An aerial photograph of a river delta in Guinea, showing a wide river branching into smaller channels. The landscape is green and hilly, with some buildings and roads visible. A black text box is overlaid on the top part of the image.

Heavy Mineral Sands Exploration in the Republic of Guinea

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Heavy Mineral Sands Exploration in the Republic of Guinea

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Abstract

The aim of this thesis study is to increase the geological knowledge on the presence of Heavy Mineral Sands (HMS) in the concession areas owned by Guinea Alluvial Mining (GAM). In order to achieve this aim the following main research question has been formulated:

Does exploration of the concession areas show sufficient Heavy Mineral Sand prospectivity for further exploration?

To answer this main research question, the following secondary research questions have been formulated:

- 1) What are the industry standards for HMS deposits?
- 2) Does literature research indicate that HMS could be discovered in the concession areas?
- 3) Do the exploration results show sufficient HMS exploration potential when compared to the industry standards for HMS deposits?

In order to answer these research questions a literature study has been conducted. In this literature study the key parameters which form HMS and the main characteristics of HMS reserves have been researched. The literature research shows that the concession areas, owned by GAM, could contain HMS deposits. Based on the literature research the most suitable sample locations and exploration methods have been chosen to explore the concession areas.

The obtained samples have been analysed at Scientific Services in South Africa and at the TU Delft. The methods which have been used to analyse the samples are size separation, heavy liquid separation, magnetic separation, microscopic analysis and XRF analysis. By using these separation and analysis methods results have been obtained on the sample size, total heavy mineral content, valuable heavy mineral content and elementary composition.

The results show that two locations contain HMS and VHM (ilmenite, rutile and zircon) anomalies. These locations are situated in the sandy coast in concession areas EP2/1 and SP1. The other geological domains in the concession areas (paleo strandlines, hydromorphic terraces and ancient terraces) did not show HMS and VHM anomalies.

To estimate an exploration target for future exploration the block model method has been used. An estimation of the exploration target size has been estimated for a worst and a best case scenario. In the best case scenario, the Total Heavy Mineral (THM) content in the first two meters of sandy coast is assumed to be continuous. In the worst case scenario, the Total Heavy Mineral (THM) content in the first two meters of sandy coast are discontinuous. In this worst case scenario, the only locations which contain HMS mineralization are the locations which have been sampled.

When compared to the minimal size of an economic deposit, the exploration target size estimated by using the exploration results, is too small to have reasonable prospects for economic extraction.

However, the estimation of the exploration target is only based on the sampled geological domains. The area west of Taboriyah contains a sandy coastline which has not been explored yet and has therefore not been taken into account when estimating the exploration target size. In addition, the exploration target is based on the first 2 meters of sediment in the sandy coast.

If a drilling survey is conducted HMS could be found deeper than 2 meters. Therefore, sufficient HMS exploration potential remains for the concession areas to be prospective.

Preface

This report is the result of my thesis project for the Master of Science degree of Resource Engineering, at Delft University of Technology. The project was carried out at Guinee Alluvial Mining Sarlu.

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List of abbreviations

1A	Apparent coast of mangroves materialized by continuous barrier of trees
1B	Apparent coastline with discontinuous border of mangroves and/or coastal mudflats (often former mangroves).
2A	Sand or silt littoral zones associated with mangroves
3C	Sandy coast
ASX	Australian Securities Exchange
AusIMM	The Australasian Institute of Mining and Metallurgy
CD	Constant density
CLT	Central limit theorem
CPDM	Centre for Mining Promotion and Development
DSP	Dry separation plant
DWT	Dead Weight Ton
EP	Exploration permit
EPCM	Engineering, procurement, construction and management
FOB	Fix on Bond
Ga	Billion years
GAM	Guinee Alluvial mining SARLu
GDP	Gross Domestic product
GMC	Guinean Mining code
GT	Guinee Titanium
HM	Heavy minerals
HMC	Heavy Mineral Concentrate
HMS	Heavy Mineral Sand
HLS	Heavy Liquid Separation
i/s	Infrastructure and service
IDW	Inverse Distance weighting
IPO	Initial Public Offering
ISO	International organization for standardization
JORC	Joint Ore Reserves Committee
LSE	London stock exchange
MC	Mining code
MEA	Middle East and Africa
MIR	Mid infrared region
MSc	Master of Science
MSP	Mineral separation plant
N/A	Not applicable
NIR	Near Infra-Red
NPV	Net present value
PPM	Parts Per Million
RAB	Rotary air blast
RC	Reverse circulation
RCN	reverse circulation drilling rigs
RPO	Recognized professional organization
SAMREC	The South African Mineral Resource Committee
Sc	Coastal dune rims, recent terraces and paleo strandlines
Sct	Ancient terraces and undifferentiated sediment formations
SG	Specific gravity
Sh	Smoothed terraces that are hydromorphic in the rainy season, sometimes more or less saline
SMU	Small mining unit
SP	Staking permit
THM	Total heavy minerals
TL	Thermal Luminescence
USD	United States Dollar
VAT	Value Added Tax
VIS	Visible infrared spectrum
VHM	Valuable heavy minerals
VMS	Valuable mineral sands
WAPP	West African Power Pool

WAC West African continent
WHO World Health organization
WSP Wet separation plant
XRF X-ray fluorescence

Introduction

1.1 Background

Guinée Alluvial Mining SARLu (GAM) was incorporated in April 2013 with the objective to explore and develop mining concessions in the Republic of Guinea (Conakry). The focus of this study is on the exploration of heavy mineral sand (HMS) on the western coast of Guinea within the concession areas owned by GAM.



Figure 1: Location of Guinea Conakry on world map

Most heavy mineral sand (HMS) deposits are produced by weathering and erosion of the earth's surface. The HMS is carried by sedimentary action to the coastline where a combination of wave action and wind action result in the concentration along strand lines and associated environments. HMS deposits are typically found in unconsolidated (fossil) shorelines up to hundreds of kilometres inland from present coastlines (Jones, 2012).

HMS typically contains the valuable heavy minerals (VHM) ilmenite, rutile and zircon (Elsner, 2011). In most HMS mines ilmenite is the primary commodity, rutile and zircon are mined as secondary minerals (Elsner, 2011). From 2005 to 2015 the price of ilmenite has increased from 90 to 95 USD/ton, of rutile from 430 to 800 USD/ton and of zircon from 600 to 1000 USD/ton (Bedinger, 2014; MiningBulletin, 2015).

1.2 Significance of Research

Exploration surveys have been performed within the concession areas currently owned by GAM by a previous owner of the exploration permits. These surveys were not performed in compliance with the standards of the Joint Ore Reserves Committee¹ (JORC, 2012) as assessed in a previous study performed at the Technical University of Delft (Roosegaard Bisschop, 2013).

GAM strives to comply with the JORC code (2012) in order to attract investors and obtain reliable results. Because there are no exploration results available which are in compliance with the JORC code (2012), the project is situated in the pre-exploration phase (target generation) at the start of this thesis work. At this stage of an exploration project the investment risk is generally high and the project value is low. The general relationship between the project value and investment risk at each stage of project development is illustrated below.

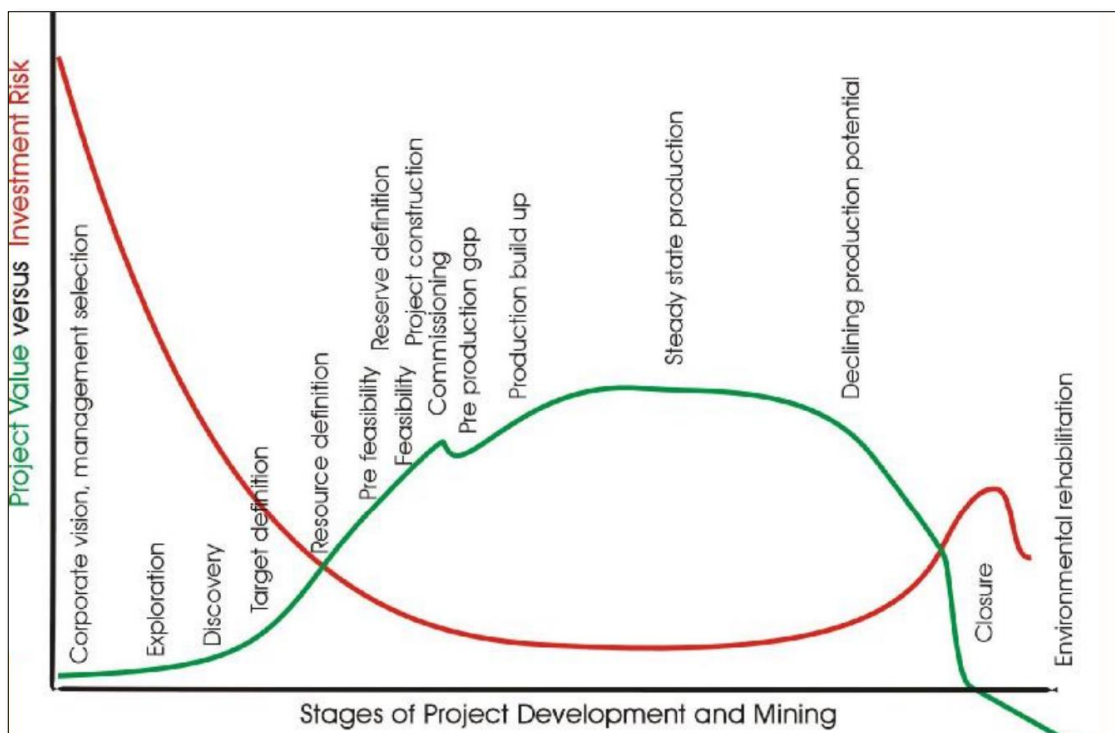


Figure 2: Investment risk at the various stages of project development (McKenzie, 2009)

¹ The JORC code (2012) provides a system for the classification of Exploration Results, Mineral Resources and Ore Reserves according to the levels of confidence in geological knowledge, technical and economic considerations in Public Reports (JORC, 2012).

In this thesis a renewed exploration survey is conducted following the guidelines of the JORC code (2012). This thesis will discuss the exploration potential within the concession areas and make recommendations for potential future investments into the project.

1.3 Aim, Research Questions and Objectives

The main aim of this thesis is to increase the level of geological knowledge and confidence of the HMS potential within the concession areas owned by GAM.

The main research question in this thesis is:

Does exploration of the concession areas show sufficient Heavy Mineral Sand prospectivity for further exploration?

To answer this main research question, the following secondary research questions have been formulated:

- 1) What are the industry standards for HMS deposits?
- 2) Does literature research show that HMS can be discovered in the concession areas?
- 3) Do the exploration results show sufficient HMS exploration potential when compared to the industry standards for HMS deposits?

In order to answer these four research questions, as described in chapter 1.3, three objectives are described below supporting the aim of this study:

- I. Target generation
- II. Exploration
- III. Estimation of exploration target prospectivity

1.4 Structure of thesis

The image below shows the structure of the thesis with the different chapters.

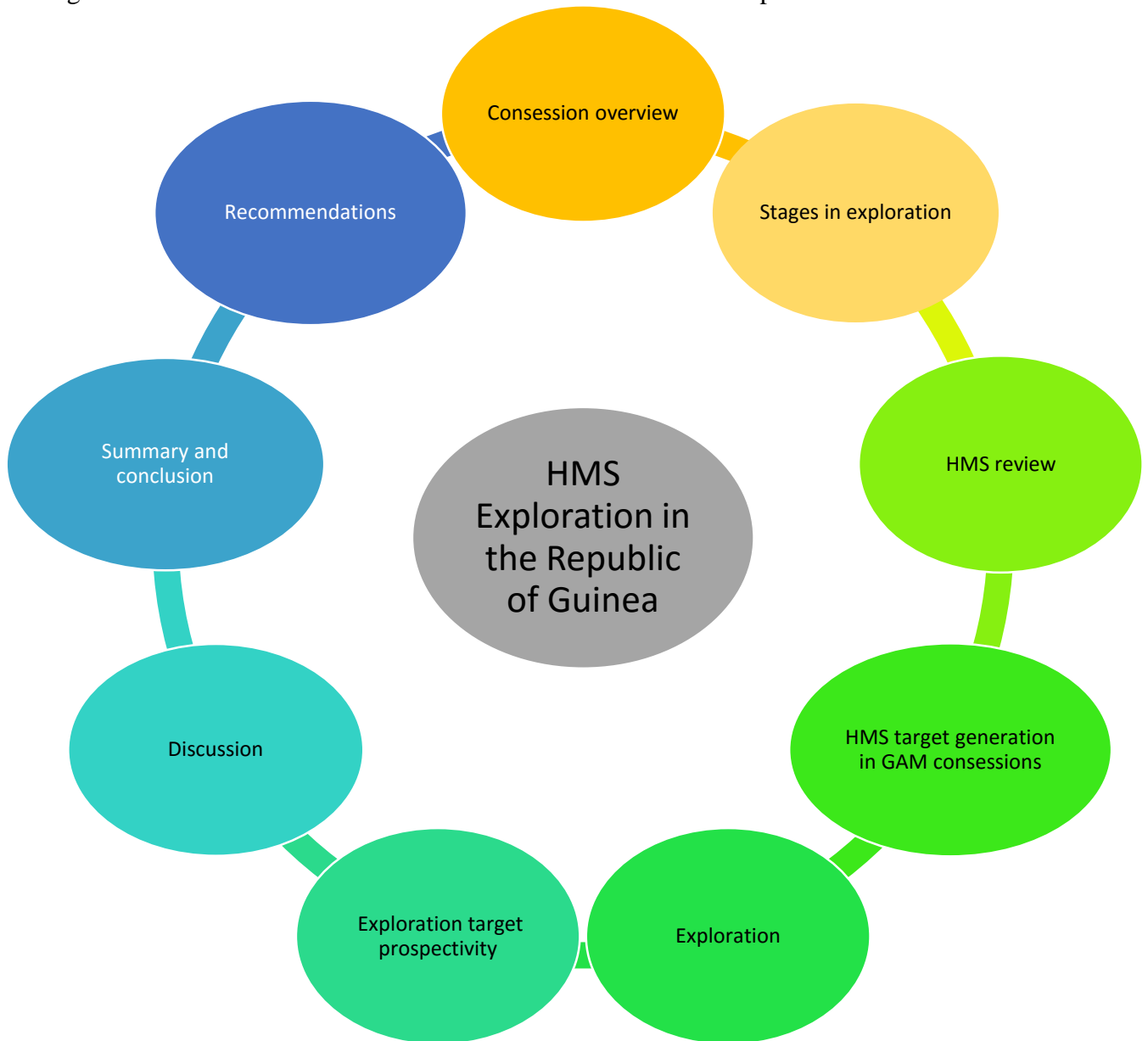


Figure 3: Structure of the thesis

1.5 Research scope and limitations

GAM has provided funds for primary exploration. This includes site exploration and the analysis of the samples at Scientific Services in Cape Town and at the Technical University of Delft. The funds provide constraints for amount and type exploration methods used within the concession areas. The research scope, in table 1 below, shows the areas covered in this thesis research and the circumstances that were not considered.

Table 1: Research scope and limitations

Objectives	Included	Excluded
I. Target Generation	Economic characteristics of HMS deposits are used as a reference Confined to concession areas	Economic parameters specifically for GAM project Areas outside of concession area in Guinea
II. Exploration	Exploration research in Guinea was constrained due to time (4 days) and available funds Analysis of the samples was constrained by available funds. Therefore 2 samples were analysed by magnetic separation and XRF analysis Sample site exploration log sheets, HLS separation, magnetic separation, optic analysis, XRF analysis and radioactivity of bulk samples	Magnetic and XRF analysis of the other 56 samples Tests on conductivity and magnetic properties of bulk samples
III. Estimation exploration target prospectivity	Exploration target based on exploration results of geological domains which have been sampled during primary exploration by pitting. Therefore only the first 2 meters of exploration potential within the sandy coast have been included in the exploration target.	Exploration target in geological domains which have not been sampled during primary exploration such as the area west of Taboriyah and drilling potential (> 2m) in concession areas.

1.6 Work division

Below the people and organizations which have been involved in this thesis are summarized.

GAM

GAM has provided the author of this thesis with the main aims and funds for primary exploration of the HMS exploration project in Guinea.

Mr. Siegfried

Mr. Siegfried is a consulting geologist for GAM. Mr. Siegfried is a competent person following the JORC code and has provided GAM with several reports which have been referred to in this thesis:

- 1) Siegfried, P., 2013. *HMS initial thoughts*, Rijswijk: GAM.
- 2) Siegfried, P., 2013. *Mineral analysis of samples*, Rijswijk: GAM.
- 3) Siegfried, P., 2013. *Proposed sampling locations*, Rijswijk: GAM.

Scientific Services

Scientific Services has analysed the samples provided by GAM. The results of the analysis performed by Scientific Services are depicted in Appendix D.

Centre de Promotion et de Developpement Miniers (CPDM)

The CPDM is the mining authority in Guinea. CPDM approved the conduction of the exploration survey within the concession areas. It was necessary to provide documentation and reporting in compliance with the mining laws of Guinea (Centre de Promotion et de Developpement Miniers, 2011) to obtain this approval. A geologist working for the CPDM, was involved in the exploration survey to ensure compliance with the mining code (Appendix F), give advice on the found mineralization (Appendix B) and ensure good relations with local inhabitants and local authorities.

Local Guinean Authorities

Local authorities have provided approval for exploration within the concession areas.

Local population concession areas

The local population within the concession areas have assisted with the exploration in the concession areas by digging pits and locating suitable routes to the target sites in the concession areas.

2

Concession Overview

GAM is developing the HMS project on the western coast of Guinea (Conakry). GAM owns two exploration permits, one operating permit and a staking permit for HMS (zircon, rutile, ilmenite, etc.) with a total area of over 200 km². The concessions are situated along the Atlantic Ocean coastline at elevations between 0 and 30 meters above mean sea level (Google Earth, 2015) and border on the administrative regions of Dubreka and Boffa. A summary of the company's concessions is shown below in table 2 and a map showing the concession locations is shown in figure 4.

Table 2: Overview GAM concessions

Abbreviation	Concession Code	Permit Number	Type of permit	Area (km²)
EP2/1	GAM/6661/EP2/1	N °A2013/6661/MMG/SGG	Exploration permit HMS (zircon, rutile, ilmenite, etc.)	40
EP3/1	GAM/6661/EP3/1	N° A2013/6661/MMG/SGG	Exploration permit HMS (zircon, rutile, ilmenite, etc.)	60,3
OP1	GAM/2189/OP1	N° A2013/2189/MMG/SGG	Operating permit HMS (zircon, rutile, ilmenite, etc.)	9,2
SP1	MAR/0000/SP1	N°233/MMG/CAB/SC/14	Staking permit HMS (zircon, rutile, ilmenite, etc.)	92,7

A more detailed explanation of the rights and obligations of the permitting is explained in Appendix F.

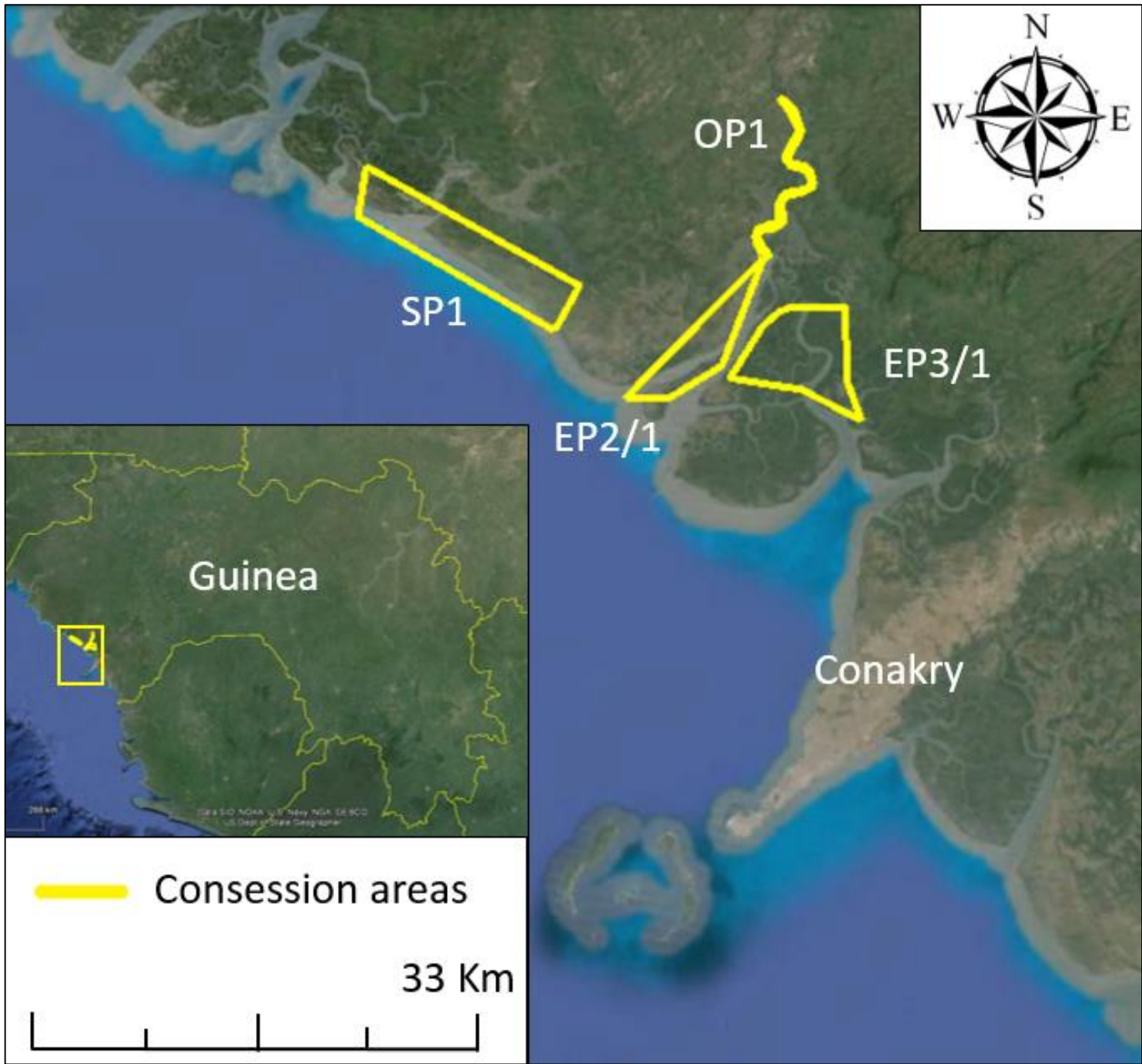


Figure 4: Shows four concession permit areas EP2/1, EP3/1, OP1 and SP1. Base modified from Google Earth (2015).

Framework of HMS Exploration project

This thesis is written within the legal boundaries set out by the Guinean mining code (Centre de Promotion et de Developpement Miniers, 2011) and the guidelines of the JORC code (2012).

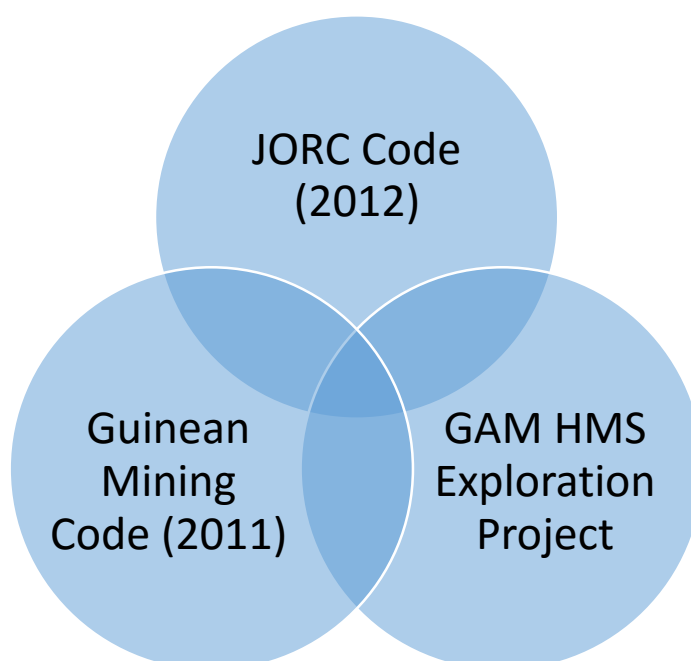


Figure 5: Relationship between the JORC code (2012), Guinean Mining code (2011) and the GAM exploration project.

Exploration has been performed within two concession areas (SP1 and EP2/1). The obtained staking permit (SP1) owned by GAM confers GAM the right to carry out staking work to explore for one or several mine substances. GAM is required to submit the results of its staking work to the state (Centre de Promotion et de Developpement Miniers, 2011). The results of exploration for concession areas SP1 and EP2/1 have been submitted to the CPDM in July 2014.

The obtained exploration permits (EP2/1 and EP3/1) confers GAM the exclusive right to prospect for HMS, within the limits of its area and without limitation as to depth. GAM is required to submit the following (Centre de Promotion et de Developpement Miniers, 2011):

- Define a minimum work program which the holder must carry out while the permit is in effect, and the minimum financial outlay it is expected to devote to exploration each year during the term of the permit and any renewals thereof. To this end, minimum expenditures per km² are instituted for exploration Permits.

- Start exploration work within the area of the permit within six (6) months from the date of issuance of the permit, and continue same diligently and according to generally accepted mining methods.
- Prepare activity reports and financial statements approved by the Administration following a period of work lasting at least three days within the exploration perimeter by at least one geologist hired by the titleholder or, alternatively, an aerial geophysical survey including at least three days of flights over the area submit copies of the environmental notice to the National Mining Authority and the Mining Promotion and Development Centre.
- Provide local authorities, for information purposes, with the Environmental Notice and an explanation of the planned mitigation and rehabilitation measures.

During exploration the guidelines of the JORC code (2012) have been followed. The JORC code (2012) provides a framework for interpreting the geological data obtained into a definable exploration target, exploration results or mineral resources. These can be assessed from an investment point of view, as a result of a described confidence level in the public reporting. The followed reporting criteria in this work are summarized in Appendix E: JORC Table 1.

Figure 6 shows the relationship for classifying tonnage and grade² estimates to reflect different levels of geological confidence and different degrees of technical and economic evaluation. Mineral resources³ can be estimated on the basis of geoscientific information with some input from other disciplines. ore reserves⁴, which are a modified sub-set of the indicated⁵ and measured⁶ mineral resources (shown within the dashed outline in figure 6), require consideration of the modifying factors⁷ affecting extraction, and should in most instances be estimated with input from a range of disciplines.

² Any physical or chemical measurement of the characteristics of the material of interest in samples or product. Note that the term quality has special meaning for diamonds and other gemstones. The units of measurement should be stated when figures are reported.

³ A 'Mineral Resource' is a concentration or occurrence of solid material of economic interest in or on the Earth's crust in such form, grade (or quality), and quantity that there are reasonable prospects for eventual economic extraction. The location, quantity, grade (or quality), continuity and other geological characteristics of a Mineral Resource are known, estimated or interpreted from specific geological evidence and knowledge, including sampling. Mineral Resources are sub-divided, in order of increasing geological confidence, into Inferred, Indicated and Measured categories (JORC, 2012).

⁴ An 'Ore Reserve' is the economically mineable part of a Measured and/or Indicated Mineral Resource. It includes diluting materials and allowances for losses, which may occur when the material is mined or extracted and is defined by studies at Pre-Feasibility or Feasibility level as appropriate that include application of Modifying Factors. Such studies demonstrate that, at the time of reporting, extraction could reasonably be justified (JORC, 2012).

⁵ An 'Indicated Mineral Resource' is that part of a Mineral Resource for which quantity, grade (or quality), densities, shape and physical characteristics are estimated with sufficient confidence to allow the application of Modifying Factors in sufficient detail to support mine planning and evaluation of the economic viability of the deposit.

⁶ A 'Measured Mineral Resource' is that part of a Mineral Resource for which quantity, grade (or quality), densities, shape, and physical characteristics are estimated with confidence sufficient to allow the application of Modifying Factors to support detailed mine planning and final evaluation of the economic viability of the deposit.

