

**GEOLOGIC SETTING AND HEAVY MINERAL SANDS
OCCURRENCE AT THE KENYAN COAST AND THE EFFECTS
OF MINING ON THE KWALE ECOSYSTEMS**

OCHOLA KEVIN

REG NO: I13/2362/2007

*A research project submitted to the department of geology in partial fulfillment of the Bachelor
of Science Degree in Geology, University of Nairobi.*

JUNE, 2011

DECLARATIONS

Declaration by student

This report is my original work and has not been presented for degree in any other university whatsoever

NAME.....

SIGNATURE.....

DATE.....

Declaration by Advisor

This report has been submitted for examination with my approval as Advisor

NAME.....

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ABSTRACT

The Kenyan coast extends from Kiunga in the North to Vanga in the South, for about 574Km. the Coastal region is bounded in the North by latitude 2°S and in the West by the meridian of longitude 38°E. The southern and eastern limits are determined by the Kenyan, Tanzanian border, the shoreline of the Indian Ocean and the longitude 40°30' E respectively. The total area is approximately 66,500 square kilometers. The altitude varies from 0m at the shore to about 2200m in the Taita hills. The region comprises of six counties; Mombasa, Kwale, Kilifi, Tana River, Lamu and Taita Taveta. The geology of the Kenyan coast is dominated by rifting and breakup of the Paleozoic Gondwana continent and the development of the Indian Ocean. The Proterozoic gneisses of the Mozambique belt (Pohl and Horke 1980) form the basement of an intracratonic basin, filled with continental permo- Triassic clastics. The geology of the Kenyan coast is a major factor in the occurrence of the heavy mineral sands. These heavy mineral sands occur in various parts of the Kenyan coast in almost similar geologic environments.

Geochemically, mineral sand deposits contain ilmenite, rutile, zirconium as well as other minerals and trace elements that could be of radioactive nature, such as thorium. Mineral sands do contain various quantities of metallic and non metallic minerals that are of economic significance; however poor mining and processing methods could results in grave environmental issues, which would jeopardize the ecosystems of the particular area of occurrence and mining. These threat can however be minimized by taking certain precautionary steps and avoiding certain methods of extraction.

ACKNOWLEDGEMENT

I would like to thank the department of geology for allowing me to pursue this project, especially the supervisors, Dr. Olago and Dr. Gichaba. Many thanks to my advisor, Dr. Ichang'I for the important assistance he provided and to my classmates for their support and input. I also wish to acknowledge The Department of Mines and Geology, for library assistance.

DEDICATION

This report is dedicated to my Parents, Brothers, Nick, Mike and Ian. Sisters, Grace and Beryl.

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CHAPTER ONE:

1.1 INTRODUCTION

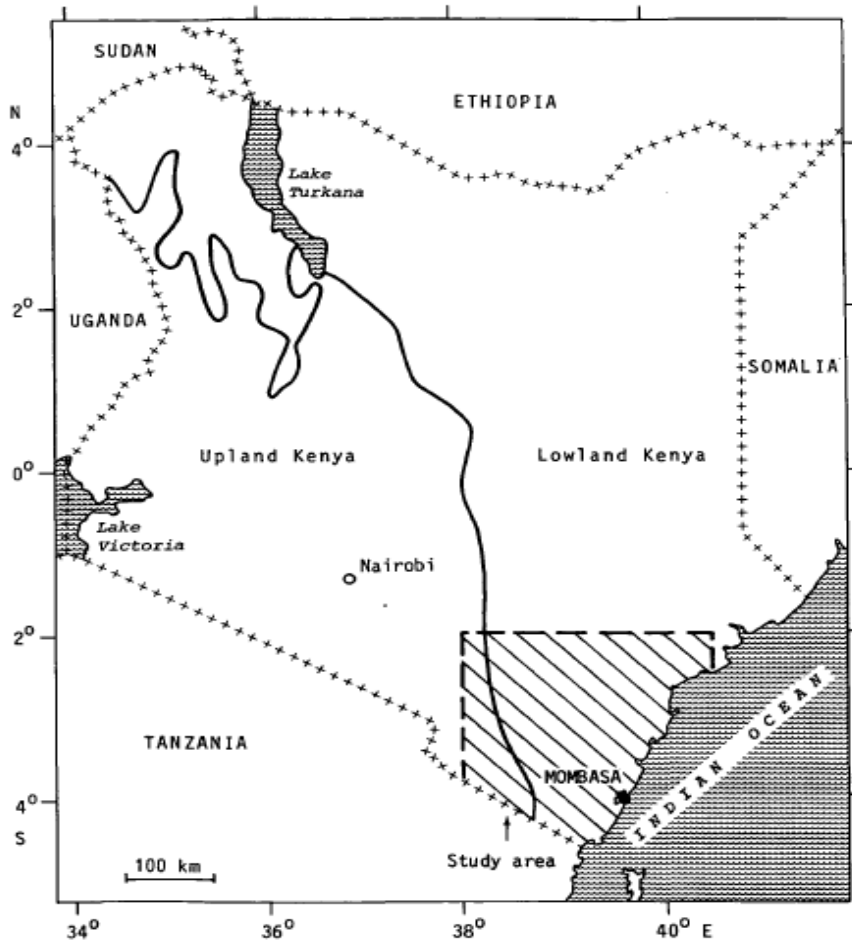


Figure 1. 1: Location of the study area.

1.1.1 Geographical setting or location

The Kenyan Coast borders the Indian Ocean to the east and has a coastline running from Kiunga in the North to Vanga in the South, for about 574Km. the Coastal region is bounded in the North by latitude 2°S and in the West by the meridian of longitude 38°E. The southern and eastern limits are determined by the Kenyan, Tanzanian border, the shoreline of the Indian Ocean and

the longitude 40°30' E respectively. The total area is approximately 66,500 square kilometers. The altitude varies from 0m at the shore to about 2200m in the Taita hills. The region comprises of six counties; Mombasa, Kwale, Kilifi, Tana River, Lamu and Taita Taveta

1.1.2 Physiographic /Geomorphologic setting

The coastal belt of Kenya comprises of the following main topographical features which are closely related to the geological characteristics of the area: the Coastal Plain, the Foot Plateau, the Coastal Range and the Nyika. The altitude of the Coastal Plain is generally less than 45 m above sea level. Different geologic features form the coastal belt. Geomorphologically, the Kenyan coastal zone is an emergent coastline. It has thus been subjected to marine regression since the Jurassic period. During the Pleistocene, sea-level fluctuations associated with glacial / interglacial phases left well developed raised platforms and beaches. The Malindi area, in the north, has experienced a shoreline progradation of up to 750 m over the last 40 years. The north coast is also characterized by a predominance of sand dunes and tombolos, exemplified at Ras Ngomeni, in addition to recognized higher land uplift and arching (Abuotha, 2004).

