglomerate. It is overlain by a psamolitic sequence which is followed in ascending order by the chemogenic sediments that host the BIF and by the deep water turbidite sequence (argillite-greywacke association) with intercalations of mafic volcanics. The supracrustal sequence is intruded by the Bondla layered mafic-ultramafic complex along a major shear zone (NW-SE) that largely controls the course of the north-westerly flowing tributary of River Mandovi. The late intrusive, Canacona potassic granite marks the culmination of these sedimentation in the Shimoga-Goa basin.

Anmod ghat trondhjemite gneiss: It is one of the oldest gneissic of India that temporally correlates with Gorur gneiss from Hassan District of Karnataka (Beckinsale et al. 1980). Migmatite Gneisses and granitoid occur in complex association and form basement over which schist belt have formed. The Anmod trondhjemite gneiss is fine grained, granulated has metamorphic fabric where plagioclase dominantly occur as porphyroblasts. The foliation trends N-S and dips steeply at 60-70 due west. It varies in composition from Trondhjemite tonalite to granodiorite.

Chandranath Granite gneiss: Granite gneiss is relatively fine grained with greasy grey colour. It is classified as granite, monzogranite (Devaraju et al., 2007) with foliation

trending NE-SW and dipping 50 due E. Recent EPMA U-Pb monazite spot ages of 2619±37 ma (Rekha et al., 2013a) match well with earlier Rb-Sr whole rock age of 2650 ±100Ma (Dhoundial et al.,1987).

Dudhsagar granite: Dudhsagar granite is coarse grained rock showing weak to moderate foliation and preferred orientation of feldspar metacysts parallel to foliation. It is either synkinematically intrusive (Gokul et al. 1985) into the metavolcanics and metasediments or late to post-tectonic intrusion (Dhoundial et al. 1987). The WNW-ESE gneiss-granite belt is flanked by the greenstones of the Barcem Formation that rest on the basement of trondhjemite gneiss.

Canacona granite: These granites are unfoliated, blastoporphyritic, coarsed grained. It preserves the euhedral/subhedral magmatic shape and exhibits a discordant relationship with WNW-ESE foliation of older TTG/migmatite (Dessai, 2011; Rekha et al., 2013a, b). It is potassic and compared to the TTG/Migmatite which are strongly foliated and relatively sodic than Canacona granites. Contacts of Canacona granites are sheared and patches and shreds of older gneiss can be traced on either side of younger intrusions. According to estimated ages, Canacona granites are stratigraphically older than Chandranath granite gneiss.

Bondla mafic- ultramafic layered complex: It trends due NW-SE. It is ophiolitic, layered and consist of gabbro, troctolite, wehrlite, dunite, peridotite, pyroxenite and chromite and serpentinite with chromite (Jena, 1980, 1985; Sreeramachandra Rao et al., 1996; Dessai et al.,

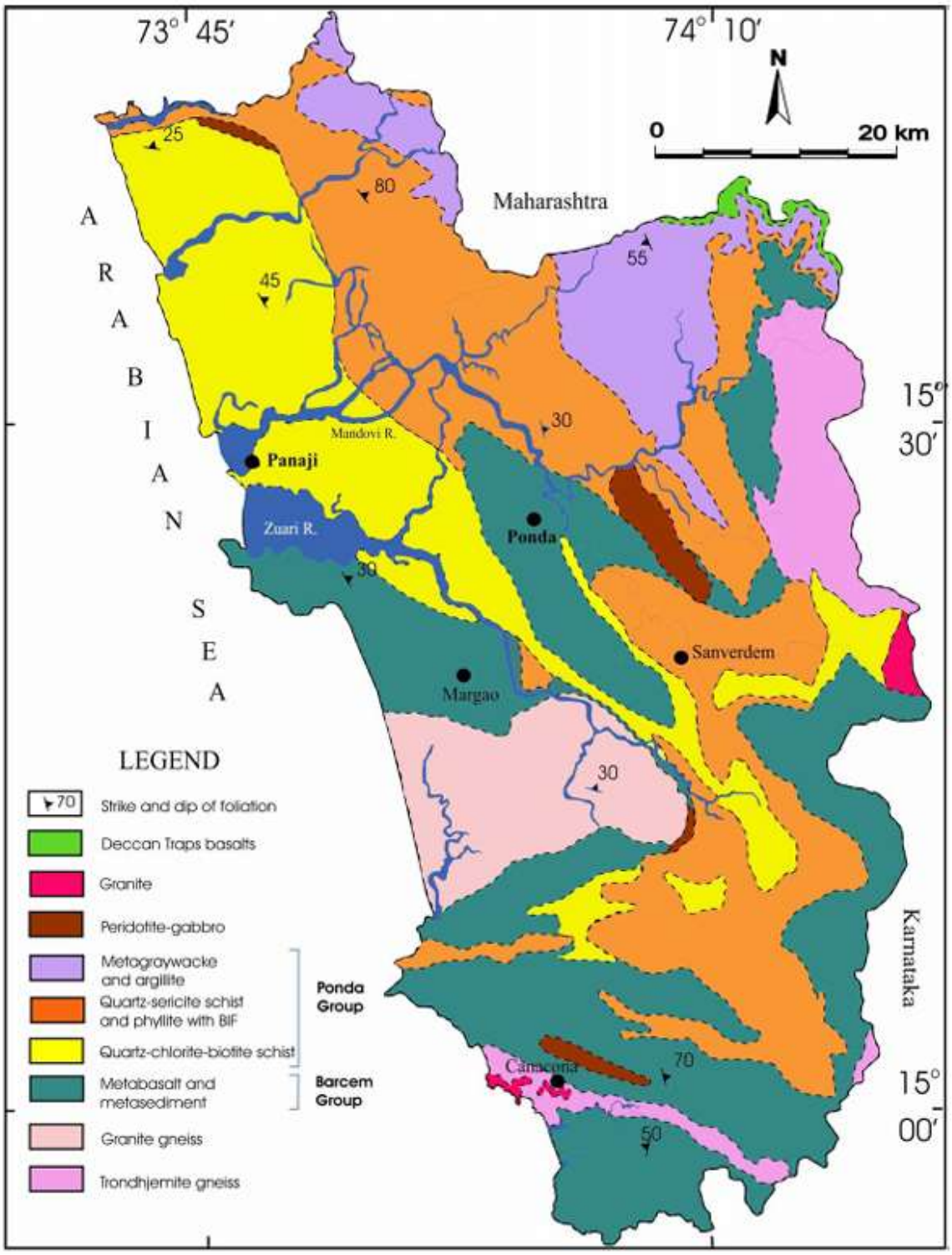

Figure 2.1 Geological map of Goa (revised after GSI, 1996, by integrating arguments based on the field, petrological, geochemical and isotope data following the works of Dhoundial et al. 1987; Devaraju et al. 2007; 2010; Dessai et al. 2009).

Barcem Group- Barcem formation was later renamed as Barcem Group and was co-related to the lower part of Kalaspura formation Bababudan Group (Dessai, 2011). Basal horizon of Barcem Group is quartz pebble conglomerate and lithounits consist of metavolcanics with intercalation of quartzite and pelites. Basic and felsic lavas, agglomerates and tuffs represents volcanics. The metasediments include quartzites, quartz-sericite schist, quartz-chlorite schist and minor phyllites. Quartz-sericite schist and quartz porphyry represents metavolcanics. At place, they are deformed and contain porphyroclasts pf quartz in a pulverized quartz-sericite matrix.

Ponda Group- The Ponda Group comprises three formations which in ascending order are the Savordem Formation, Bicholim Formation and Vagheri Formation.

- Savordem Formation:- The Sanvordem Formation of the Ponda Group overlies on Barcem Formation. The basement for Sanvordem Formation is Chandranath Granite Gneiss, this formation comprises of metagreywackes, metaconglomerates and argillites. The rocks of Sanvordem Formation are exposed along the Sanvordem railway station and periodic accounts over the thickness above 1200m (Dessai, 2011).

- Bicholim Formation:- has an area over thickness of 1.4 km and consist of amphibole schist, ferruginous and manganiferrous phyllite, limestone and banded ferruginous quartzite(BHQ) ,that occur as intercalations with the phyllites (Gokul et al., 1985). BHQ's serves iron ore deposits that are extensively developed in the formation.

- Vagheri Formation:- it overlies the Bicholim Formation and it is the top most and the youngest formation of the Ponda group .The formation consist of metagraywackes and matabasalts. The rocks of Vagheri Formation are well exposed to the NE of Valpoi region.

Mafic Intrusive Rocks:- Igneous mafic intrusives are a common feature and cross-cut the entire sequence of Goa Group of rocks. Selected dykes from the coastal part of North Goa are geochemically akin to Deccan type magmatic products and specifically to transitional

Ambenali-Mahabaleshwar magma type (Widdowson et al. 2000). These same dykes were dated using the 40Ar/39Ar technique to 62.8 ± 0.2 Ma (Widdowson et al., 2000), an age that is significantly younger than the current estimates for the age range of Deccan Traps volcanism (~65-69 Ma) (Sprain et al., 2019). The ages are looked upon with caution owing to the absence of any plateau ages (Baksi, 2014).

Few dykes in south Goa (Canacona region) reveal geochemical similarity to normal MORB (mid-oceanic ridge basalts) and IAT (island arc tholeiites) (Fernandes and Widdowson, 2009).

These dykes are dated using 40Ar/39Ar laser ablation technique yielded variable ages from 2.7– 4 Ga with the majority of the feldspar ages occurring within the 2.7 – 3.4 Ga range (Fernandes and Widdowson, 2009).

Komatiitic ultramafites of Goa: Serpentinised peridotites occur at Netorlim along the Netorlim-Verlem road. They occur as lenticular bodies within the metasediments, while many of these ultramafic lenses may represent intrusives but pillow-like structure indicative of subaqueous eruption are poorly preserved in the ones found at Netorlim. In some cases, the rock exhibits ‘spinifex’ texture with acicular olivine

(serpentinised) in a groundmass of devitrified glass (e.g. Dessai and Deshpande, 1979 a). In most cases the acicular mineral in the rock is not olivine but a metamorphic amphibole. The veins of chrysotile asbestos occur in these rocks. Chemically the rocks contain high percentage of MgO (>17 wt %), very low TiO2(< 0.6 wt %), K2O (< 0.4 wt %), SiO2 (< 50 wt %) and CaO/Al2O3 >1, hence bearing similarities to the komatiites of South Africa. The existence of rocks of komatiitic characteristics in Goa leads one to believe that vestiges of pristine crust may be present in this part of the Dharwar Craton.

Deccan Traps:- The Deccan Trap flood basalt province covers an area of 500,000 km.sq of Indian states viz. Maharashtra and adjoining regions in Gujarat, Madhya Pradesh, Andhra Pradesh, Karnataka and northeastern strip of Goa (Krishnan, 1960; Agashe and Gupte, 1971; Raja Rao et al., 1978). Off shore drilling in the western India continental coast has revealed its subsurface extension is sometimes lying 1500 m below the mean sea level (Valdiya, 2016). With original lava volumes above (1-3) ×106 km3 (Wadia, 1975; Sen, 2001), they are mostly composed of laterally extensive flat- lying tholeiite flows (West 1959; Raja Rao et al. 1978).

The basalts flows are of two types, “compound” and “simple” (Bondre et al., 2004a, b). Several methods have been used to estimate the age of the Deccan Traps that include stratigraphical, paleontological, paleomagnetic and radiometric methods (Baksi, 1994; Jaeger et al., 1989; Vandamme et al., 1991; Venkatesan et al., 1993; Venkatesan and Pande, 1996; Hofmann et al., 2000; Pande, 2002; Schoene et al. 2015; 2019; Sprain et al., 2019). There are estimates of a very rapid eruption of the basalts over perhaps a million year at 67.6± 0.3 Ma (Courtillot et al., 1986, 1988; Duncan and Pyle 1988; Allegre et al., 1995; Hofmann et al., 2000). However, contrary to the suggestions of the Pande (2002) and Schoene et al. (2019) episodic nature of Deccan

volcanism, Sprain et al. (2019) suggest that >80% of volcanism took place within 1 million years.

Laterite:- Goa is covered by a layer of laterite ranging in thickness from a few meters to 25 meters. It is generally pisolitic (Gokul et al., 1985). Apart from granite exposures in Goa, laterite has developed almost overall lithologies especially over metabasalts of the Barcem Group and metagraywacke and argillite of the Sanvordem Formation which underlie many of the coastal plateau area (Widdowson, 2009).

1.3 Geology of the study area.

Geology of river Sal

The Sal River flows through the Salcete sub-district of Goa, which is underlain by rocks belonging to the Dharwar Supergroup. This supergroup comprises Archaean-Proterozoic metasedimentary and metavolcanic rocks, including banded iron formations (BIFs), quartzites, metaconglomerates, schists, and limestones. These rocks are overlain by a thick layer of laterites, formed by the weathering of underlying rocks. Laterites are typically rich in iron and aluminium oxides and can be quite resistant to erosion. While detailed information about the Sal River's geology is scarce, it's likely that similar rock types as mentioned above (BIFs, quartzites, schists, etc.) underlie the riverbed and its surrounding areas. Studies suggest that the riverbed sediments themselves contain high levels of certain metals like cobalt, nickel, and zinc, potentially indicating anthropogenic inputs due to pollution.

Geology of river Mandovi

The Mandovi River in Goa flows through a fascinating geological landscape, primarily dominated by ancient rocks dating back to the Archaean-Proterozoic era. Here's a breakdown of its geological story:

Underlying Rock Formations:

• Goa Group: The majority of the Mandovi's journey involves traversing rocks belonging to the Goa Group, part of the larger Dharwar Supergroup. These rocks are mainly metamorphic, formed from ancient sedimentary and volcanic rocks through intense heat and pressure. Common rock types include metagreywacke, conglomerate (tilloid), and argillite.

• Laterite: In the upper reaches of the Mandovi, particularly in the eastern hills, laterite, a reddish-brown, iron-rich rock formed by the weathering of other rocks, becomes more prominent.

• Other: Near the coast and river mouth, some areas might reveal younger sedimentary rocks like sandstones and clays.

Specific Locations such as Upstream that Closer to the source in the Western Ghats, the Mandovi encounters rocks like granites and metamorphics of the Dharwar Supergroup alongside the dominant Goa Group rocks and Downstream when the river approaches the Arabian Sea, the influence of laterite diminishes, and sedimentary deposits gain significance.

CHAPTER II

CHAPTER 2

LITERATURE REVIEW

2.1 Heavy mineral studies globally

Heavy mineral deposits exist all over the world, most concentrated in Australia, Asia (particularly along the Indian Ocean border), and Africa. Mineral deposits can be found on land or in the sea and come from a variety of geological environments.