⁷ 'Modifying Factors' are considerations used to convert Mineral Resources to Ore Reserves. These include, but are not restricted to, mining, processing, metallurgical, infrastructure, economic, marketing, legal, environmental, social and governmental factors

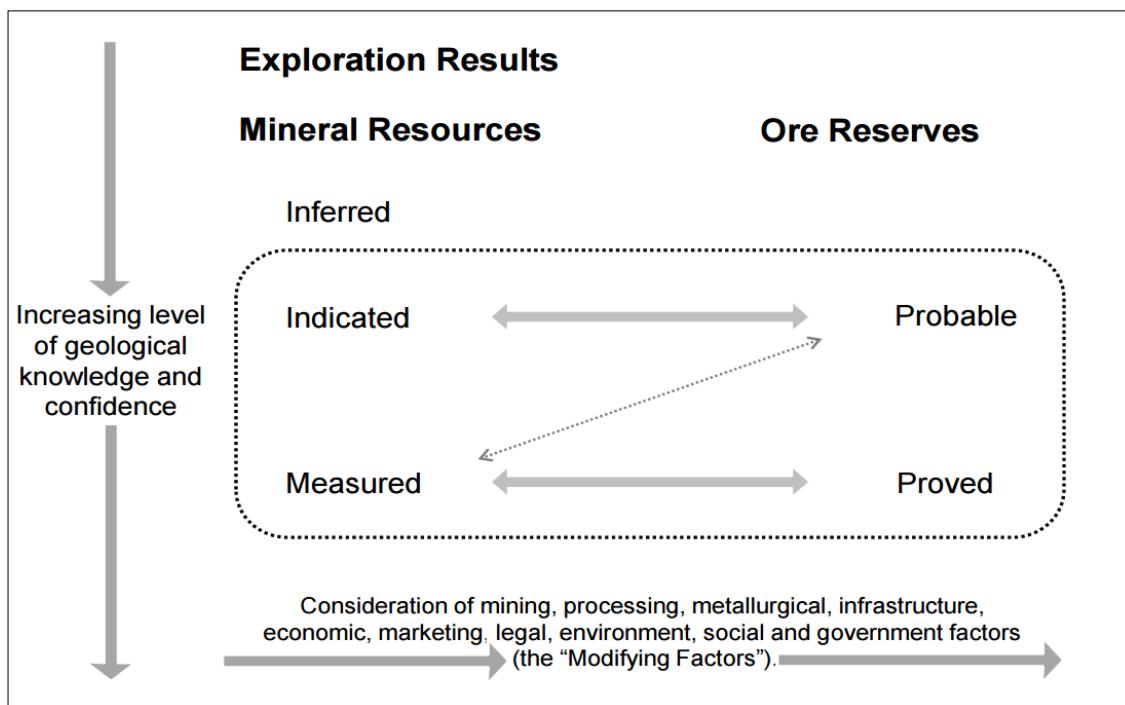


Figure 6: General relationship between exploration results, mineral resources and or ore reserves (JORC, 2012)

It is common practice for a company to comment on and discuss its exploration in terms of target size and type. The most important difference between an inferred mineral resource and an exploration target is that all reports of mineral resources must satisfy the requirement that there are reasonable prospects for eventual economic extraction (i.e. more likely than not), regardless of the classification of the resource. An exploration target does not have to satisfy this requirement.

Public reports⁸ are prepared for the purpose of informing investors or potential investors and their advisers on exploration results⁹, mineral resources or ore reserves (JORC, 2012). Therefore, the potential value of the mining project is captured and evaluated through these public reports by complying with the JORC code (2012). The public reports can also be used for internal investment decisions.

A public report must be based on, and fairly reflect the information and supporting documentation prepared by a competent person¹⁰. The competent person which has consulted GAM is P. Siegfried. Following the JORC code (2012) any comment in a public report discussing exploration results, exploration targets, mineral resources and ore reserves must comply with the requirements described below (JORC, 2012):

1. A public report that includes an exploration target must be accompanied by a competent person statement taking responsibility for the form and context in which the exploration target appears.

⁸ Public Reports are reports prepared for the purpose of informing investors or potential investors and their advisers on Exploration Results, Mineral Resources or Ore Reserves. They include, but are not limited to, annual and quarterly company reports, press releases, information memoranda, technical papers, website postings and public presentations.

⁹ Exploration Results include data and information generated by mineral exploration programs that might be of use to investors but which do not form part of a declaration of Mineral Resources or Ore Reserves.

¹⁰ A 'Competent Person' is a minerals industry professional who is a Member or Fellow of The Australasian Institute of Mining and Metallurgy, or of the Australian Institute of Geoscientists, or of a 'Recognized Professional Organization' (RPO), as included in a list available on the JORC and ASX websites. These organizations have enforceable disciplinary processes including the powers to suspend or expel a member. A Competent Person must have a minimum of five years relevant experience in the style of mineralization or type of deposit under consideration and in the activity which that person is undertaking (JORC, 2012).

2. In any statement referring to potential quantity and grade of the target, these must both be expressed as ranges and must include a detailed explanation of the basis for the statement, including specific description of the level of exploration activity already completed.
3. If a public report includes an exploration target the proposed exploration activities designed to test the validity of the exploration target must be detailed and the timeframe within which those activities are expected to be completed must be specified.
4. If an exploration target is shown pictorially (for instance as cross sections or maps) or with a graph, it must be accompanied by text that meets the requirements above.
5. All disclosures of an exploration target must clarify whether the target is based on actual exploration results or on proposed exploration programs.
6. Where the exploration target statement includes information relating to ranges of tonnages and grades these must be represented as approximations. The explanatory text must include a description of the process used to determine the grade and tonnage ranges used to describe the exploration target.
7. For an exploration target based on exploration results, a summary of the relevant exploration data available and the nature of the results should also be stated, including a disclosure of the current drill hole or sampling spacing and relevant plans or sections.

The JORC code (2012) states that an exploration target¹¹ can be estimated if there has been insufficient exploration to estimate a mineral resource. An inferred mineral resource¹² estimation can be made if geological evidence is sufficient to imply but not verify geological and grade (or quality) continuity. It must also satisfy the requirement for a resource classification that there are reasonable prospects for eventual economic extraction (i.e. more likely than not).

When the guidelines of the JORC code (2012) and the Guinean mining code (2011) are followed, the results of this thesis can be used in the compilation of a public report, which is in compliance with both codes. This public report can then be used to attract investment to further develop the GAM exploration project.

At the start of the MSc thesis GAM is situated in the target generation stage. Following the HMS review in chapter 4, target areas are generated within the GAM concessions in chapter 5. In chapter 6 the followed exploration methods and the results of the exploration are discussed. In chapter 7 the results of the exploration are used to estimate the prospectivity of the concession areas.

¹¹ An exploration target is a statement or estimate of the exploration potential of a mineral deposit in a defined geological setting where the statement or estimate, quoted as a range of tons and a range of grade (or quality), relates to mineralization for which there has been insufficient exploration to estimate a Mineral Resource (JORC, 2012).

¹² An 'Inferred Mineral Resource' is that part of a Mineral Resource for which quantity and grade (or quality) are estimated on the basis of limited geological evidence and sampling. Geological evidence is sufficient to imply but not verify geological and grade (or quality) continuity. It is based on exploration, sampling and testing information gathered through appropriate techniques from locations such as outcrops, trenches, pits, workings and drill holes.

HMS Review

The aim of this chapter is to provide general information on the definition of HMS, the importance of the HMS industry, how HMS deposits¹³ are formed, how HMS are mined and the HMS industry standards. From this generic information the HMS target areas are generated in the concession areas as discussed in the next chapter (chapter 5). The industry standards are compared with the exploration results in chapter 6. The subjects of this chapter are shown below in Figure 7 and are discussed in the subsections of this chapter.

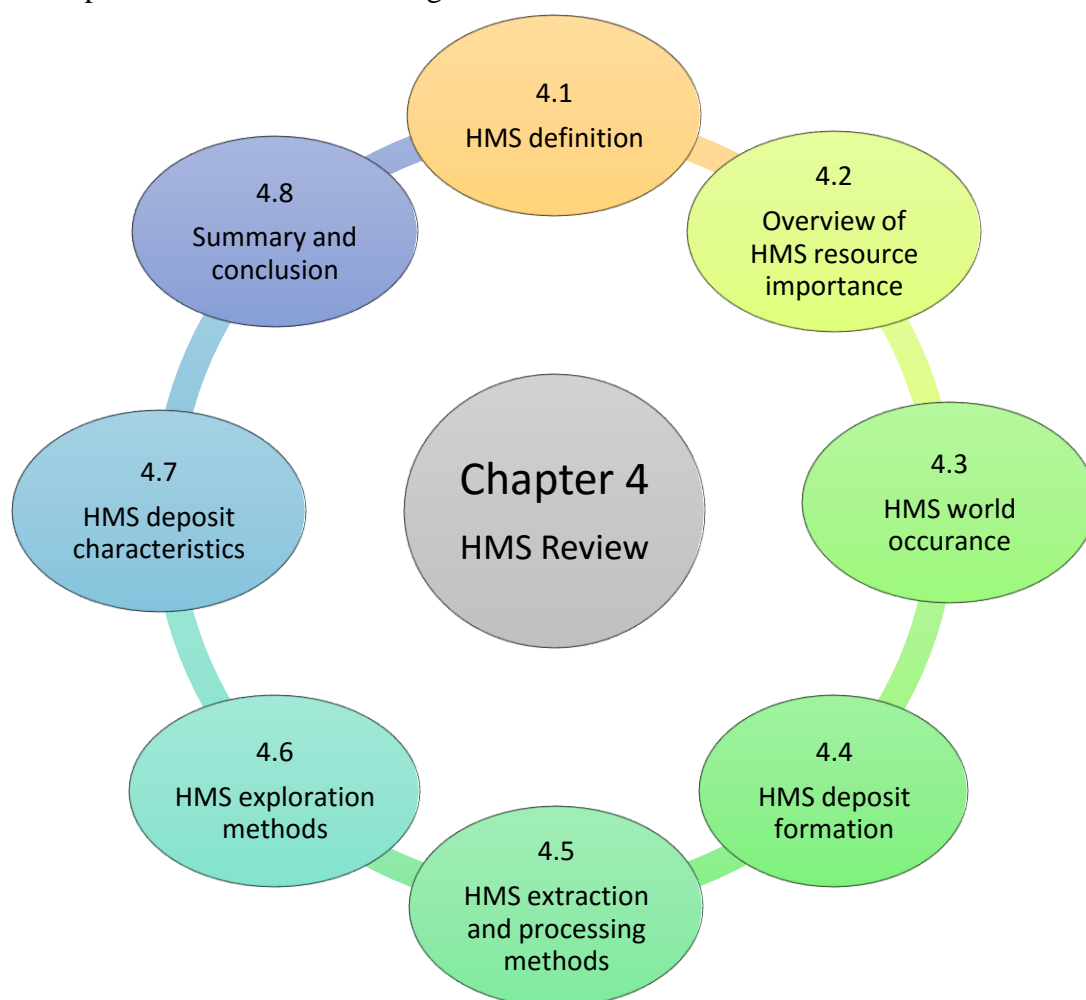


Figure 7: Subchapters discussed in HMS review.

¹³ A deposit is consolidated or unconsolidated material that has accumulated by a natural process or agent (Encyclopedia, 2015).

4.1 HMS definition

Voluminous deposits of heavy minerals are hosted by sediments of sand, silt, and clay deposited in coastal environments. These types of sedimentary deposits can contain economic concentrations of heavy minerals, in which the ore minerals (heavy minerals) are relatively easy to recover and then are used in a variety of industrial mineral applications. In this thesis work this deposit type is referred to as “heavy mineral sands” (Bradley, et al., 2010).

In this thesis work heavy minerals are defined as minerals having a higher density greater than 2.9 t/m^3 (Benjamin, 2011). In contrast, minerals with a lower density than heavy minerals, for example most mica minerals, dolomite, magnesite and quartz, are called light minerals.

Of the numerous heavy minerals, only a few have economic significance due to their properties and prevalence. These are called valuable heavy minerals, abbreviated as VHM. Heavy minerals enriched in placers that can be exploited commercially include (Elsner, 2011):

- ilmenite and its weathering products up to leucoxene
- rutile and anatase
- zircon
- monazite and xenotime
- staurolite
- aluminum silica minerals, i.e. kyanite, andalusite and sillimanite
- minerals of the garnet group
- magnetite
- chromite
- cassiterite
- tantalite-columbite
- wolframite and scheelite
- precious metals, i.e. gold and platinum
- gemstones, i.e. diamond, ruby and sapphire

The principal valuable heavy minerals (VHM) in the majority of HMS operations are ilmenite, rutile and zircon (Bradley, et al., 2010). Images of these minerals are shown in figure 8.



Figure 8: Images of VHM minerals ilmenite, rutile and zircon (Minerals.net, 2015).

4.2 Overview of HMS resource importance

4.2.1 Background

Deposits of HMS in coastal environments play a substantial role in the global mineral economy. As the most noteworthy example, HMS are the world's primary source of titanium feedstock for the titanium dioxide (TiO_2) pigments industry; the titanium is obtained from the minerals ilmenite (FeTiO_3), rutile (TiO_2), and leucoxene (an alteration product of ilmenite). Another source of titanium are anorthosite bodies, represented by two mines, one in Canada (Lac Tio in Quebec) and one in Norway (Tellnes) (Bradley, et al., 2010).

HMS are also the principal source of the mineral zircon (ZrSiO_4), obtained as a coproduct during the separation and recovery of the titanium minerals (Bradley, et al., 2010).

For most commodities, unit cash cost is used to benchmark projects' relative economics. In this instance, the grade of valuable mineral, scale and mining method, and associated costs, are key factors influencing unit costs. However, most mineral sands mines produce several product streams. The primary mineral produced is ilmenite, with lesser quantities of the more valuable minerals rutile and zircon. The weighting of each of these minerals (referred to as the assemblage of the deposit) varies significantly by deposit, but with ilmenite typically dominating the assemblage and zircon the minor constituent (as shown in figure 9) (Iluka, 2015).

For this reason, the industry tends to use a margin curve or revenue (Iluka, 2015). This margin curve, which is used to assess the relative attractiveness of mineral sands deposits and operations is shown in figure 9. This graph shows that the Zircon: TiO_2 ratio generally lies below 0.5.

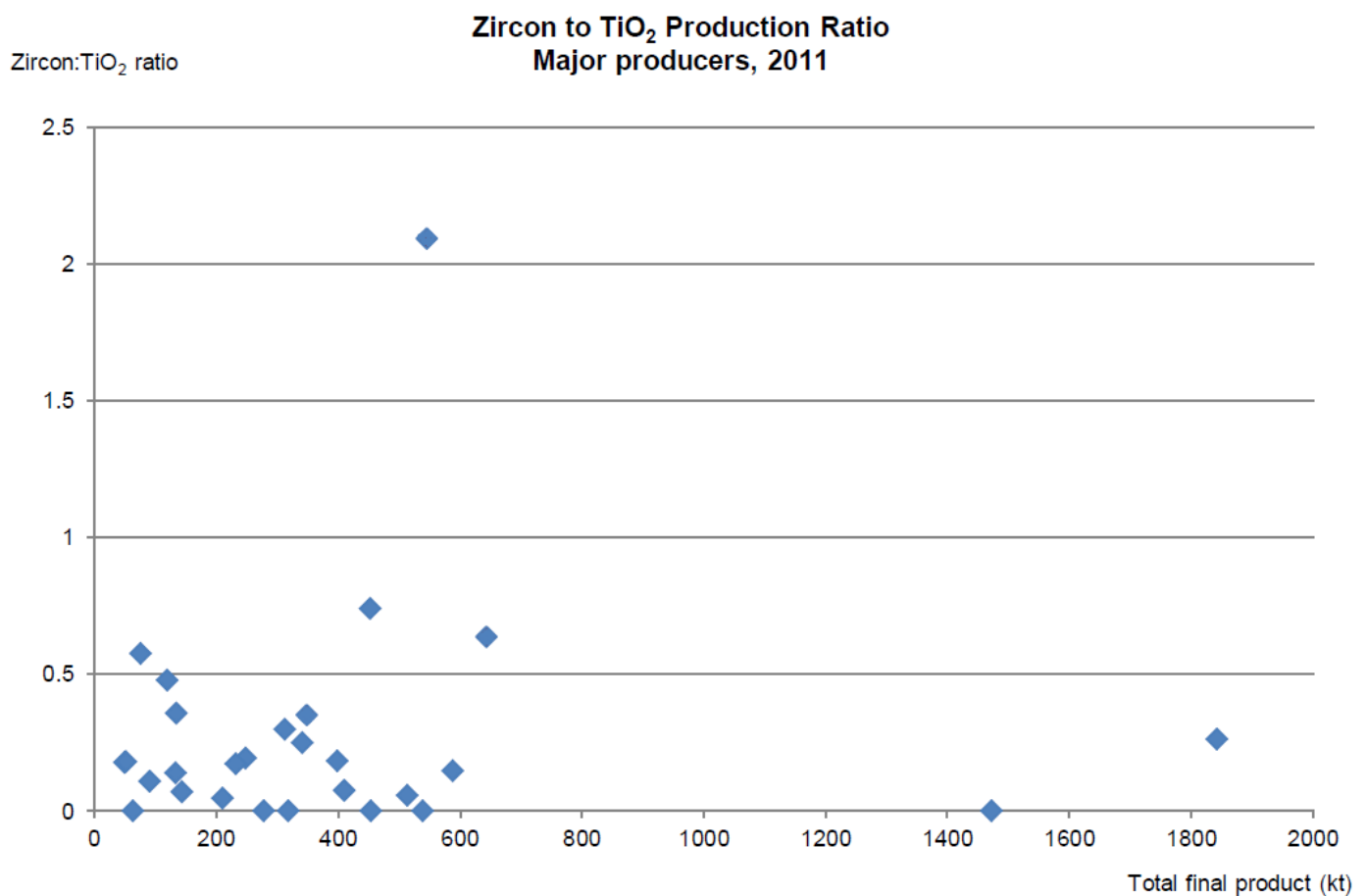


Figure 9: Zircon to TiO_2 production ratio major producers 2011 (Iluka, 2015).

4.2.2 Market

The mineral sands market is typically characterized by contractual arrangements, involving bulk shipments contracted on a volume and price basis for a set period, typically 12 months. Only a relatively small spot market exists for mineral sands products and there is no “screen traded” equivalent in mineral sands (Iluka, 2014).

Because the valuable minerals present in the THM are used in different markets below the titanium dioxide (ilmenite and rutile) and the zircon markets are evaluated separately in the next subsections.

4.2.2.1 Titanium dioxide

4.2.2.1.1 Demand

In 2010 91% of the titanium dioxide (TiO_2) was used as the feedstock for the manufacture of white pigment (as shown in Figure 9 10), with the remainder used to produce titanium sponge, which is used in the manufacture of titanium metal, as well as in welding as an electrode flux (Fernley & Drolla, 2011).

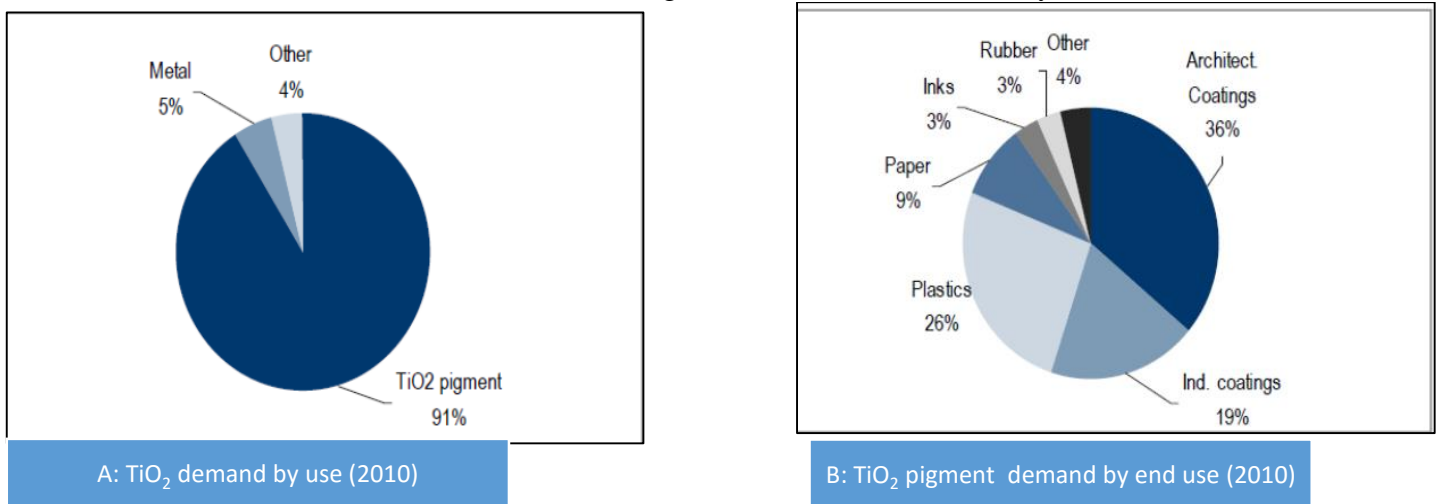


Figure 10: A: TiO_2 demand by use and end use (2010); B: TiO_2 pigment demand by end use (2010) (Fernley & Drolla, 2011).

Titanium pigment demand in 2010 was 6.3 Mt (Fernley & Drolla, 2011). Titanium dioxide is sought after in pigment because:

- Of its high refractive index (which means it is able to scatter and bend light well, giving an appearance of opacity and bright whiteness).
- Of its ability to absorb UV light. When added to materials such as paints and plastics it prevents UV degradation. It may also be used as a component in sunscreens, cosmetics and skin care products designed to protect human skin from UV damage.
- It is non-toxic and biologically inert making it safe for use in consumer applications.

The high titanium dioxide levels of rutile and synthetic rutile, and low levels of impurities, make these premium products for the manufacture of pigment. The properties described mean that there are no economic or environmentally safe substitutes for titanium dioxide in the pigment industry (Fernley & Drolla, 2011).

High grade titanium dioxide products are the principal feed for the manufacture of titanium metal. Titanium is an important metal particularly in commercial aerospace (its fastest growing segment), military and industrial applications. Titanium is characterized by its high strength-to-weight ratio (it is twice as strong as steel and 45% lighter) and corrosion resistance (Fernley & Drolla, 2011).

The mineral sands industry was characterized over the past 25 years by stable demand growth, long-term

pricing contracts and relatively low prices. However, the strength of emerging markets growth, particularly China, in recent years has changed this.

As described above the bulk of titanium dioxide feedstock produced in the world goes into the titanium pigment industry, and within that major uses are paints (coatings) and plastics. 36% of total pigment is used in the architectural coatings industry (as shown in figure 10) and a large proportion of plastics demand is in PVC, meaning that construction is a major end market for titanium pigment use (Fernley & Drolla, 2011).

The significant construction and urbanization in emerging markets over the past 10 years has substantially altered the shape of global titanium dioxide demand. Previously demand was dominated by the mature economies of Western Europe and North America (as shown in figure 11), but now Asia Pacific economies are of increasing importance, and these may have growth rates that are 4-5 times as fast as developed markets (Fernley & Drolla, 2011).

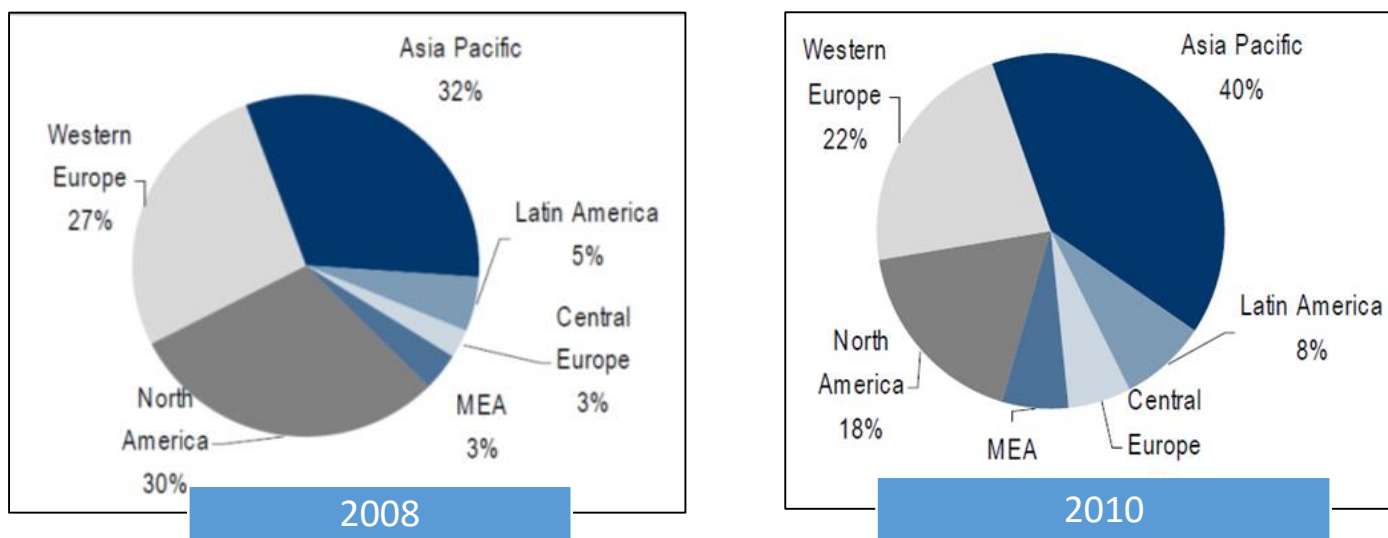


Figure 11: Global TiO₂ demand by region in 2008 and 2010 (Fernley & Drolla, 2011).

The relationship between titanium pigment demand growth and GDP growth for emerging economies suggests that in the early stages of economic development, pigment demand growth is much more elastic to GDP than at later stages. Hence we should expect pigment demand in emerging economies to continue to accelerate at high levels in coming years, particularly bearing in mind the UN's forecasts for urban population growth in emerging economies, which suggest a 25% increase in China's urban population over the next 10 years and a 29% increase in India's (Fernley & Drolla, 2011).

A comparison of TiO₂ intensity of use (consumption per unit of GDP) also suggests significant upside with India currently consuming circa 0.15kg of TiO₂ pigment per capita and China 0.85kg compared to Japan at 1.60kg and the US at 2.74kg (Fernley & Drolla, 2011).

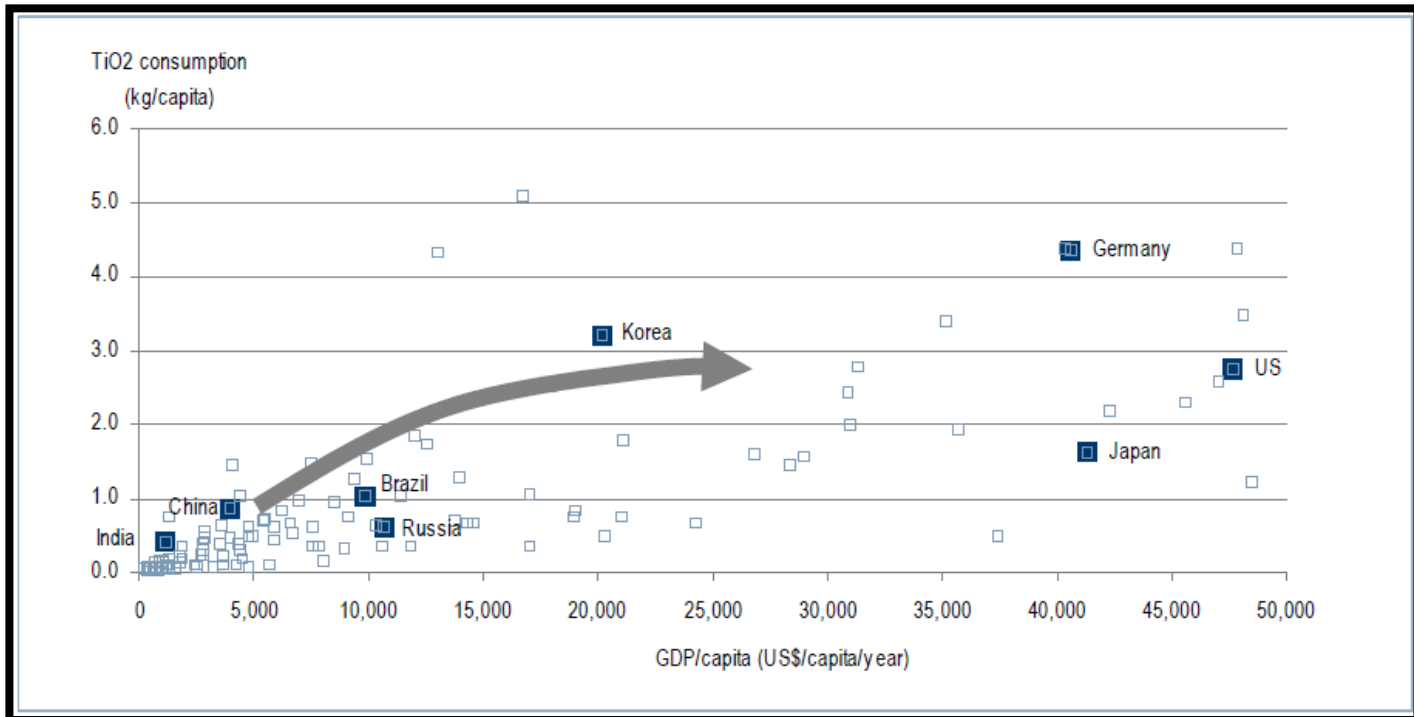


Figure 12: Relationship between TiO₂ consumption and GDP/capita 2011. Arrow indicates expectations for growth in China (Fernley & Drolla, 2011).