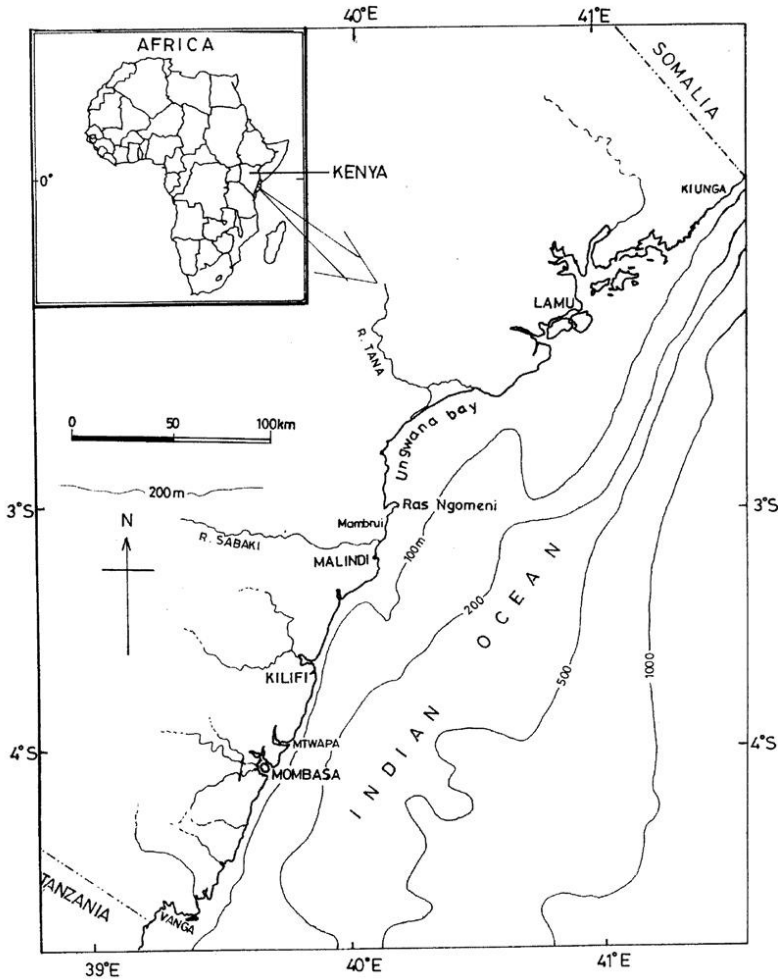


Figure 1. 2: Geomorphologic map of the Kenyan Coast. (Abuotha,2002)

1.1.3 Literature Review

Various authors have conducted field studies at the Kenyan Coast, in order to investigate the coastal features, such as the shoreline and terraces along the coast (Sikes, 1930; Caswell, 1953; Thompson, 1956; Hori, 1970;Toya et al, 1973; Ase, 1978; Read, 1981; Braithwate, 1984; Oosterom, 1988; Abuotha 1992. Most of the authors were concerned with the dating of the terraces, as resulted from a field based geological mapping survey or from aerial photographs. Musyoki, 1994, also studied the sedimentary rock formation in the area. Ojany, 1984: Generalised geological map of the Kenyan coast. Horkel et al, 1984; Notes on the geology and mineral resources of the southern Kenyan coast. Tiomin resources Inc. 1998. Titanium sands-

Geology of the Kwale deposit. Internal report, August 1998, by N. Ross. Other works have been done in order to investigate the mineralization of Heavy mineral sands.

1.1.4 Statement of the problem

The geology of the Kenyan coast is a major factor in the occurrence of the heavy mineral sands. These heavy mineral sands occur in various parts of the Kenyan coast in almost similar geologic environments. Geochemically, mineral sand deposits contain ilmenite, rutile, zirconium as well as other minerals and trace elements that could be of radioactive nature, such as thorium. Mineral sands do contain various quantities of metallic and non metallic minerals that are of economic significance; however poor mining and processing methods could results in grave environmental issues, which would jeopardize the ecosystems of the particular area of occurrence and mining. These threat can however be minimized by taking certain precautionary steps and avoiding certain methods of extraction.

CHAPTER TWO: METHODOLOGY AND OBJECTIVES

2.1 Methodology

Acquiring information on the geology of Coastal Kenya from previous reports and Journals and geological reports of the heavy mineral sands occurrence areas

Using available geochemical data analysis, findings and interpretations

Acquiring information on the available methods that could be used to mine the Heavy mineral sands.

Using information on various cases of mining of similar deposits, in other parts of the world, in order to relate to the occurrence.

Investigating the population distribution patterns and Human activities/ economic activities.

Identifying how the ecosystem would be affected by mining processes.

Estimating the potential gains and losses to the community, by interpreting data on the economic and environmental aspects of the proposed project.

2.2 Objectives

To highlight the relationship between the geology of coastal Kenya and the occurrence of the mineral sands.

To determine the geochemistry of the heavy mineral sands and the possible effects of their chemical composition on the ecosystem of Kwale, in the event of mining.

To establish the measure to be deployed to minimize adverse effects on the fragile ecosystem.

CHAPTER THREE:

3.1 Geology of the Kenyan coast

The geology of the Kenyan coast is dominated by rifting and breakup of the Paleozoic Gondwana continent and the development of the Indian Ocean. The proterozoic gneisses of the Mozambique belt (Pohl and Horke 1980) form the basement of an intracratonic basin, filled with continental permo- Triassic clastics.

According to Oosterom, 1988, a mainly Paleozoic to Mesozoic platform cover occurs at the Kenyan coast. The older part of it consisting of fluviatile, lacustrine and deltaic sandstones and shales. The rocks belong to the Karoo system of Kenya and form a lithostratigraphical unit known as the duruma group(cannon et al, 1981a, p. 421).

3.1.1 Stratigraphy and geological history

The coastal region of Kenya is characterized by superficial sediments which have originated from marine processes(Oosterom, 1988). It consists of slightly folded and tilted sandstones, shales and limestones. In the north and east, these rocks are overlain by cainozoic sands, clays and soft limestone. The interior is however, characterized by deposits which are associated with terrestrial processes. The subsurface mainly consists of the Precambrian metamorphic rocks and Paleozoic to Mesozoic sedimentary rocks.

The mainly permo- Triassic deposits of the coastal region are overlain by marine Mesozoic sedimentary rocks. Lithological and paleontological evidence shows that the sea in which the material deposited had an epicontinental character. The exposures of the Mesozoic sediments form a narrow strip of land down faulted against the rocks of the Karoo system. The southeastern part of the region contains the igneous Jombo complex of the late cretaceous (Pulfrey, 1989). A cycle of erosion was initiated, resulting in a rejuvenation of the Jurassic and early cretaceous landscapes.

According to Ojany, 1984, the stratigraphical setting of the Kenyan coast is such that rocks of; the upper Proterozoic (Mozambique belt), Paleozoic, Mesozoic and cainozoic ages are represented as follows;