Hongli pang had conducted a study on heavy minerals analysis and provenance of yellow river sediments around the China Loess Plateau in Key Laboratory of Western China's Environmental Systems (Ministry of Education), College of Earth and Environmental Science, Lanzhou University, Lanzhou, Gansu 730000, PR China and Department of Earth and Environmental Sciences, University of Milano–Bicocca, 20126 Milano, Italy. (Elseveir 2016)

The middle and upper reaches of the Yellow River have a high sand content after crossing. Vast desert areas and the Loess Plateau of China. Understanding the sediment composition of riverbeds. This waterway is crucial in elucidating the possible origin, transport of aeolian sand, and the connection of the Loess Plateau to the Yellow River. To address these issues, we have collected the following information: Fifty-two samples from modern riverbeds, nearby deserts, and major tributaries are collected and analysed for particle size, grain morphology, and heavy mineral composition to determine the spatial distribution and characteristics of source areas and riverbed sediments. Heavy mineral aggregates Significant differences can be seen in different sections of the Yellow River. Riverbed samples from upstream are dominated by opaque

minerals (limonite and magnetite), amphibole, and epidote, with small amounts of zircon, tourmaline, and rutile. The riverbed sediments of the middle reaches are rich in garnet, reflecting the widespread distribution of Mesozoic sandstones. of Variations accurately reflect the source region. Our data indicate that seasonal tributaries ('Ten Valleys') carrying debris from the Ordos Plateau may be responsible for locally high garnet concentrations in the upstream Inner Mongolia region. I am. Scanning electron microscopy (SEM) images of quartz grains show that river sediments are characterized by a complex microstructure Obtained in both the river and wind environment of Hedong Desert, Ulanbu Desert, and Kubuku Desert. The mineral composition of the upper reaches (Lanzhou-Yinchuan) is similar to that of sediments on the Loess Plateau and northeastern Tibetan Plateau (west Lanzhou). However, the configuration is different It is clearly different from the upper and middle reaches of Inner Mongolia. This variation indicates that in the upstream region, the northeast Tibetan Plateau contributes a significant amount of water. Sediments to the Yellow River and Loess Plateau, but the composition changes throughout the upper and middle Inner Mongolia regions due to localized sediment supply from arid desert areas and seasonal tributaries.

Heavy minerals in modern Yellow River sediments and potential sources (deserts and tributaries). Opaque minerals include limonite, magnetite, ilmenite, anatase, and leucosin. ZTR= Zircon Tourmaline Rutile (Hubert et al., 1962). More stable minerals are zircon, tourmaline, rutile, garnet, monazite, titanite. Less stable minerals include epidote, amphibole, and pyroxene (Zuffa et al., 2007). The black straight line indicates the main wind direction, and the black dotted line indicates the wind direction. Line indicates crosswind direction.

The main transparent minerals are amphibole (2% to 48%), which is mainly dark green, green, and brown in color, and garnet, which is mainly pink in color (6% to 60%), from rounded to rounded. Other mineral types include epidote (0.4% to 28%), zircon (0.6% to 19%), apatite (0.04% to 3%), and pyroxene. (0-5%), titanite (≤ 3%).

In this study, Hongli Panga combines heavy mineral analysis and particle surface structure analysis to conduct a detailed study of riverbed sediments in the middle and upper reaches of the Yellow River, along the Great Bend, and adjacent headwaters. This study aims to provide insights into the relationship between the Yellow River the Loess Plateau, and the surrounding desert. This helps determine controlling factors and distinguish major additional sediment source areas, thereby improving understanding of upstream-to-midstream coarse sediment distribution characteristics in alluvial area.

According to Younus I. Al-Saady published on 2020, the diverse nature of the lithology, morphometry, and geomorphology of the Lesser Zab River Basin (LZRB), NE Iraq provides a unique framework for research Spatial distribution pattern of heavy mineral accumulation Relationship between river sediments and their source rocks.

This study (i) provides a detailed description of the heavy mineral assemblages of the LZRB and their distribution patterns in surface sediments along the main basin and tributaries of the downstream region; (ii) provides a detailed description of the layer microstructure and This is an attempt to identify the shape of selected mineral grains, (iii) to determine the provenance of heavy

minerals, and (iv) the relationship between heavy mineral accumulation and tectonics is interpreted. attitude.

The Lesser Zab River (LZR) is Iraq's largest tributary, with a basin area of approximately 20,000 square kilometers, most of which is in Iraq, where it flows into the Tigris River. The river passes through highly folded and faulted igneous and metamorphic belts in northeastern Iraq. They studied heavy minerals in recent sediments of the Lesser Zab River Basin (LZRB) and determined their mineralogy, accumulation pattern, distribution mode, spatial variability, microtexture, origin, and tectonic environment. Twenty-four sediment samples were analyzed to determine heavy mineral composition using standard petrographic methods. Scanning electron microscopy (SEM) was used to measure the particle morphology of selected heavy minerals. Heavy minerals identified in the studied sediments include dark colors such as magnetite, ilmenite, hematite, and goethite. A transparent mineral represented by amphibole, tremolite, and actinolite. pyroxene, epidote, zircon, tourmaline, rutile, garnet, staurolite, kyanite, and layered minerals such as muscovite, chlorite, biotite, and phlogopite. The investigated sediments are considered immature because they have the lowest concentrations of ultrastable minerals by comparison. They contain unstable heavy minerals, confirming that the surface sediments of the LZR and its tributary subbasins were deposited in an active tectonic environment on a continental margin.

This study showed that weight percentages of the heavy mineral fractions in the sediment samples vary widely, ranging from 0.95 to 29.58% in the LZR mainstream and 0.57 to 27.71% in the sub-basin tributaries. The significant variation in lithology of the LZRB is the main factor influencing the heavy

mineral assemblage in these sediments and study also shows that the LZR and the sub-basins sediments are mineralogically immature.

Most grains were angular-to-subangular and subrounded, and the percentage of subrounded grain is higher than rounded grains. Hence, the sediments are mostly close to their provenance.

Special accumulations of heavy minerals characterize specific plate tectonic environments and therefore unique gravity. The mineralogical composition of the investigated samples indicates an active tectonic environment of the continental margin. SEM examination of all chlorite, amphibole, and clinopyroxene grains reveals a variety of microstructures created by mechanical and chemical processes in the LZR and lower basin sediments.

Heavy mineral studies have been conducted in a variety of geological settings in Nigeria, including the Niger Delta, the Benue Trough, and the Sokoto Basin. These studies have provided valuable information for understanding the geological history of these regions and for exploring for mineral resources.

The Niger Delta is one of the depositional basins in Nigeria and it has been accommodating sediments since the Palaeocene. Omotoye S.J (June 2016) along with his team studied and analysed sediment samples from Well-S, Niger Delta, Nigeria. The aim of their work was to study sedimentological properties of sediments from 2 deepwater Niger Delta wells penetrated in the sequence and subsequently establish the provenance and environment of deposition of the sediments. So, they carried out study on sedimentology and petrographic analysis on thirty ditch cutting samples from well-S, Niger Delta, Nigeria. Samples were Soxhlet extracted to remove soluble organic matter and particle

size analysis was performed using pipette and Emery sedimentation techniques to determine the particle size distribution of the precipitate. Bromoform was used to separate heavy minerals from the samples, allowing petrographic analysis of heavy minerals under polarized light microscopy. The data obtained from the granularity analysis was used to create a histogram from which some simple statistical parameters were derived. The average values of the obtained graphs range from 0.74 to 2.64 Ø, suggesting that the deposits are mainly fine- to medium-grained. The comprehensive standard deviation values range from 0.53 to 1.24Ø, indicating that the sediments are moderately to moderately sorted. Graph kurtosis values of 0.29 to 0.70 indicate that the sediments range from finely graded to very finely graded, while graph kurtosis values of 0.61 to 1.54 indicate that the sediments are primarily It shows a very tabular shape, suggesting a low-energy depositional environment. The multimodal features shown indicate that the sediments came from different sources. The study concluded that the sediment was deposited in a fluvial environment. The deposits were also found to be mineralogically mature to immature, originating from metamorphic and acidic igneous rocks of the Nigerian Underground Complex. They resulted that the heavy minerals present in the sediments analysed are Staurolite, zircon, rutile, garnet, amphibole, kyanite, tourmaline, olivine, monazite and opaque minerals. The heavy mineral assemblages were dominated by opaque minerals in the samples analysed. Emphasis is placed on non-opaque minerals in this study because the opaque minerals are of little importance in provenance determination. They are anhedral in shape with very irregular outlines. The succession of heavy minerals indicates that the sediments in the study area are likely derived from acidic igneous and metamorphic rocks

that are part of the underground rock complex of Nigeria. The simultaneous presence of stable heavy minerals such as tourmaline, zircon, rutile, and garnet indicate the mineralogical maturity of the deposit.

2.2 Heavy mineral studies in India

India is rich in deposits of heavy minerals, which are a group of valuable minerals with high densities. These minerals are found in beach sands and inland placers throughout the country. The Indian Bureau of Mines estimates that the country has around 348 million tonnes of ilmenite, 107 million tonnes of garnet, 21 million tonnes of zircon, and 18 million tonnes of rutile in its beach sands deposits. This makes India a major player in the global market for these minerals. The coastal stretches of Kerala, Tamil Nadu, Andhra Pradesh, and Odisha. These areas are home to some of the world's richest beach sand deposits.

G. S. Gayathri and R. G. Rejith (October 2017) along with their team worked on heavy mineral resources in Tamil Nadu, India. (This study attempted to compile an insight into the mineral sands of Tamil Nadu in terms of their geological and mineralogical distributions of heavy minerals. The study region is chiefly underlain by the crystalline rocks of Archean age consisting of gneisses, charnokites, granites and alluvium or laterites of recent or Pleistocene age. This coastal belt is rich in garnet, ilmenite and monazite minerals. The origins of heavy minerals and transport routes to their current locations suggest that the climatic conditions prevailing in the late Quaternary hinterland controlled their weathering, erosion, and contribution. Other factors that may have controlled their formation include river flow, sea level changes, and ocean

circulation. Climate has also caused erosion reactivation and soil restructuring in source areas.

The heavy mineral accumulation of the coastal facies mainly consists of ilmenite, rutile, leucosine, garnet, zircon, monazite, sillimanite, etc. The total concentration of heavy minerals in different regions of the Tamil Nadu region varies depending on the climate and seafloor topography. Therefore, coastal heavy mineral sequences exhibit strong fluctuations, and their distribution patterns change with latitude. Teri sands accounts for almost 83% of the alluvial gold-titanium mineral resources identified so far across Tamil Nadu. However, higher ilmenite values are limited in the Manavaraklichi sector. The high concentration of heavy minerals over approximately 25 km of the Bember Kallar area is probably due to the arcuate nature of the coastline. Heavy minerals are mainly affected by near-shore currents and onshore and offshore movements.

The study of heavy minerals in the beach around the Kali River in Karwar, West coast of India by G. N. Nayak and V. C. Chavadi (1989) identified heavy minerals along with their dominance that includes Magnetite, Ilmenite, Hornblende, Tremolite, Epidote and Zircon. Along the west coast of India, three fractions had been studied along 11km stretch of the beach sediments and 14 heavy minerals were identified such as magnetite, ilmenite, garnet, hornblende, tremolite, epidote, pyroxene, tourmaline, zircon, monazite, rutile, apatite, sphene, biotite. The mineral assemblage indicates mixed provenance of metamorphic and igneous rocks. Kali river catchment area and cliffs facing the sea are the probable provenance for these beach sediments. The mineral

distribution indicates drifting of these sediments towards southern as well as northern sides. This may be due to cell flow near the estuary.

2.3 Heavy mineral studies in Goa

According to research, the heavy mineral composition of beach sands on the central west coast of Goa includes ilmenite, magnetite, zircon, rutile, amphibole, epidote, kyanite, and tremolite. Concentrations of heavy minerals are highest in the supratidal zone, the area above the high tide line, compared to the intertidal zone, the area between the high and low tide lines. Goa's heavy mineral deposits are estimated at 2.33 million tonnes (MT), with ilmenite at 0.55 MT, magnetite at 0.98 MT and chromite at 0.032 MT.

A. Sreenivasa from the department of geology, Karnataka university, has studied on heavy minerals of beach sands of Vagathor, North Goa, India (August 2014). The aim for the study was (i) To determine the grain size character, mineralogy and grain to understand the environment of deposition and the nature of sediments in the area. (ii) To quantify the various mineral components with special emphasis on heavy mineral content. (iii) To estimate the heavy mineral resources of the area. (iv) To decipher the source of these minerals through mineralogy and transportation history of surficial textures.

The Chapora River and its tributaries flow throughout the Vagator Beach area. flows from east to south direction. The drainage channels are well developed and structurally controlled and the length of the river is approximately Goa. It is 31 km long and passes through Pernem Taluka and Bardez Taluka at the mouth of Vagator Beach in North Goa.

The Chapora River and its tributaries flow throughout the area that makes up Vagator Beach. It flows from northeast to southwest. The drainage pattern is structurally controlled. The Chapora river originates from the Ramghat hills in Belgaum district of Karnataka and flows into Goa through the Tillari Ghat. Its length in Goa is approximately 31 km long and includes river estuaries, mud banks, and mangrove swamps.

The heavy mineral suite comprises of opaque (magnetite and ilmenite) and transparent minerals like hornblende, epidote, garnet, rutile, zircon, enstatite and minor amounts of tourmaline. The light minerals mainly quartz and feldspars, magnetite concentration ranges between 2.01 to 56.86 %, ilmenite between 2.83 to 41.04 % and non-magnetic between 1.18 to 44.81 %. The SEM study of all the grains of ilmenite, magnetite and quartz, shows variety of micro textures developed by mechanical and chemical processes acting in the coastal area. Mechanical process leads to form the concoidal fracture pitted surface, groves and furrows. Dissolution chemical process generates concavities, solution pits, etch V marks and chemical process develops silica precipitation.

Mechanically formed grooves are predominant features followed by V marks and concoidal fractures. Rounded grains and smoothening of edges indicates high energy zones, etch V’s and solution pits are dominant features by precipitation of chemical processes. The observed mineral assemblage on the surface features collectively suggest the derivation of source rocks like mixtures of igneous and metamorphic rocks, crystalline gneisses and schist’s.

Hence this study is such an attempt to understand the Riverine deposits. Following objectives have been framed.

2.4 Objectives

- To identify the heavy mineral assemblages in river sediments.
- To analyze the distribution of heavy minerals along the course of river.
- To determine the Grain Morphology.