4.2.2.1.2 Supply

The titanium feedstock industry is relatively highly consolidated with the top five producers contributing 54% of global supply. Within that rutile is by far the most consolidated market with the top five producers controlling circa 71% of global supply. Of this 76% the top three producing countries (Australia, South Africa, Sierra Leone) contribute circa 86% of supply (Fernley & Drolla, 2011).

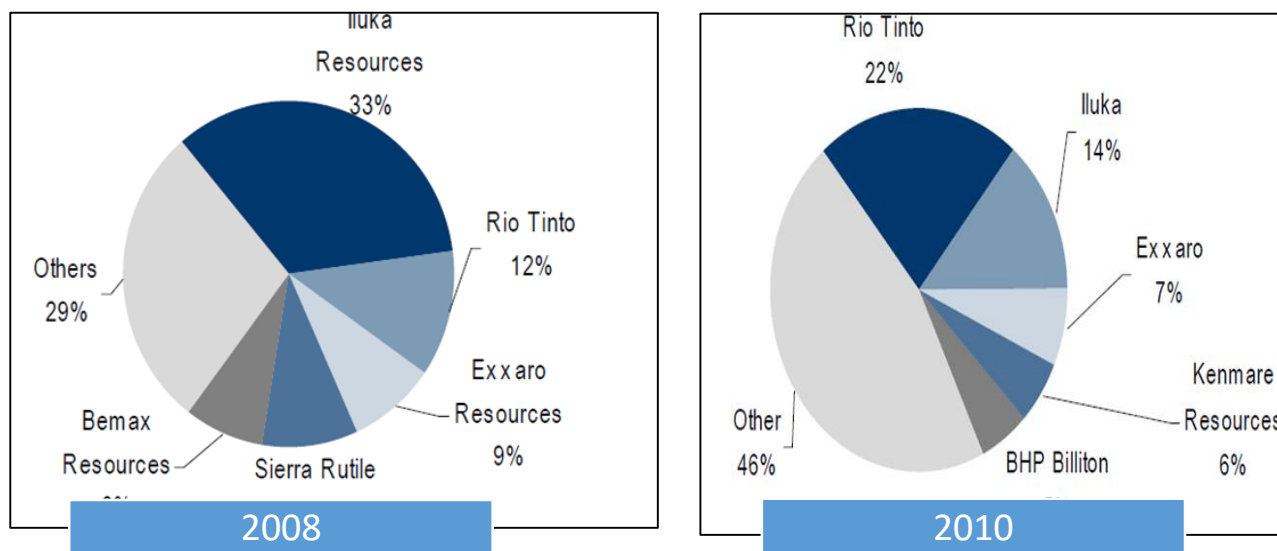


Figure 13: Global titanium feedstock by company (2008 and 2010) (Fernley & Drolla, 2011)

Rio Tinto is currently the largest producer of TiO₂ feedstock, followed by Iluka and Exxaro, while Iluka dominates supply in high titanium feedstock (Fernley & Drolla, 2011).

Australia is the largest producer of titanium feedstock in the world, with industry leading positions in both ilmenite and rutile. South Africa is also a major produce of both commodities although it is difficult to

source statistics for its ilmenite production as a large percentage is produced as slag. There are a number of hard rock ilmenite mines in Scandinavia and Canada (Fernley & Drolla, 2011).

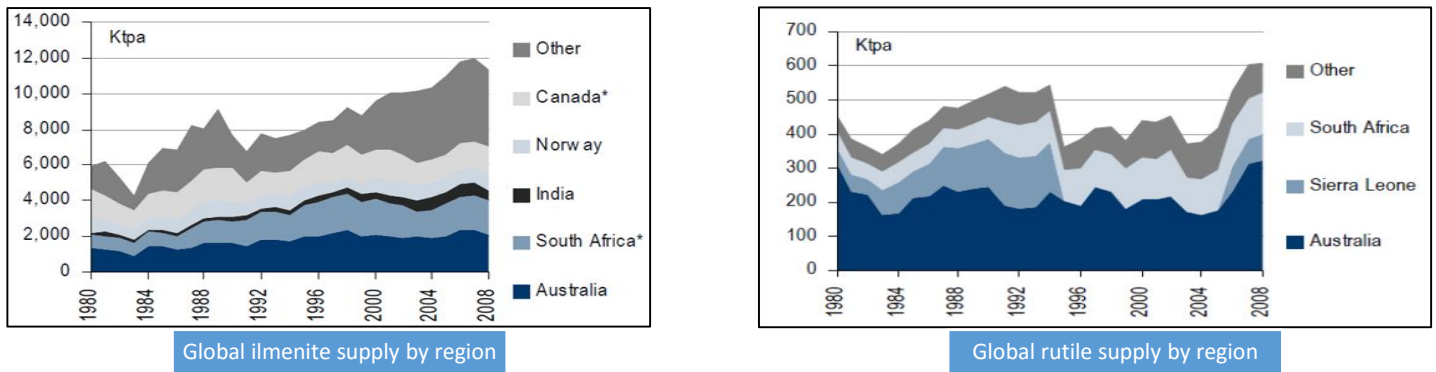


Figure 14: Global ilmenite and rutile supply by region 1980-2008 (Fernley & Drolla, 2011).

4.2.2.2 Zircon

4.2.2.2.1 End Users

The key properties of zircon are its high temperature resistance and resistance to chemical attack. Its largest end use is as an opacifier in the manufacture of ceramics based products (as shown in figure 15) including refractory bricks, tiles, sanitary ware and tableware. One fast growing segment is the production of zirconia, zirconium based chemicals and zirconium metal for industrial and chemical applications (Fernley & Drolla, 2011).

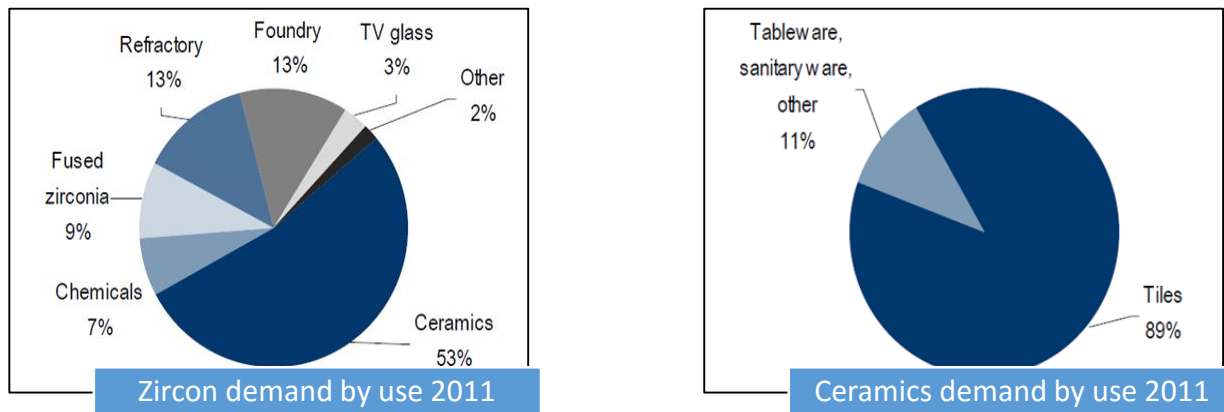


Figure 15: Zircon and ceramics demand by end use (Fernley & Drolla, 2011).

In the ceramics industry zircon is used as an opacifier in glazes and opaque frits (a type of ceramic glass added to glazes for water, abrasion and chemical resistance) and as a whitener in porcelain tiles. Most zircon consumed is in the form of a finely milled sand of circa 1.5 microns (Fernley & Drolla, 2011).

4.2.2.2.2 Demand

As noted above circa 53% of zircon consumption goes into ceramics and of that 89% is used in tiles (circa 47% of total zircon consumption). As with architectural paints, this application is also highly leveraged to residential construction in the emerging markets (Fernley & Drolla, 2011).



Figure 16: Global zircon demand by region 2005 and 2010 (Fernley & Drolla, 2011).

Demand from the chemicals sector is the fastest growing with annual average growth of over 10%. The sector caters to an increasingly diverse array of end applications, utilizing zircon’s unique properties. These include catalytic converters, nuclear fuel rods, electronics and pressure and oxygen sensors (Fernley & Drolla, 2011).

Zircon use in the refractories and foundries sectors has been relatively flat in recent years due to technology improvements. Growth drivers for zircon demand include urbanization, construction and industrial production (Fernley & Drolla, 2011).

4.2.2.2.3 Supply

Zircon is even more consolidated than titanium with the top five producers supplying 75% of global zircon production in 2010. Iluka contributed 32% of global supply, with Rio Tinto and Exxaro also large producers (Fernley & Drolla, 2011).

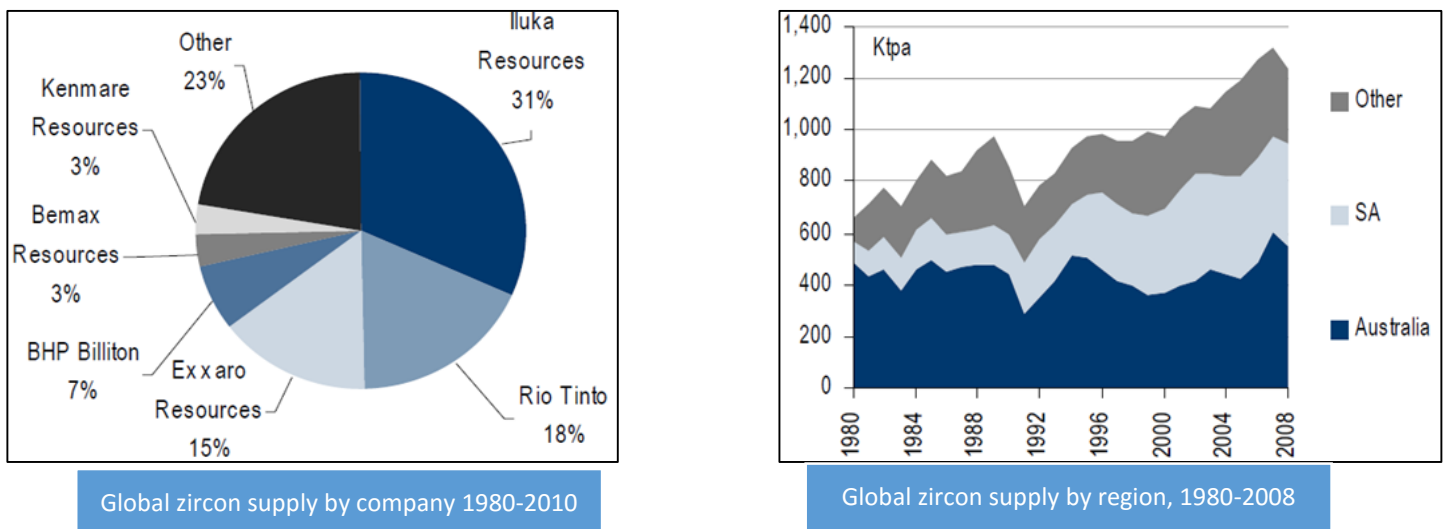


Figure 17: Global zircon supply by company and by region (Fernley & Drolla, 2011).

New supply opportunities are relatively hard to come by in mineral sands following a number of years of low prices and under-investment in the industry. There are a number of brownfield projects (Richards Bay, Moma expansions, etc.), projects which are close to production and beyond that a few projects which have been uneconomic in recent years but are now viable and are at the advanced feasibility/early development stages (Fernley & Drolla, 2011).

4.2.3 Price

Prices are set under long term contracts between producers and consumers. HMS sand prices are principally determined by derived demand (Hubbart, 2014). In the table below the prices (July 2015) at which the VHM are traded and the price prediction for March 2016 are shown.

Table 3: Commodity prices of VHM (MiningBulletin, 2015; Hubbart, 2014

Commodity	Trade price July 2015 Min (USD)	Trade price July 2015 Max (USD)	Predicted trade price march 2016 (USD)
Ilmenite	95	120	218,1
Rutile	800	880	1256
Zircon	1000	1125	1330

In the image below the price variations from 2007-2014 are shown.

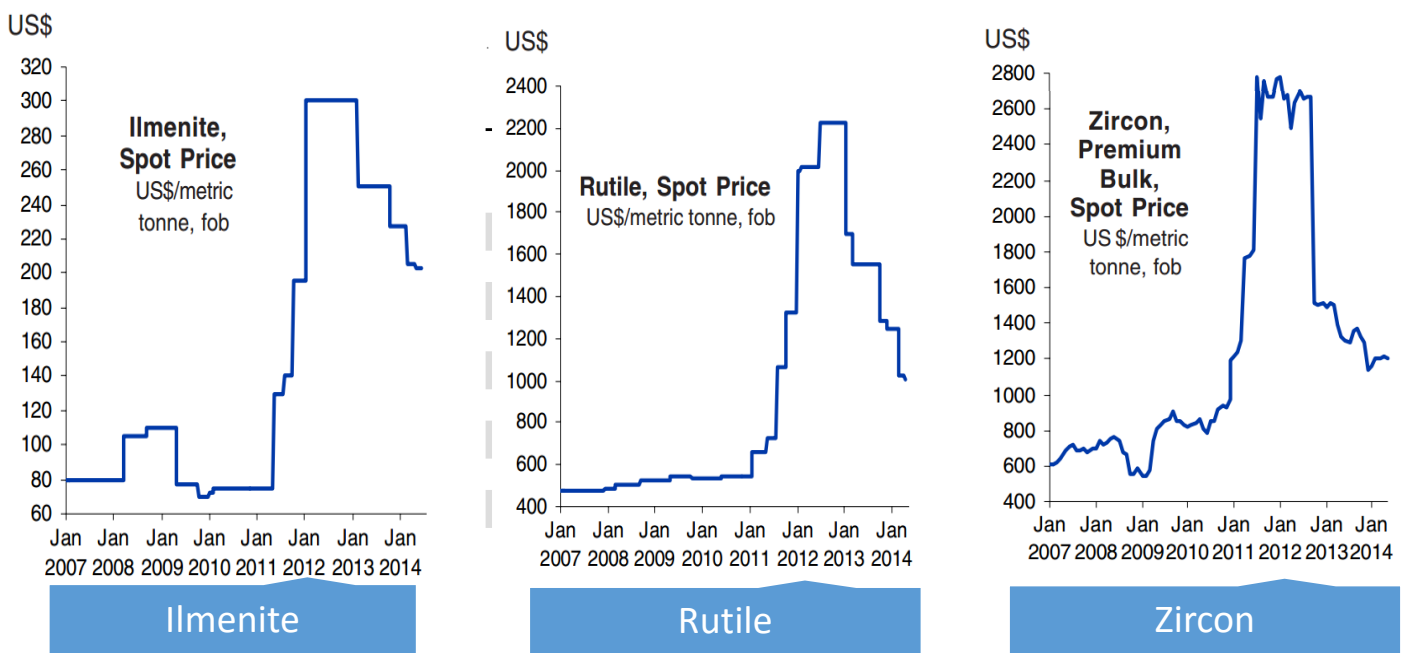


Figure 18: Ilmenite, rutile and zircon spot prices (2007-2014) (Hubbart, 2014).

4.3 HMS world occurrence

HMS deposits are found on every continent, with the exception of Antarctica (Bradley, et al., 2010). The worldwide occurrence of HMS deposits are shown in figure 19 below.

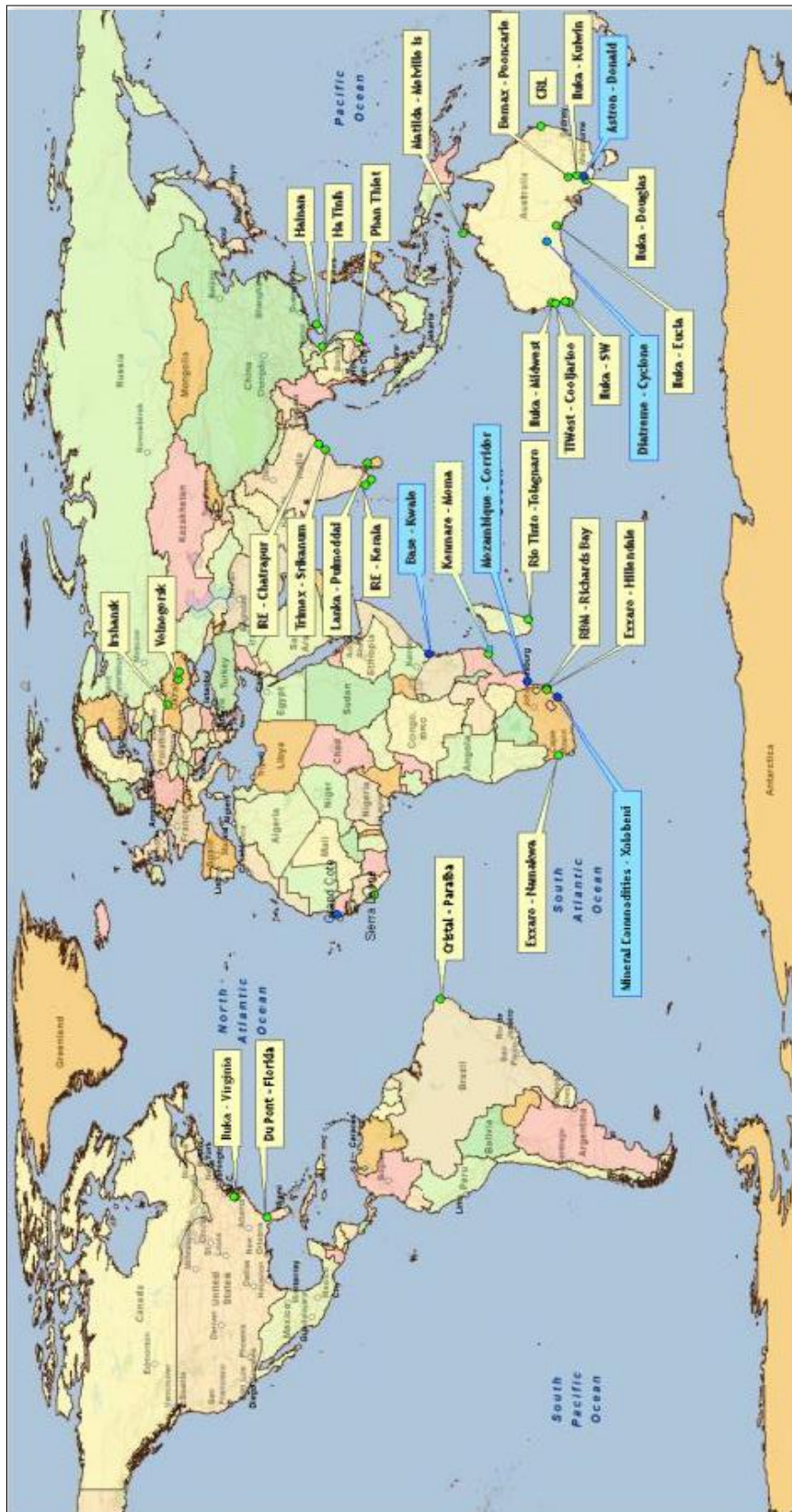


Figure 19: World occurrence HMS deposits (Benjamin, 2011).

Variations in coastal HMS deposits exist owing to many factors, but some common features characterize fossil and modern examples. Force (1991) notes that strandline deposits of Quaternary age share three basic characteristics: the deposits lie on passive margins¹⁴ of continents, the heavy minerals originate primarily in high-grade metamorphic¹⁵ terranes, and these deposits generally lie at middle to low latitudes (approximately 35° North to 35° South).

The sand body complexes are generally oriented parallel to the coast and the paleo strandlines, corresponding to past fluctuations in local sea level. Many modern coastal plains and shores provide analogues to fossil HMS deposits. Modern examples are typically coastlines along passive margins that experience turbulent-swell wave action and are cut by rivers and streams that supply sediments from inland crystalline rocks¹⁶ (Bradley, et al., 2010).

4.4 Model for HMS deposit formation

The processes that form coastal deposits of HMS begin inland. High grade metamorphic¹⁷ and igneous¹⁸ rocks, that contain heavy minerals, are broken down by processes of weathering and erosion. This sediment is subsequently transported by the action of wind, water, or ice and/or by the forces of gravity acting on the particles. By these processes sediment composed of sand, silt, clay and heavy minerals reach the fluvial systems. Streams and rivers carry the sediment to the coast, where the sediment is deposited in a variety of coastal environments, such as deltas, the beach face (foreshore), the near shore, barrier islands or dunes, and tidal lagoons, as well as the channels and floodplains of streams and rivers in the coastal plain. The sediments are reworked by waves, tides, longshore currents, and wind, which are effective mechanisms for sorting the mineral grains on the basis of differences in their size and density. The result is that heavy minerals accumulate together, forming laminated or lens shaped, heavy mineral rich sedimentary packages (as shown in figure 20) that can be several meters and even as much as tens of meters thick. These types of sedimentary deposits can contain economic concentrations of heavy minerals (Bradley, et al., 2010).

¹⁴ A passive margin is the transition between oceanic and continental lithosphere which is not an active plate margin (Geology.com, 2015).

¹⁵ High-grade metamorphism takes place at temperatures greater than 320°C and relatively high pressure. As grade of metamorphism increases, hydrous minerals become less hydrous, by losing H₂O, and non-hydrous minerals become more common (Geology.com, 2015).

¹⁶ Rock made up of minerals in a clearly crystalline state (Encyclopedia, 2015).

¹⁷ Metamorphic rocks have been modified by heat, pressure and chemical processes, usually while buried deep below Earth's surface. Exposure to these extreme conditions has altered the mineralogy, texture and chemical composition of the rocks. There are two basic types of metamorphic rocks. Foliated metamorphic rocks such as gneiss, phyllite, schist, and slate have a layered or banded appearance that is produced by exposure to heat and directed pressure. Non-foliated metamorphic rocks such as hornfels, marble, quartzite, and novaculite do not have a layered or banded appearance (Geology.com, 2015).

¹⁸ Igneous rocks are formed from the solidification of molten rock material. There are two basic types. Intrusive igneous rocks crystallize below Earth's surface and the slow cooling that occurs there allows large crystals to form. Examples of intrusive igneous rocks are diorite, gabbro, granite, pegmatite, and peridotite. Extrusive igneous rocks erupt onto the surface where they cool quickly to form small crystals. Some cool so quickly that they form an amorphous glass. These rocks include andesite, basalt, obsidian, pumice, rhyolite, scoria, and tuff (Geology.com, 2015).



Figure 20: Lamination of heavy mineral sand (Bradley, et al., 2010)

Economic deposits of HMS encompass modern and ancient examples. HMS operations exploit deposits that range in age from Cretaceous to Holocene. They include Holocene (recent) sediments on modern coasts as well as coastal deposits formed by transgressions¹⁹ and regressions²⁰ of the seas during intervals in the Quaternary, Tertiary, and Cretaceous (Bradley, et al., 2010).

In this subsection the general parameters necessary for a HMS deposit to form are further discussed. McQueen (2005) describes four general parameters which are required for an ore deposit to form. These four parameters are:

- 1) Source rocks which contain the minerals that form HMS are required to be present.
- 2) A mechanism that either transports these components to the ore deposit site and allows the appropriate concentration or removes non ore components to allow residual concentration.
- 3) A depositional mechanism (trap) to fix the components in the ore body as ore minerals and associated gangue.
- 4) A process or geological setting that allows the ore deposit to be preserved.

4.4.1 Source rocks for Heavy Mineral Sands

The foundation for locating deposits of HMS of considerable size are identification of ancient or modern coastal plains fed by streams and rivers that drain terranes where abundant high grade metamorphic rocks or igneous rocks crop out. These rock types tend to be particularly enriched in titanium oxide minerals, specifically ilmenite and rutile (Bradley, et al., 2010).

There exist three types of source rocks for HMS, namely:

- 1) Sedimentary rocks²¹
- 2) Igneous rocks
- 3) Metamorphic rocks

¹⁹ Geologic evidence of landward extension of the sea. Also known as invasion; marine transgression (Encyclopedia, 2015).

²⁰ Geologic evidence of the retreat of the sea from the land (Encyclopedia, 2015).

²¹ Rocks that have developed through the deposition of matter in water or sometimes from the air or through glacial action on the earth's surface and in sea and ocean basins (Encyclopedia, 2015).

Sedimentary rocks can be intermediate hosts of the heavy minerals that are later deposited in HMS. Sedimentary rocks in coastal regions can contain enrichments in heavy minerals derived from erosion of older igneous and metamorphic rocks. Erosion of the sedimentary rocks (“intermediate host rocks”) by fluvial processes, storms, waves, and currents along the coast can liberate the detrital heavy minerals from the consolidated sedimentary rocks; in this way the heavy minerals are remobilized and re-deposited, this time in coastal sands (Bradley, et al., 2010).

Igneous rocks are significant sources of the heavy minerals that are ultimately deposited in coastal environments. Proposed igneous sources of the heavy minerals must in particular account for ilmenite and rutile (Bradley, et al., 2010). Force (1991) describes several magmatic rock associations as potential sources of ilmenite or rutile, such as anorthosite-ferro diorite massifs and associated contact-metasomatic rutile deposits; alkaline igneous complexes, particularly pyroxene units in these complexes; some granitic rocks; some basaltic rocks; layered mafic intrusions; and kimberlites. In addition zircon is a common mineral constituent of most granitic and felsic igneous rocks.

High grade metamorphic rocks are considered the predominant original source of the titanium oxide minerals found in HMS (Force, 1991). Many studies implicate inland complexes of high grade metamorphic rocks as the primary source of the heavy minerals deposited in a particular coastal basin.

4.4.2 Transport mechanism

Rivers and streams carry sediments to coastal areas, where the detritus are deposited, reworked by waves, tides, and wind, and thus concentrated in a variety of coastal depositional environments (Bradley, et al., 2010).

4.4.3 Depositional mechanism

Most HMS deposits are deposited in the shore environment and therefore the depositional mechanisms in this environment are described. The forces of waves, tides, and longshore drift work the sediment, selectively carrying off lighter grains and leaving a fine grained accumulation of heavy, dense mineral grains. Variations in particle settling velocities due to differences in mineral densities work in concert with wave and tide actions in the swash zone to effectively segregate heavies from lights. The resulting sands are typically well sorted, medium- to fine-grained, well-rounded, and not indurated (Force, 1991).

The most important mechanisms which sort and concentrate the heavy minerals in the shore environment are (Force, 1999):

- 1) Surf wave action in the swash zone of a beach
- 2) Marine longshore drift
- 3) Wind and high energy surf and surge
- 4) Leucoxenation

These mechanisms are described in the subsections below.

4.4.3.1 Surf wave action in the swash zone of a beach

The principal zone of mineral separation is the upper part of the beach face, also known as the swash zone (the foreshore). The heaviest grains, which have the highest settling velocities, are deposited at the bottom of the swash zone. Coarse low-density detritus is carried by backwash to the wave zone, whereas heavy minerals tend to settle out and accumulate on the upper beach face (Komar and Wang, 1984). Thus, Force (1991) describes heavy-mineral concentration as “a process involving lag enrichment on the swash face,” in which erosion dominates deposition and “backwash efficiently sorts the available material, to produce a layer enriched in fine dense minerals.” Economic deposits of HMS represent innumerable thin layers of heavy mineral accumulations separated by very small unconformities (Bradley, et al., 2010).