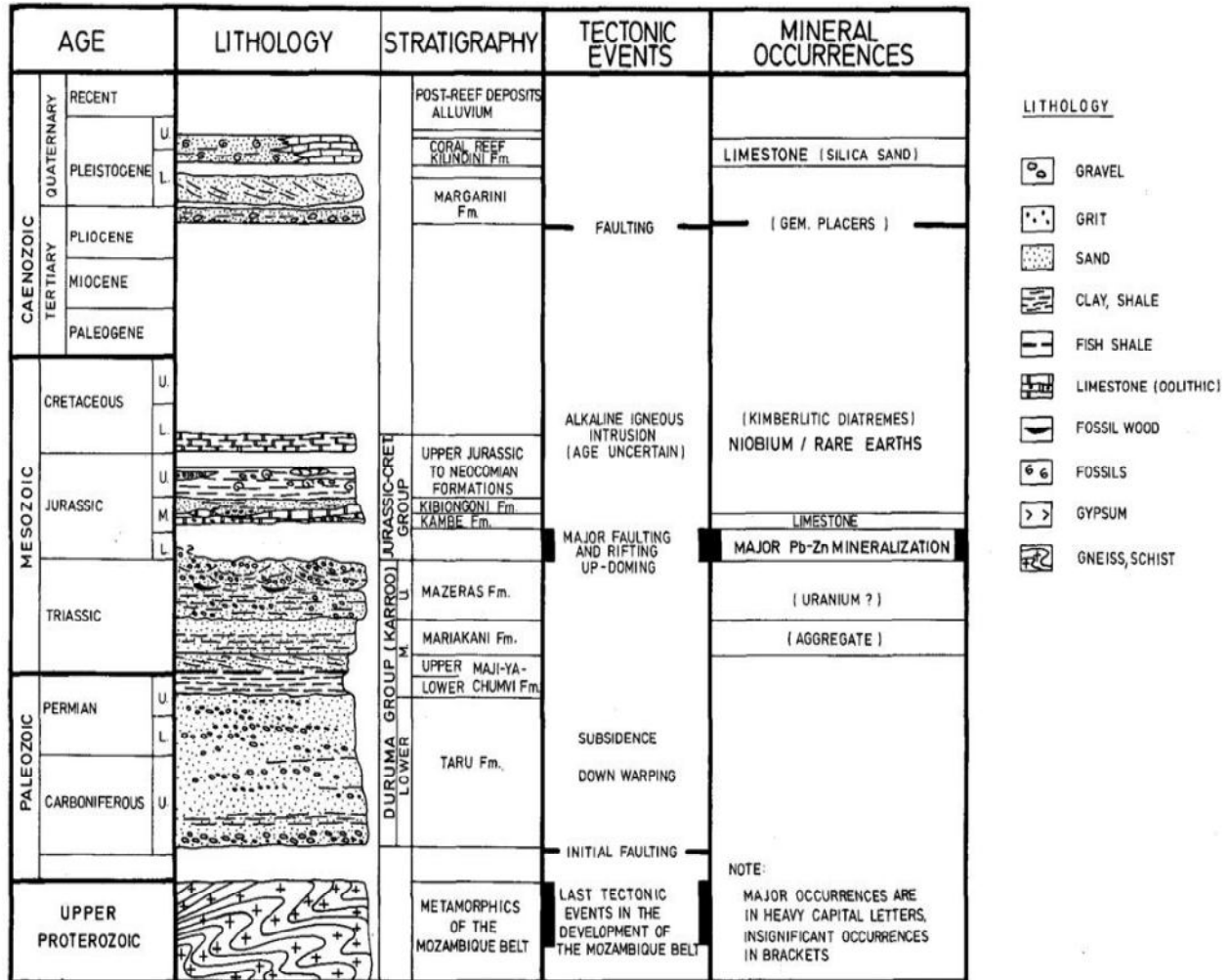


Figure 3. 1: stratigraphy of the Kenyan coast (Horkel et. al, 1984)

Duruma Group (Permo-Triassic)

Most of the area is underlain by continental Permo-Triassic sediments assigned to the Duruma Group ("Duruma Sandstone Series" CASWELL 1953), which is generally considered as the Kenyan equivalent of the Karroo system of southern Africa. The Duruma sediments essentially comprise elastics (grits, arkosic sandstones, and shales), accumulated under lacustrine, sub-aerial conditions with minor marine ingressions in a broad, roughly NNE-SSW trending intracratonic trough, which formed towards the end of the Paleozoic within the Proterozoic gneisses of this part of the Gondwana continent. During the initial development stages of this trough,

downwarping was fairly rapid, and the basal **Taru formation** (exposed inland of the area investigated) consists mainly of coarse-grained, poorly sorted arkoses. Intercalated shales contain fresh water fauna. Intraformational reworking and sedimentary structures are widespread, and indicate rapid denudation and short transport with subsequent re-deposition in a high-energy lacustrine environment. Towards the top, the grain size of the Taru sediments decreases and the generally fine-grained **Maji-ya-chumvi** formation overlies the Taru sediments along a slight Unconformity. Current bedding and ripple marks are common and indicate deposition in shallow water. A basal sequence, composed of fissile dark shales with thin intercalations of sandy siltstones, frequently shows rain pits and desiccation cracks together with appreciable amounts of precipitated salts. It therefore indicates a period of arid climate during which the trough apparently dried-up frequently. This facies is terminated by a marine ingressión which deposited fish-bearing shales followed by flaggy, fine-grained argillaceous sandstones, siltstones, and shales with a wealth of sedimentary structures (cross-, current-, and convolute bedding, rippled laminations, slump folding, etc.); they contain Triassic fauna indicating the return of brackish and even fresh-water conditions. During the deposition of the **Mariakani formation**, which conformably overlies the Maji-ya-chumvi beds, erosion became more intensive and a rhythmic succession of fine to medium grained sandstones and impure shales was deposited, probably again under lacustrine conditions. Massive, fine-grained sandstones with distinct mottling prevail in the basal part of the formation, flaggy arkosic sandstones with usually well developed cross-bedding in the upper part. More pronounced erosion persisted during the deposition of the **Mazeras formation**, which unconformably overlies the Mariakani formation. It starts with coarse grained, cross-bedded arkoses, with lenses of grits and minor siltstone/shale intercalations. The sedimentation rate eventually surpassed the rate of subsidence of the trough, and dry areas covered by *Dadoxylon* forest emerged, as evidenced by a well-defined horizon containing abundant fossil wood. Coarse-grained, massive arkoses and grits of terrestrial origin with infrequent sub-aqueous intercalations terminate the Mazeras formation. This decline of the subsidence rate possibly already indicates incipient up-doming prior to the Jurassic rifting of Gondwana (Neugebauer 1978).

Marine Jurassic - Cretaceous Sediments

After the termination of the Duruma sedimentation, major faulting and rifting led to the break-up of Gondwanaland; it caused a fundamental facies change from a continental cratonic trough to a marginal marine basin with neritic sediments, located at the trailing edge of the continent. This transition is marked by a middle Jurassic (Bajocian) marine ingress. The basal Bajocian sediments of the **Kambe formation** were deposited under nearshore neritic and estuarine conditions. Basal transgression conglomerates, largely composed of Duruma detritus, are overlain by impure **micritic limestones**, occasionally with small bioherms, and near-shore **oolithic limestones**, which were deposited in a shallow shelf environment with only moderate terrigenous contamination. **The Kibiongoni formation**, comprising shales, sandy siltstones, impure sandstones and grits, represents a partly contemporary estuarine facies with strong terrigenous influence. Apparently seaward drainage was restricted by coastal ranges, probably resulting from up-doming prior to rifting. Clastic detritus was thus transported into estuaries just by a few rivers breaching this coastal range whilst the limestones of the Kambe formation formed in the clean, agitated sea between the estuaries. With increasing denudation of the coastal range, they were partly later covered by estuarine Kibiongoni sediments. Kambe and Kibiongoni formations are overlain by a monotonous sequence of fossiliferous Upper Jurassic calcareous shales and mudstones with occasional thin lenses of impure or oolitic limestones. Four formations extending from the Calloway into the Kimmeridgian were discerned on a biostratigraphical basis by Caswell (1953 & 1956).