CHAPTER III

CHAPTER 3

MATERIALS AND METHODS

3.1 Study Area and Sampling Method

The present study is based on understanding the distribution of heavy minerals focusing on two major river systems, Sal and Mandovi. The Sal River is a small river in Salcete, Goa, India. The river originates near Verna and flows in a south-western direction for approximately 16 kilometres. Along its course, it passes through several villages, including Nuvem, Mongul, Seraulim, Colva, Margao, Benaulim, Navelim, Varca, Orlim, Carmona, Dramapur, Chinchinim, Assolna, Cavelossim, Mobor and Finally, it drains itself into the Arabian Sea at Betul.

The Mandovi River which is also known as Mahadayi River originates from a cluster of springs at Bhimgad in the Western Ghats of Belgaum district in Karnataka state. It flows for about 75 kilometers before meeting the Arabian Sea. The Mandovi River basin drains an area of 2,032 square kilometers, of which 1,580 square kilometers are in Goa.

3.2 Sediments sampling

Sampling was done along the river Sal from Margao till Betul in the South Goa and river Mandovi from Ribandar ferry point to Usgao (West to East). Total 39 Samples were collected from both the river and main Tributaries.

The following are the requirements for sampling

- Showel
- PVC pipe 2 inch
- GPS device
- Sampling bags and labels
- Notebook, pen and permanent marker
- Google Earth software

Twenty-one sampling sites along river Sal were identified using Global Positioning System (GPS) and marked on Google Earth using Measuring Scale of 1.5km to 2km distance. The samples for sediments was done from the Shoreline of both the rivers.

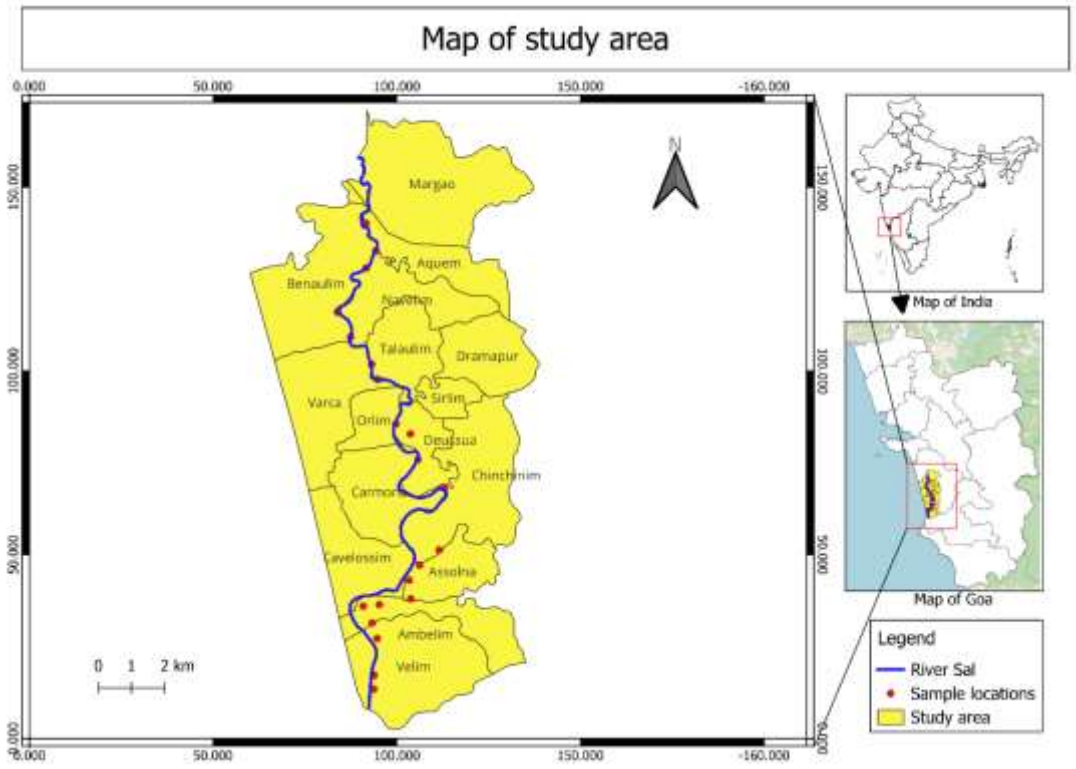

Figure 3.1 Study area of river Sal and Sampling sites

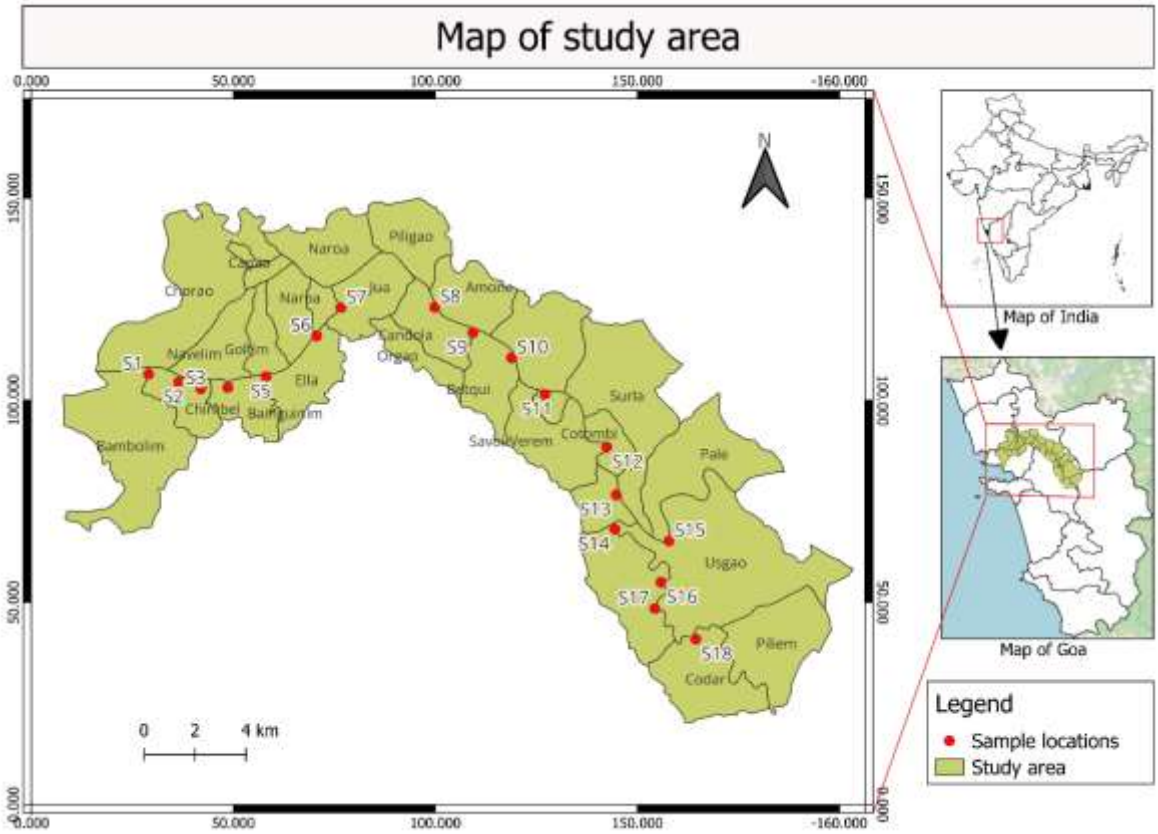

Figure 3.2 Study area of river Mandovi and Sampling sites

About 250gm of sediment samples was sampled from each sampling site at the shorelines of both the rivers by using the shovel at the intervals of 1km to 1.5km range at the best expose area for the sample collection. A Square of 15cm x 15cm was made for a good representative sample.

Figure 3.3 15cmx15cm square for a good representative sample

Each sample was packed in a sample bag and labelled accordingly for laboratory analyses. A total of 39 samples sampled from both the study area.

Half amount of the sample was transferred in a 250ml beaker and labelled according to their Sample numbers and kept it in the Oven for drying for atleast 48hours at the temperature of 60º. Coning and Quartering (Fig: 3.3) was done to any bias and to give the best representative sample for further process.

Figure3.4 Coning and Quartering

25gm of the samples was taken in the beakers and added 25ml of Hydrogen Peraoxide (H2O2) for removing the organic matter for further analysis and then kept the beakers for 24 hours for the completion of the reaction. Later added Distilled water to the beakers upto the mark of 200ml and then allowed it for settling for 48 hours because mud samples take a long time to settle. Decant the water from the samples after 48 hours at a minimal level and kept for drying on hot plate and dried completely until no moisture left in the sample. The samples were weighed on weighing machine after the H2O2 treatment and weight was noted.

Figure 3.5 Vigorous reaction after H2O2 treatment

3.2.1 Sieving for Separating coarse grains

Sediment samples may contain a mixture of clay, silt, sand and gravel and thus need to be sieved before heavy mineral separation. In poorly sorted sediments, the presence of detrital grains with great size differences within a single concentrate makes mounting and identification difficult. For this reason, we routinely consider a mesh size of 44 mesh number (400 microns). Below 400 micron every grain is considered for further process. Wet sieving is particularly recommended for poorly sorted sediments including mud. The weighted aliquot of the original sample was pre-soaked in the water to break the clumps. Later placed the sieve stack on the top of the funnel, which should be positioned over the container for the coarse fraction (beaker).

Then poured the pre-soaked sediment sample to the top of the sieve and gently washed it onto the sieve with distilled water from a spray bottle and then by using hand swirl in a circular motion to distribute the sediment particles across the sieve. And then after the use of continuous wash with the spray bottle the fine grains were washed in the container through the sieve mesh openings and the grains were completely separated.

We stored the large grains (>400microns) separately and the fine grains (<400microns) were allowed to settle in the beaker. Then the additional water was removed and dried it completely for further processes.

Figure 3.6 Separated coarse grain >400 microns

Figure 3.7 Separated fine grain <400 microns

3.2.2 Heavy mineral segregation using Bromoform

The heavy minerals were separated using bromoform at Sp.Gr. 2.90 using procedure (Milner 1962). (Fig.no; 3.6)

Materials Used

- Bromoform
- Separating funnel
- Beakers
- Filter paper
- Conical flask
- Weighing machine
- Distilled water

The sediments were treated with chemicals (H2O2 and HCL in order to get rid of organic matter and carbonates respectively). After the stand setup was done 30ml of bromoform was added to the separatory funnel. The Fine-grained sieved sample was weighed and 6gm was taken for bromoform method and then it was added in the separatory funnel containing 30ml of bromoform. The mixture is then gently swirled to allow for proper contact between the minerals and the dense liquid. The mixture was then allowed to settle. Heavy minerals will sink to the bottom of the separatory funnel, while the lighter minerals will float on the bromoform layer. The stopcock of the separatory funnel was carefully opened to drain the lower bromoform layer containing the heavy minerals into conical flask. The collected heavy minerals were then washed with a solvent (Acetone) to remove any residual bromoform. Acetone is miscible with bromoform and will dissolve it, leaving the heavy mineral concentrate behind. Then the rinsed heavy minerals were dried in the oven at 40º. The light

sediments were removed by washing the separatory funnel with distilled water by the spray bottle and it was preserved in labelled containers.

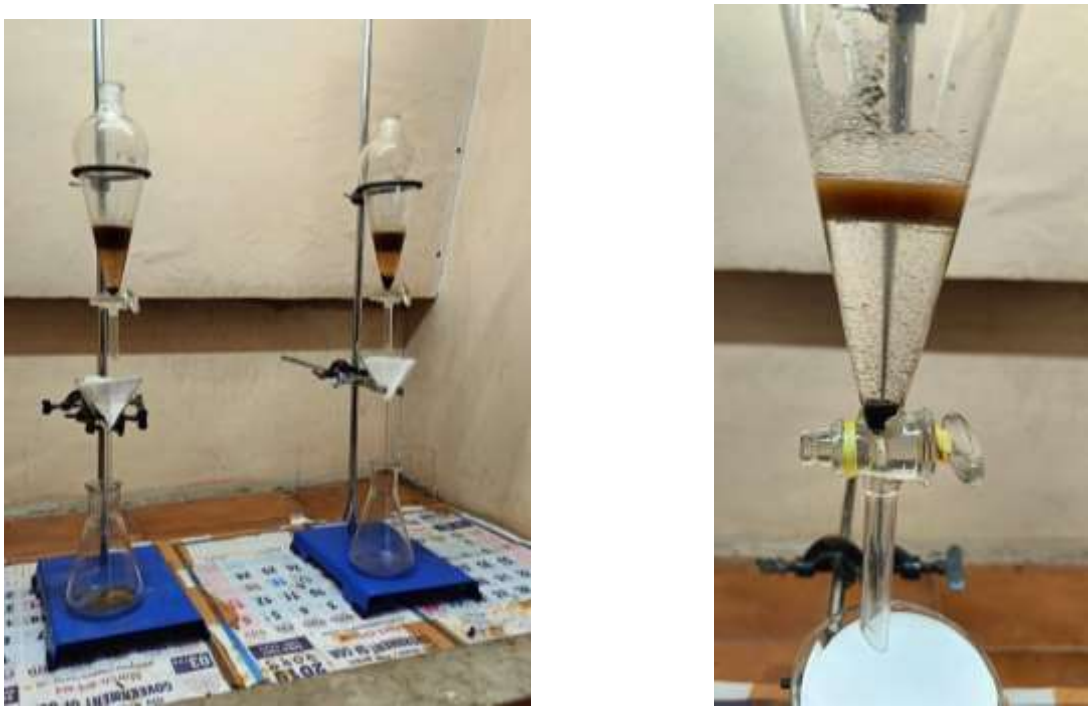

Figure 3.8 *Bromoform Analysis settled heavy minerals and floating light minerals.*

3.2.3 Separation of Magnetic and Non-Magnetic minerals

Magnetic separation of mineral particles depends on the magnetic susceptibility of the minerals were separated. This is a complex phenomenon which is a function of chemical composition, especially minor amounts of iron or manganese, and atomic-lattice structure.

The heavy minerals were spread evenly on a A4 size paper. Using Neodymium magnet, the magnetic minerals were separated from their non-magnetic counterpart for each sample (Fig: 3.8).

Figure 3.9 *Magnetic minerals separation*

3.3.4 Preparation of samples for X-ray diffraction (XRD)

XRD analysis were carried out to identify the opaque magnetic minerals using Morter and Pestle the sample was crushed to fine powder. Using the best facility available at our own Goa University at department of chemistry block E. The samples were

analysed for XRD. The XRD instrument was setup and the scan parameters such as the step size, scan speed and Theta angle were selected and slide was prepared by using the powdered sample on the slide and covering it with the cover slip. The slide was then aligned in the holder for further data. The instrument irradiates the sample with X-rays, and the detector measures the intensity of the diffracted beams at various angles. The collected data is a plot of intensity versus diffraction angle (2 Theta). Origin 2024 software was used to analyse the peaks in the pattern, which corresponds to specific atomic arrangement in the material. By comparing the pattern with reference databases, the magnetic minerals were identified.