4.4.3.2 Marine longshore drift

Once the sediment reaches the estuary the sediment is further transported into the ocean (the lighter sediment) or along the coast line through the process of longshore drift (the heavier sediment) (Bradley, et al., 2010).

Longshore sediment transport rates are largely determined by the near shore wave heights and directions with transport mostly generated by waves from oblique angles. Sediment transport rates increase with increasing angles of wave incidence and wave height (Bradley, et al., 2010).

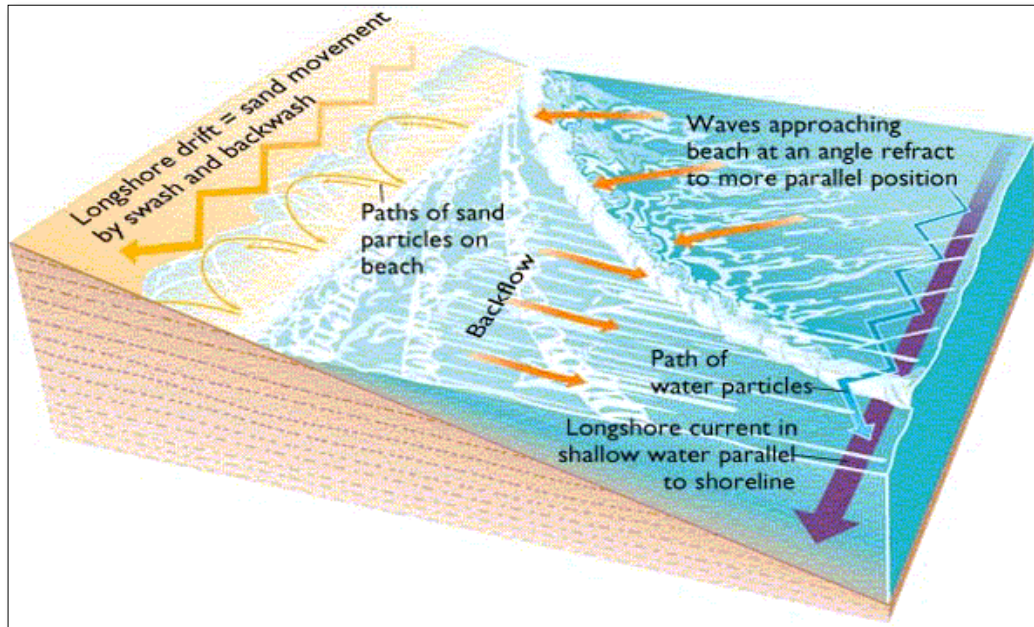


Figure 21: Longshore drift (Tribune, 2014).

The characteristics of marine longshore drift deposits have been defined by Benjamin (2011):

- Typically represent fossilized and buried beaches
- Often occur as multiple geomorphological settings: beaches, strand plains and/or barrier islands (Garnett, 2005)
- Typically well-defined edges, long (>km), width (~100-300 meters) and thickness (2-5 meters)
- High grade concentrations of valuable heavy minerals (VHM), 15-30+% HM and 50-90% VHM (includes ilmenite)
- Amenable to selective (dry) mining

4.4.3.3 Wind and high energy surf and surge

After sands accumulate on the beach, particularly in the backshore, winds can rework these sands and form sand dunes. Some of these Aeolian deposits can contain substantial concentrations of heavy minerals. Wind can be a very effective mechanism for sorting the heavy, dense minerals from the lighter grains of sand. Aeolian processes created many of the world's largest fossil and recent HMS deposits (Bradley, et al., 2010). An example of the formation of such a dune is shown in figure 22.



Figure 22: Shows two views of an area of Assateague Island, Maryland, photographed before and after Hurricane Sandy. Yellow arrow (A, B) points to same feature; red arrow (B) points to dark concentrations of heavy minerals on the upper shore face (USGS, 2015).

The characteristics dune deposits are generally (Benjamin, 2011):

- Consists of vegetated, massive parabolic dunes at or near sea level. The geomorphological forms where HMS placers are identified with Aeolian deposits are dunes (Garnett & Basset, 2005).
- Multiple dune-building periods coinciding with Pleistocene glacial maximums ranging from 300,000 – 20,000 years before present.
- Typically gradational grade boundaries (onion skin) long (>10 km), width (~ 1-5 km) and thickness (>100 meters).
- Typically low to very low grade concentrations of VHM, 0.5 to 3% HM but 40-80% VHM (includes ilmenite)
- Amenable to bulk (dredge, hydraulic) mining

4.4.3.4 Leucoxenation

Erosion leads to the breakdown of the rock matrix and the ‘release’ of the ilmenite. Progressive chemical weathering always results in an increase in the primary TiO₂ content at the expense of the Fe content, and therefore an increase in the value of the ilmenite. This process is called leucoxenation. The end product of this process is rutile (Elsner, 2011).

4.4.4 Preservation potential

The interplay of two (perseveration) mechanisms, the transgressive (prograding) nature of the coast and the relative strength of tidal and wave energy at the shoreline determines the size, location, morphology²², grade, and preservation potential of economic HMS deposits (Garnett & Basset, 2005).

Paleo strandline deposits are often correlated to regional sea level events. Sea level was lower than the present level during the majority of the Quaternary. Reductions in sea level during the Pleistocene are commonly linked to ice ages (Chappell, 1986). Lowering of sea level (regression) is thought to enhance erosion inland and may be accompanied by erosion of the upper parts of shores, which is the zone most often enriched in heavy minerals (Force, 1991). As a result regression should promote HMS deposition on continental shelves (Grosz, 1987).

Pliocene transgression has been linked to HMS deposition in coastal basins across the globe (Bradley, et al., 2010). High stands of local sea level can be represented by distinct terraces, which are composed of shoreline and associated facies. Many parts of the terrace or strandline systems can contain heavy minerals (Baxter, 1977; Roy and Whitehouse, 2003; Hou and others, 2008). A coastal sedimentary basin can contain many strandline complexes, each due to separate major changes in sea level. The paleo strandlines represent intermittent transgressions and regressions that can encompass millions of years.

The mineralizing processes in the paleo strandline deposits are closely linked to transgressions and regressions of the sea, which can oscillate across a coastal basin for tens of millions of years. Because heavy-mineral deposits are most likely to be eroded and destroyed in coastal environments and preserved only rarely, time spans of continuous heavy mineral deposition are difficult to determine. That is, more time is missing from the sedimentation record than is represented in a sedimentary basin (Bradley, et al., 2010).

²² Morphology is the study of how things are put together, like the make-up of animals and plants, or the branch of linguistics that studies the structure of words (Encyclopedia, 2015).

4.5 HMS resource characteristics

A deposit is an accumulation of raw natural mineral material of industrial significance. In figure 23 below the key (economic) HMS deposit characteristics are identified. The HMS properties show the economic potential of the HMS deposit. At this stage of the GAM HMS project the costs and profits cannot be calculated and therefore it is also not possible to calculate the cut-off grade²³. Therefore, the characteristics which form HMS resources are investigated by looking at the HMS industry standards. These industry standards can then be used to evaluate the results of exploration.

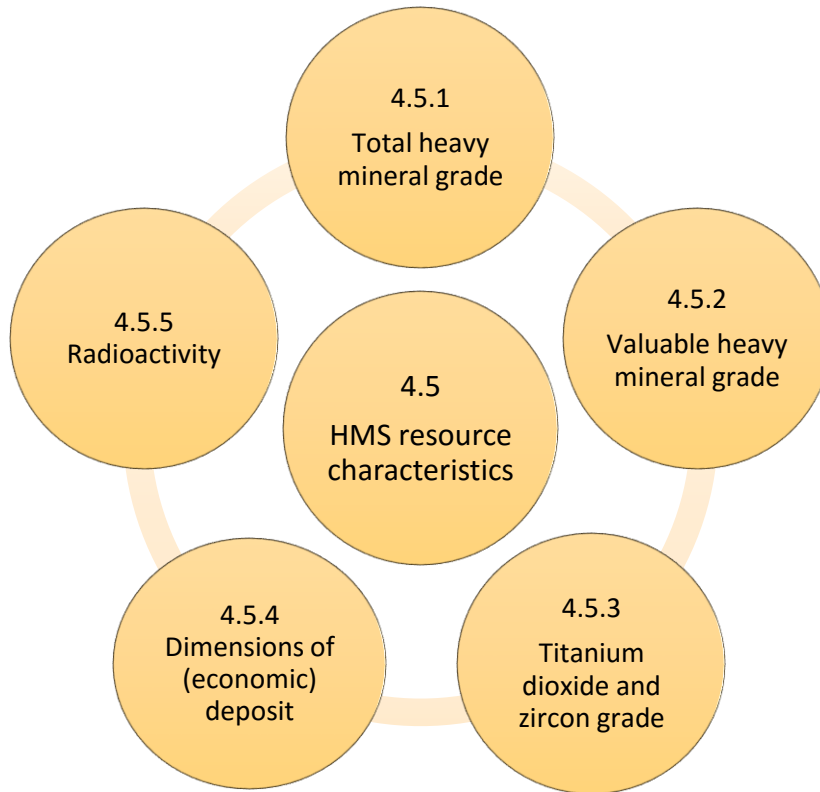


Figure 23: Overview of key HMS deposit characteristics

4.5.1 Total heavy mineral grade

The Total Heavy Mineral grade (%THM) provides an indication the presence of a resource. The %THM of HMS mines, which are currently in the operational phase, indicate that the %THM varies between 0,8 and 15%, as shown in figure 24 (Elsner, 2011). The Pulmoddai deposit can be interpreted as an outlier.

²³ The lowest grade, or quality, of mineralized material that qualifies as economically mineable and available in a given deposit. May be defined on the basis of economic evaluation, or on physical or chemical attributes that define an acceptable product specification (JORC, 2012).

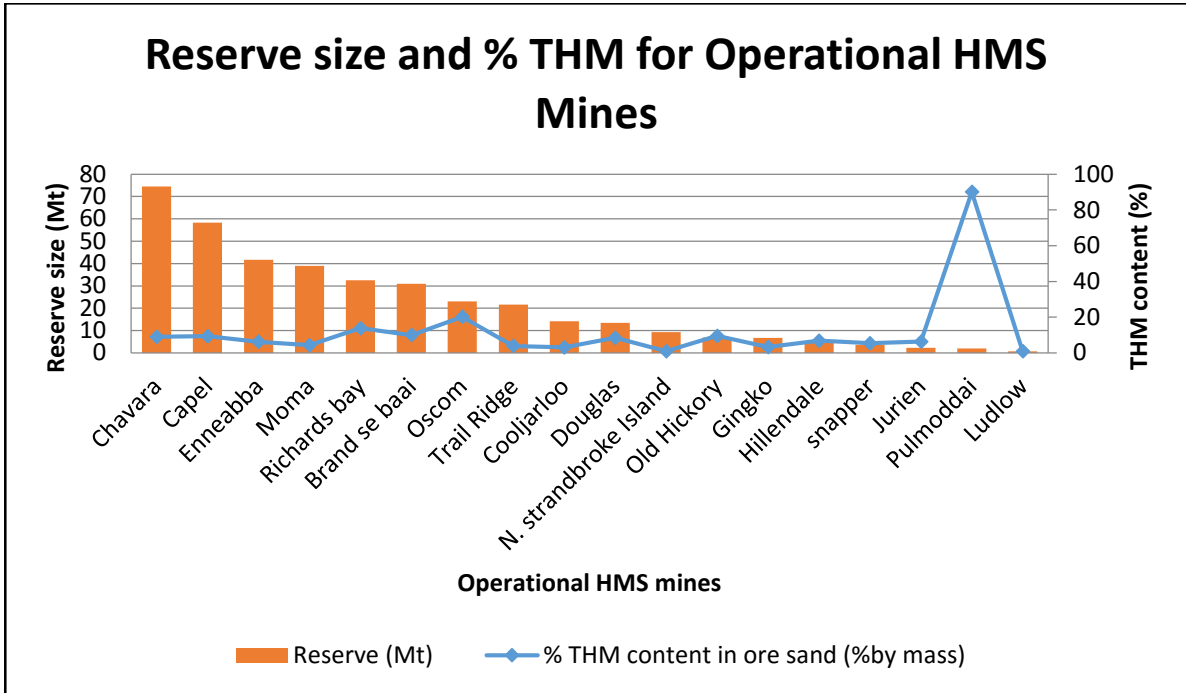


Figure 24: Reserve size and %THM for operational HMS mines. Data modified from Elsner (2011).

4.5.2 Valuable heavy mineral grade (% ilmenite, % rutile and % zircon)

The valuable heavy mineral grade (% VHM) refers to percentage of valuable heavy minerals ilmenite, rutile and zircon. The % VHM of HMS mines which are in the operational phase (2003) indicate that the % VHM varies between 38,5 and 83 % as a percentage of the THM, as shown in figure 25 (Elsner, 2011). The Chavara and Tamil Nadu reserves are interpreted to be outliers. In the graph below the relative amount of VHM %TiO₂ minerals (ilmenite and rutile) versus %zircon minerals in THM versus reserve tonnage for active HMS mines are shown.

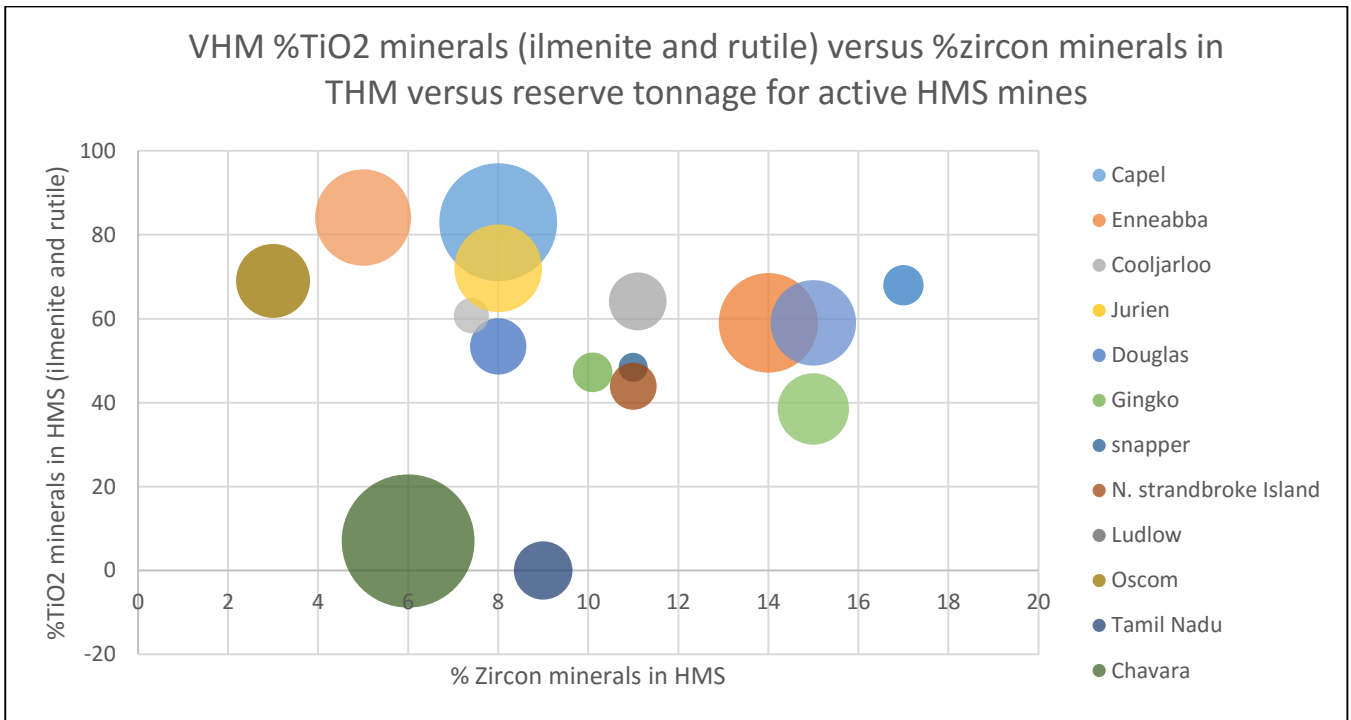


Figure 25: %TiO₂ minerals (Ilmenite and Rutile) versus % zircon in THM versus reserve tonnage for active (producing) HMS mines. Data modified from Elsner (2011).

4.5.3 Titanium dioxide and zircon grade

On the market ilmenite is traded containing a minimum of 50% TiO₂. Zircon is traded containing a minimum of 66% ZrO₂ (MiningBulletin, 2015).

4.5.4 Dimensions of economics deposit (HMS mineral reserves)

4.5.4.1 Dimensions

HMS resources can exceed more than 1.000 Mt of ore (total sand bodies). The heavy mineral-rich sand deposits that form a district can be vast in size, ranging from several kilometres to as much as tens of kilometres in length (Bradley, et al., 2010).

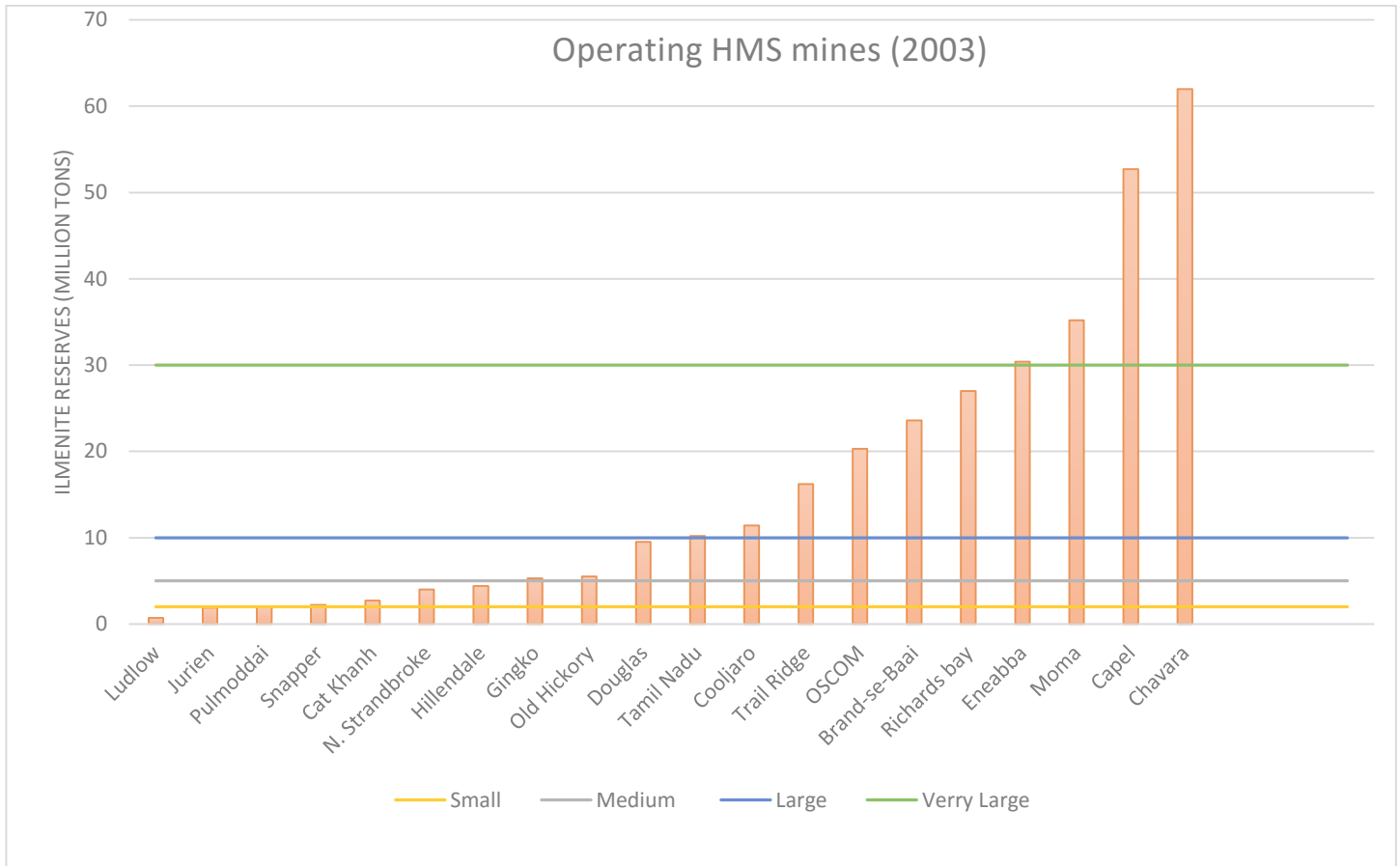


Figure 26: Ilmenite reserves of operating HMS mines. Data modified from Elsner (2011).

The smallest size of a HMS mineral reserve (mined in 2003) is the Ludlow reserve which contains 700.000 tons of ilmenite. Reserves containing 2-5 million tons of ilmenite mineral content are interpreted as small reserves, 5-10 million tons are medium reserves, 10-30 million tons are large reserves and larger than 30 million tons are considered very large reserves (Elsner, 2011).

Other accompanying VHM's, mainly rutile and zircon are secondary minerals within the HMS deposit. These are therefore also important for the economic viability of the mining of some deposits. shows data for the assessment of rutile and zircon deposits (Elsner, 2011).

Table 4: Reference values for the assessment of rutile and zircon deposits (Elsner, 2011)

Reserve size	Rutile and Zircon placer mineral content (thousand tons)
Not mineable	<100
Small	100-250
Medium	250-500
Large	500- 1000
Very Large	>1000

Individual bodies of HMS are typically 0.4 to 4 km wide and more than 5 km long (Force, 1991). However, stating a typical deposit size is somewhat misleading because single deposits are generally developed as part of a district of similar deposits. Many HMS districts extend for more than 10 km, encompassing several individual deposits. Heavy minerals deposits in a basin lie discontinuously along the strike of a strandline and as stratigraphically stacked deposits that represent different sea level events through time (Bradley, et al., 2010).

4.5.5.2 Vertical Extent

Although they can be very large in area, economic deposits of HMS are not thick. Reported thicknesses of economic deposits range from 3 to 45 m (Bradley, et al., 2010).

4.5.5.3 Form and Shape

Deposits of HMS are generally elongate, oriented roughly parallel with the strike of the paleo shoreline for fossil deposits. In cross section, the deposits have convex lens-shaped profiles, similar in cross-section form to channel deposits of fluvial systems. Ore bodies are lens-shaped packages of heavy-mineral-rich sediments. Along the length of the strandlines, these lens-shaped ores are stacked and offset in the sedimentary stratigraphy, separated by intervals with low heavy-mineral content (Bradley, et al., 2010).

Terraces associated with this deposit type most likely represent major sea level events of paleo strandlines rather than faulting or other structural features. Terraces form during local high stands of the sea, and are now manifested as ridges that are as much as tens of meters high and located inland by as much as several tens of kilometres (Bradley, et al., 2010).

4.5.4.4 Host Rocks

HMS deposits are unconsolidated to weakly consolidated layers of sediments, and they are thus generally not hosted in bedrock. As a result, these deposits (sediments) are relatively easy to excavate and likewise easy to disaggregate for mineral separation, which greatly reduces the cost of mining and processing these deposits. Minor production of heavy minerals has occurred in the past from sandstones that are particularly rich in heavy minerals (Force, 1991).

4.5.5 Radioactivity

As a bearer of Uranium (U) and Thorium (Th), zircon is slightly radioactive and therefore carcinogenic. Monazite and xenotime, which also occur in HMS, are also radioactive. In general, a global limit of 500 ppm U + Th or U + (0.4 x Th) <100 ppm applies (Elsner, 2011). The lower the level of Uranium and Thorium, the higher its marketing potential. Moreover, according to current legislation, zircons with Uranium and Thorium levels exceeding the legal limits do not constitute valuable heavy minerals, but radioactive waste material. Radioactive zircons (which are often weakly magnetic) must therefore be separated out during processing. This, however, leads to high production losses and to the storage of radioactive materials zircon, xenotime and monazite, which is undesirable in ecological terms (Elsner, 2011).

4.6 HMS exploration methods

The location and the interaction between geological facies have an important impact on the spatial variability of all relevant properties (Benndorf & Wambeke, 2014). Therefore, the exploration is not only aimed at locating HMS but also obtaining insight in the regional geology.

Type 1: Regional geology

The first type of survey is a mapping of the (areal) distribution of a particular rock or soil characteristic. These measurements need not have any immediate or direct relevance to the ore body sought. The data is used in conjunction with bedrock or regolith maps from direct surface observations in order to produce an interpretation of three-dimensional geology. Geological models are then used to predict where ore might be found and so guide subsequent search (Marjoribanks, 2010).

Type 2: Ore targeting (detecting anomalies)

The second type of survey is aimed at measuring unusual or atypical features of rocks that directly reflect, and have close spatial relationships to, economic mineralization. Following the geological interpretation (and often iteration between stages) is the development of metallurgical bulk samples to provide information on the identified domains (Marjoribanks, 2010). There can be considerable mineralogical and quality variability within strandlines and deposits, so it is important to obtain the best compromise for sample delimitation versus cost while at the same time targeting different domains (Jones, 2012).

The critical step in analysing the results of ore-targeting surveys is to select those measurements that can be considered as “anomalous”. The selected anomalies are then analysed to determine the probable nature, size, position and shape of the causative body as a prelude to a follow-up detailed exploration program, usually drilling (Marjoribanks, 2010).

4.6.1 Exploration techniques

To conduct the two types of surveys described in the previous chapter, different exploration techniques exist to best obtain the required data. In this chapter remote sensing, pitting, trenching and drilling exploration techniques are described.

Table 5 shows the properties of the main VHM in a HMS deposit. The mineral properties described in this table are of importance from an economical point of view but also of importance for the choice of exploration and processing methods.

Table 5: Mineralogy, Petrography and Chemistry of ilmenite, rutile and zircon (Elsner, 2011; MiningBulletin, 2015; Iluka, 2014).

Characteristics	Ilmenite	Rutile	Zircon
Chemical formula	FeTiO ₃	TiO ₂	ZrSiO ₄
Chemistry	50% by mass TiO ₂ FeO.TiO ₂	95-97% by mass TiO ₂	66 % by mass ZrO ₂ ZrSiO ₄
Density (g/cm ³)	4.72	4.25	4.65
Magnetic susceptibility	High	Low	Low
Electrostatic Conductivity	High	High	Low
Radioactivity	Non-radioactive	Non-radioactive	Possibly radioactive

4.6.1.1 Remote sensing techniques

The remote sensing methods and their suitability for HMS exploration are shown in figure. The table identifies the utility of each method in airborne or ground applications. The results of remote sensing

methods alone cannot lead to resource estimation according to the JORC code (2012). Remote sensing techniques can be used to interpret the continuity of anomalies and thus support a resource statement based on drilling or pitting and trenching results.

As can be seen from figure 27 below, according to an article published by Campbell & Walker (2014), the most effective remote sensing technique, for regional geology and direct targeting of the VMS (Valuable Mineral Sands), are ground and or air magnetic exploration. The reason that this technique is best suitable is because ilmenite and associated magnetic minerals (such as magnetite) have magnetic properties. The applicability of the magnetic method and the other geophysical exploration methods relevant to HMS exploration are described in this paragraph.

Geophysical Method	Air or Ground	Application	
Magnetic	Air	Geologic Framework	●
		Direct Targeting	●
	Ground	Geologic Framework	●
		Direct Targeting	●
Electro-magnetic	Air	Geologic Framework	●
		Direct Targeting	●
	Ground	Geologic Framework	●
		Direct Targeting	●
Electric	Ground	Geologic Framework	●
		Direct Targeting	●
Gravity	Air	Geologic Framework	●
		Direct Targeting	●
	Ground	Geologic Framework	●
		Direct Targeting	●
Radiometric	Air	Geologic Framework	●
		Direct Targeting	●
	Ground	Geologic Framework	●
		Direct Targeting	●
Seismic	Ground	Geologic Framework	●
		Direct Targeting	●

Qualitative Applicability Rating of Geophysical Method:

- Highly Effective
- Moderately Effective
- Generally Effective

Figure 27: Utility of geophysical methods in exploration for valuable mineral sand deposits (Campbell & Walker, 2014)

Magnetic Signature

Magnetic anomalies highlight lateral contrasts in rock magnetic minerals, such as magnetite, titanomagnetite, magnetite, and hematite, integrated over depth. If those or other magnetic minerals are present within a heavy mineral assemblage, they may generate a measurable anomaly, depending specifically on material properties and quantity of those materials. Whereas magnetite, titanomagnetite, and other magnetic minerals are typically found only in trace amounts in placer deposits (partly due to oxidation and other processes that alter magnetite), other minerals such as ilmenite, which has weaker magnetic properties, might contribute to magnetic anomalies if quantities are abundant enough (Bradley, et al., 2010).