Tertiary sediments

Plio-Pleistocene Deposits Erosion prevailed during the Tertiary until the Upper Pliocene, when tectonic reactivation resulted in increased erosion from structural highs. Fluvial pebble beds, gravels and sands of the **Magarini formation** were deposited on down-faulted and eroded Jurassic and Duruma sediments. After a regression during the lowest Pleistocene, dunes which form the bulk of the Magarini formation were blown-up. The younger Pleistocene was marked by eustatic fluctuations of the sea level, by the erosion of the Magarini sediments, the growth of a coral reef and the deposition of the associated lagoonal sands and backreef deposits of the **Kilindini formation**.

Tertiary- Recent volcanics

The generally close relationship of continental rifting with alkaline magmatism is documented at the southern Kenyan coast by the Jombo-Mrima alkaline complex, tentatively dated as Cretaceous (Walsh 1969). The major alkaline intrusions of Jombo Hill and Dzirihini consist of cores of nepheline syenites surrounded by mafic alkaline rocks (malignites, ijolites, melteigites, juvites, and foyaites). Associated with them are the carbonatite complex forming Mrima Hill as well as agglomerate vents, kimberlitic diatremes, and minor volcanic vents. Lamprophyric dykes (monchiquites, vogesites, camptonites, and tinguatites) as well as nephelinite and syenite aplites cut across the igneous rocks and the surrounding Duruma sediments, which show in places intense fenitization by insitu alkali metasomatism. Active hot springs are recent vestiges of volcanic activity.

Quaternary sediments

Pleistocene formations identified along the coastal plain from the west to the east are; the Holocene (Recent) reef deposits, Shanzu calcarenites member, Mombasa limestone member and the Kilindini sands member. The reef deposits consist of an assemblage of coral limestone, calcarenites and intercalations of quartz sands, sandstone pebbles, silt and calcareous algae. This reef formation extends 3 – 5 km from the present shoreline, underlying the coastal plain, and attains elevations of up to 30 m above sea level. The Kilindini sands comprise mainly quartz sands with subordinate silts and clays (Abuotha, 2003).

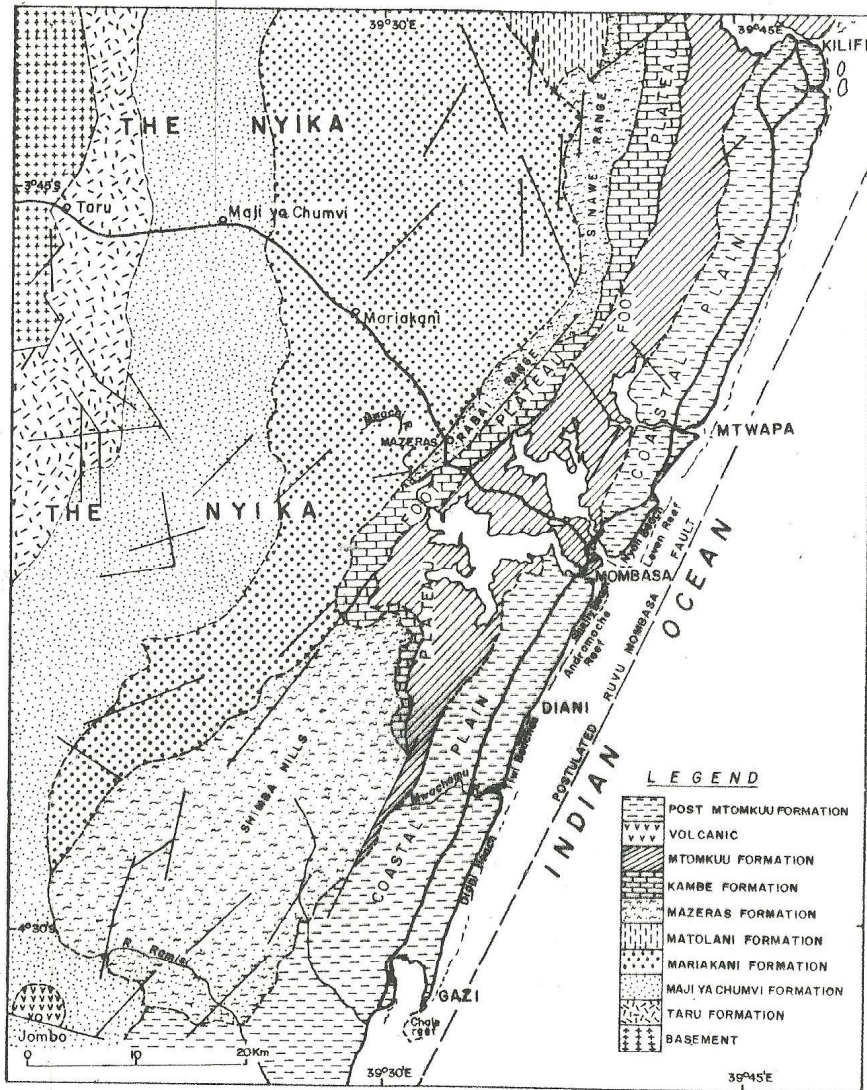


FIG. GENERALISED GEOLOGICAL MAP OF THE SOUTHERN PORTION OF THE KENYA COASTAL BELT (Modified after Rais-Assa, 1987).

Figure 3. 2: geological map of the south coastal belt

CHAPTER FOUR:

4.1. The heavy mineral sand deposits of Kwale

Introduction

Heavy mineral sands are defined as a loose aggregate of unlithified mineral or rock particles of sand size (generally 0.02 to 2.0 mm) forming an unconsolidated or moderately consolidated sedimentary deposit consisting essentially of medium grained clastics. These are derived from the weathering of pre-existing rocks, and accumulated by wind or water. Mineral sand deposits are syngenetic concentrations of valuable mineral particles with high specific gravity accumulated within the sand deposits.

The Kwale deposit is located 50 kilometers south of Mombasa and about 10 kilometers inland from the coastline. Roads and tracks give good access to the site from the main coastal highway. There are two areas separated by the Mukurumudzi River that contain economically exploitable concentrations of heavy minerals. One is the Kwale Central Dune, which is approximately 2 km long and 1 km wide. The other is the Kwale South Dune, which is slightly larger in area, being approximately 4km long and 1km wide. Lower grade mineralization is encountered within the North Dune. The concession area is located in the coastal uplands formed by a series of ancient dunes that run parallel to the coastline.

4.1.1. Geological setting

The rocks of the area are essentially of sedimentary origin and range in age from late Carboniferous to Recent. Most of the area is underlain by continental Permo-Triassic sediments assigned to the Duruma Group ("Duruma Sandstone Series" Caswell 1953), which is considered as an equivalent of the Karroo system of southern Africa. The Duruma sediments comprise elastics (grits, arkosic sandstones, and shales), accumulated under lacustrine, sub-aerial conditions with minor marine ingressions in a broad, roughly NNE-SSW trending intracratonic trough, which formed towards the end of the Paleozoic within the Proterozoic gneisses Duruma Sandstone Series. The Shimba grits and Mazeras sandstone are of late Triassic age and form the Upper Duruma Sandstone. The Magarini sands form a belt of low hills running parallel to the coast. They rest with slight unconformity on the Shimba grits and Mazeras sandstone. The

Kilindini sands are of Pleistocene age and consist of unconsolidated erosion products of Magarini Formation, Shimba grits and Mazeras sandstone.