Figure 3.10 XRD instrument

Figure 3.11 Slide Preparation

3.3.5 Scanning Electron Microscope (SEM)

SEM analysis (Fig:3.10) to investigate the properties of a sample. SEM allows high-resolution imaging of surfaces using an electron beam. SEM images reveal surface topography, crystal structures, and compositional variations.

Figure 3.12 SEM instrument (JEOL Jsm-6360LV)

The non-magnetic heavy minerals were identified based on their physical properties on the Stereo zoom Microscope (Olympus SZ) and were further used for SEM analysis. Each heavy mineral grains were mounted on the Stub (Fig:3.12) which was covered with the Carbon Tape and then the stub was mounted in the coating machine to coat. Platinum coating (Highest Grade) was done to produce better quality images and to protect the surface from getting damage by the rays (Fig:3.11).

A focused beam of electrons scans the surface of the sample in a raster pattern. Then the interaction between the electrons and the sample generates various signals that the SEM detector capture. These signals are used to create high-resolution images of the sample's surface topography. The obtained images were than interpreted and analysed the surface textures to understand the sample' properties.

Figure 3.13 Coating machine (JOEL JFC-1600 Auto finer coater)

Figure 3.14 Heavy minerals mounted on Stub

CHAPTER IV

CHAPTER 4

RESULTS

4.1 Identification of Heavy minerals

The heavy minerals present in the sediments are analyzed and identified based on the physical properties as listed in Table 4.0 According to Carver (1971), heavy minerals are accessory minerals present in concentrations of less than 1%. They are chiefly silicates and oxides, many of which are very resistant to mechanical abrasion and chemical weathering. The heavy mineral assemblages were dominated by opaque minerals such as Magnetite, Hematite, Ilmenite in the samples analysed. Prominence is placed on non-opaque minerals. The non-opaque minerals include Tourmaline, Staurolite, Rutile, Zircon, Apatite, Epidote, Pink Garnet, Hornblende.

Mineral	Shape or crystal system	Colour	Lustre	Others
Tourmaline	Prismatic	Yellow, brown, dark brown, dark green, black		They appear as Elongated minerals
Rutile	Tetragonal	Yellow, reddish brown, red	Sub-vitreous	Particles are irregular and generally with sharp edges
Hornblende	Long, blade like prims, two cleavages	Dark brown and green to dark green	Glassy	Prismatic and it is elongated
Garnet	Cubic or Dodecahedral	Colourless, pale pink, yellow	Glassy to dull	Crystal shape, concoidal fractures
Epidote	Monoclinic	Pale green yellow to lemon yellow	Glassy to dull	Particles are greenish yellow,
Staurolite	Short prisms	Yellow, golden, brown	When altered it is dull to earthy. When fresh it is vitreous	Particles irregular and platy sometimes

Table 4.2: Physical properties of heavy minerals in stereo zoom microscope (By Omotoye S.J et.al 2016)

A brief description of the physical properties as seen in Stereo zoom microscope of each heavy mineral type is shown in Table 4.2 of river Sal and Mandovi.

Sample number	Heavy minerals identified
1	Epidote, staurolite, tourmaline, zircon
2	Epidote, hornblende, chlorite, garnet
3	Epidote, chlorite, tourmaline, hornblende
4	Epidote, hornblende, chlorite, garnet
5	Epidote, chlorite, apatite, tourmaline
6	Epidote, chlorite, hornblende, apatite
7	Epidote, chlorite, apatite
8	Epidote, hornblende, apatite
9	Epidote, chlorite, hornblende, apatite, garnet
10	Epidote, Rutile, Zircon
11	Epidote, Zircon, hornblende, tourmaline
12	Epidote, chlorite, Staurolite
13	Epidote, chlorite, hornblende, staurolite
15	Epidote, chlorite, tourmaline, zircon
16	Epidote, tourmaline, garnet
17	Epidote, chlorite, hornblende, tremolite-actinolite
18	Epidote, tremolite-actinolite,
19	Epidote, hornblende
20	Tremolite-actinolite

Table: 4.0 Identified heavy minerals of sediment samples of river Sal

Sample number	Heavy minerals identified
1	Tourmaline, garnet
2	Epidote, hornblende, chlorite,
3	Epidote, chlorite, tourmaline, hornblende
4	Epidote, hornblende,
5	Epidote, tourmaline
6	Epidote, chlorite, Staurolite
7	Epidote, hornblende
8	*
9	*
10	Epidote, zircon
11	Staurolite, tourmaline, tremolite-actinolite
12	*
13	*
15	Epidote, chlorite
16	*
17	Hornblende, chlorite
18	Epidote, chlorite, hornblende

Table 4.1 Heavy minerals of sediment samples of river Mandovi
(*-Samples covered with mud cannot be identified)

Table no. 4.0 and 4.1 are the identification done on the heavy minerals of each sample according to the sample number

Abundance of epidote, chlorite and hornblende has been noted in all the samples of river Sal. Epidote was subangular to subrounded in shape where as chlorite occurred as flake like crystals. Hornblende as a common heavy mineral in the sediments of this river which occurs as prismatic grains. Epidote occurs mainly as pale green, irregular and sub-rounded grains.

The photomicrographs of some of the heavy minerals are shown in below Figs.

Figure 4.1 Tourmaline grains (scale 1 unit=0.1cm)

Figure 4.2 Epidote grains (Scale 1 unit= 0.1cm)

Figure 4.3 Chlorite grains (1 unit= 0.1cm)

Figure 4.4 Tremolite-Actinolite grains (1 unit= 0.1cm)

4.2 X-ray Diffraction analysis

X-ray Diffraction (XRD) was carried out for 12 magnetic samples of both the rivers. It was used for understanding the characteristics and identification of the heavy mineral grains. The width of the peaks is inversely proportional to the crystal size. The intensity of the peaks is related to the number of molecules in that phase or with that spacing. The most comprehensive description of scattering from crystals is given by the dynamical theory of diffraction. In this study the powder diffraction is a scientific technique by X-ray, neutron or electron diffraction on powder or microcrystalline samples for structural characterization of materials. A thinner peak corresponds to a bigger crystal. A broader peak means that there may be a smaller crystal, defect in the crystalline structure, or that the sample might be amorphous in nature, a solid long peak means perfect crystallinity. The magnetic minerals identified were Magnetite, Goethite, Hematite, Ilmenite and Siderite. Ilmenite was abdundant in every mineral with broad and solid peaks.

Interpreting XRD data involved analyzing the pattern generated by the X-ray diffractometer. This pattern typically consists of peaks at specific angles, which correspond to the distances between atomic planes in the crystal. By comparing the pattern to a database of known materials, we have identified the crystalline phases present in the sample.

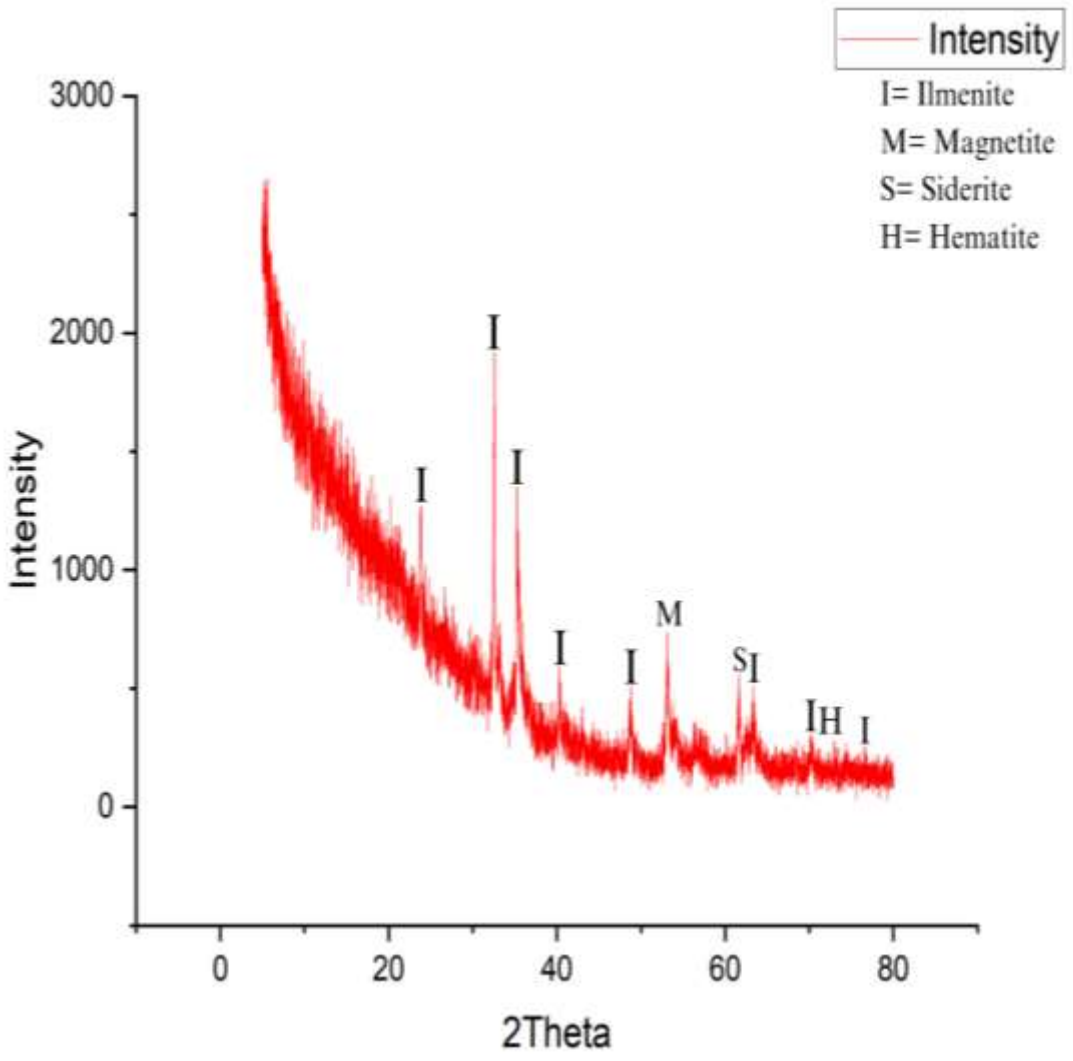

Figure 4.5 Sal sample 5

This sample is dominated by Ilmenite. The long solid sharpe peaks indicates a bigger crsytal-cyrstal with perfect crystallinity. The broader peaks depicts that the crystal is amorphous and the crystal may be small with defects in the crystalline structures. The longer peaks are mostly between 20-40° with intensity between 1000-2000. Magnetite was encountered at 53.12° and Siderite was at 61.64°. Hematite was identified at a very small and broad peak with defects in the crystal structure.

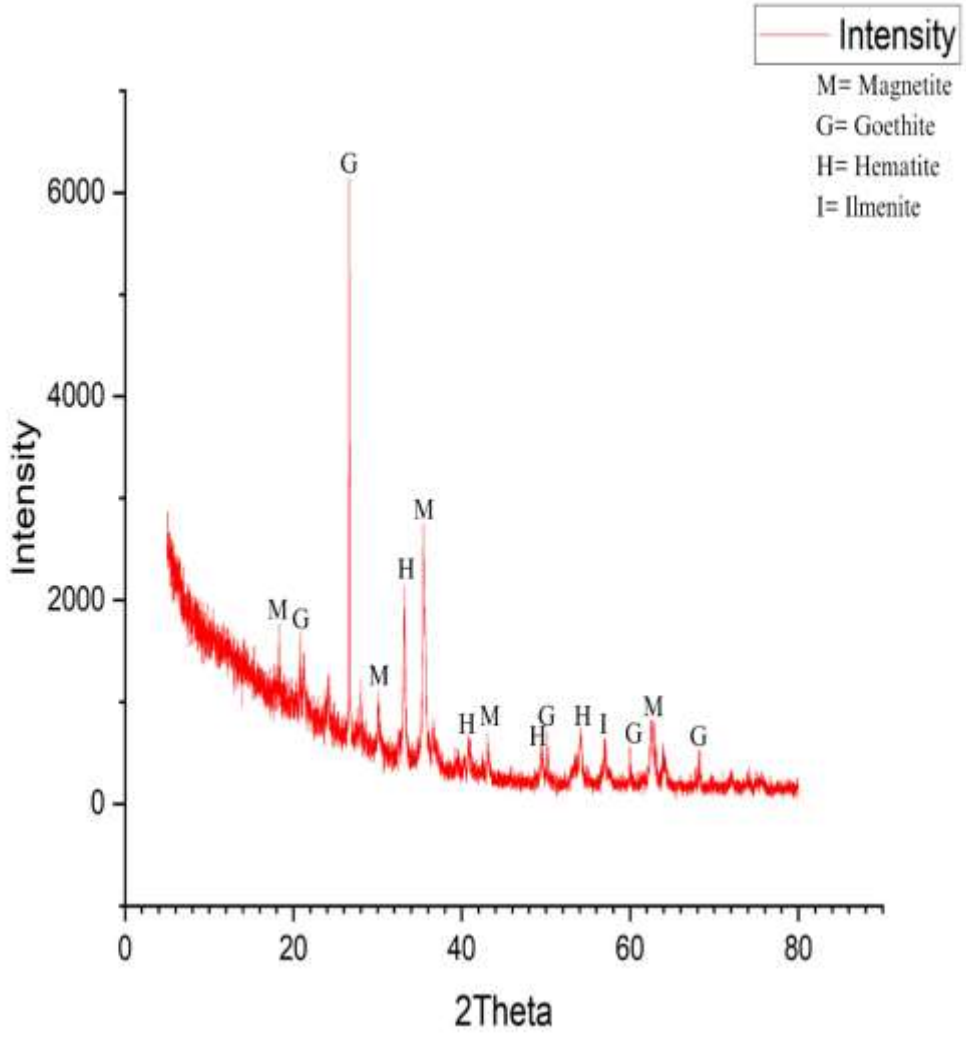

Figure 4.6 Sal sample 12

This sample is dominated by Goethite, Magnetite. The long solid sharpe peaks indicates a bigger crsytal-crystal with perfect crystallinity. The broader peaks depicts that the crystal is amorphous and the crystal may be small with defects in the crystalline structures. The longer peaks are mostly between 20-40° with intensity between 1000-3000. One peak of Goethite is bigger crystal with the intensity of 6000 with perfect crystallinity. Small peaks of Hematite and Ilmenite are mostly between 40-60°.