The likelihood of success from magnetic methods can be enhanced through laboratory studies of magnetic mineralogy. Force and others (2001) and Shah and others (2012) determined a likely contribution of remnant magnetization to observed anomalies, which indicates the importance of ferromagnetic minerals such as magnetite. Where such minerals are present, even in trace amounts, their contribution to magnetic anomalies may be considerable and, in general, the magnetic response of HMS can vary widely from one region to another. Furthermore, such minerals may provide a greater contribution to the magnetic signature than other minerals such as ilmenite which, although considered magnetic, typically has a lower magnetic susceptibility and cannot support remnant magnetization (Bradley, et al., 2010).

Gravity Signature

Gravity surveys are not typically used to delineate placer deposits but may assist characterization of surrounding geologic features. Gravity anomalies measure lateral contrasts in rock densities integrated over depth. Heavy mineral sediment concentrations should by definition be associated with a local density contrast. For example, for a 10 percent concentrate of heavy minerals having an average density of 4.5 g/cm^3 and background sediments, such as quartz, with a bulk density of 2.6 g/c m^3 , the associated density contrast would be 1.9 g/c m^3 . Such density contrasts are commonly measured for bodies that are several hundred meters thick and wide. Placer deposits are often thinner, but basic calculations show that a body close to Earth's surface that is less than 100 m thick would produce an anomaly of about 0.7 milligals (mgal). Such an anomaly is small but measurable with modern instruments. However, the lateral extent of heavy-mineral concentrations can be limited or quite variable. Because a single ground gravity measurement typically takes several minutes, surveys to delineate heavy-mineral concentrations are likely to be very time-consuming and labour-intensive compared to other approaches such as magnetic and radiometric methods. Additionally, it may be difficult to distinguish anomalies attributable to placer sources from those attributable to deeper or shallower density variations (Bradley, et al., 2010).

Electrical Signature

Electrical methods measure differences in rock conductivity, such that different methods address properties at different scales. The use of electrical methods to delineate heavy-mineral sands has been explored most fully through the use of induced polarity (IP), which uses time-varying currents to measure how well charges are retained (Bradley, et al., 2010).

Radiometric Signature

Radiometric methods measure instances of natural gamma radiation and use the associated energy spectra to calculate relative amounts of K, U, and Th. These measurements typically represent rocks within about 1 m of Earth's surface. Although gamma particles may be emitted from deeper rocks, scattering against overlying and surrounding rock prevents most gamma particles from reaching the surface and thus an instrument sensor.

Several components of heavy-mineral concentrates can generate a radiometric anomaly. The most prominent is monazite, which is apparent as elevated Thorium in spectral data (Force and others, 1982; Grosz and others, 1989, 1992; Grosz and Schruben, 1994). Radiometric Thorium anomalies may be of particular interest because of the potential of monazite to contain REE. Zircons may also generate Thorium and possibly Uranium anomalies. Minerals observed outside of heavy mineral assemblages, such as Kalium-feldspar and micas, can also contribute to total-count surveys, but these appear as Kalium highs in the gamma spectra. Similarly, other Uranium-rich phosphates will generate radiometric anomalies, and although they are often of economic interest, they are rarely found in placer deposits (Force and others, 1982; Grosz and others, 1989).

Radiometric methods especially have been used in the south-eastern United States for the detection of heavy-mineral concentrations. However, whereas anomalies have indicated the presence of such deposits, many are

not of economic interest because of grain size considerations (Force and others, 1982; Grosz and others, 1989). Conversely, heavy-mineral concentrations containing limited amounts of monazite, or those buried several meters below Earth's surface, are unlikely to generate a corresponding radiometric anomaly because signatures will be too weak (for example, Grosz and Schruben, 1994).

Visible to mid-infrared region (VIS-MIR)

Laboratory spectra of the minerals related to heavy-mineral sands show a wide range of spectral features in the visible (VIS) to mid-infrared (MIR) region of the electromagnetic spectrum (Hunt, 1982; Salisbury and others, 1991; Clark and others, 2007). HMS contain 90–99 percent light minerals, which generally include large concentrations of quartz and clay minerals. Quartz sand spectra are transparent in the VIS to near-infrared (NIR) range, but diagnostic features caused by asymmetric stretch fundamentals, bending modes, and symmetric stretch fundamentals occur in the MIR region (7.0–25.0 micrometres (μm)) of the electromagnetic spectrum (Salisbury and others, 1991; Clark, 1999). Clay vibrational features are typically seen at approximately 2.2 μm and are generally associated with kaolinite in heavy-mineral sands. Other less abundant light minerals such as amphiboles, biotite, and muscovite also have Mg-OH or Al-OH vibrational absorption features in the 2.0 μm region; these minerals have different diagnostic spectral bands that allow the identification of each mineral within the spectrum (Bradley, et al., 2010).

Approximately 80 percent of the heavy-mineral suite is typically ilmenite, rutile, iron-oxide minerals, and zircon, with lesser amounts of leucoxene, monazite, garnets, sillimanite, and staurolite. The titanium-bearing minerals in the heavy fraction of the mineral sands, such as ilmenite, rutile, and leucoxene, all lack definitive diagnostic features in the VIS to NIR. The Fe^{2+} ion in ilmenite causes a broad, weak absorption feature near 0.5 μm , but the overall low reflectance level of ilmenite can make identification of this band difficult when ilmenite is mixed with other minerals in sand (Clark, 1999). The Ti-O stretching bands in the MIR are diagnostic and can be used to identify the Ti-bearing minerals. Spectra of zircon and monazite show fine structure in the VIS to NIR that are caused by crystal field f-f transitions of REE ions present in the minerals. These sharp spectral bands allow accurate identification of the minerals when they are present in large concentrations and can also help identify the REEs within their structure. The remaining heavy minerals, mainly garnet, sillimanite, and staurolite, are aluminium silicates that have their fundamental absorptions in the MIR and lack diagnostic features in the NIR (Salisbury and others, 1991; Clark and others, 2007). Iron-oxide minerals are also common in heavy minerals sands and generally originate from iron that is leached from ilmenite (Force, 1991; Paine, 2005). Iron-oxide has a broad absorption band near 1.0 μm caused by a Fe^{2+} electron transition.

Diagnostic spectral features make identification of each of these minerals possible with laboratory and imaging spectroscopy; however, there are significant challenges when trying to identify these minerals in poorly sorted sediment. Current VIS to NIR imaging spectrometers generally cover the 0.35–2.5- μm spectral range. The VIS to NIR spectra of heavy-mineral sands possess spectral features within the same intervals as clays (in the 2.0 μm region) and Fe^{3+} in iron oxides (in the 1.0 μm region) (Clark, 1999). Minerals such as zircon and monazite, which do have unique spectral features in the shorter wavelengths, occur in concentrations that are very difficult to detect by using airborne or space borne remote sensing.

Quartz sand and titanium minerals lack sufficient diagnostic absorption features in the VIS to NIR, but their respective Si-O and Ti-O fundamental stretches within the MIR wavelength region can be used for identification (Salisbury and others, 1991; Clark and others, 2007). Thermal sensors can detect these absorption features, but mixtures of these minerals as found in natural deposits, also limit the utility of a thermal sensor. For instance, quartz sand is the most abundant mineral in most beach sediments, and its Si-O-Si asymmetric stretch fundamental band near 9.0 μm is so strong that it is impossible to detect the weaker features of ilmenite, rutile, or leucoxene.

Indirect detection of heavy-mineral sands using night-time thermal-infrared sensors combined with digital elevation model (DEM) or airborne electromagnetic (AEM) data may be possible (Fabris, 2002; Hou and others, 2011). Thermal inertia can differ for different materials on the basis of their soil or rock properties (their ability to store heat), water content, porosity, and density. Fabris (2002) suggests that the thermal inertia of water and materials associated with heavy-mineral sands may be used to identify subsurface paleo channels and strandlines.

Laboratory and imaging spectroscopy have become effective tools for mineral exploration, but additional investigations are needed to determine the effectiveness of using this technology to identify the minerals of interest related to heavy-mineral sands. In particular, additional studies are needed to determine the lower detection limits of the minerals of interest within heavy beach sands and the spectral and spatial resolution needed to accurately identify their spectral bands.

4.6.1.2 Drilling techniques

Once a zone of mineralization (potential ore) has been discovered, and its shape approximately outlined, it needs to be defined in detail by a follow-up program of step-out²⁴ and infill²⁵ drilling programs (Jones, 2012). Usually small four wheel drive mounted reverse circulation air-core (RC) drilling rigs are used. In table 6 below the different drilling methods are shown.

Table 6: Comparison of exploration drilling methods best suited for HMS exploration (Marjoribanks, 2010).

Drill type	Indications	Advantages	Disadvantages
Hand auger	Geochemical sampling in upper few meters of unconsolidated material	Hand portable and operable. Uncontaminated sample. Cheap	Poor penetration
Power auger	Geochemical sampling in upper few meters of unconsolidated material	Small lightweight machine – vehicle mounted or hand operated. Quick, cheap	Poor penetration (better than hand auger). Sample contamination
Rotary air blast (RAB)	Geochemical sampling to base of regolith Ideal regolith sampling tool	Large sample volume. No site preparation needed. Quick and relatively cheap. Some rock chip geological data	Poor penetration of hard rocks. Sample contamination. Limited depth. No structural data. but can be ineffective below the water table
Air core	Geochemical sampling where good characterization of bedrock required	Small rock core return. Minimal contamination. Relatively quick and cheap. Can penetrate heavy clay/mud	Small sample size
Reverse circulation (RC)	Geochemical sampling hard and soft rocks to 200 m + Ore body proving above water table	Uncontaminated large volume sample. Rock chip geological data. Relatively quick and cheap cf. diamond. Capable of drilling beneath the water table.	Large heavy rig may need access preparation. Limited structural data. Poor orientation control
Diamond	Ore targeting and proving to 1,000 m and high quality sample. Contributes to the geological and/or structural understanding	Maximizes geological information. Non-contaminated, undisturbed high-recovery sample. Accurate hole positioning/control	Some site preparation required. Water supply required. Relatively small sample size. Slow. Expensive

From almost all points of view, the larger the core diameter the better. Large diameter holes provide better core recovery and deviate less. Lithology and structure are much easier to recognize in the larger core sizes and a larger volume sample is better for geochemical assay and ore reserve calculations. However, as the

²⁴ Step out drilling programs have a fixed starting point from which they intend to expand the mineralization zone (Undervalued Equity, 2015).

²⁵ Infill drilling programs are used to confirm the presence of mineralization between the step-out drill holes (Undervalued Equity, 2015)..

cost of diamond drilling is roughly in proportion to the core size, a compromise on hole size is usually necessary (Marjoribanks, 2010).

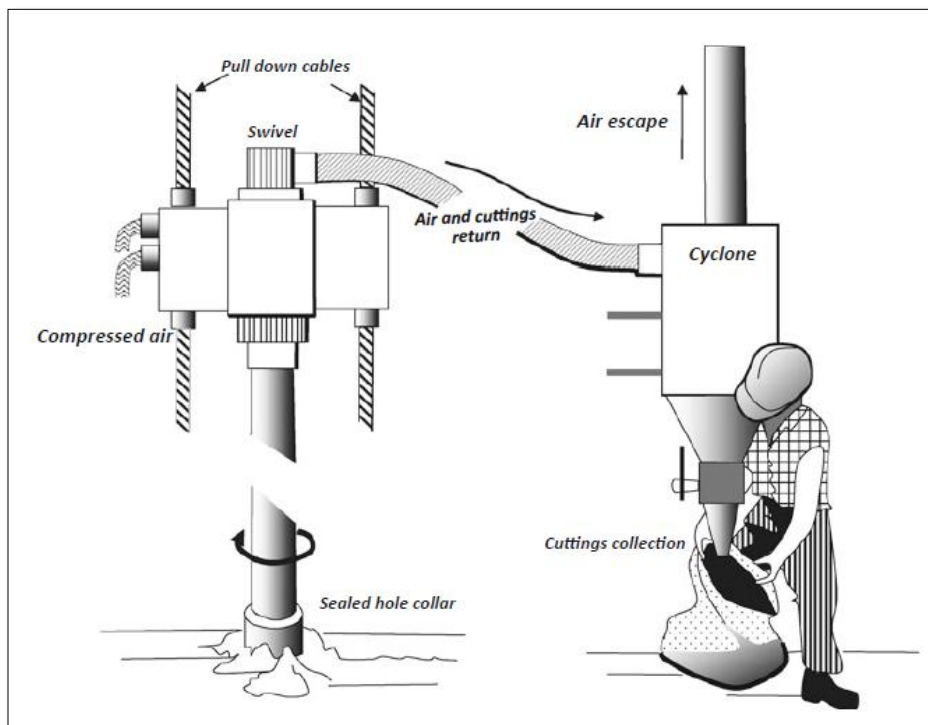


Figure 28: Collecting the rock cuttings from a reverse circulation (RC) drill (Marjoribanks, 2010).

The RC drilling method, where air or water is forced down an annular tube and cuttings are returned up the central tube, produces a clean uncontaminated sample at the surface (given ideal conditions) (Jones, 2012).

4.6.1.3 Pitting and trenching

Pits and trenches can be dug by excavator, backhoe or by hand. Pits and trenches provide large sample sizes compared to drilling. Large sample sizes are necessary to overcome problems of variable grade distribution, which are a characteristic feature of HMS deposits (Marjoribanks, 2010). Trenches are usually employed to expose steep dipping bedrock buried below shallow overburden, and are normally dug across the strike of the rocks or mineral zone being tested (Marjoribanks, 2010). As the style of HMS mineralization is flat lying pitting is preferred to trenching.

4.6.2 Exploration costs

In the previous paragraphs the different exploration methods have been discussed with their possible application in HMS exploration. Table 7 indicates the costs for the different exploration methods.

Table 7: Indicative costs of exploration excl. mobilization (Rudenno, 2012)

Exploration Techniques	Exploration Cost		Unit
	Min (USD)	Max (USD)	
Remote sensing techniques			
Aeromagnetic	25		per km
Gravity	125		per km
Onshore 2D		10.000	per km
Ground geophysics	50	2.000	per km
Drilling Techniques			
Rock, RC sample or diamond	200	500	per sample
Pitting and Trenching			
Soil geochemistry (pitting/trenching)	10	20	per sample

4.7 HMS extraction and processing methods

In this section an overview is given of the typical extraction and processing methods used in the HMS industry. At this stage of the exploration it is important to take these methods into account to identify the potential problems and opportunities for extraction and processing of the HMS.

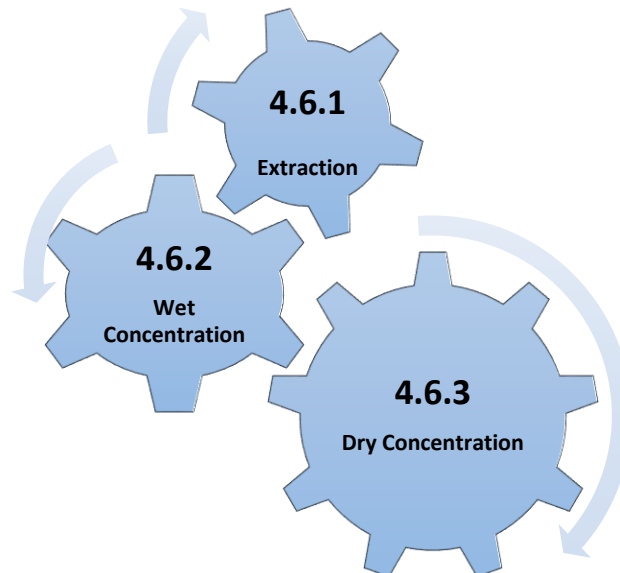
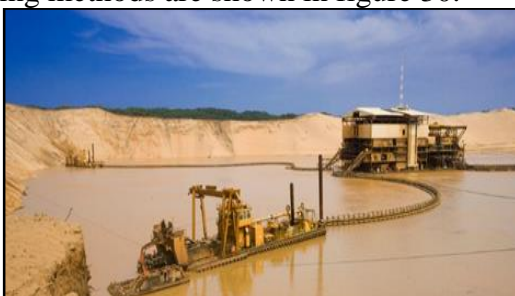


Figure 29: Relationship between extraction and processing methods

4.7.1 Extraction

In the first stage of extraction dredges (wet mining method) or excavators (dry mining method) are used to extract the HMS and transport the sand to the wet concentration plant (WCP). The product of the WCP is concentrated HMS. The concentrated HMS is then processed further into ilmenite, rutile, zircon and possibly other VHM present within the HMS in the dry concentration plant. The dry (excavator) and wet (dredge) mining methods are shown in figure 30.



A: Wet mining method



B: Dry mining method

Figure 30: Wet (A) and Dry mining methods (B) (Rio Tinto, 2014; Iluka, 2014)

It is important to choose the correct mining method for extraction of HMS deposits. While dredging is generally cheaper than excavating in operating costs, the capital costs are higher (Fernley & Drolla, 2011).

4.7.2 Wet concentration process

The objective of wet concentration is to produce a high grade (between 85 and 98 per cent) heavy mineral concentrate (HMC), retaining valuable minerals and minimizing gangue within the concentrate. In the wet concentration process the separation is based on the difference in specific gravities between the gangue

minerals (tailings) and the heavy mineral concentrate (HMC). In the next concentration process, the dry concentration process described in paragraph 4.6.3, the magnetic and electrical properties are used to separate the valuable from the non-valuable minerals. The properties relevant to the (wet and dry) HMS concentration process are shown in table 8.

Table 8: Mineral properties relevant to the (wet and dry) concentration of HMS. Data modified from Iluka (2014) and USGS (2015).

Minerals	TiO₂ (%)	Magnetic susceptibility	Electrical Conductivity	Specific Gravity
Ilmenite	52-54	High	High	4,7
Rutile	95-97	Low	High	4,2-4,3
Synthetic rutile	88-95	Low	High	4,2-4,4
Leucoxene	70-91	Semi	High	3,5-4,1
Zircon	0	Low	Low	4,7
Monazite	0	Semi	Low	4,6-5,4
Staurolite	0	Semi	Low	3,6-3,8
Kyanite	0	Low	Low	3,6-3,7
Garnet	0	Semi	Low	3,4-4,2
Quartz	0	Low	Low	2,7
Casserite	0	Low	High	7

A flow sheet of a typical HMS wet concentration plant (WCP) is shown below in figure 31.

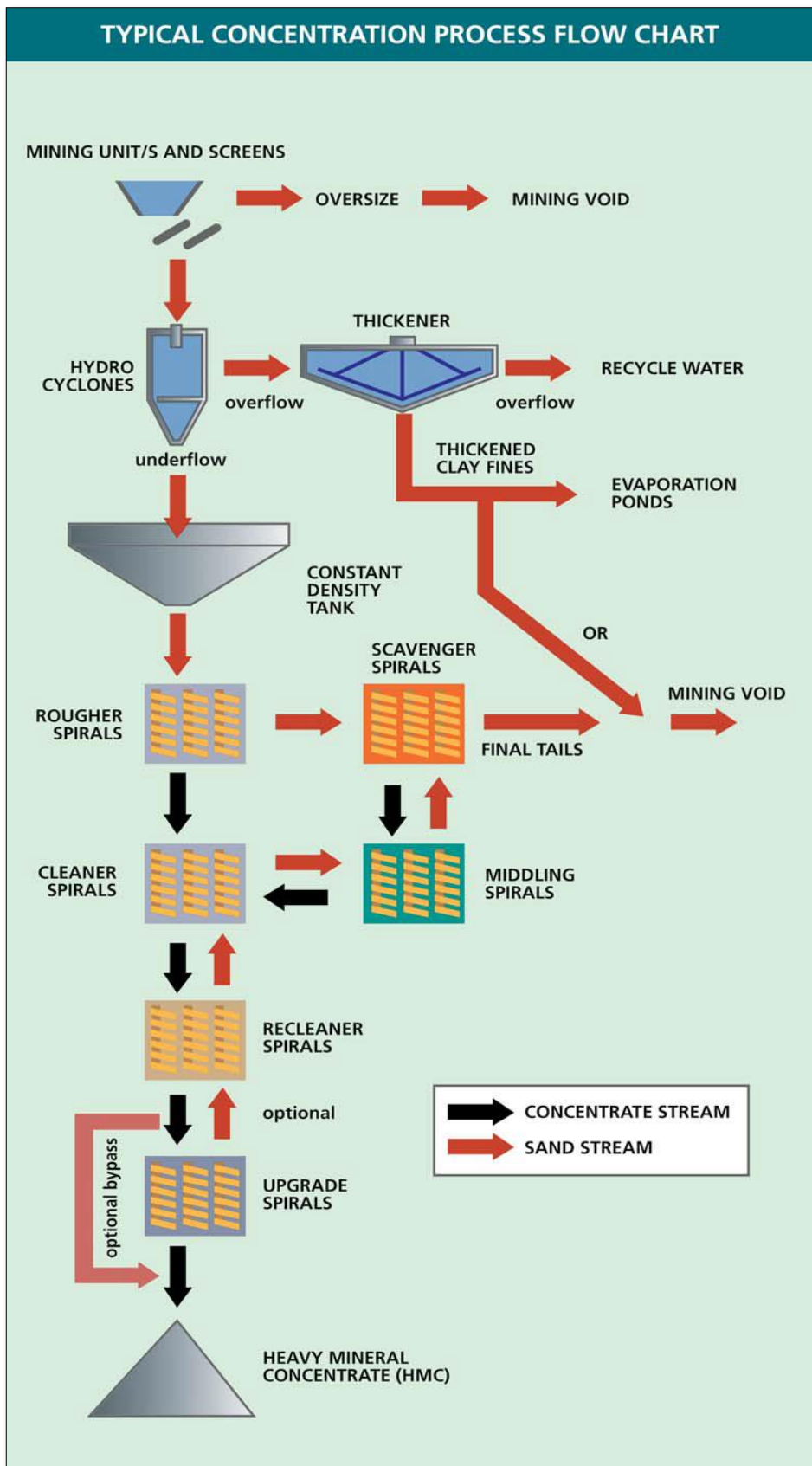


Figure 31: Typical wet concentration plant process (WCP) flow sheet (Jones, 2012).

Ore that passes through the primary scrubbing and screening plant (sizing when material greater than 150mm is screened out using vibrating grizzlies) is slurried and then pumped to a hopper at the wet concentration plant (WCP). This is then pumped to a bank of hydro cyclones that remove very fine particles (generally less than 63 μm and consists predominantly of clay) (Jones, 2012).

The slime (undersize less than 63 μm) and the oversize content (larger than 1mm) influence the extractability and processibility of the HMS. High slime content increases the risk of the formation of clay balls in the processing plant and results in a long settling time of the slurry in the pond (Benndorf & Wambeke, 2014). In most cases a maximum content of 10% undersize is acceptable (Siegfried, 2013). The maximum amount of coarse sediment is 20% (Siegfried, 2013).

Fine material is then separated from the heavy minerals (HM) and quartz sand is mixed with flocculent to induce settling and is thickened, remixed with the quartz sand tails and pumped to the mining void. Alternatively, the thickener underflow is pumped to solar evaporation ponds where it is dried. The dried clay is then returned to the mining pit or mixed with topsoil material to enhance the rehabilitation process (Jones, 2012).

The hydro cyclone underflow (or coarser material) is fed to a constant density (CD) tank. This is then pumped, at a constant density, feed rate and HM grade (to optimize mineral concentration and recovery) to primary spiral concentrators in the WCP (Jones, 2012).

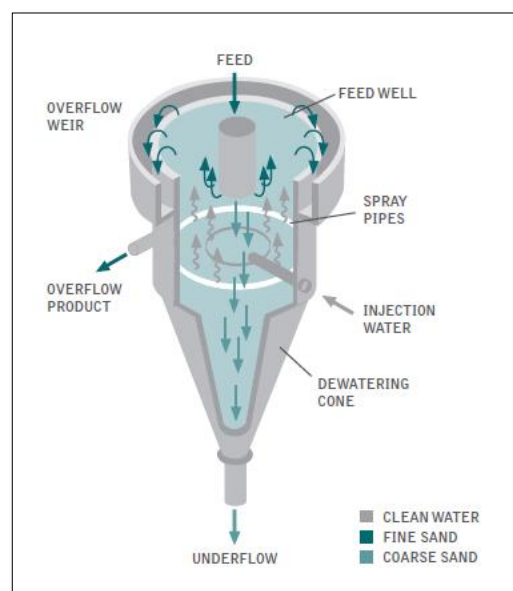


Figure 32: Hydro cyclone (Iluka, 2014).

Spiral separation of HM from the quartz sand on the spirals occurs through gravity separation. The spirals' troughs are raked at an angle and the heavy mineral moves to the inside of the trough as the slurry travels down the spiral. WCP spiral circuits generally consist of four to six different stages:

- Primary or rougher spiral stage
- Middling's spiral stage
- Cleaner spiral stage
- Re-cleaner and/or upgrade spiral stage
- Scavenger spiral stage



Figure 33: Spiral concentrator (Iluka, 2014).

Intermediate heavy mineral concentrate (HMC) from each spiral stage passes to the next stage to be further concentrated. Spiral middlings are usually recirculated, and tails scavenged to collect un-recovered HM. WHIMS (Wet High Intensity Magnets) can be used at the end of the wet concentration stage to separate magnetic ilmenite from other VHM. Final HMC is stockpiled on site using dewatering cones or cyclone stackers and allowed to drain to minimize moisture content before transportation to the secondary concentration plant (Jones, 2012).

WCP sand tailings are pumped to the mining pit where it is discharged via a monitoring device or cyclone stackers. The sand is re-contoured before overburden, clay and topsoil replacement, ready for rehabilitation (Jones, 2012).

4.7.3 Dry concentration process

Following wet processing the HMC undergoes a number of dry processing stages to separate the valuable minerals. These stages are shown in figure 34. Rare earth drum and roll magnets remove most of the ilmenite, as it is the most magnetic of the minerals in the dry mill feed. Electrostatic separation, using high tension roll and plate electrostatic machines, separate the non-conductive minerals such as zircon, kyanite, staurolite, quartz and monazite from conductive minerals such as rutile, leucoxene and residual ilmenite (Jones, 2012).