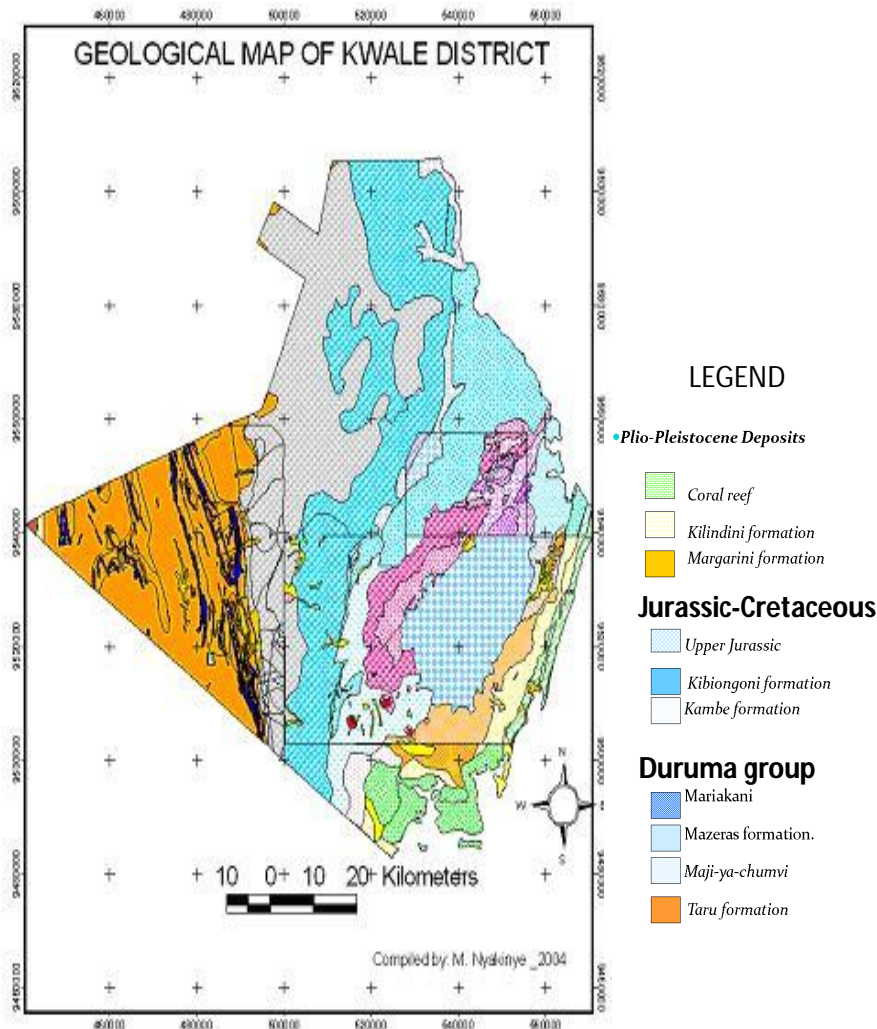


Figure 4. 1: Geological map of Kwale

Mineralization

The deposit lies within the Magarini sands formation, which forms a belt of low hills running parallel to the coast. The formation was deposited during Pliocene times and consists of unconsolidated sediments derived from the Duruma sandstone series. The Magarini sands are believed to be of aeolian origin, deposited as coastal dunes after conditions of intense erosion. The general stratigraphic sequence is composed of brown sand at the surface followed by orange or reddish sand becoming more beige or pinkish at depth. The base of the deposit is weathered

sandstone from the basal formation. White sand and clay is also described at the bottom of several holes.

The Kwale mineralized zones have been subdivided in Central Dune, South Dune and North Dune. The Central Dune envelope is 2 km long and 800-1,250 m wide with an average thickness of 29 m. The upper section has higher grade (>5% THM) than the lower section (1-5%). There is a particularly high grade in the northern part of the Central Dune where grades can exceed 10% THM. For the dune as a whole, the heavy mineral content averages 5.7%. The South Dune envelope is 4.5 km long and 600-800 m wide and has an average thickness of 19 m. The deposit lies directly on a paleotopographic surface occurring at a depth varying from 6 to 24 m. This marked paleosurface separates the higher-grade mineralized orange sands unit from the lower-grade beige to pink sands unit. Within the area, the heavy mineral content averages 3.5%. The North Dune is 2 km long and 500-1000 m wide and the ore envelope extends to depth of up to 66 m. However, there is a low-grade layer on the top. The heavy minerals content averages 2.1% THM for the North dune as a whole.