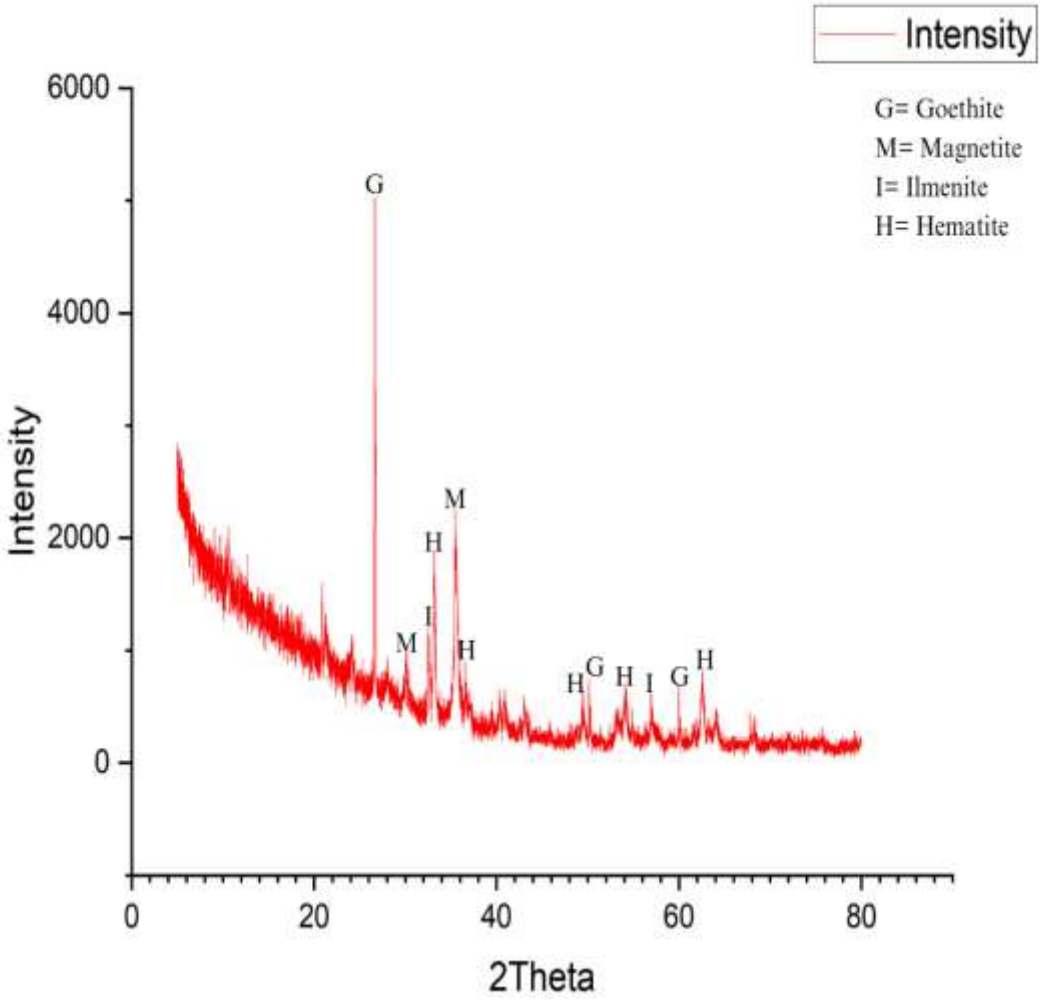

Figure 4.7 Mandovi sample 15

This sample is dominated by Goethite, Magnetite with small as well as large peaks. The long solid sharpe peaks indicates a bigger crystal with perfect crystallinity. The broader peaks depicts that the crystal is amorphous and the crystal may be small with defects in the crystalline structures. The longer peaks are mostly between 20-40° with intensity between 1000-3000. One peak of Goethite is bigger crystal with the intensity of 6000 with perfect crystallinity. Small peaks of Hematite and Ilmenite are mostly between 40-60°.

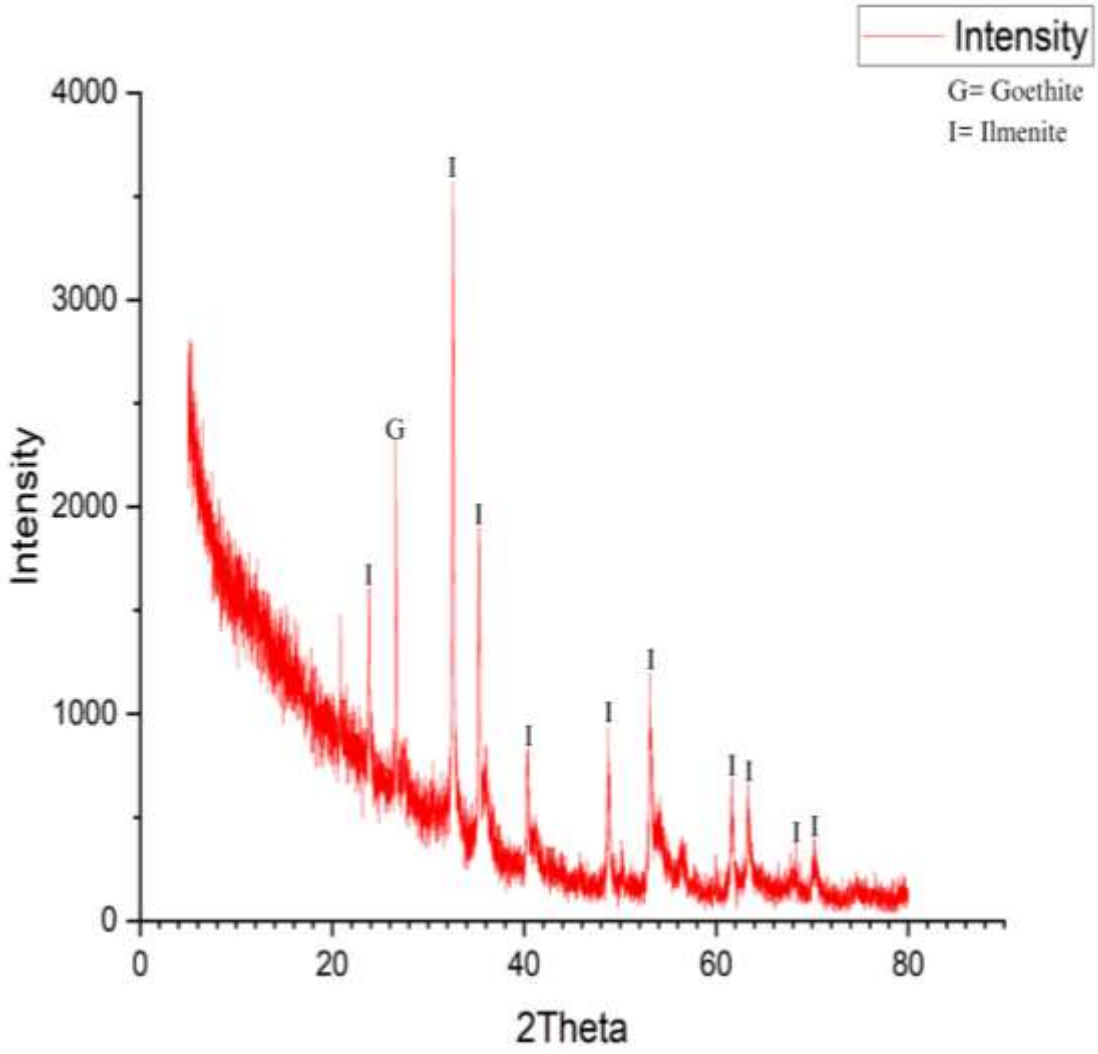

Figure 4.8 Sal sample 14

This sample is dominated by Ilmenite with small and large peaks both. The long solid sharpe peaks indicates a bigger crystal with perfect crystallinity. The broader peaks depicts that the crystal is amorphous and the crystal may be small with defects in the crystalline structures. The longer peaks are mostly between 20-40° with intensity between 500-2000. One peak of Ilmenite depicts bigger crystal with the intensity of >3500 with perfect crystallinity. This sample has abundace of Ilmenite at different peak points and different theta angle and intensity.

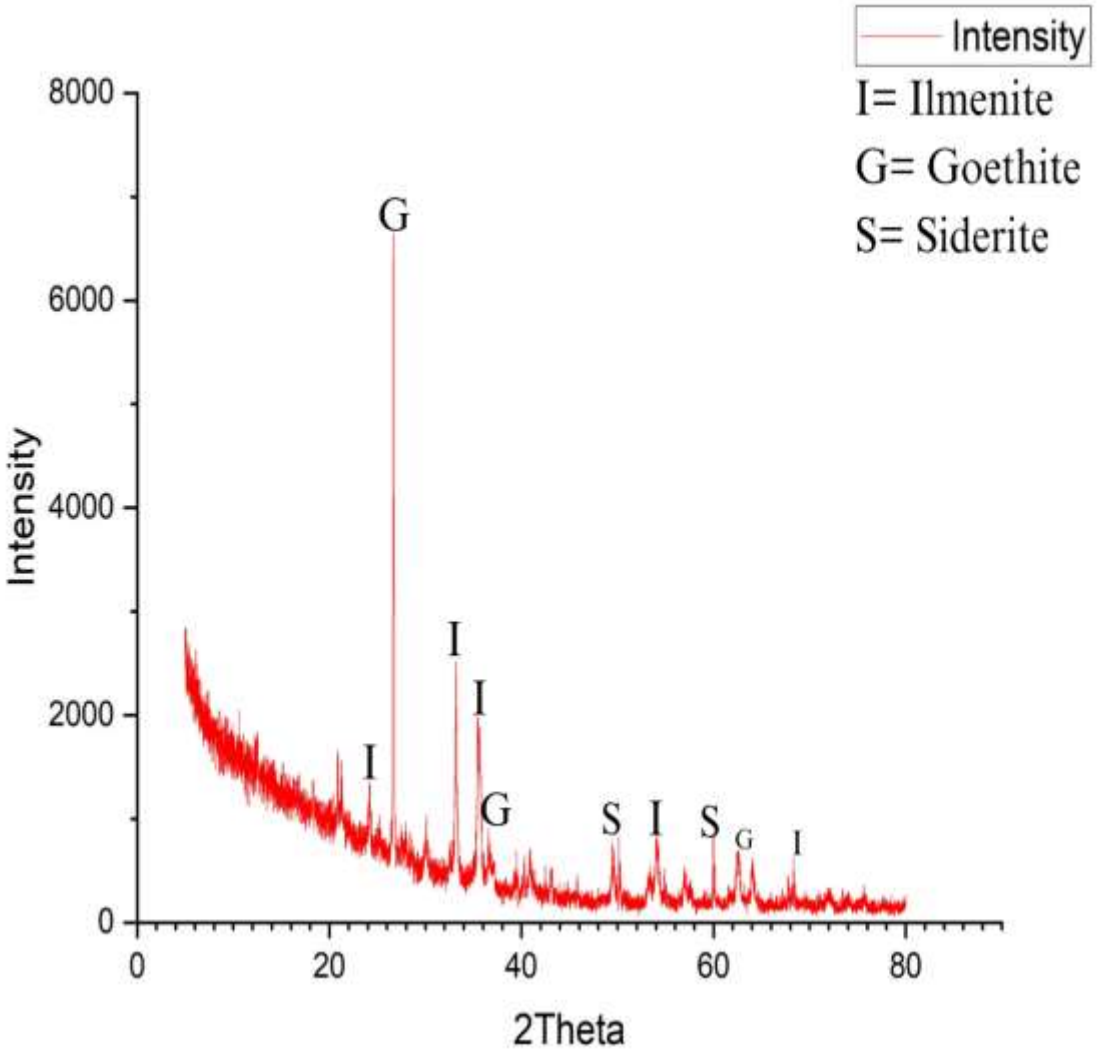

Figure 4.9 Mandovi sample 7

This sample is dominated by Ilmenite with small and large peaks both. The long solid sharpe peaks indicates a bigger crystal with perfect crystallinity. The broader peaks depicts that the crystal is amorphous and the crystal may be small with defects in the crystalline structures. The longer peaks are mostly between 20-40° with intensity between 0-2500. One peak of Goethite depicts bigger crystal with the intensity of >6000 with perfect crystallinity. Siderite is present between 40-60°. This sample has abundace of Ilmenite at different peal points and different theta angle and intensity.

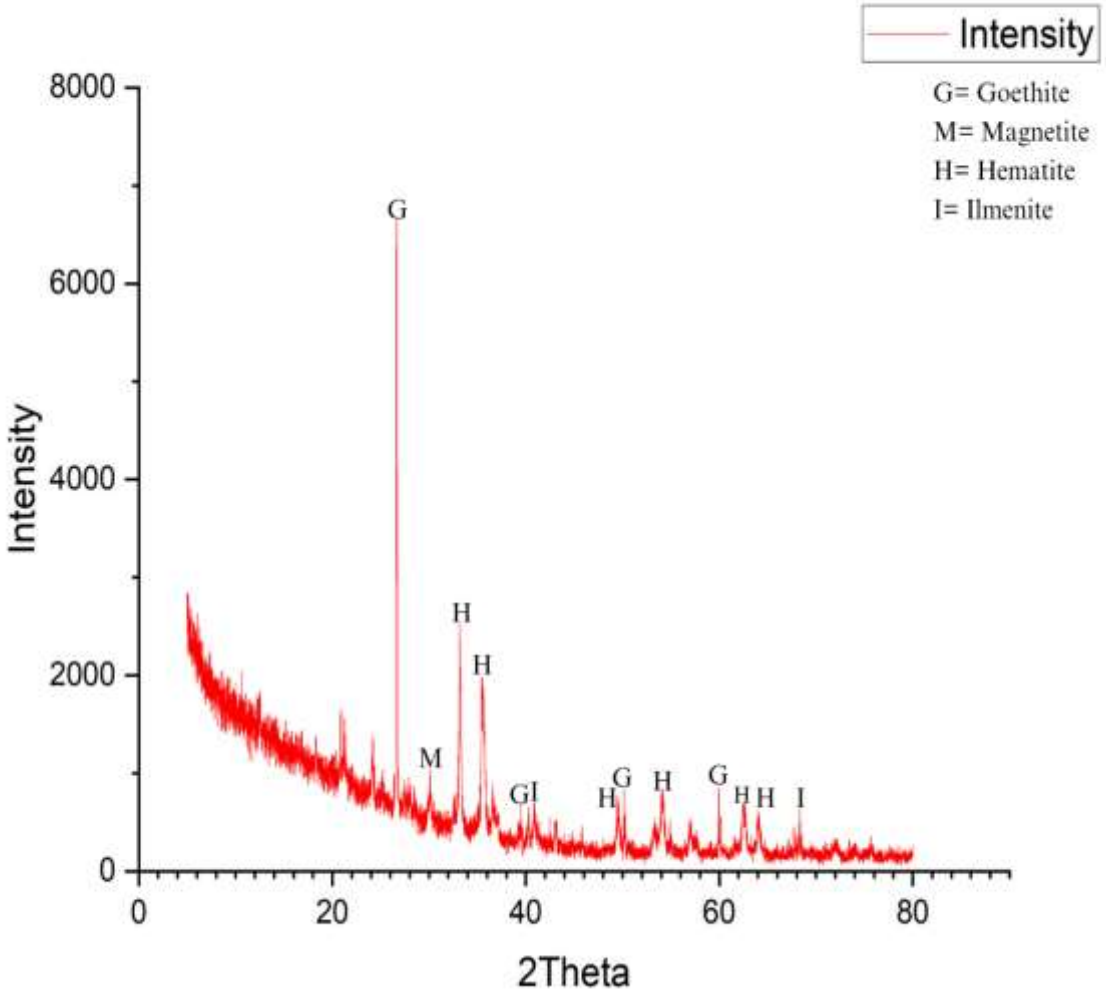

Figure 4.10 Sal sample 10

This sample is dominated by Hematite with small and large peaks both. The long solid sharpe peaks indicates a bigger crystal with perfect crystallinity. The broader peaks depicts that the crystal is amorphous and the crystal may be small with defects in the crystalline structures. The longer peaks are mostly between 20-40° with intensity between 0-2500. One peak of Goethite depicts bigger crystal with the intensity of >6000 with perfect crystallinity. Magnetite is present between 40-60°.