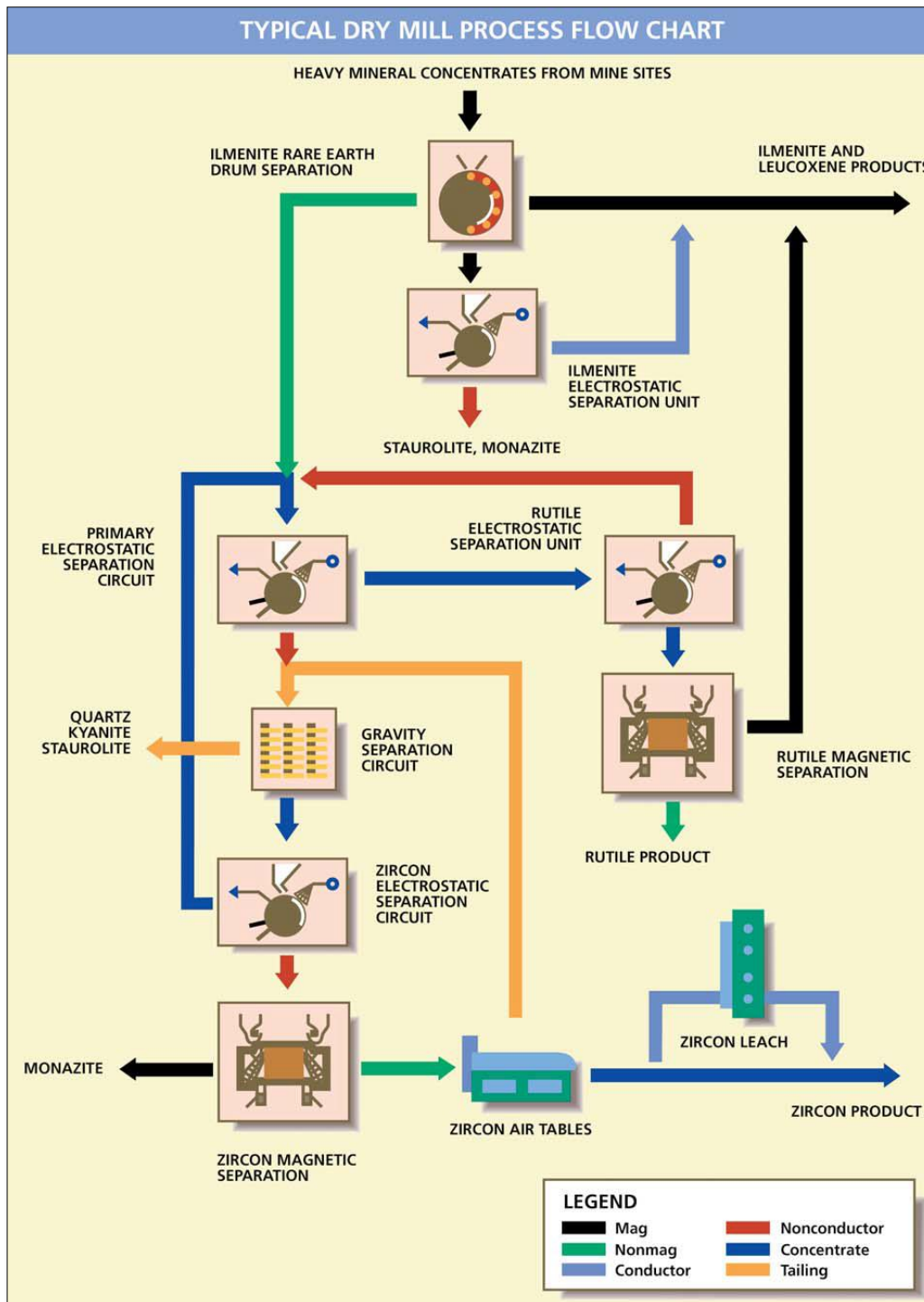


Figure 34: Typical Dry Mill Process Flow Chart (Jones, 2012).

Dry mill processing uses screening, magnetic, electrostatic and gravity separation circuits to separate valuable minerals from non-valuable minerals, and also to make different ilmenite, rutile, leucoxene and zircon product grades for specific customer requirements (Jones, 2012).

Rare earth drum magnets are used to remove ilmenite from HMC feed. Ilmenite is the most magnetic of the minerals in the MSP feed (occasionally magnetite is present, however generally not in economic quantities). This allows most of the ilmenite to be recovered as final product with no further processing (Jones, 2012).

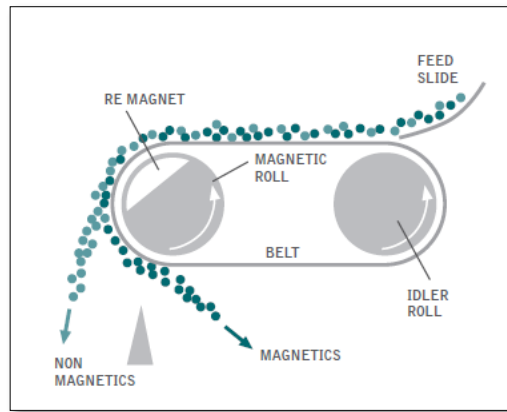


Figure 35: Rare Earth magnetic roll separator (Iluka, 2014).

Not all of the ilmenite can be separated from the non-valuable semi-magnetic minerals at this stage. Ilmenite that is weathered and altered loses iron (Fe) and becomes less magnetic. A small proportion of the ilmenite must go through electrostatic separation to remove non-conductor mineral contaminants such as monazite, garnet and staurolite from the conductive ilmenite. Non-magnetic minerals go on to a primary electrostatic separation circuit. Several stages of high tension roll separators and electrostatic plate separators are used to separate non-conductors (consisting of zircon, kyanite, quartz, monazite and staurolite) from conductive minerals (rutile and leucoxene). The non-conductive minerals pass to a gravity separation circuit to remove the lower specific gravity material (quartz, kyanite, garnet, and staurolite) from the higher specific gravity zircon (Jones, 2012).

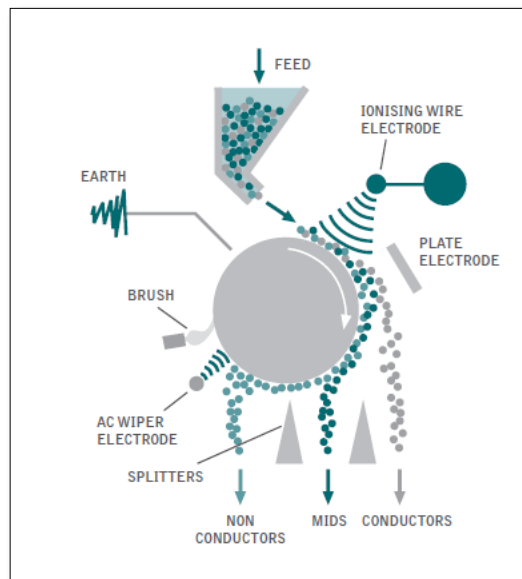


Figure 36: High tension roll separator (Iluka, 2014).

Electrostatic separation after gravity separation removes residual conductors from the zircon. Traces of monazite and staurolite are removed with induced roll magnets. A final pass across an air table removes fine quartz and residual kyanite that has not been rejected by the gravity separation circuit. Zircon can be stained by iron oxide coatings and sulphuric acid leaching is used to strip these coatings from the zircon particle surfaces to make it more acceptable for use in ceramic glazes. The non-conductive minerals in the primary electrostatic separation circuit rutile-rich conductor stream are removed using additional electrostatic

separation stages. Induced roll magnets are used at the final stage to produce separate leucoxene, which is semi-magnetic, and rutile products (Jones, 2012).

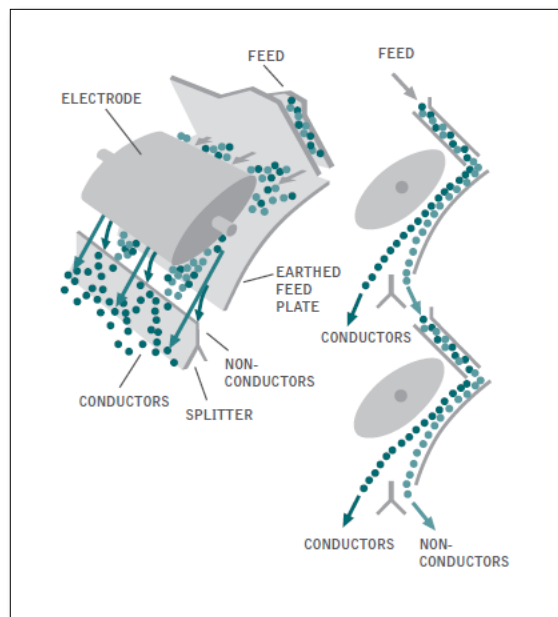


Figure 37: Electrostatic plate separator (Iluka, 2014).

4.8 Summary and conclusion

In this thesis work heavy minerals are defined as minerals having a higher density greater than 2.9 t/m^3 . Of the numerous heavy minerals, only a few have economic significance due to their properties and prevalence. These are called valuable heavy minerals (VHM). Voluminous deposits of heavy minerals which are hosted by sediments of sand, silt, and clay deposited in coastal environments are defined as heavy mineral sands (HMS). These types of sedimentary deposits can contain economic concentrations of heavy minerals. The HMS generally contains the VHM's ilmenite, rutile and zircon. Ilmenite is generally the primary valuable mineral and composes the largest fraction of VHM within the HMS.

Deposits of HMS in coastal environments play a substantial role in the global mineral economy. As the most noteworthy example, HMS are the world's primary source of titanium feedstock for the titanium dioxide (TiO_2) pigments industry; the titanium is obtained from the minerals ilmenite (FeTiO_3), rutile (TiO_2), and leucoxene (an alteration product of ilmenite). HMS are also the principal source of the mineral zircon (ZrSiO_4), obtained as a coproduct during the separation and recovery of the titanium minerals.

The HMS market is typically characterized by contractual arrangements, involving bulk shipments contracted on a volume and price basis for a set period. The contractual arrangements for ilmenite are currently (July 2015) 95-120 USD/ton, for rutile 800-880 USD/ton and for zircon 1000-1250 USD/ton.

McQueen (2005) describes four general parameters which are required for an ore deposit to form. These general parameters have been further elaborated for HMS specifically:

- 1) Source rocks
 - a. Sedimentary: can be intermediate hosts of the heavy minerals
 - b. Igneous: can account for ilmenite and rutile
 - c. Metamorphic: are considered the predominant original source of ilmenite and rutile
- 2) Transportation mechanism
 - a. Rivers and streams carry sediments to coastal areas
- 3) A depositional mechanism
 - a. Surf wave action in the swash zone of a beach
 - b. Wind and high energy surf and surge driven by turbulence during storm events
 - c. Long shore drift
 - d. Leucoxyenation
- 4) A process or geological setting that allows the ore deposit to be preserved

At this stage of the project the costs and profits cannot be estimated due to insufficient knowledge and confidence on the geological, mining and processing parameters. Therefore it is also not possible to calculate cut-off grade. To be able to identify an exploration target the key economic parameters and their industry standards have been evaluated. The values of these parameters are used to evaluate the exploration results in chapter 6. In this thesis work the minimal economic HMS deposit characteristics for the HMS have been researched, these industry standards are:

- Minimum of 0,8% THM grade
- Minimum of 50% TiO_2 in ilmenite and 66% ZrO_2 in zircon
- Minimum of 700.000 tons of ilmenite content
- Maximum of 500 ppm Uranium + Thorium

When HMS is found within the concession areas it will be necessary to consider the most likely extraction and processing method (wet mining method and/or dry mining method). Additional data from this point of view will give information on the potential problems and opportunities for the HMS extraction and processing. The (minimal) parameters on the processing considerations are:

- Maximum of 10% Undersize (<45 microns)
- Maximum of 20% Oversize (>1mm)
- Deposit depth
- Groundwater level

When sufficient geological knowledge is present the mining and processing parameters for the HMS project in Guinea can be determined. The costs and profits and therefore the cut-off grade can then be estimated. In this manner the economic viability of the HMS project can be assessed in a more specific manner.

HMS target generation in GAM concessions

Target generation includes all exploration on the prospect undertaken prior to the drilling of holes directly targeted on potential ore (Marjoribanks, 2010). The subjects involved in the generation of a target are shown in Figure 38 below and discussed in the subsections of this chapter.

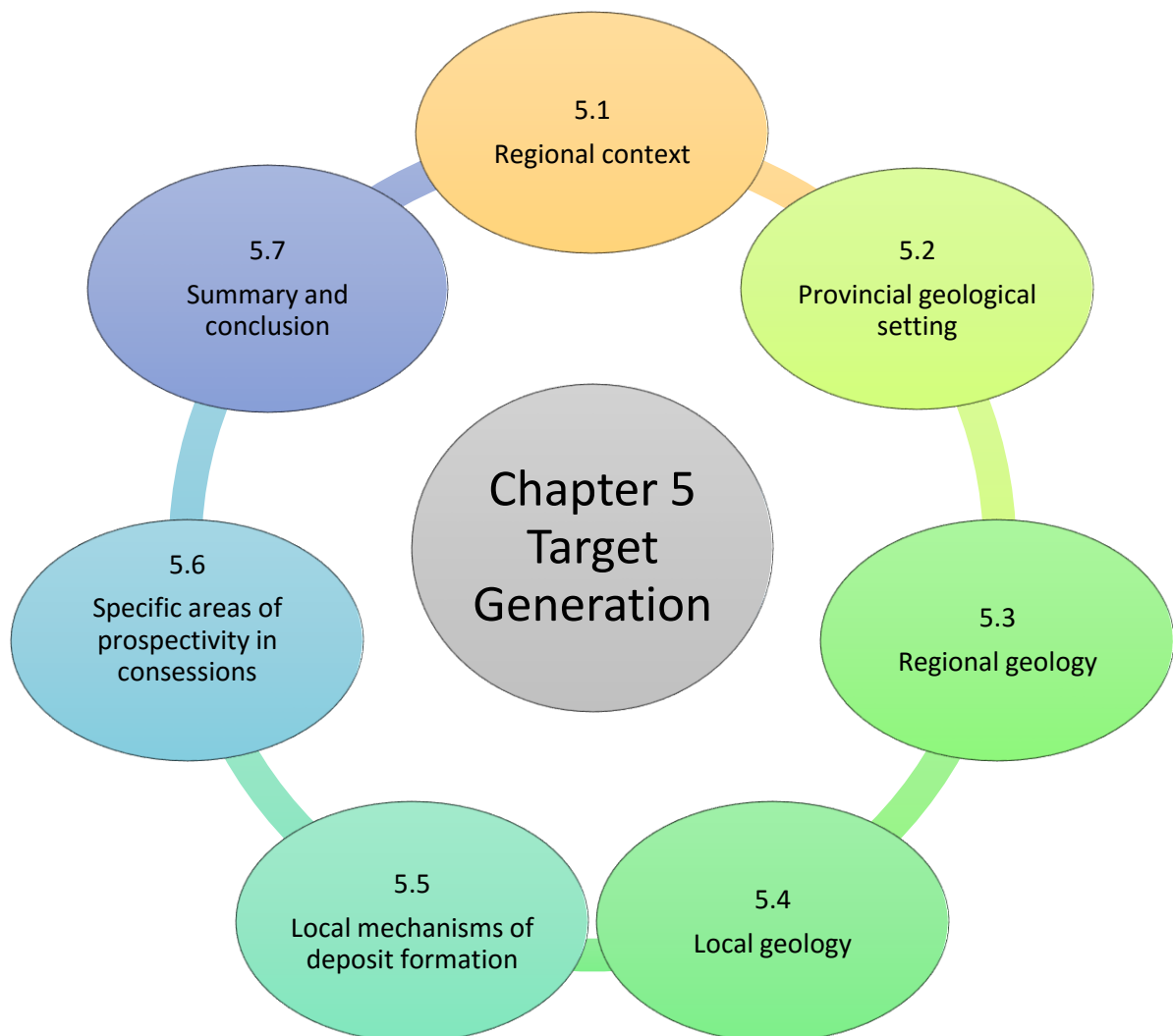


Figure 38: Overview of chapter 5

5.1 Regional context

The regional context of where the GAM HMS project is situated will pose risks to the development of the project. These risks are discussed in this paragraph.

5.1.1 Legal and political risk

Changes in the political regime or local laws and regulations can affect the viability of a development or mining operation. An annual survey has been conducted by the Fraser Institute of Vancouver to assess these risks. In the report of 2013, 690 mining and exploration professionals responded to the survey, which calculates the policy potential index, the mineral potential index and the investment attractiveness (Wilson & Cervantes, 2014).

5.1.1.1 Policy perception index

The Policy Perception Index (PPI), is a composite index, measuring the overall policy attractiveness of the 112 jurisdictions in the survey. The index is composed of survey responses to policy factors that affect investment decisions (Wilson & Cervantes, 2014).

Policy factors examined include uncertainty concerning the administration of current regulations, environmental regulations, regulatory duplication, the legal system and taxation regime, uncertainty concerning protected areas and disputed land claims, infrastructure, socioeconomic and community development conditions, trade barriers, political stability, labour regulations, quality of the geological database, security, and labour and skills availability. The PPI is normalized to a maximum score of 100 (Wilson & Cervantes, 2014).

Table 9: Policy Perception Index (PPI) for Guinea from 2010-2013 (Wilson & Cervantes, 2014)

	2013	2012/2013	2011/2012	2010/2011
Scores	28,2	26,4	16,6	40,2
Rank	77/112	76/96	83/93	51/79

As indicated in the table above the PPI index for Guinea has been increasing from 2011/2012 due to the new mining code which is aimed at attracting more investment to Guinea.

5.1.1.2 Mineral potential index

The Best Practices Mineral Potential Index rates a region's attractiveness based on mining company executives' perceptions of a jurisdiction's geology. Survey respondents were asked to rate the pure mineral potential of each jurisdiction with which they were familiar, assuming their policies are based on "best practices" (i.e., a world class regulatory environment, highly competitive taxation, no political risk or uncertainty, and a fully stable mining regime) (Wilson & Cervantes, 2014).

In other words, respondents were asked to rate the attractiveness of the region's "pure" mineral potential independent of any policy restrictions. The "best practice" index ranks the jurisdictions based on which region's geology "encourages exploration investment" or is "not a deterrent to investment". The maximum score possible on this index is 1 (Wilson & Cervantes, 2014).

Table 10: Mineral Potential Index for Guinea 2010-2013 (Wilson & Cervantes, 2014).

	2013	2012/2013	2011/2012	2010/2011
Scores	0,54	0,43	0,66	0,73
Rank	69/112	82/96	50/93	39/79

5.1.1.3 Overall investment attractiveness index

An overall Investment Attractiveness Index is constructed by combining the Best Practices Mineral Potential index, which rates regions based on their geologic attractiveness, and the Policy Perception Index, a composite index that measures the effects of government policy on attitudes toward exploration investment. In an effort to determine a weighting that reflects the perceived importance of policy versus mineral potential, the survey respondents were asked what weights they would place on policy and mineral potential, and use that data when compiling the Investment Attractiveness Index. In most years, the split was nearly exactly 60 per cent mineral potential and 40 percent policy. In 2013, the answer was 59.64 percent mineral potential and 40.36 per cent policy. The maximum score possible on this index is 100 (Wilson & Cervantes, 2014).

Table 11: Overall Investment Attractiveness Index in Guinea (Wilson & Cervantes, 2014)

	<i>2013</i>	<i>2012/2013</i>	<i>2011/2012</i>	<i>2010/2011</i>
<i>Scores</i>	43,8	35,8	46,1	59,7
<i>Rank</i>	78/112	89/96	78/93	48/79

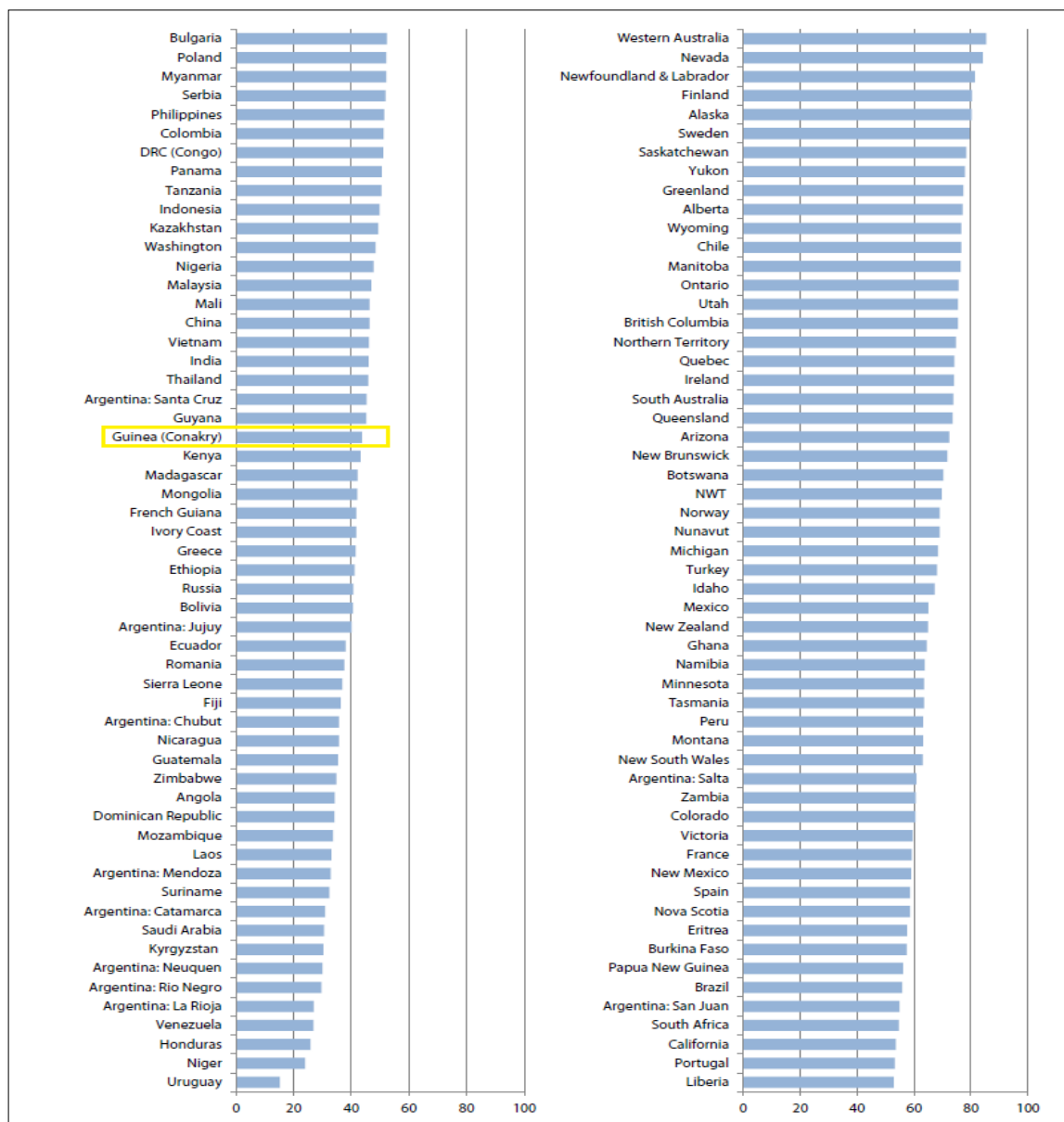


Figure 39: Overall Investment Attractiveness Index in 112 countries, Guinea in yellow (Wilson & Cervantes, 2014).

5.1.2 Guinean mining law and regulations

In this paragraph the Guinean mining law and regulations (Centre de Promotion et de Developpement Miniers, 2011) are discussed.

5.1.1.1 Mining titles application method, rights and obligations

In Appendix F the application procedures for the different permits (staking, exploration, industrial operating and mining permit) are shown. The ‘upgrading’ of the staking permit to an exploration permit and to an industrial mining permit requires GAM to comply with the Guinean mining code. If GAM does not comply with the code the concessions can be revoked by the state and the investment in the project is lost.

When new permitting is applied for or renewed, a risk is involved because the Guinean mining authorities can decline the request for application or renewal. As the exploration permits for GAM have been granted in December 2013 it is advised that exploration is performed to determine if an inferred mineral resource is present within the concession areas before the first renewal period in December 2016, to determine if further investment is warranted. It also needs to be considered that following the first renewal half of the concession

area needs to be given back to the state. A summary of the fees and grants of maximum period for the different mining titles is shown in the table below (based on an exchange rate of 1 USD: 10.000 GNF):

Table 12: Fixed surface fees (Centre de Promotion et de Développement Miniers, 2011)

Description	Period	Fixed fees (USD)	Surface fees (USD/km ² /year)
Reconnaissance permit			
Delivery	6 months	Free	Free
Renewal	6 months		
Exploration permit			
First Delivery	3 years	200	0,05
First Renewal	2 years	200	0,1
Second Renewal	2 years	300	0,2
Transfer		300	
Extension	1 years		0,25
Industrial operating permit			
First Delivery	15 years	100	1,5
1 st Renewal	5 years	150	3
2 nd Renewal	5 years	150	4
Transfer		150	
Mining concession permit			
First Delivery	25 years	1.500	20
Renewal	5 years	2.000	20
Transfer		2.000	
Extension			30

5.1.1.2 Taxes, leasing fees, royalties

The following list indicates an overview of the Guinean tax rates. These tax rates are of importance when the GAM mining project enters the mining phase.

Table 13: Applicable taxation rates (Centre de Promotion et de Développement Miniers, 2011)

Tax type	Tax rate (%)	Comments
Corporate Income Tax Rate	35	(the minimum tax is 3% of turnover)
Capital Gains Tax Rate	35	
Branch Tax Rate	35	(the minimum tax is 3% of turnover)
Dividends and Directors' Fees	10	
Interest	10	
Royalties from Patents, Know-how, etc.	15	(applies to non-residents)
Capital Gains on Shares	10	
Payments for Services	15	(applies to payments of residents to non-residents for services)
Rent	15	(only to rent paid to individuals)
Technical Services	15	
Management Services	15	

Based on the GMC (2011) there are three main taxes due if the project reaches the mining phase:

- 1) Tax on extraction which applies to mineral substances other than precious metals (the Extraction Tax) 3% for base metals.
- 2) Export tax: The Mineral Substance Export Tax is due at the time of export of the mineral, with the exporter being the main payer and any customs applicant acting under a representation mandate being jointly and severally liable for payment. 2% fix on bond (FOB) price.
- 3) Cooperate tax at 35% commercial profit

5.1.1.3 Environmental protection

Any application for an Authorization or Mining Operation Title must include an Environmental section in accordance with the Environmental Code and its implementing regulations as well as internationally accepted standards in this area. Requirements of the Administration depend on the extent of the scheduled work, ranging from simple Environmental Impact Notice for an Exploration Permit to a detailed Environmental and Social Impact Study including a Hazard Study, a Risk Management Plan, a Hygiene, Health and Safety Plan, a Rehabilitation Plan, a Resettlement Plan for persons displaced by the project and measures to mitigate negative impacts and optimize positive impacts, for an Operating Permit or a Mining Concession (Centre de Promotion et de Developpement Miniers, 2011).

In order to ensure the rational exploitation of mineral resources in harmony with the protection of the environment and the preservation of health, holders of Authorizations, of Mining Titles, must address: the prevention or minimization of any adverse effects on the health and the environment due to their activities, including:

- the use of harmful and hazardous chemicals
- noise emissions which are harmful to human health
- unpleasant odours which are harmful to human health;
- the pollution of water, air and soil, the degradation of the ecosystem and biological diversity;
- the prevention and/or treatment of any spillage and/or waste to neutralize or minimize their effect on nature;
- the promotion or maintenance of the living conditions and general good health of the population;
- the prevention and management of HIV/AIDS at the local level;
- Effective waste management by minimizing its production, ensuring that it is entirely innocuous, and disposing of non-recycled waste in an environmentally friendly manner after informing and receiving the approval of administrations in charge of Mines and Environment.
- Planned land-clearing consisting of cutting or removing trees or plants, as well as excavation work, Mine and Quarry operation, building communication transmission lines, which are contemplated to be performed within the perimeter of a Mining Title, shall be subject to a prior Authorization of the Minister responsible for Forestry and, where applicable, the granting of a cutting or clearing Permit.

The Guinean mining code (2011) requires mining companies to prevent and minimize negative environmental and health outcomes of mining activities. Mining right holders are required to prevent and/or treat spillages and waste, minimize the use of harmful and hazardous chemical products and prevent water, air and soil pollution (Bhatt, 2013).

5.1.1.4 Cultural and social issues

The Resettlement Plan for persons displaced due to Mining Activities must, in addition to the infrastructural aspect, include compensation for loss of income and means of subsistence resulting from such displacement. The settlement and related compensation will be implemented at the expense of the company holding the Mining Title or Authorization in accordance with a procedure determined by the Government that will incorporate international principles of participation and consultation of the Local Community (Centre de Promotion et de Developpement Miniers, 2011).

Appropriate techniques and methods must be used to protect the environment and the safety of the workers and Local Community in accordance with the Environmental Code or international best practices in this area (Centre de Promotion et de Developpement Miniers, 2011).

The GMC (2011) specifically requires mining companies to plan for and mitigate hardship for those forced to move owing to mining activities. The GMC (2011) requires companies to provide compensation to displaced persons for loss of income in accordance with international principles aligned to the World Bank policy objectives for involuntary resettlement, which include minimizing involuntary resettlement, consulting with affected communities and providing adequate compensation where resettlement occurs (Bhatt, 2013).