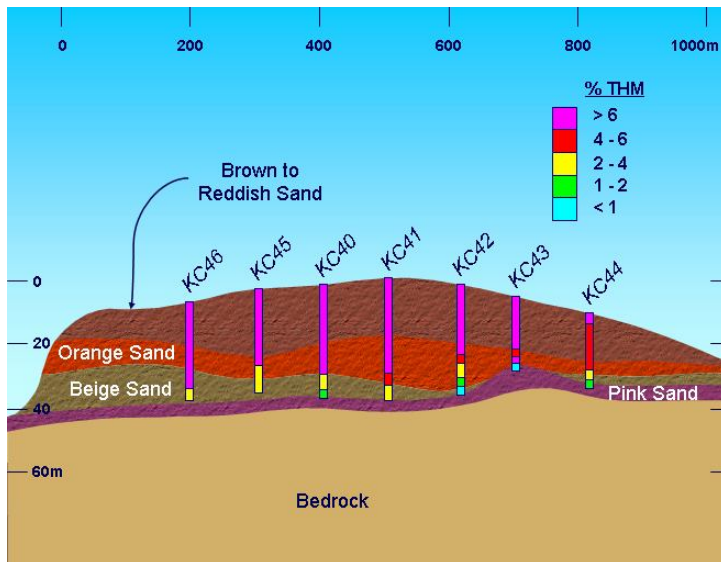


Figure 4. 2: Cross-section of the mineralisation of the central dune

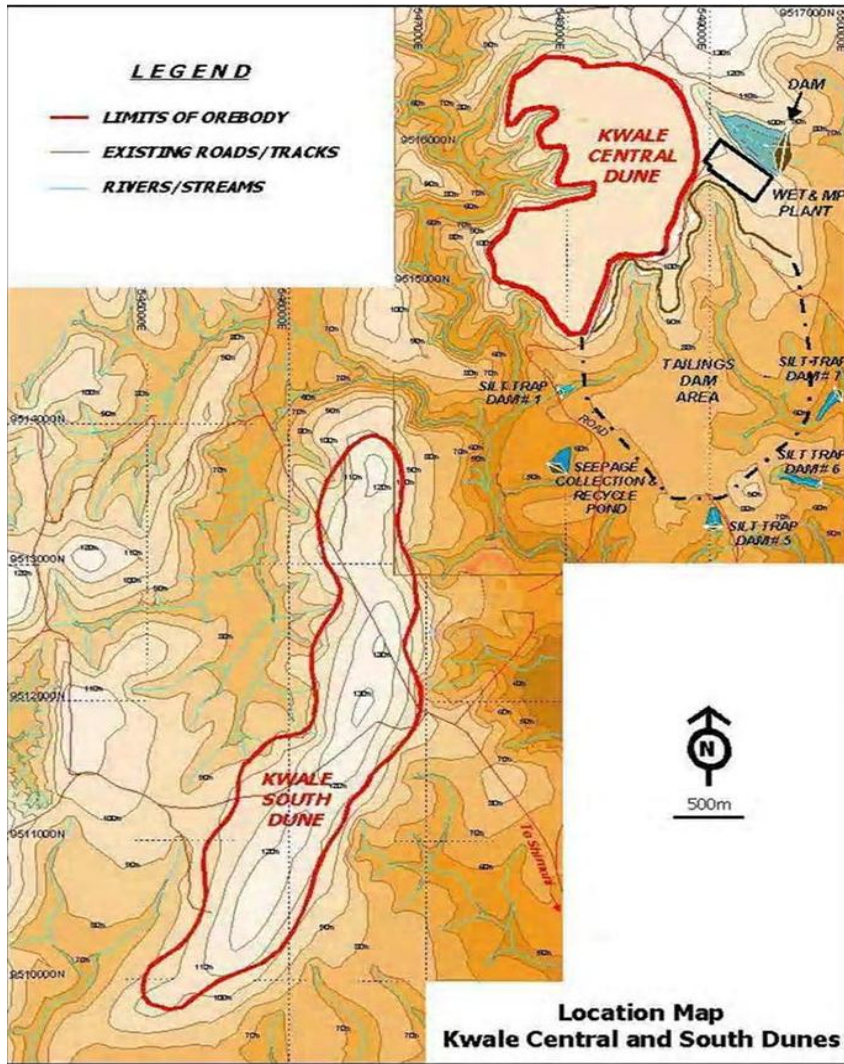


Figure 4. 3: Location map of the central and south dunes (tiomin)

4.1.2. Geochemical assessment

Generally, heavy mineral sands are known to comprise the following minerals;

- Ilmenite (4.5 to 5.0 specific gravity), the most abundant mineral of titanium on earth
- Rutile (4.25 specific gravity), a high grade titanium mineral
- Zircon (4.6 to 4.7 specific gravity), constitutes the main ore for zirconium
- Monazite (4.6 to 5.4 specific gravity), with thorium as its principal component, a rare earth phosphate
- Leucoxene

- Other heavy minerals that may occur are magnetite, kyanite, sillimanite, garnets, and tourmaline.

Geochemical analyses have been done in the mineral sands of Kwale in attempts to determine other earth materials present in the mineral sands in addition to the titaniferrous minerals.

Surface sampling and auger drilling was carried out at the beginning of 1997 to investigate

The mineralised Magarini Formation sand in the Kwale area. The results of this preliminary work showed high rutile and zircon grades and identified three main zones of mineralization in the concession: the Central, the South Dune and the North Dune.

At the same time, a study was also undertaken on Tiomin's other licence areas to test the applicability of the reverse circulation air flush method. The results showed that the method suffered from limited penetration due to the nature of the material drilled and sample losses (Ross, 1999). A top drive rotary rig, using polymer/water as the flushing agent was then introduced and applied as the main method in the Kwale licence. An initial drilling program aimed at a preliminary evaluation of the mineralised dunes was completed during the second quarter of 1997 on the main zones. The initial 49 drill holes (1,800 m) confirmed a mean depth of 30 m above the sandstone basement (Tiomin Resources, 1998). Following this initial drilling campaign, a detailed drilling program of 198 drill holes was initiated in July 1997 focussing on the high-grade zones. The drill holes totalling 4,710 m covered the two main dunes as well as the northern part. Subsequently, twenty-two open flight auger holes of 600 mm diameter were drilled in the Central and South Dunes to provide 100 tonnes of pilot plant sample from each. In 2000, Tiomin completed an infill drilling program on the Central Dune comprising 28 holes with a spacing of 50 m by 100 m and a small area of detailed infill drilling at a 25 m by 50 m grid (Tiomin Resources, 2000). Quality control checks on results and the methods used for sampling and drilling in 1997 as well as sampling by different expert groups, concluded that the drilling method and sampling techniques were reliable.

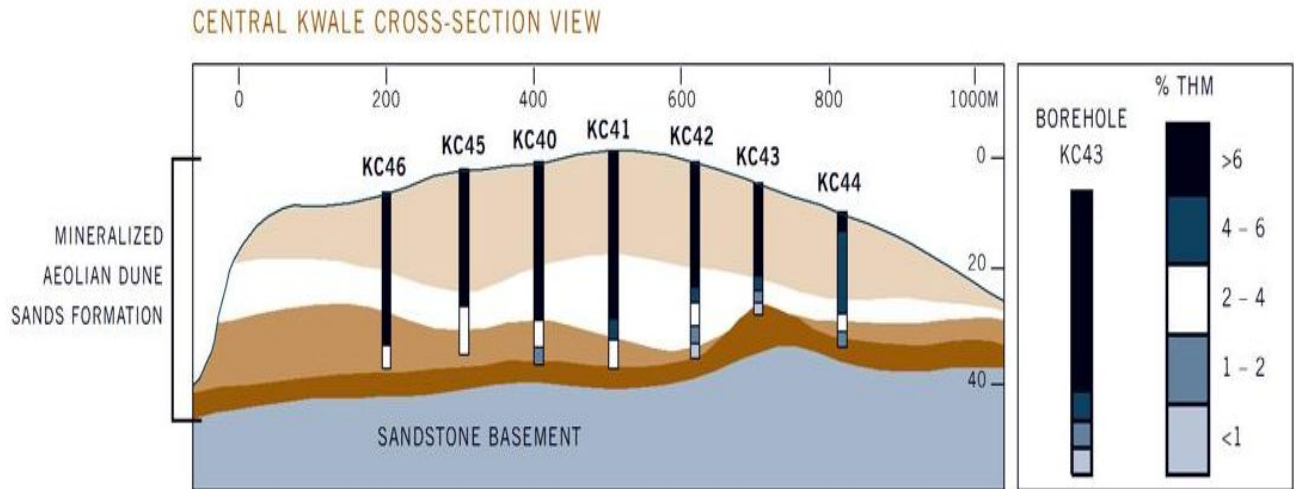


Figure 4. 4: concentrations of the central dune

Table 4. 1: concentration of major minerals in the Kwale deposit

FIG. 1
KWALE DEPOSIT
RESOURCE CALCULATION

| | CENTRAL DUNE | | SOUTH DUNE | | NORTH DUNE | | TOTALS |
|----------|--------------|-----|------------|-----|------------|-----|--------|
| | GRADE % | MT | GRADE % | MT | GRADE % | MT | MT |
| ILMENITE | 3.0 | 2.3 | 1.2 | 1.0 | 1.5 | 0.7 | 4.0 |
| RUTILE | 0.8 | 0.6 | 0.4 | 0.3 | 0.2 | 0.1 | 1.0 |
| ZIRCON | 0.4 | 0.3 | 0.2 | 0.2 | 0.14 | 0.1 | 0.6 |

75 Million Tonnes of Mineralized Sand
78 Million Tonnes of Mineralized Sand
47 Million Tonnes of Mineralized Sand
200 Million Tonnes of Mineralized Sand

The main chemical compounds found in the survey of the area were the two titaniferous minerals; rutile(TiO_2) and ilmenite($\text{FeO} \cdot \text{TiO}_2$), Zircon (ZrSiO_4), Monazite($\text{Ca, La, Y, Th PO}_4$) and Leucuxene. Radioactive elements are also present, albeit in small amounts in Monazite and some in the zircon. Monazite is the source of most of the rare earth elements. Thorium (Th) approximately-3.84 ppm and Uranium (U)-(5.6 ppm) are the main fissionable elements highlighted.