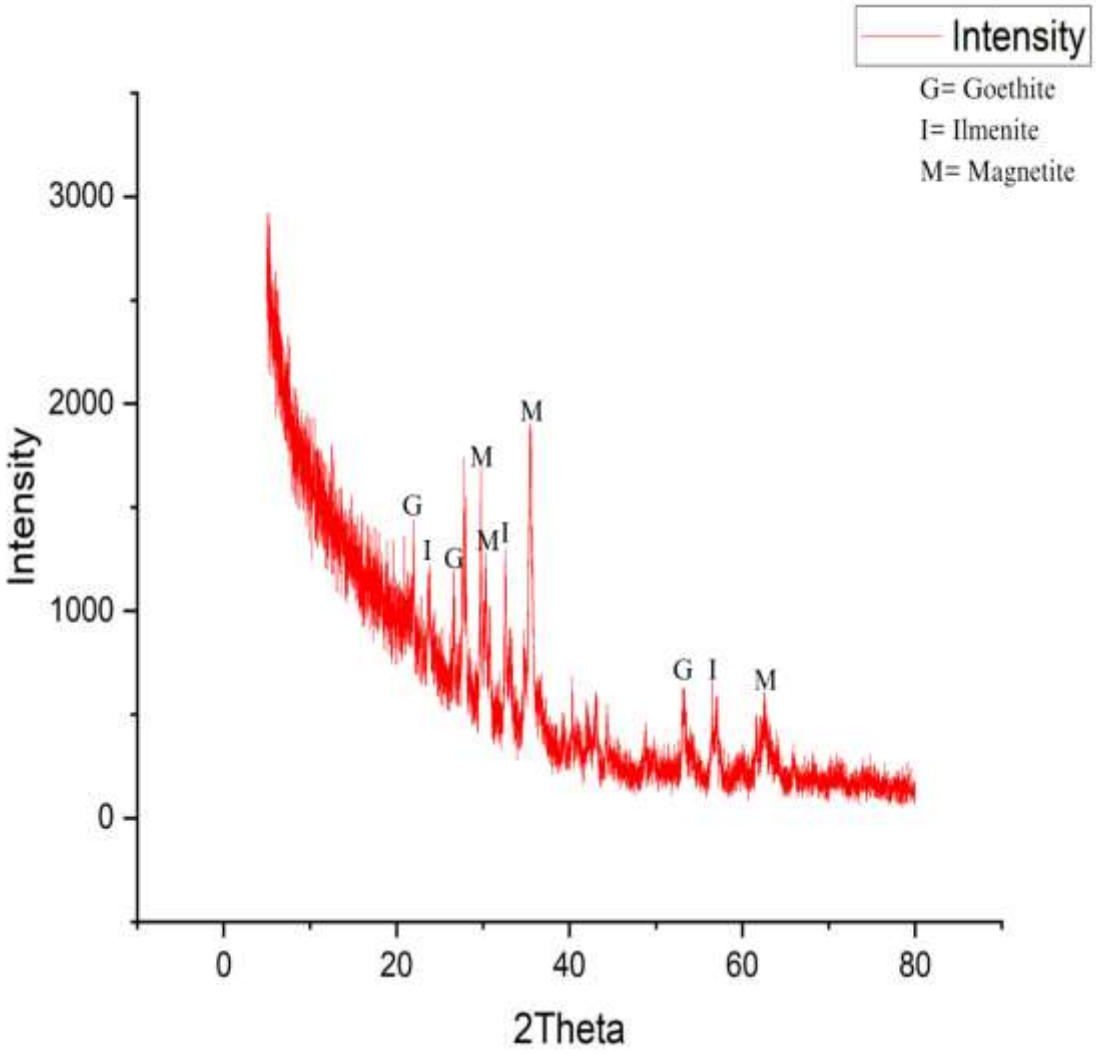

Figure 4.11 Mandovi sample 1

This sample has Goethite, Magnetite and Ilmenite with small and large peaks both. The long solid sharp peaks indicates a bigger crystal with perfect crystallinity. The broader peaks depicts that the crystal is amorphous and the crystal may be small with defects in the crystalline structures. The peaks are mostly between 20-40° with intensity between 500-2000. There are small and broad peaks of Goethite, Ilmenite and Magnetite at same intensity and between 45-65°.

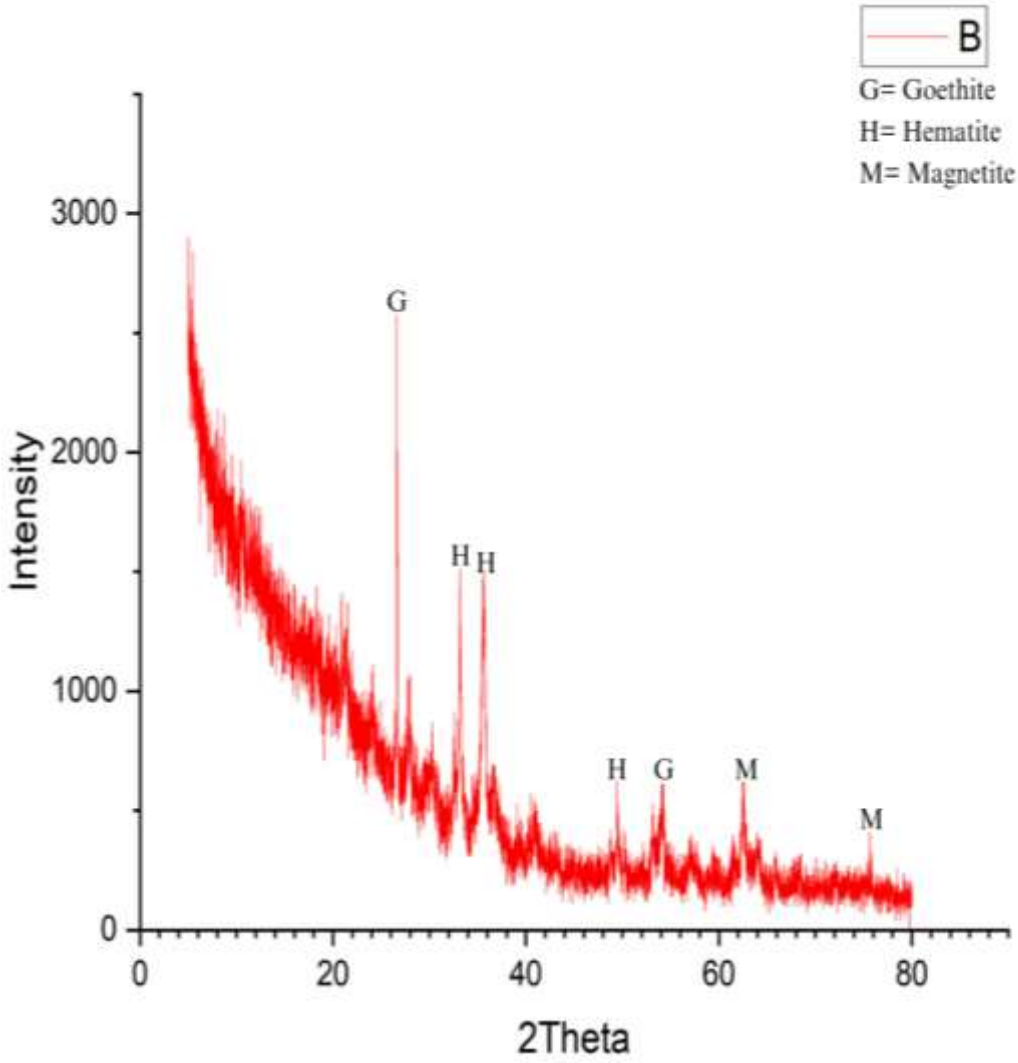

Figure 4.12 Sal sample 2

This sample has Hematite, Goethite, Magnetite with small and large peaks both. The long solid sharpe peaks indicates a bigger crystal with perfect crystallinity. The broader peaks depicts that the crystal is amorphous and the crystal may be small with defects in the crystalline structures. The peaks are mostly between 20-40° with intensity between 0-2000. One peak of Goethite depicts bigger crystal with the intensity of >2000 with perfect crystallinity. The small broad peaks of Magnetite are also present. Two long peaks of Hematite can be seen at 33.18° and 35.64° and intensity of 1500.

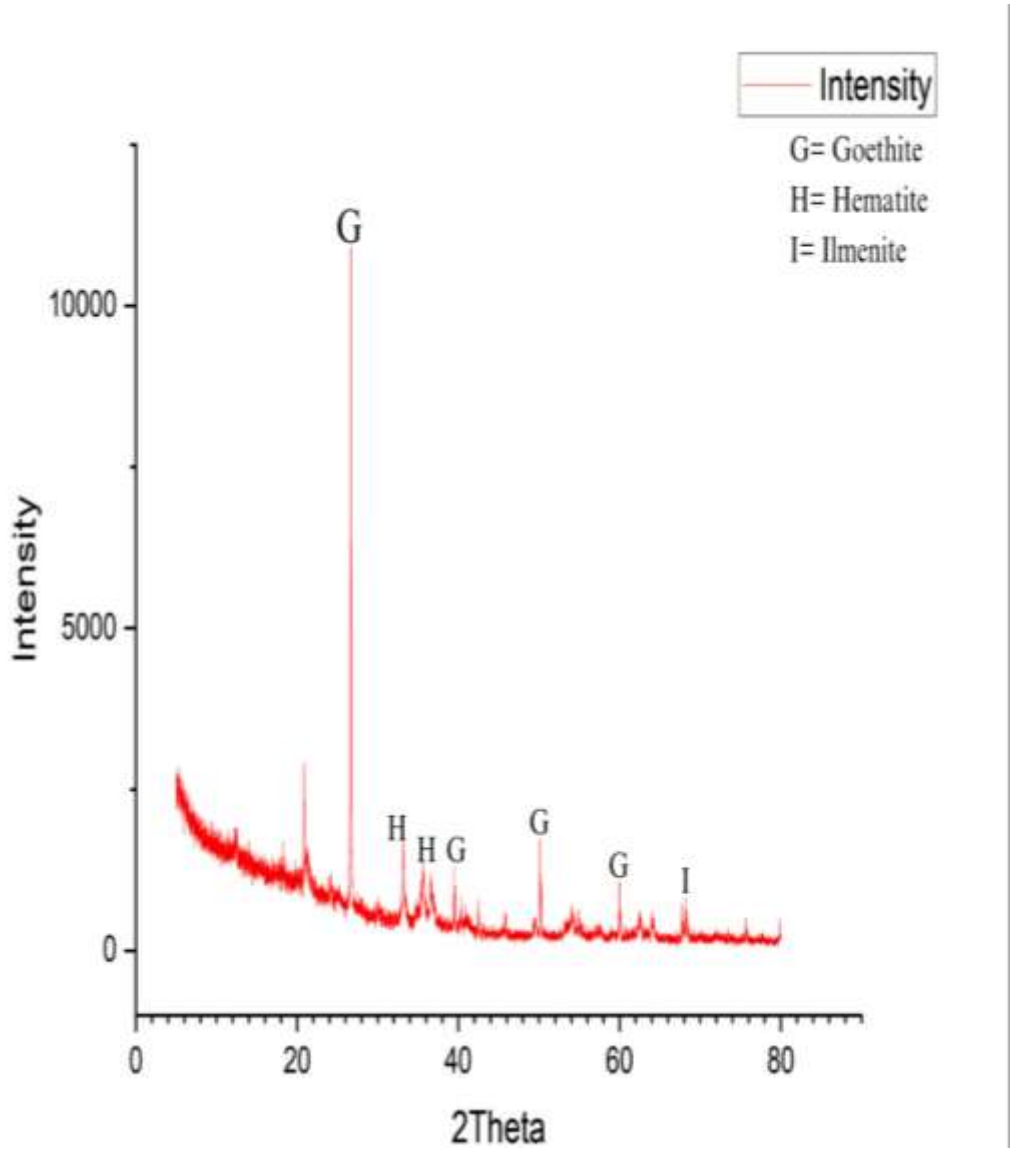

Figure 4.13 Mandovi sample 12

This sample is Dominated by Goethite with small and large peaks both. The long solid sharpe peaks indicates a bigger crystal with perfect crystallinity. The broader peaks depicts that the crystal is amorphous and the crystal may be small with defects in the crystalline structures. The peaks are mostly between 20-40° with intensity between 0-5000. One peak of Goethite depicts bigger crystal with the intensity of >10,000 with perfect crystallinity. The small broad peaks of hematite are also present will Ilmenite.