There are settlements throughout the study area who use the littoral and coastal plain areas for agricultural activities, such as rice fields, and the beaches and mudflats for fishing activities, such as the collection of bait, positioning of fish traps and for the landing of fishing vessels (Figure 40). The wider coastal region and rivers are used for fishing by local fisherman. Therefore, resettlement for persons will need to include a settlement with the local population for the loss of income.

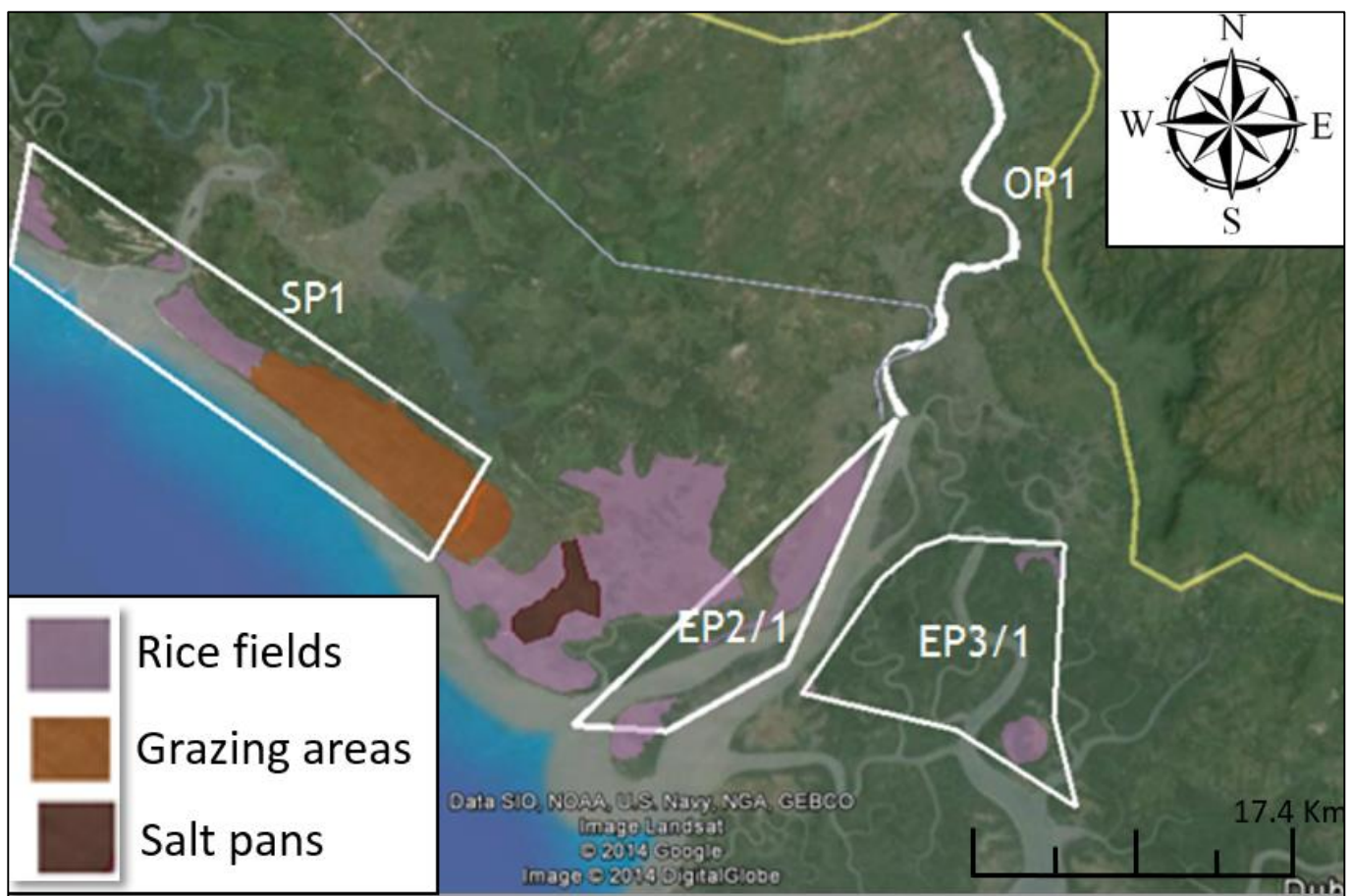


Figure 40: Shows agricultural use by interpreting Google Earth satellite imagery (2015). Base modified from Google Earth (2015).

5.1.3 Accessibility, infrastructure and climate

5.1.3.1 Accessibility

The project area is located near the capital Conakry, which can be accessed by air through commercial carriers. Road access to the concession areas is provided by the N1 and N3 (144km). The roads are in good condition, as they are paved. Road access to the concession is provided by the primary roads N1 and N3

from Conakry and the secondary road to Taboriyah. Although the roads (N1 and N3) are in quite good condition the traffic in the capital itself is busy which would extend the journey from an expected 2 hours to at least 5 hours, dependent on traffic.

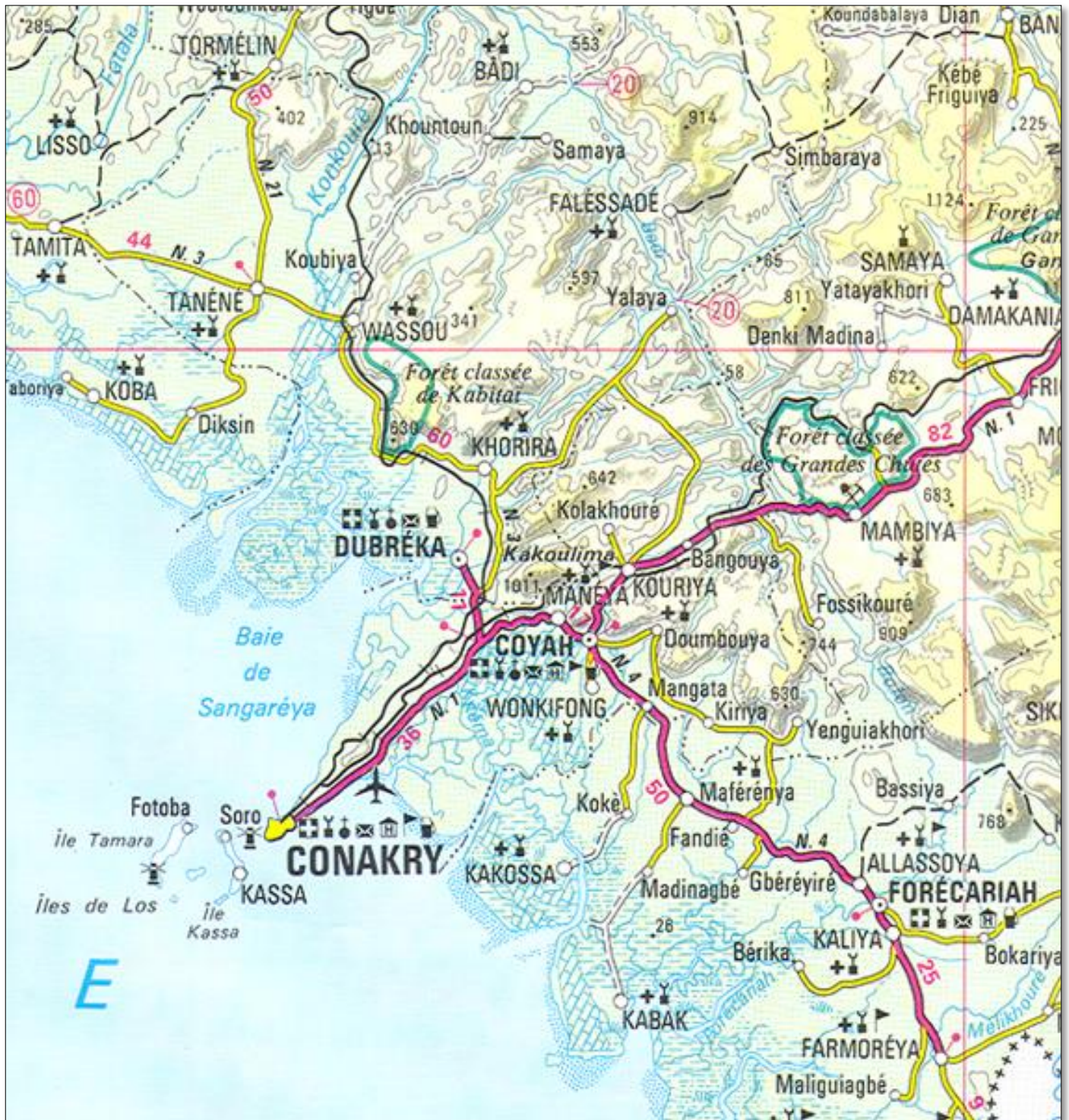


Figure 41: Road map of Guinea Conakry (Mapshop, 2015).

Within the concession the roads are in poor condition, but OP1 and SP1 can be accessed by season specific off road vehicles such as all-terrain vehicles. Local access to individual concessions EP2/1, EP3/1 and the region in SP1 west of Taboriyah is via boat.

5.1.3.2 Infrastructure

The necessary infrastructure which will be able to support a HMS mine is dependent on the reserve size. If the mining project reaches the construction phase heavy equipment will need to be able to reach the concession areas, this would require navigable roads. If the mining project is in the mining phase the products (ilmenite, rutile and zircon) would need to be transported to the harbour in Conakry for further transport to the customer by bulk carriers.

The port of Conakry currently exports alumina (treated bauxite), bananas, oranges, pineapples, coffee, palm and fish (Bollore, 2014). The harbour and port facilities are currently capable of servicing ships up to deadweight tonnage 50.000 dead weight ton (Bollore, 2014). If the project reaches the mining phase the capacity present will be a constraint on the size of the bulk carriers.

5.1.3.3 Climate

Guinea's climate is tropical, with a monsoonal rainy season from April to November. Across the country, average annual rainfall ranges from 1.500 millimetres (mm) to 4.300 mm. The western part of the country receives more rain than the eastern part. The temperature range is 22–25 degrees Celsius (°C) in the wet season and 25–27 °C in the dry season (Chirico, et al., 2014).

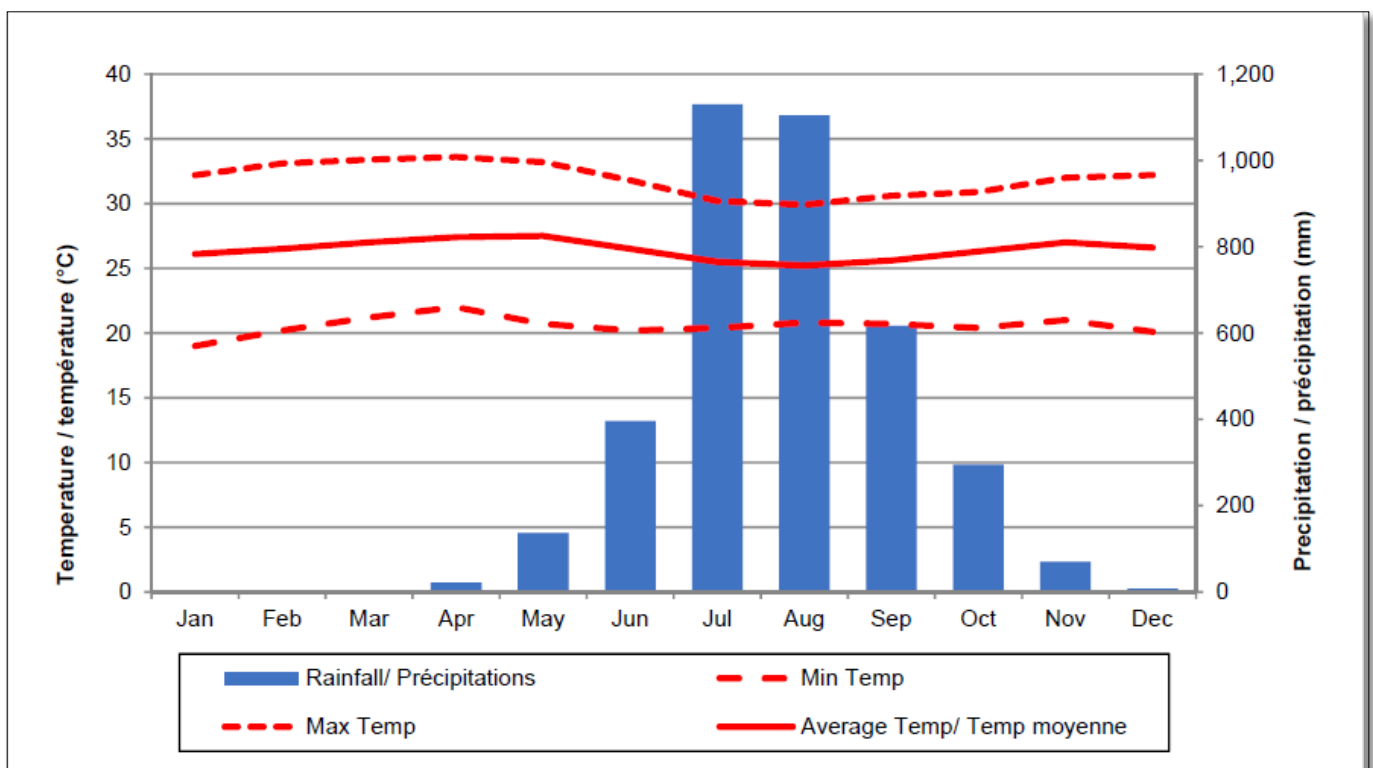


Figure 42: Historical Climate Data for Conakry – Mean Temperature and Rainfall, 1961-1990 (Weather.gov, 2014).

5.1.4 Health risk

Guinea has been one of the countries affected by the Ebola disease. The Ebola virus causes an acute, serious illness which is often fatal if untreated (World Health Organization, 2015). Guinea is one of the most severely affected countries. Guinea has a very weak health systems, lacks human and infrastructural resources, and have only recently emerged from long periods of conflict and instability (World Health Organization, 2015).

The West Africa Ebola outbreak has had profound economic, humanitarian, political and security dimensions. As of 5 April 2015 (week 14), the world health organization (WHO, 2015) reports a total of 25.550 confirmed, probable, and suspected cases of Ebola virus disease, including 10 587 deaths in three

affected countries (Guinea, Liberia and Sierra Leone) and six previously affected countries (Mali, Nigeria, Senegal, Spain, the UK, and the United States of America).

The WHO Situation Report of 8 April 2015 points to the outbreak reaching its tail end. Thirty confirmed cases of Ebola Virus Disease (EVD) were reported in week 14 (29 March–5 April) from only two countries, namely Sierra Leone (9 cases) and Guinea (21 cases). No new cases were reported from Liberia during this week. This is the lowest weekly total since the third week of May 2014 (European Centre for Disease Prevention and Control, 2015):

- Guinea: 3 515 cases and 2 333 deaths
- Liberia: 9 862 cases and 4 408 deaths
- Sierra Leone: 12 138 cases and 3 831 deaths

In Guinea the transmission is centred in and around the capital of Conakry, near the concession areas. Only about half of the new cases come from registered contacts. Although this is a marked improvement, it is far from the target of 100%, and too many new cases are still resulting from unknown chains of transmission. The number of confirmed deaths due to Ebola in the community has fluctuated, but there has been no clear reduction over time. The number of unsafe burials remains high (European Centre for Disease Prevention and Control, 2015).

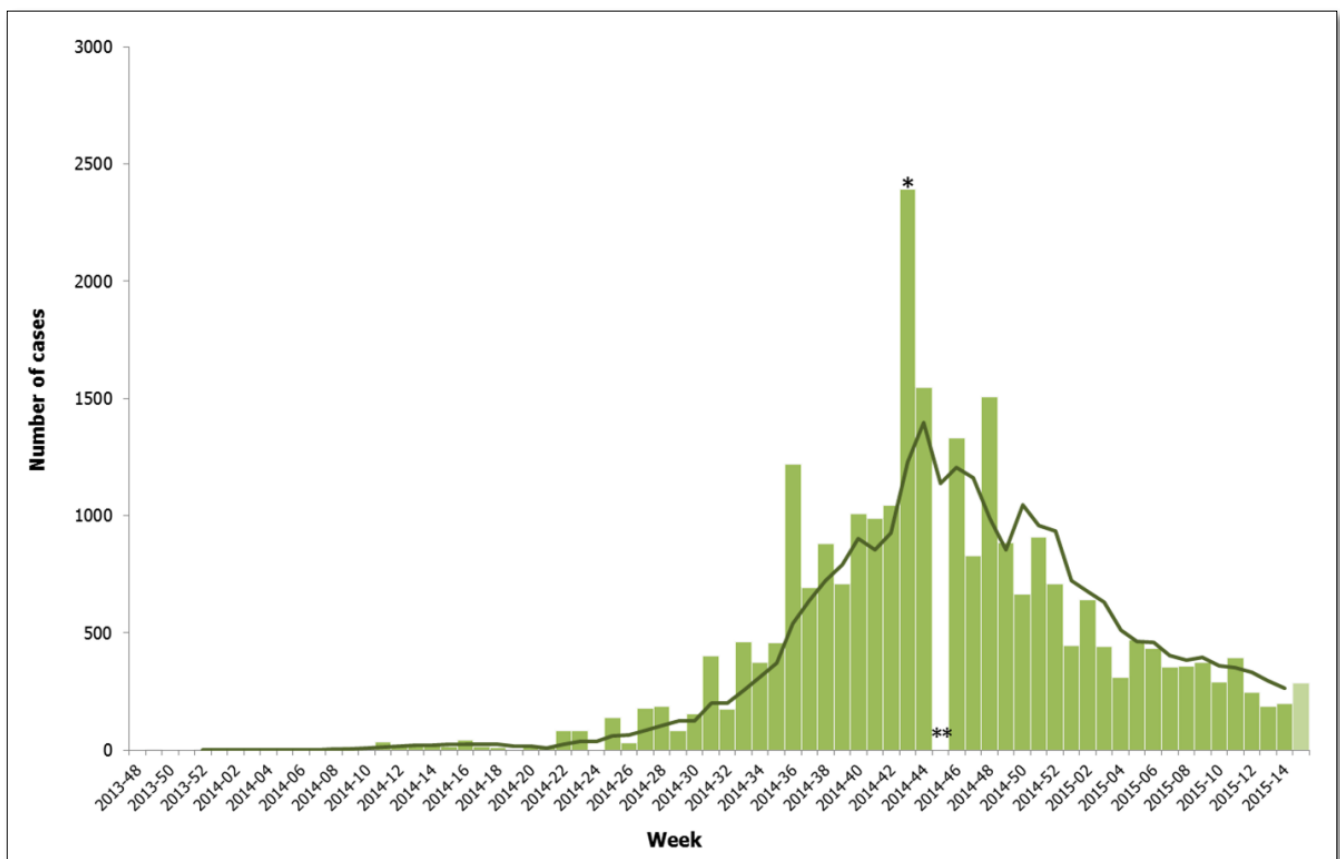


Figure 43: Distribution of EVD cases by week of reporting; Guinea, Sierra Leone, Liberia, Nigeria, Senegal and Mali; week 48/2013 to week 15/2015, as of 5 April 2015 (European Centre for Disease Prevention and Control, 2015)

The concession area is one of the areas where Ebola occurs in relatively high amounts. As can be seen from Figure 43 the outbreaks of EVD are expected to decline. But because new outbreaks are also possible, a time limit for when the epidemic will be over cannot be estimated. Therefore, travelling through Conakry into the concession areas would at the moment pose a threat to the health for the employees of GAM and thus this is not advised.

5.2 Provincial geological setting

The West African Craton (basement), with the Kénéma-Man Ridge or Leonian-Liberian Massif of Archean and the Lower Proterozoic age, dominates the entire south of Guinea (Figure 44). The Archean basement (3.5 Ga of age) is dominated by migmatite²⁶ or gneiss²⁷ of varying granitic composition containing small amphibolite²⁸ lenses (Mamedov, et al., 2010); (Diallo & Galperov, 1983). The Craton outcrops at only two places separated by the Taoudéni Basin: the Réguibat Ridge in Mauritania and the Man Ridge in southern Guinea (Feybesse, 2004). As can be seen from the image below the concession areas lie in the Bove basin which contains Intracambrian- Paleozoic sediments.

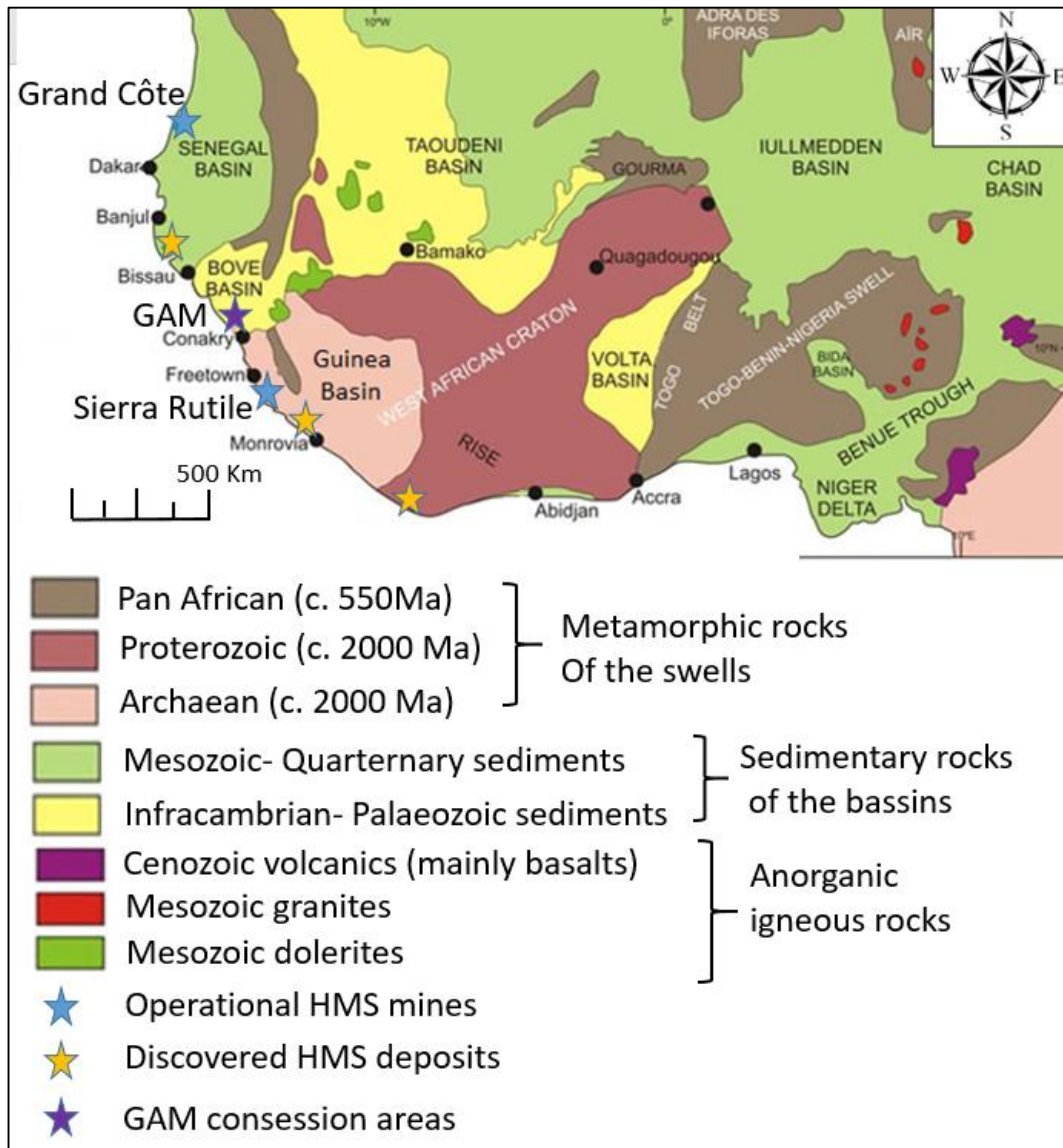


Figure 44: Map showing the provincial geology of West Africa and the HMS deposits and operational mines (Hancox & Brandt, 1999; Fernley & Drolla, 2011; Bermudez -Lugo, 2003). Base modified from Schutler (2008).

²⁶ A migmatite is a banded, granular metamorphic rock that contains light colored bands with evidence for partial melting (Imperial college London, 2015).

²⁷ Gneiss is a foliated metamorphic rock identified by its bands and lenses of varying composition, while other bands contain granular minerals with an interlocking texture. Other bands contain platy or elongate minerals with evidence of preferred orientation. It is this banded appearance and texture - rather than composition - that define a gneiss (Imperial college London, 2015).

²⁸ Amphibolite is a widespread metamorphic rock. Amphibolite is made of amphiboles (usually hornblende) and plagioclase. Most amphibolite's have a relatively simple composition: hornblende + plagioclase. Garnet (almandine), pyroxene, biotite, titanite, magnetite, epidote, chlorite, and quartz are also frequent constituents (Imperial college London, 2015).

HMS resources have been located along the coast of West Africa in Senegal (2361 Mt), Gambia (1 Mt), Sierra Leone (605 Mt) and Liberia (0, 7447 Mt) (Hancox & Brandt, 1999; Fernley & Drolla, 2011; Bermudez -Lugo, 2003)

Because of the difference in geology (as shown in Figure 44) and the distance between the deposits, which involve different drainage basins, the deposits are not compared to each other or to the potential HMS occurrence within the concession areas in Guinea.

5.3 Regional geology

Major parts of Guinea are underlain by Precambrian rocks, which form the southern part of the West African Craton. The eastern two thirds of the country are dominated by rocks of the Kenema Man domain and the Paleoproterozoic Birimian System. Neoproterozoic and Palaeozoic sediments with a basal tillite and overlying sandstones, marls and quartzite's cover wide parts of northern Guinea. Along the coast there exists a strip of Neogene marine and alluvial sediments (Schutler, 2008). In Figure 45 the general geology of Guinea is shown.

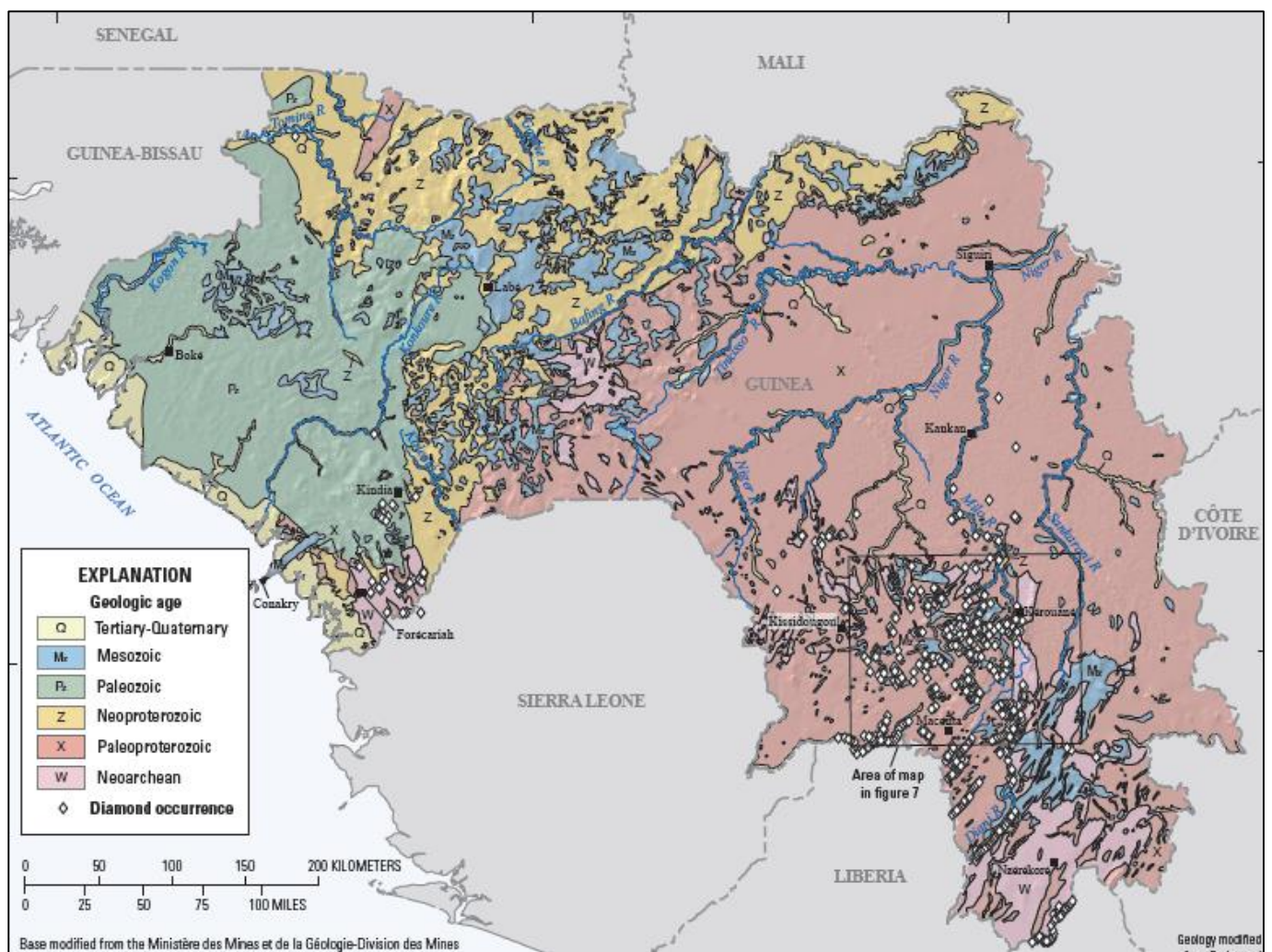


Figure 45: The general geology of Guinea (Chirico, et al., 2014).