Geochemical results were due to testing of the samples through various geochemical techniques especially, X-ray Diffraction, Atomic Absorption and X-ray fluorescence.

4.1.3. Mining and processing

Mining of Mineral Sand Deposits is usually performed by open-pit methods, which may include wet techniques such as dredging, or dry methods using trucks, loaders, scrapers and bulldozers. Heavy mineral fractions are recovered by gravity concentration. Minerals are separated by the use of cones, spirals, and shaking tables. The sand often contains coated grains with impurities that require attrition and scrubbing with chemical solutions, such as caustic soda, following primary concentration prior to dry ore processing. Primary gravity concentrates consist of titanium minerals, zircon, monazite, and garnets, which need to be separated. This separation is done using high-tension electrostatic separators and by magnetic separators of different intensities.

A sulfate or chloride chemical process is used to make high-purity titanium oxides. The sulfate process is capable of processing low-grade ilmenite directly, but has the disadvantage of reducing acidic ferrous sulfate waste.

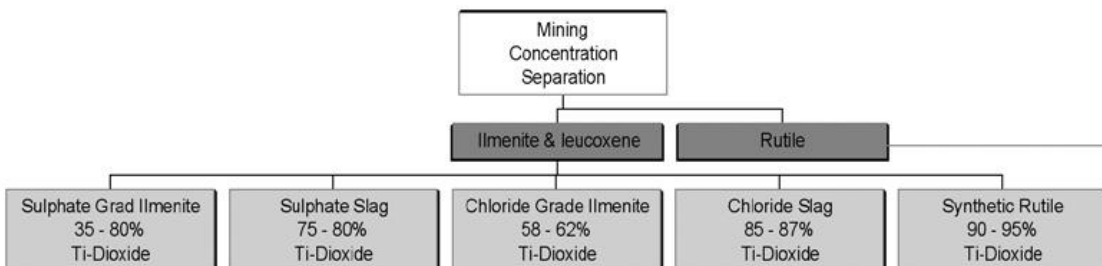


Figure 4. 5: Steps in preparing TiO_2 from the mineral sand deposit

The base case for the Project provides for:

- Mining using a single bucket wheel excavator (BWE) supported by a conventional mining fleet

- Sale of ilmenite produced direct from wet magnetic separation
- Rutile and zircon produced by standard wet and dry separation techniques that is, no hot acid leaching.
- Contracted power supply using HFO powered generation units.
- Process water supply from dam, river and aquifer sources
- Conventional mobile shiploading at Likoni
- Sale of all ilmenite, rutile and zircon.

From the BWE and ancilliary mining operations ore will be fed by an overland conveyor to a Wet Plant (WP) where the slimes and tails are removed and a heavy mineral concentrate (HMC) will be delivered to a Minerals Processing Plant (MPP) for separation of the three valuable products ilmenite, rutile and zircon.

The products will be trucked to a port installation at Likoni where they are stored in silos prior to loading ships via a conveyor loading system.

4.2. Discussions and conclusions.

Thorium and Uranium-based NORM levels in titanium minerals are lower than the regulatory exemption limit of 1 Bq g⁻¹ as given by IAEA Basic Safety Standards. However, it has been established in some parts of the world where similar mineral sands occur that, During the chemical processing of ilmenite to upgrade TiO₂, the ²³²Th and ²²⁸Ra ends up in solid wastes and liquid effluent. The activity levels in the solid wastes and ²²⁸Ra in liquid effluents from synthetic rutile production may be of concern in certain cases. Further studies are required to assess the water dissolution characteristics of these solid wastes. The study indicates that regular monitoring and appropriate engineered protection measures are required to control long-term impacts on the waste disposal environment, Puranik et al. (2007).

CHAPTER FIVE:

5.1 Impacts of the project on the Kwale ecosystem

An ecosystem is a biological environment consisting of all the organisms living in a particular area, as well as the non living, physical components of the environment with which the organisms interact, such as air, soil, water and sunlight. Examples of ecosystems include; Agro ecosystems, aquatic ecosystems, Human ecosystem, and Marine ecosystem

5.1.1 Nature and composition of the fragile Kwale ecosystem

a. Population.

The Kwale district has three constituencies: Msambweni, Matuga, and Kinango with a population of 496,133, of which, 61,586 live in urban centres. Durumas and Digos are the major tribes though there are some Kambas at Shimba hills and some Masaais at Mackinnon Road.

| Division | Population | Urban pop | Headquarters |
|--------------|------------|-----------|--------------|
| Kinango | 72,027 | 1,626 | Kinango |
| Kubo | 48,769 | 0 | - |
| Matuga | 73,377 | 3,996 | Kwale |
| Msambweni | 211,814 | 55,964 | Msambweni |
| Samburu | 91,011 | 0 | Samburu |
| Shimba hills | 135 | 0 | |
| Total | 496,133 | 61,586 | - |

Table 5. 1: Population of Kwale area (1999 census)

b. Vegetation

The vegetation falls into two belts, divided by a line running parallel to the coast through Mariakani. East of this line open grasslands with occasional palms and baobabs predominate,

while to the west thorn and cactus scrub is prevalent becoming more desolate as the Taru desert west of Taru is approached.

c. Marine life.

The area being in the Coastal belt comprises a very fragile composition of marine life. Both plants and animals that adopt well in the marine environments are thus part and parcel of the consideration of whatever project to be initiated within this area

5.1.2 Envisaged effects on the ecosystems

A fragile ecosystem is an important ecosystem, with unique features and resources. The significance of the natural phenomena in Kwale is an indication of the special need to preserve and ensure the smooth prevalence of the various ecosystems. Heavy mineral sands, however, may be a source of economic development and at the same time be detrimental to the various ecosystems.

1) Impacts on Marine ecosystems

According to the Environmental impact assessment test conducted on the proposed project, The construction of a jetty may cause a low impact on the benthic habitat, but any substantial spillage of heavy mineral, which is unlikely to occur because the conveyor will be enclosed, could cause a localised moderate impact. The effects of propeller wash on channel edge communities and the effects of opportunistic species are unknown, while invasive marine species could cause moderate impacts on species composition. There will be no dredging in the channel. In the event that a ship going aground or oil spills there would be an impact on the benthic, inter-tidal and sub-tidal habitats. However, assessments of navigation and maneuvering requirements at Shimoni combined with the design of the dock have determined that the risk of shipping accidents is extremely low.

2) Impacts on terrestrial environments

According to the environmental impact assessment, the mining operations will result in permanent changes to the topography of the Central and South dunes and the tailings dam area. The EIA report states that the development of a ship loading facility and access road will have a moderate impact on plant species diversity, as the coral rag forest is relatively diverse and a

portion of it will need to be cleared. It will cause a high negative impact on habitat diversity because the cleared area may include a number of plant species of special concern. Clearing areas for the facilities and access roads will cause a loss of forest habitat and the fragmentation of the forest, which will cause impacts of high significance on fauna.