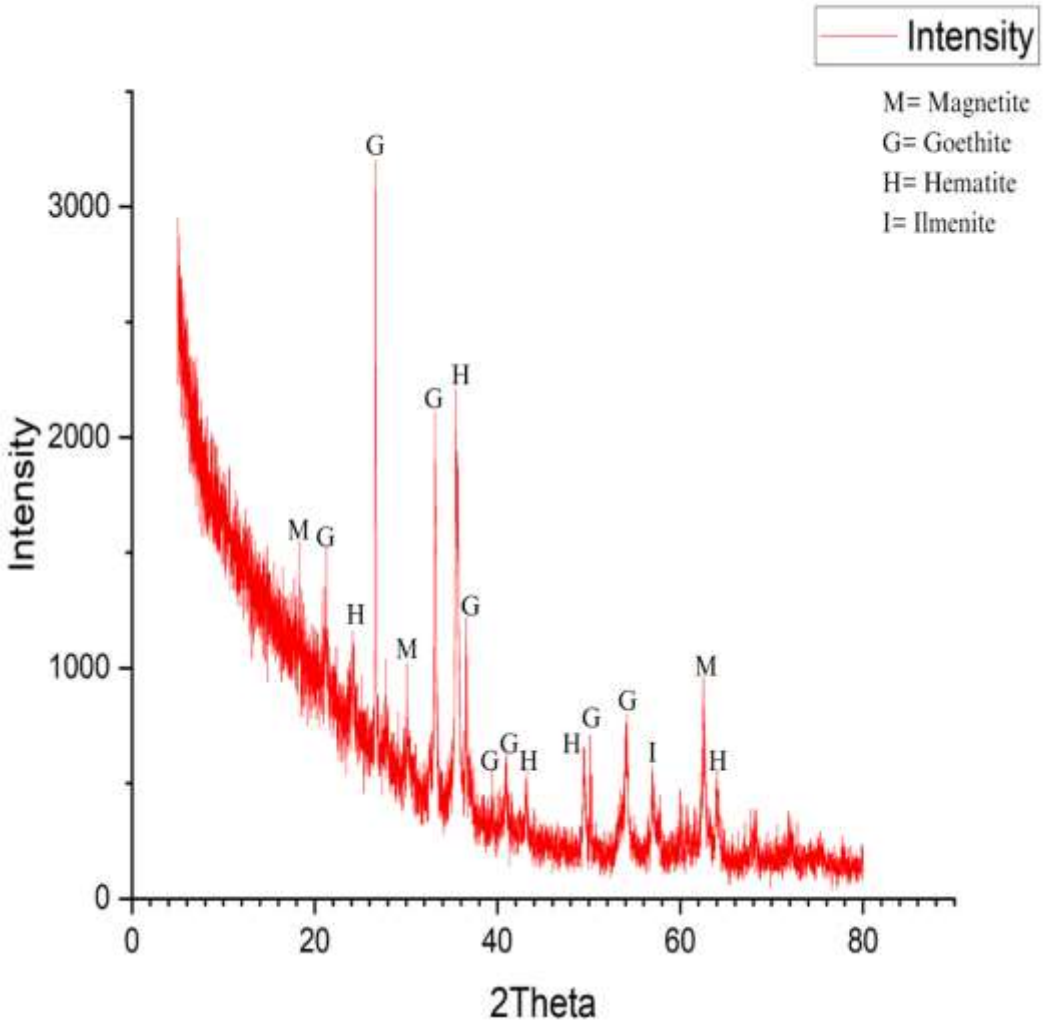

Figure 4.14 Mandovi sample 11

This sample is Dominated by Goethite and Hematite with small and large peaks both. The long solid sharpe peaks indicates a bigger crystal with perfect crystallinity. The broader peaks depicts that the crystal is amorphous and the crystal may be small with defects in the crystalline structures. The longer peaks are mostly between 20-40° with intensity between 0-2500. One peak of Goethite depicts bigger crystal with the intensity of >3000 with perfect crystallinity.and same for hematite at peak value of 35.45°. The peaks of hematite and magnetite is small and broad between 40-70°.

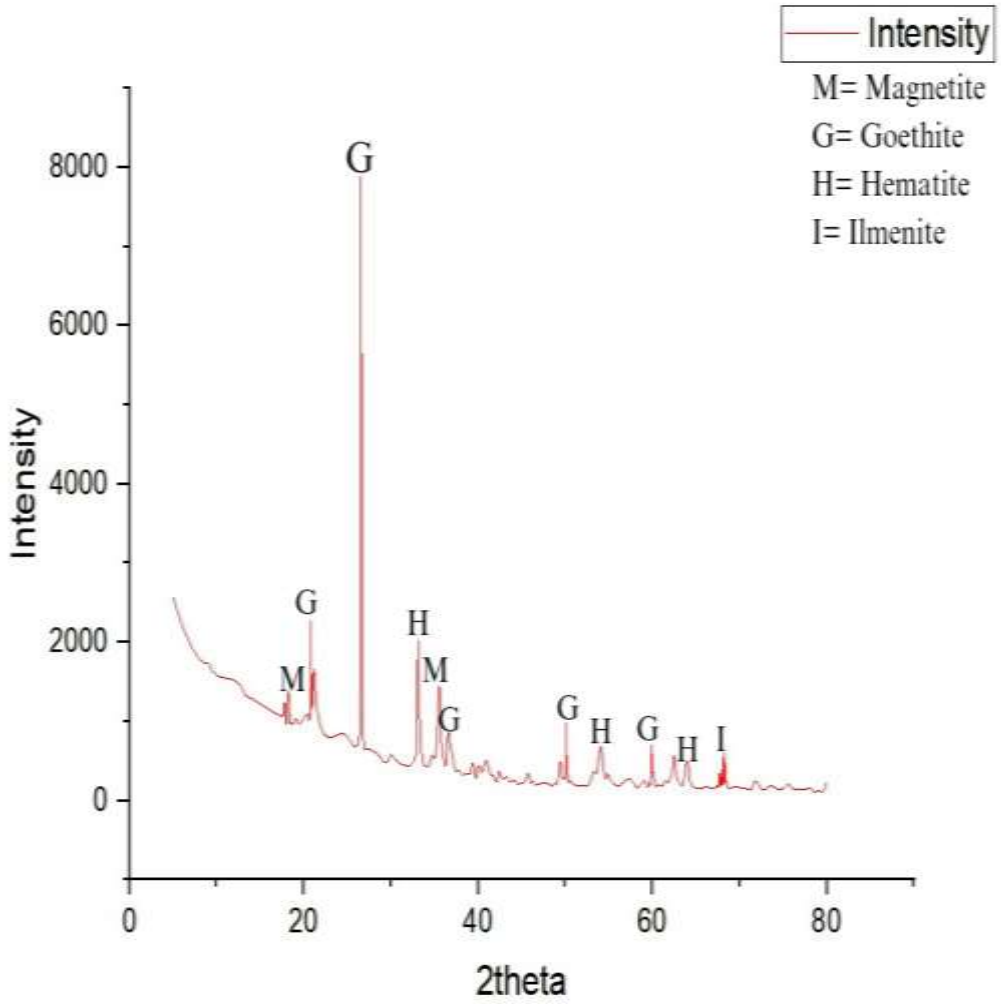

Figure 4.15 Mandovi sample 18

This sample is dominated by Goethite with small and large peaks both. The long solid sharpe peaks indicates a bigger crystal with perfect crystallinity. The broader peaks depicts that the crystal is amorphous and the crystal may be small with defects in the crystalline structures. The longer peaks are mostly between 20-40° with intensity between 0-2500. One peak of Goethite depicts bigger crystal with the intensity of >6000 with perfect crystallinity. The peaks of hematite and magnetite is small and broad between 30-70°.

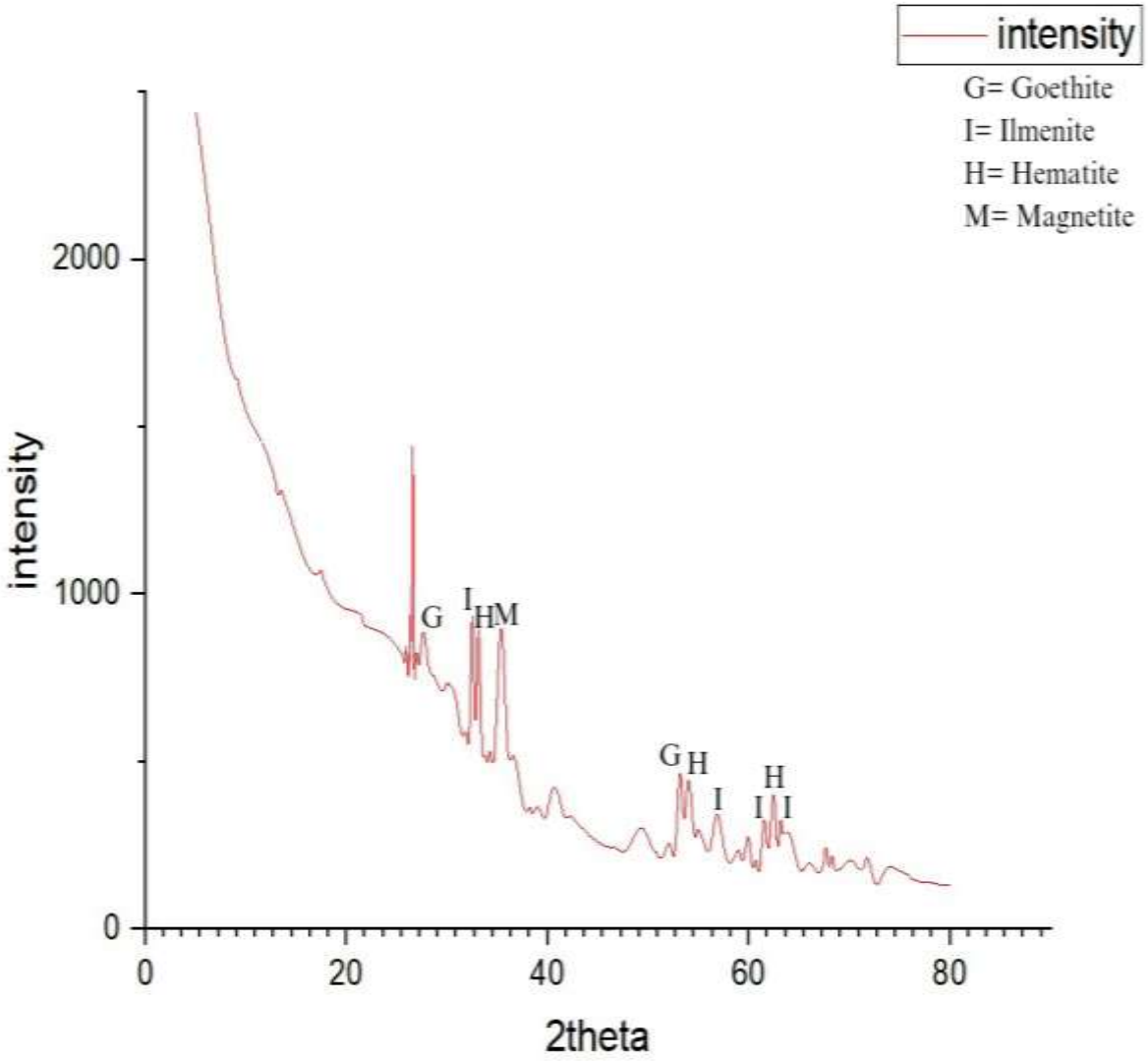

Figure 4.16 Sal sample 13

This sample is dominated by Ilmenite with small peaks. The long solid sharpe peaks indicates a bigger crystal with perfect crystallinity. The broader peaks depicts that the crystal is amorphous and the crystal may be small with defects in the crystalline structures. The longer peaks are mostly between 20-40° with intensity between 0-1000. All the peaks are below 1000 intensity and broad peaks.

4.3 Results for Scanning Electron Microscope (SEM)

During the process of transportation and deposition the sand grains are exposed to continuous mechanical and chemical action. As a result, various micro features are developed on the surface of the mineral grains. This study of the heavy mineral grains under the scanning electron microscope, observed the micro textures developed in it. There are 3 processes involved for the textures present in the heavy mineral which are mechanically, chemical and dissolution chemical. Concoidal fractures, pitted surface, grooves and furrows are formed by the mechanical process. Chemical process develops silica precipitation and dissolution chemical process lead to generate concavities, solution pits, etch V marks. For example the tourmaline grain from Sal sample 5, even smooth surface having a perfect euhedral shape depicting less transportation, less weathering and erosion. Rutile from Mandovi river had sharp edges and polished surface with some pitted patches on it. Grooves has been noted in the sediment sample that are elongated or channels.

In most samples, grains of the same mineral present a mixture of different populations with a variety of morphologies. The euhedral grains have well-conserved angle edges and mechanical textures: conchoidal fractures and some grooves. The sub-euhedral grains show a tendency to the rounding of the angle edges and present conchoidal fractures with signs of reworking, some grooves and surface textures of chemical origin: solution hollows. Within the anhedral morphology, sub-rounded, rounded and angular grains can all be distinguished. Sub-rounded grains show bulbous edges, old mechanical markings (conchoidal fractures and grooves), solution hollows and chemical etch pits; the surfaces of some present generalised polishing. Rounded grains present numerous upturned plates, curved grooves and solutions pits and hollows with conchoidal fractures in some cases.

CHAPTER V

CHAPTER 5

DISCUSSION

This study is based on understanding the heavy mineral deposits along the two major rivers of Goa namely Sal and Mandovi. The Identified heavy minerals along with the dominance have been presented in Table 4.0 and 4.1. Of the 8 minerals identified, Epidote and chlorite are dominant and they occur in various geometric forms. Epidote is sub angular to sub rounded in shape whereas chlorite occurs as flat shape and subangular. Hornblende, the common heavy mineral in the sediments of these rivers occurs as prismatic grains. Tremolite-Actinolite also occurs as prismatic and elongated grains but with diagonal fractures, rugged edges and light colour. Epidote occurs mainly as pale green and irregular grains. Zircon occurs as euhedral prismatic grains with pyramidal terminations. It is colourless to brownish yellow with strong closely packed zones. Garnet occurs as irregular and subrounded grains with variety of colours such as colourless, pale pink and yellow to brown. Brown coloured tourmaline grains occurs as angular to subangular shapes with elongated shapes. Rutile occurs as irregular, oval shaped, deep reddish colour and sometimes occurs with sharp edges.

In the study area of river Sal and Mandovi, the heavy mineral mainly consists of epidote, tourmaline, staurolite, rutile, hornblende, zircon, tremolite-actinolite, apatite and garnet with minor amount of other colourless to green colour minerals. It is evident from this account that the minerals of these rivers indicate a mixed provenance of metamorphic and igneous rocks. The distribution of heavy minerals has been studied on 21 location points of river Sal and 18 location points of river Mandovi. It is clear from the tables (Table 4.0 and 4.1) that there is a considerable variation in the

heavy mineral distribution on the shoreline of both the rivers. It is generally observed that the heavy mineral concentration increases as the grain size decreases. The source for this heavy mineral is yet not identified but high chances because of the lithology present nearby the shoreline or long transported sediments may be had deposited in these rivers.

The results of X-ray diffraction plots the intensity of the signal for various angles of diffraction at their respective two theta positions. The two theta positions correspond to a certain spacing between the crystals or atoms in the samples, determined by the angle of diffraction from the incident x-ray beam sent into the sample. The width of the peaks is inversely proportional to the crystal size. A thinner peak corresponds to a bigger crystal. A broader peak means that there may be a smaller crystal, defect in the crystalline structure, or that the sample might be amorphous in nature, a solid lacking perfect crystallinity.

Twelve Magnetic samples of river Sal and Mandovi were analyzed for X-ray Diffraction and the minerals found was Magnetite, Ilmenite, Goethite, Hematite and Siderite by the interpretation of the peaks. Goethite had long solid and high intensity peaks depicting that mineral have bigger crystal with perfect crystallinity and on the other side Siderite occurs as broad and short peaks that depicts, the grain is amorphous in nature with defects in the crystal structure and grain size may be small. Ilmenite and Hematite occurs as long peaks with high intensity depicting perfect crystallinity. Goethite and Ilmenite is dominating in most of the samples.

Scanning Electron Microscope study of the selected heavy mineral grains revealed a variety of microtextures developed by mechanical, chemical process and chemical dissolution processes on the grain surface that are controlled by mineral’s physical

properties. Notable morphology of the grains includes: characteristic surface textures such as conchoidal fractures on angular grains, indicative of a high-energy subaqueous abrasive action associated with short-distance transportation. Sediments of rivers are mainly characterized by angular, subangular, and subrounded grains with different types of micro-textural features. Figure 5.1, exhibits the highest frequency of cleaved surfaces on the tourmaline grains.

Mechanical processes result in predominantly conchoidal fractures, and fresh V-shaped percussion cracks, which indicate limited sediment transport and high-energy conditions in the fluvial environment. Grooves were also recognized on the surface of other mineral grains. It can be inferred that sediment grains have moved into the main channel under high-energy conditions, undergoing abrasion by colliding with each other. Rounded grains and smoothening of edges may be the result of reworking of the sediments derived from older stratigraphic units. Lower energy discharge conditions are inferred from chemical-precipitation and chemical-dissolution features, evidenced by the presence of hollows and pits on grain surfaces. Pits also indicate longer residence time of grains in the basin (Pan et al. 2016).

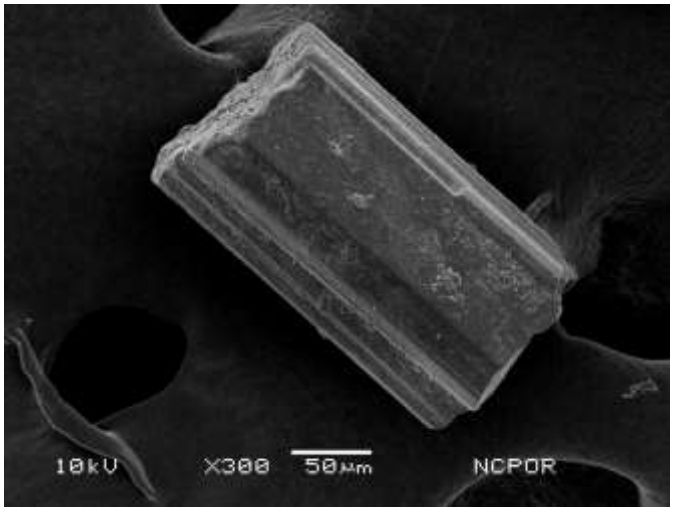

Figure 5.1 Tourmaline grain from river Sal having smooth surfaces with some pitted texture showing perfect crystal faces (Euhedral)

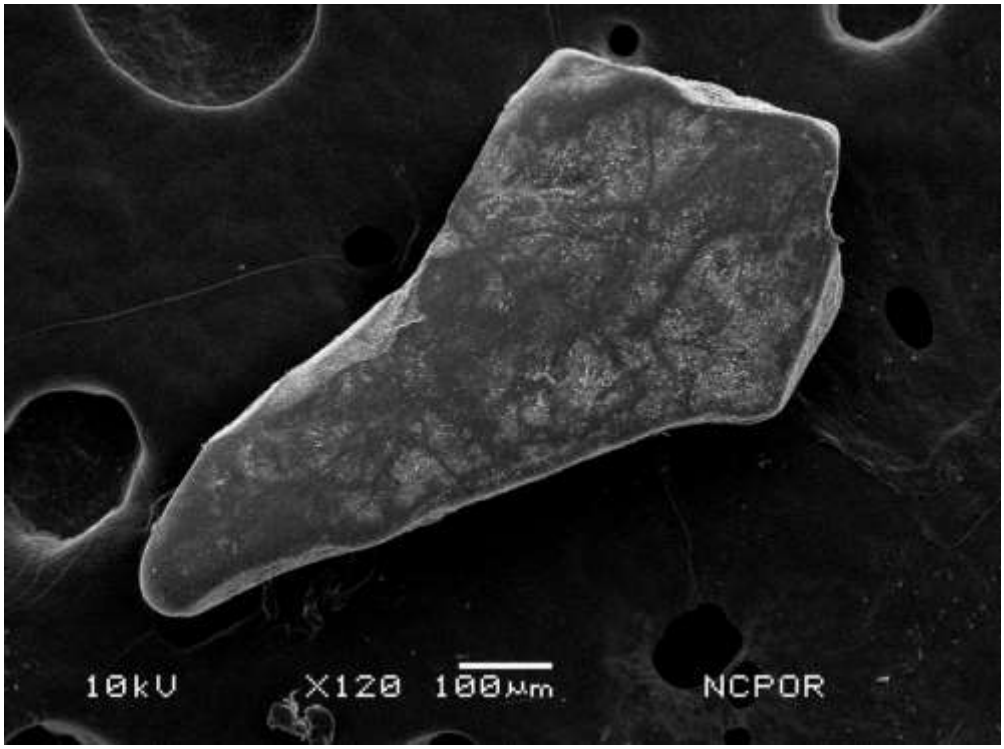

Figure 5.2 Rutile grain having sharp edges having irregular surface with some groove texture on it depicting high energy currents.

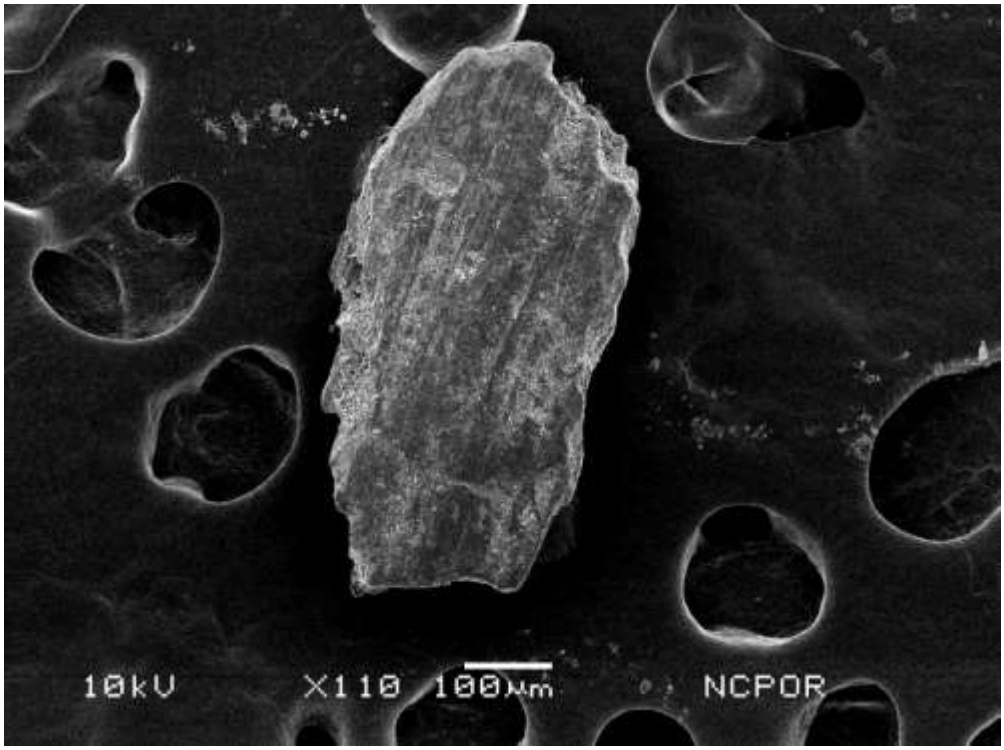

Figure 5.3 Sub-euhedral chlorite grain from river Mandovi, with many chemical surface textures; irregular surfaces and solution pits which depicts longer residence time in the basin.

CHAPTER VI

CHAPTER 6

CONCLUSION

This study is particularly focusing on to analyze the heavy mineral components with special importance to the content of heavy minerals, to determine grain morphology and surface textures. For these two important rivers from Goa were chosen; River Sal and River Mandovi. From both the rivers and its tributaries total 39 Samples were collected. The Heavy minerals distribution in the river Sal and Mandovi sediment samples shows significant variability controlled by the combined effect of provenance, river morphology, hydrodynamic conditions and sediment dispersion by the rivers and their sub-basins tributaries. In addition to the dominant minerals, many other heavy minerals were identified in the samples. In the present study, heavy mineral assemblages were found to be dominated by Epidote, Tourmaline, Tremolite-Actinolite, Chlorite. Magnetic minerals such as Hematite, Goethite, Magnetite and Ilmenite was encountered as dominant mineral through X-ray Diffraction analysis. The mineralogical diversity and variation along the profile of the river Sal and Mandovi could be explained by the mixing sediments of different compositions by various source such as lithology of the area or sediment transportation through small tributary streams. In general, most grains are angular-subangular and sub rounded, and the percentage of subrounded grains are higher than rounded grains. Hence, the sediments are mostly close to their provenance. Scanning Electron Microscope (SEM) study of the grains of non-magnetic minerals such as Chlorite, Tourmaline, Epidote, Rutile and other minerals shows a variety of microtextures developed by mechanical, chemical and dissolution chemical processes operating in the river Sal and river Mandovi. Mechanical process leads to form the concoidal fracture pitted surface,

groves and furrows. Dissolution chemical process generates concavities, solution pits, etch V marks. A chemical process develops silica precipitation. Mechanically formed grooves are predominant features followed by V marks and concoidal fractures. Rounded grains and smoothening of edges indicate high energy zones, etch V's and solution pits are dominant features by precipitation of chemical processes.

REFERENCE

- Al-Saady, Y. I., Al-Obaydi, M. M., Othman, A. A., & Hasan, S. E. (2021). Distribution pattern of heavy minerals assemblages in recent sediments of Lesser Zab River Basin (LZRB), NE Iraq. *Environmental Earth Sciences*, *80*(4), 155.
- Cardona, J. M., Mas, J. G., Bellón, A. S., Domínguez-Bella, S., & López, J. M. (2005). Surface textures of heavy-mineral grains: a new contribution to provenance studies. *Sedimentary Geology*, *174*(3-4), 223-235.
- Dessai, A. G. (2011). The geology of Goa Group: revisited. *Journal of the Geological Society of India*, *78*, 233-242.
- DeWitt, K. M., Batson, J., Witkowski, M., Ranieri, N., & Richards-Waugh, L. (2015). X-ray powder diffraction method development and validation for the identification of counterfeit pharmaceuticals. *US Food and Drug Administration: Cincinnati, OH, USA*.
- Gujar, A. R., Iyer, S. D., Udayaganesan, P., Ambre, N. V., Mislankar, P. G., & Dhinesh, S. (2021). Nature, characterization and resource potential of littoral placer deposits of Goa, central west coast of India. *Journal of Sedimentary Environments*, *6*(3), 359-380.

- Gujar, A. R., Iyer, S. D., Udayaganesan, P., Ambre, N. V., Mislankar, P. G., & Dhinesh, S. (2021). Nature, characterization and resource potential of littoral placer deposits of Goa, central west coast of India. *Journal of Sedimentary Environments*, *6*(3), 359-380.

- Hegde, V. S., Shalini, G., & Kanchanagouri, D. G. (2006). Provenance of heavy minerals with special reference to ilmenite of the Honnavar beach, central west coast of India. *Current Science (00113891)*, *91*(5).

- Holder, C. F., & Schaak, R. E. (2019). Tutorial on powder X-ray diffraction for characterizing nanoscale materials. *Acs Nano*, *13*(7), 7359-7365.
- J., O. S., L., F. S., & A., A. T. (2016, June 1). Sedimentological study and heavy mineral analysis of sediment samples from well-S, Niger Delta, Nigeria. Universal Journal of Geoscience. https://www.hrpub.org/journals/article_info.php?aid=5060
- Kessarkar, P. M., Suja, S., Sudheesh, V., Srivastava, S., & Rao, V. P. (2015). Iron ore pollution in Mandovi and Zuari estuarine sediments and its fate after mining ban. *Environmental monitoring and assessment*, *187*, 1-17.
- Kiprotich, K. K. (2016). *Characterization Of Sands For Heavy Minerals, Selected Heavy Metals Distribution And Profiling Along River Tiva, Kitui County, Southeastern Kenya* (Doctoral dissertation, University of Nairobi).
- Mallik, T. K. (2018). A guide to rapid identification of heavy minerals and highlights of heavy mineral distribution pattern along Indian coasts. *MOJ Eco Environ Sci*, *3*(4), 260-263.
- Mohammad, A., & Dhanamjayarao, E. N. (2021). The impact of seasonal changes on heavy minerals concentration from a part of east coast of India. *Malaysian Journal of Geosciences*, *5*(1), 12-21.
- Nayak, G. N., & Chavadi, V. C. (1989). Distributions of heavy minerals in the beach sediments around Kali river, Karwar west coast of India.
- Pan, B., Pang, H., Gao, H., Garzanti, E., Zou, Y., Liu, X., ... & Jia, Y. (2016). Heavy-mineral analysis and provenance of Yellow River sediments around the China Loess Plateau. *Journal of Asian Earth Sciences*, *127*, 1-11.

- Rahman, M. J. J., Pownceby, M. I., & Rana, M. S. (2022). Distribution and characterization of heavy minerals in Meghna River sand deposits, Bangladesh. *Ore Geology Reviews*, *143*, 104773.
- Schulz, B., Sandmann, D., & Gilbricht, S. (2020). SEM-based automated mineralogy and its application in geo-and material sciences. *Minerals*, *10*(11), 1004.
- Sreenivasa, A., Jayasheela, H. M., Bejugam, P., & Gujar, A. R. (2014). Heavy mineral studies of beach sands of Vagathor, North Goa, India. *Int J Mod Eng Res (IJMER)*, *4*(70-78).
- Whittig, L. D., & Allardice, W. R. (1986). X-ray diffraction techniques. *Methods of Soil Analysis: Part 1 Physical and Mineralogical Methods*, *5*, 331-362.