Although the concerned parties argue that the radiation levels would not be of serious concern, various radiological studies have been carried out in areas of similar mineral sand occurrence, such as in India. Results have shown that the typical ^{232}Th activity concentration in ilmenite, the major titanium mineral, was 0.6 Bq g⁻¹ and the progeny nuclide ^{228}Ra is in secular equilibrium. Lower concentrations were observed in other forms such as rutile and TiO_2 pigment. This study estimated a potential external gamma exposure of 1 mSv and an inhalation dose of 0.7 mSv annually to the occupational worker due to the presence of NORM in these industries processing titanium minerals. The specific activity of ^{232}Th and ^{228}Ra in solid waste samples were higher than that in minerals, and significant disequilibria with respect to ^{228}Ra were observed in such samples. During the chemical processing of ilmenite to upgrade TiO_2 , the ^{232}Th and ^{228}Ra ends up in solid wastes and liquid effluent. The activity levels in the solid wastes and ^{228}Ra in liquid effluents from synthetic rutile production may be of concern in certain cases.

3) Socio- cultural impacts

It is estimated that there are about 450 households that may be affected. Of these, 25% are landowners with title deeds and 75% are squatters. The average household size is about seven people per household, which means that approximately 3000 individuals may be affected over a period of 10-15 years by the proposed project. In general, families have well-developed shambas. Although the size of the various shambas differs, plot sizes range between 4-8ha (10-20 acres) for landowners, while squatters have plots of about 2ha (5 acres). Christianity and Islam are the dominant belief systems in the area, with Digo being pre-dominantly Moslem and the Kamba being Christian. Almost half the households in the study area had one or more graves on their shamba, which are recognised as sites of particular spiritual importance, as they are associated with ancestral spirits. Men are generally the heads of households and about 70% of them are farmers, 10% businessmen, 4% teachers and 2% civil servants.

CHAPTER SIX

6.1 CONCLUSION AND RECOMMENDATION

6.1.1 CONCLUSION

In general, the Kenyan coast is mainly a sedimentary platform with few igneous occurrences.

The general stratigraphy provides a series of sedimentary sequences of ages between the Permian and the Cenozoic. Major structures include faults with the major ones occurring due to the rifting of the Gondwana supercontinent. The major fault occurs parallel to the coastline and extends from south to near the Sabaki River. The fault occurs on a reef formation hence it is believed to have resulted in the present positioning of the coastline and beaches.

The East African Coastline is part of a stretch of the sub-saharan coast that is of valuable mineral sand potential. Various occurrences in related locations in India and Australia have shown significant potential for the deposits. , the development of the mineral sands mine will impact on the physical, natural and social environments of Kwale.

The mining operations will result in permanent changes to the topography of the Central and South dunes and the tailings dam area. Mitigation measures will however, maintain the agricultural potential of the Central and South dunes and will improve the land capability of the tailings dam area. The operations will have no effect on the soil hardness or its susceptibility to erosion. Changes to the topography will affect the local surface drainage pattern. The mining operations will probably not affect the main deep aquifer in the mining area, but some of the springs may experience a change in yield, change position or disappear.

Planned mitigation measures including a rehabilitation and management programme should reduce the overall eco-logical impacts. Employment resulting from mining operations and associated services will be the main socio-economic benefit for the affected community. The resettlement of people living in the mining area and the relocation of community infrastructure are the most negative impacts on the community. Clearing an area of 5-10ha of coastal forest for the construction of a ship loading facility and access road in Shimoni will impact on the vegetation and the fauna. This will result in a loss of forest habitat and the fragmentation of the forest. No dredging will be done in Wasini channel, but the construction of a jetty will slightly affect the benthic habitat of the area. The report therefore recommends the establishment of an

environmental management plan, which will include a detailed rehabilitation plan, and a resettlement plan. Implementation of these plans will ensure that the overall benefits of the project exceed the costs.

6.1.2 RECOMMENDATIONS

From the synthesis of information it is certain that ecosystems in the Kwale area are a useful resource to the Nation just as much as the potential that lies in the heavy mineral sands. For this reason various measures need to be put in place to ensure deplorable conditions are prevented. New technology for handling mineral include developments in spiral circuits, applications of power ultrasound for cleaning mineral sands, electrostatic and high-tension electrostatic separation, as well as improved gravity separation techniques (Abela, 2003; Germa *et al.*, 2003). Technological advances in a number of fields should increase the profitability of Heavy Minerals as much as they limit the environmental effects. Such advancements include; Removal of radioactive nuclides. (U and Th often occur in trace amounts in the zircon crystal lattice. The decay of these radioactive elements leads to a gradual breakdown in the crystal structure to a metamict form, and discolours the mineral.), and Mineral separation processes. Further studies are required to assess the water dissolution characteristics of solid wastes. The regular monitoring and appropriate engineered protection measures are required to control long-term impacts on the waste disposal environment.

References;

- Abuotha, J. O. Z., 2003. Grain size distribution and composition of modern dune and beach sediments, Malindi bay coast, Kenya.
- Abuodha, P.A.W., 1992. Geomorphology and sedimentology of the Mombasa- Diani area: implications for coastal zone management, unpub. M.sc. Thesis, univ. Nairobi, 155.
- Ase, L. E., 1978. Preliminary report on studies of shore displacement at the southern coast of Kenya – geografisker annaler, 60a, 3-4, 209-221.
- Ase, L. E., 1981. Studies of shores and shore displacement on the southern coast of Kenya - especially in Kilifi district. – geografisker annaler, 63a, 3-4, 303-310.
- Braithwaite, C. J. R., 1984. Depositional history of the late Pleistocene limestones of the Kenya coast – journal of geological society, London, 141, 685 - 699.
- Brakel, W. H., 1984. Seasonal dynamics of suspended sediment plumes from the Tana and Sabaki rivers, Kenya: analysis of landsat imagery, remote sensing of environ, 16, 165-173.
- Caswell, P.V., 1953. Geology of the Mombasa - Kwale area, geological survey of Kenya report, 24, 69. 8.
- Gichaba, C. M., 1991. Groundwater potential in tertiary and Triassic sediments in kidiani area, Kwale district, Kenya. (Unpublished).
- Hori, N., 1970. Raised coral reefs along the southeastern coast of Kenya, East Africa, Department of Geography, Tokyo University 5, 25 – 47.
- Kairu, K. K., 1997. Vulnerability of the Kenyan shoreline to coastal instability. Paper presented at the Unesco 1997 seminar, 13-25.
- Ojany, F. F., 1984. Some aspects of the geomorphic evolution of the Kenya coast with special reference to the Kambe limestone rocks of the Kilifi area – in - natural and man – induced environmental changes in tropical Africa: case studies in Cameroon and Kenya. A preliminary report of the tropical African geomorphology and late quaternary palaeoenvironments research project 1982/83, Sapporo, Japan, 117 - 127.
- Oosterom, A. P., 1988. The geomorphology of southeast Kenya - PhD. Thesis, Wageningen agricultural university, 227.

Pohl, W. & Horkel, A. D., 1980. Notes on the geology and mineral resources of the Mtito Andei – Taita area (southern Kenya). - Mitt, Oesterr. Geol. Ges, Vienna v73 pp.135-152

Read, A. N., 1981. Sedimentology and lithification of quaternary reef-rock, on the coast near Mombasa, Kenya - unpub. PhD. Thesis, univ. Leeds, 287.

Sikes, H. L., 1930. The drowned valleys on the Kenyan coast – journal of east African historical society and national museum 18, 1 – 9.