According to Lang and Paradis (1977; 1984), the last glaciation period, around 18,000 years before present, resulted in a lowering of sea levels of about 100-150m along the entire Gulf of Guinea coastline. Beginning

around 10,000 years before present, sea level rose again due to the melting of the glaciers, and reached a new maximum between 6,500 and 4,500 years before present during the Nouakchottian transgression (Anthony, 1989). All valleys and river mouths were flooded in Senegal, Gambia, Guinea, Côte d'Ivoire and Gabon (Bellan & Saenger, 1995).

The Nouakchottian transgression also left sand deposits considerable distances inland, many of which still exist today and comprise the landward margins of the coastal plains as, for example, in Côte d'Ivoire, Ghana, Benin, Sao Tome and Angola (Bellan & Saenger, 1995). Towards the end of the Nouakchottian transgression, between 4,800-4,200 years before present, a north-south (along the Senegal to Guinea coast) and an east-west (along the Gulf of Guinea) littoral drift became established which gradually caused littoral sand-barriers to close the gulfs which had been formed. This phenomenon was progressive, starting in Mauritania (4,000 years before present), then Senegal (as shown in the image above, 3,900-3,200 years before present) and subsequently in Guinea, Côte d'Ivoire and Benin. By about 2,000-1,500 years before present the Atlantic coastline of Africa had largely developed its present configuration (Bellan & Saenger, 1995).

Over the last 1,500 years, sea level fluctuations have been small and difficult to establish with certainty, although sea level rises of between 1-3.4mm/year have been reported from this region (Bellan & Saenger, 1995).

The transport mechanism from the source rock into the estuary, where the concession areas are located, is the Konkouré River. The Konkouré takes its source in the Fouta-Djallon Mountains. The Konkouré Estuary, vegetated by mangroves, has an area of 320 km² and drains a total area about 17,000 km². The drainage basin of the Konkouré River is shown in Figure 46.

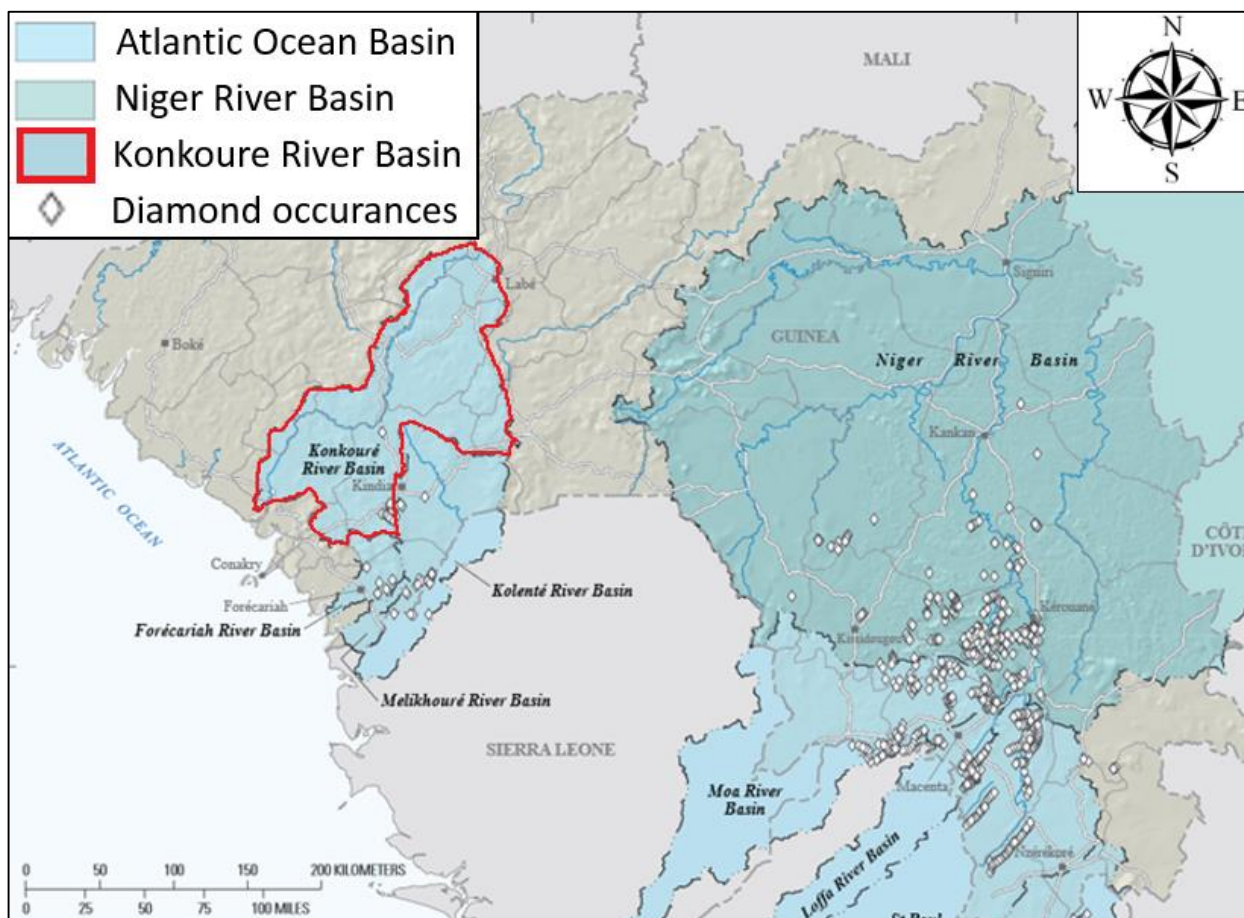


Figure 46: The Niger River, Konkouré river and Atlantic drainage basin watersheds in Guinea. Base modified from Chirico et al. 2014.

To identify the types of minerals which can be encountered within the concession areas the drainage basin of the Konkouré and geology of Guinea have been combined in figure 47.

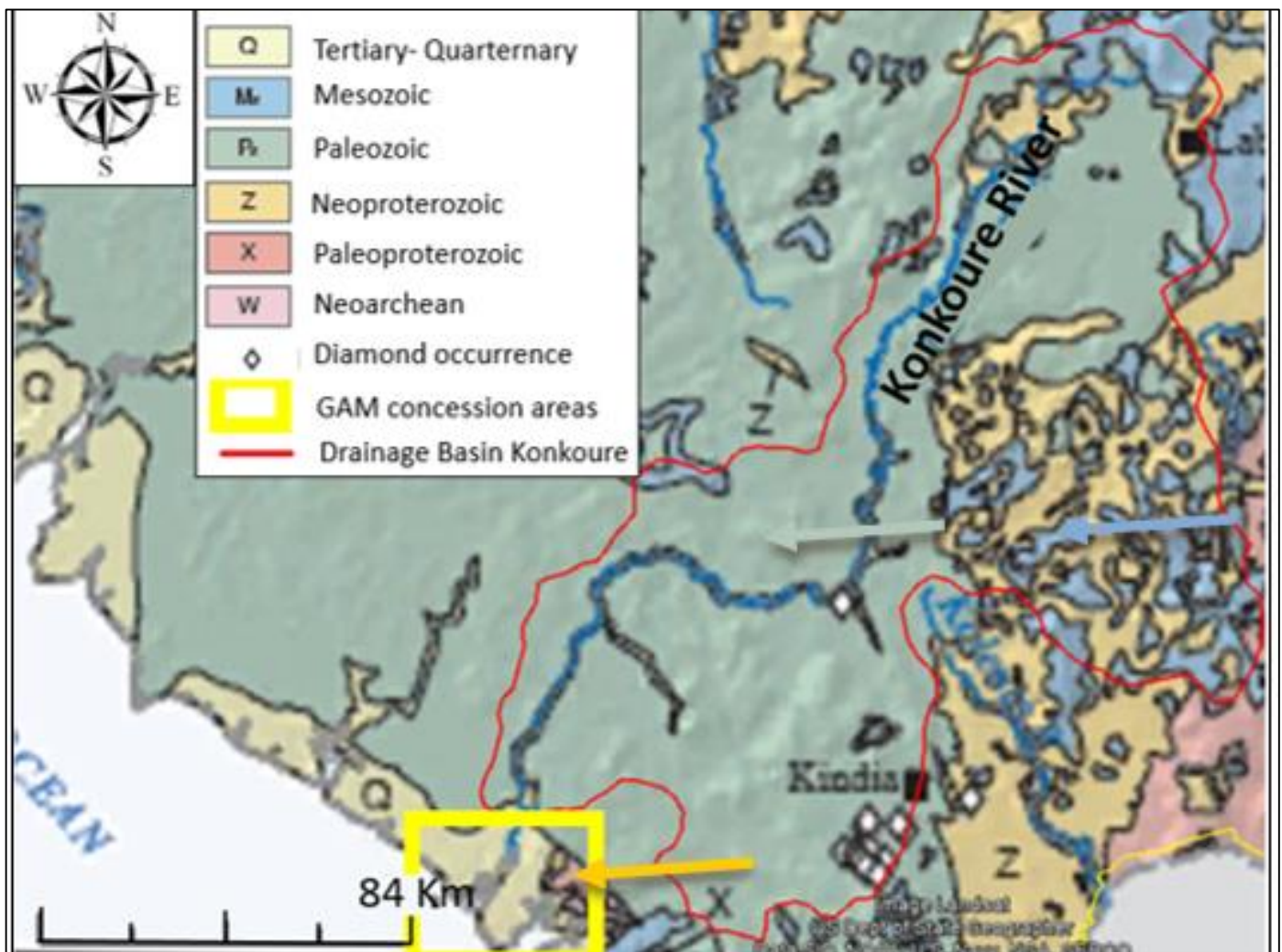


Figure 47: Drainage basin of the river Konkouré with intersection of geology. Water basin and geological base modified from Chirico et al. (2014).

Highly metamorphic rocks from the Paleoproterozoic are potentially the main source rocks for ilmenite and rutile in the drainage basin of the Konkouré river that leads to the concession areas (indicated by the orange arrow in figure 47).

Igneous rocks from the Mesozoic are could be the secondary source rocks for ilmenite, rutile and zircon. These igneous rocks mainly consists of Dolerites, Gabbro-Dolerites, Dunites sills and dikes and Gabbro's areas (indicated by the blue arrow in figure 47).

The Palaeozoic sediment (indicated by the blue arrow in figure 47) consists mainly of terrigenous deltaic and littoral deposits. These areas could contain the type of intermediate source rocks for HMS.

5.4 Local geology

From a study by Goussard (2010) several different geological domains have been determined, as shown in Figure 48. Outside of the concession areas coastal dune rims and recent terraces have been identified which are interpreted as the same geological domain as the paleo strandlines in this thesis work.

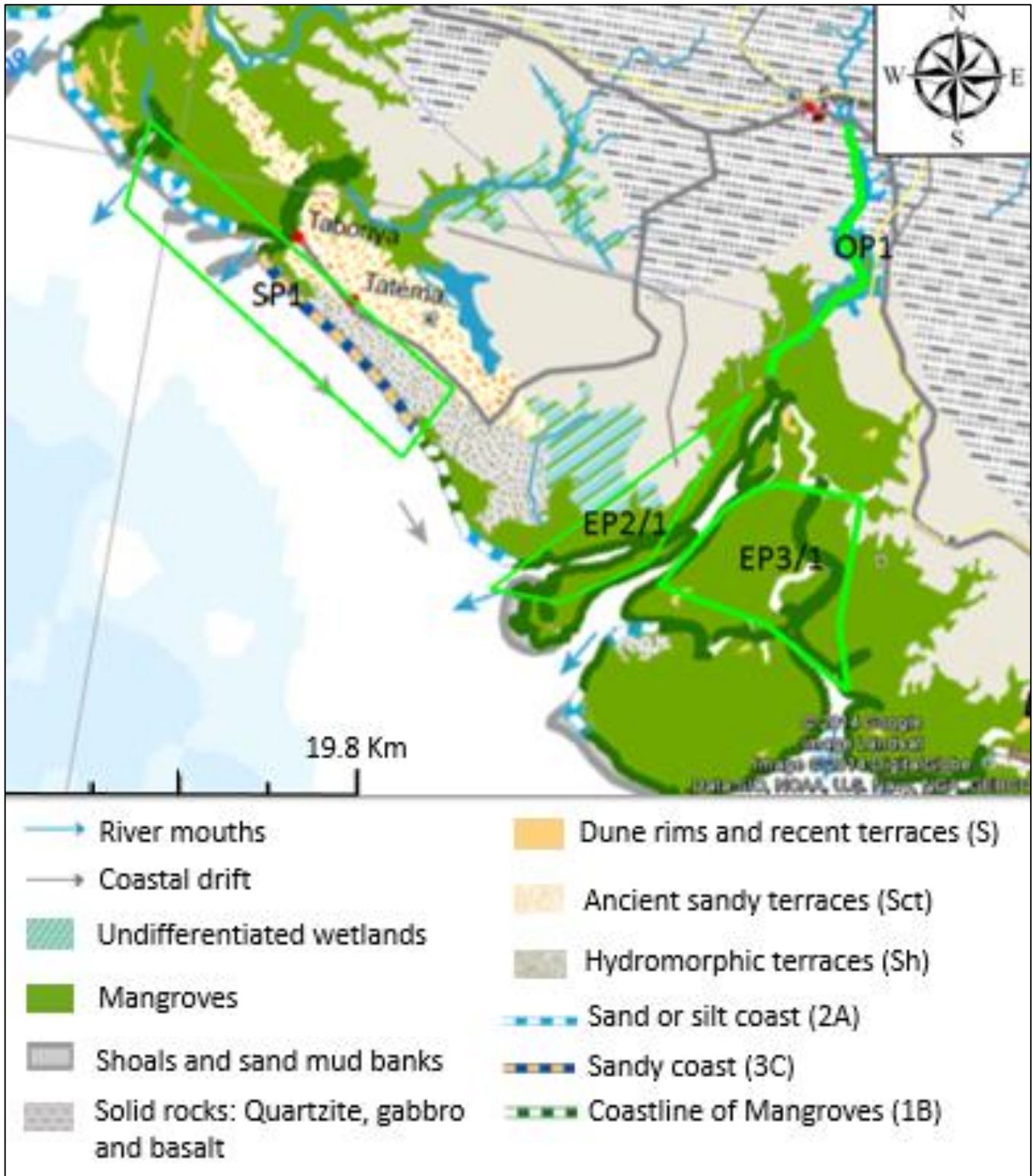


Figure 48: Regional geology of concession areas. Base modified from Goussard (2010).

Based on the geological domains described by Goussard (2010) and the interpretation of the paleo strandlines by Siegfried (2013) the different geomorphological zones are shown in table 13. In this thesis work the same codes have been used as by Goussard (2010).

Table 14: Morphological zones within concession area

Abbreviation	Description
<i>Sc</i>	Coastal dune rims, recent terraces and paleo strandlines
<i>Sh</i>	Hydromorphic terraces
<i>Sct</i>	Ancient sandy terraces
<i>3C</i>	Sandy coast
<i>1A</i>	Mangroves
<i>2A</i>	Sand or silt coast

5.5 Local mechanisms of deposit formation: prospectivity

The general depositional mechanisms for deposit formation have been discussed in paragraph 4.4.3. In this paragraph the mechanisms for formation in the GAM concession areas are identified.

Strand lines (including paleo strandlines) form along the shore of a sea that experiences water level fluctuations during periods of transgression and regression. This environment can result in large accumulations of sediment along the beach in which heavy minerals are concentrated by the wave action. These (paleo) strandlines are identified as potential exploration targets within the GAM concession areas.

In paragraph 4.4.3.2 the importance of longshore drift is explained. As can be seen in figure 48 the longshore drift in the concession areas is in a South-easterly direction. Therefore it is expected that potential HMS mineralization could also follow this direction until a mechanism stops the longshore drift and traps the HMS.

After sands accumulate on the beach, particularly in the backshore, winds can rework these sands and form sand dunes. Some of these Aeolian deposits can contain substantial concentrations of heavy minerals. Therefore, the dune rims, recent terraces and paleo strandlines (*Sc*) within the concession areas are expected to contain HMS and are therefore target areas.

Capo et. Al (2006) described the lower Konkouré River as a shallow, funnel shaped, meso-tidal, mangrove-fringed, tide dominated estuary. A meso-tidal shoreline is a shoreline where the tidal range is 2-4m (Garnett & Basset, 2005). These characteristics have moderate potential with preservation only after peak of the transgression (Garnett & Basset, 2005). It is important to note that this is for the present day situation. In the past there might have been another type of estuary or delta which would have resulted in different estuary characteristics.

5.6 Specific areas of prospectivity in concessions

5.6.1 Review of concession data

A geochemical survey was conducted by Jansen (2006) within the concession areas OP1 and EP2/1, these concessions can be seen in figure 4. Also a drilling survey containing 5 drillings within the Konkouré River itself using a pontoon (Diallo, 2008) was performed in 2008 within the same concession areas.

In the government geological literature (Lommonosov, 2010) a HMS survey outside of the concession areas is reported (Appendix B). This survey was conducted along the coastline in the prefectures of Boffa and Boke.

In these reports concentrations of HMS have been reported. The surveys have been evaluated on their validity and reliability, using the JORC code (2012 edition) as a reference, in a report written by the author of this thesis (2013). The reports have been found not to meet the standards of the JORC code (2012) due to insufficient information on the sampling techniques and data acquisition. Also the majority of the most important results are missing such as location and HMS concentration. Therefore, the data is considered as unreliable and not taken into account for the generation of an exploration target, as this thesis strives to follow the requirements of the JORC code (2012) and conclusions made based on this data cannot be justified.

5.6.2 Interpretation of satellite imagery

Interpretations of aerial photographs and satellite photos are shown in figure 51. The image below is a Landsat image. The recent coastal sands which would be the target area for HMS placers can be seen as the pink area extending along the coastline (Siegfried, 2013). The areas which have a green colour are interpreted to consist mainly of mudflats or mangroves (as indicated by arrows in figure 51).

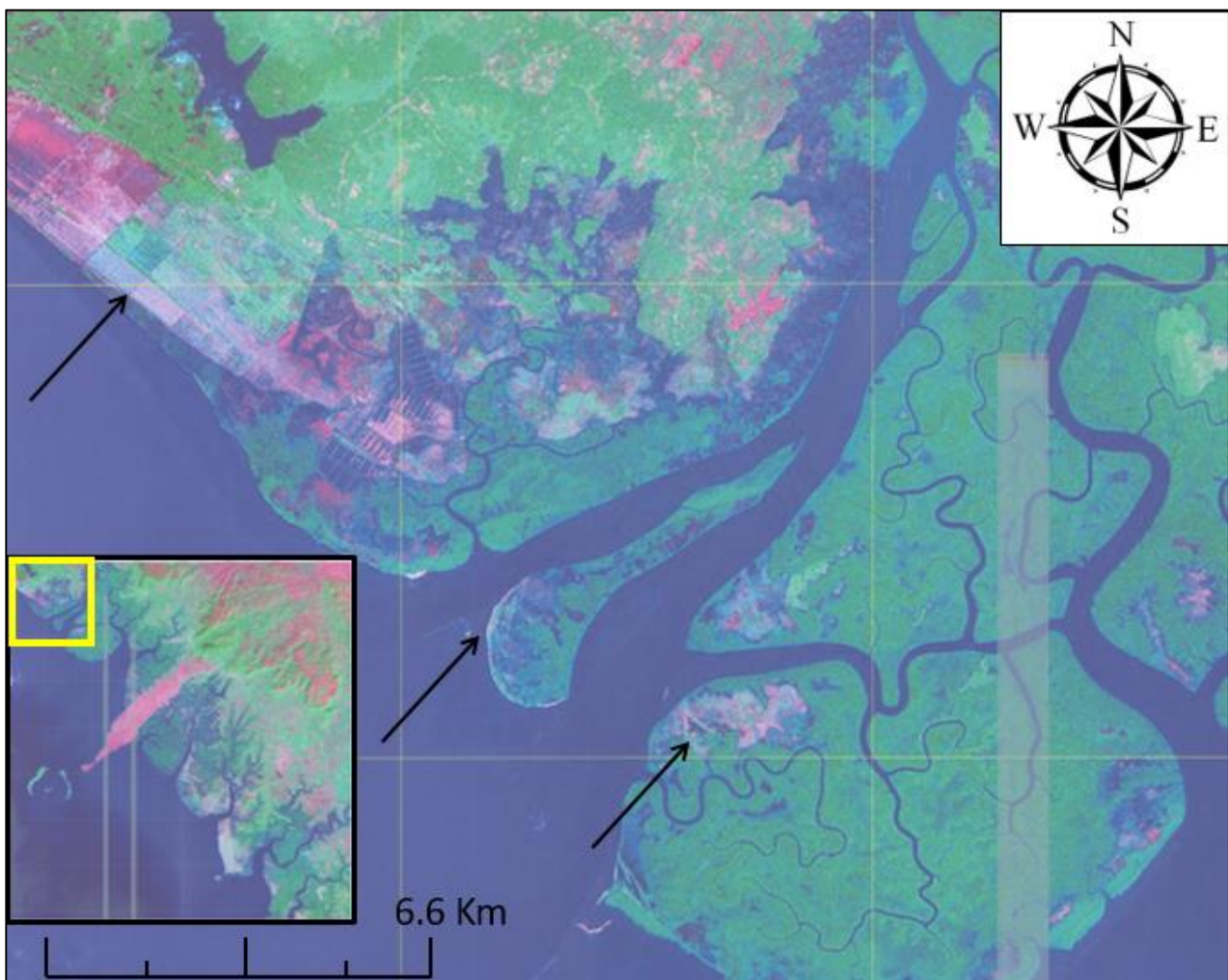


Figure 49: Interpretation of the locations of the recent coastal sands by Siegfried (2013). The recent coastal sands (light pink areas) are indicated by arrows. Base modified from Landsat 7 edge (2008) enhanced data.

The data in Figure 50 is provided through Map source and contains a Radar satellite image. In this map subtle topographic changes in areas of flat land or little surface expression can be identified. Topographic highs in the coastal plain can indicate paleo strandlines (in red). These paleo strandlines have been identified (within the EP2/1 and SP1 concession areas). These zones extend towards the southeast and possibly as far as the Konkouré River where they are truncated (Siegfried, 2013). In the northeast the highly metamorphic rocks (Kassila, Babola, Mani Sub-series) can be seen as the mountain ranges bordering the estuary.

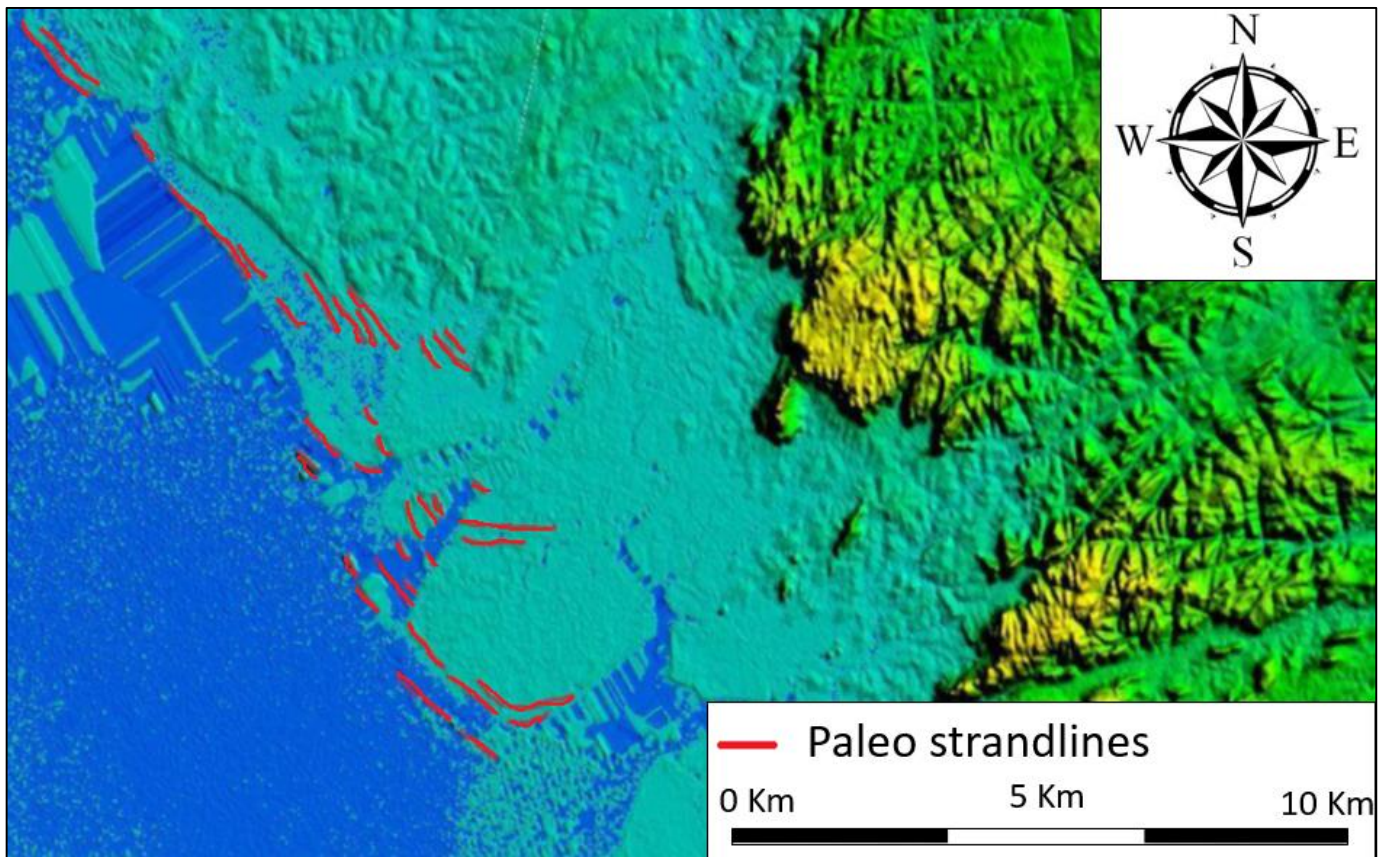


Figure 50: Interpretation of the locations of the recent paleo strandlines by Siegfried (2013). Base modified from RADARSAT data (2010).

5.6.3 Areas of prospectivity within concessions

5.6.2.1 Concession SP1

In concession SP1 the southern coastline (east of Taboriyah) is dominated by a sandy coastline (3C). More northerly (West of Taboriyah) the coastline is dominated by sand or silt coast (2A). Land inwards the sedimentological units of the coastal fringe east of Taboriyah consist of hydromorphic terraces (Sh) and ancient terraces (Sct) (Goussard, 2010). and inwards west of Taboriyah mangroves dominate the coastal fringe. Shoals are also present in the river opening near Taboriyah. The grey arrows in figure 48 indicate that the longshore drift transports the sediments in a South easterly direction (Goussard, 2010).

In figure 51 a more detailed interpretation of the active and paleo strandlines is shown (Siegfried, 2013). The active and paleo strandlines are interpreted to be the main areas of prospectivity in concession areas SP1 (Siegfried, 2013).

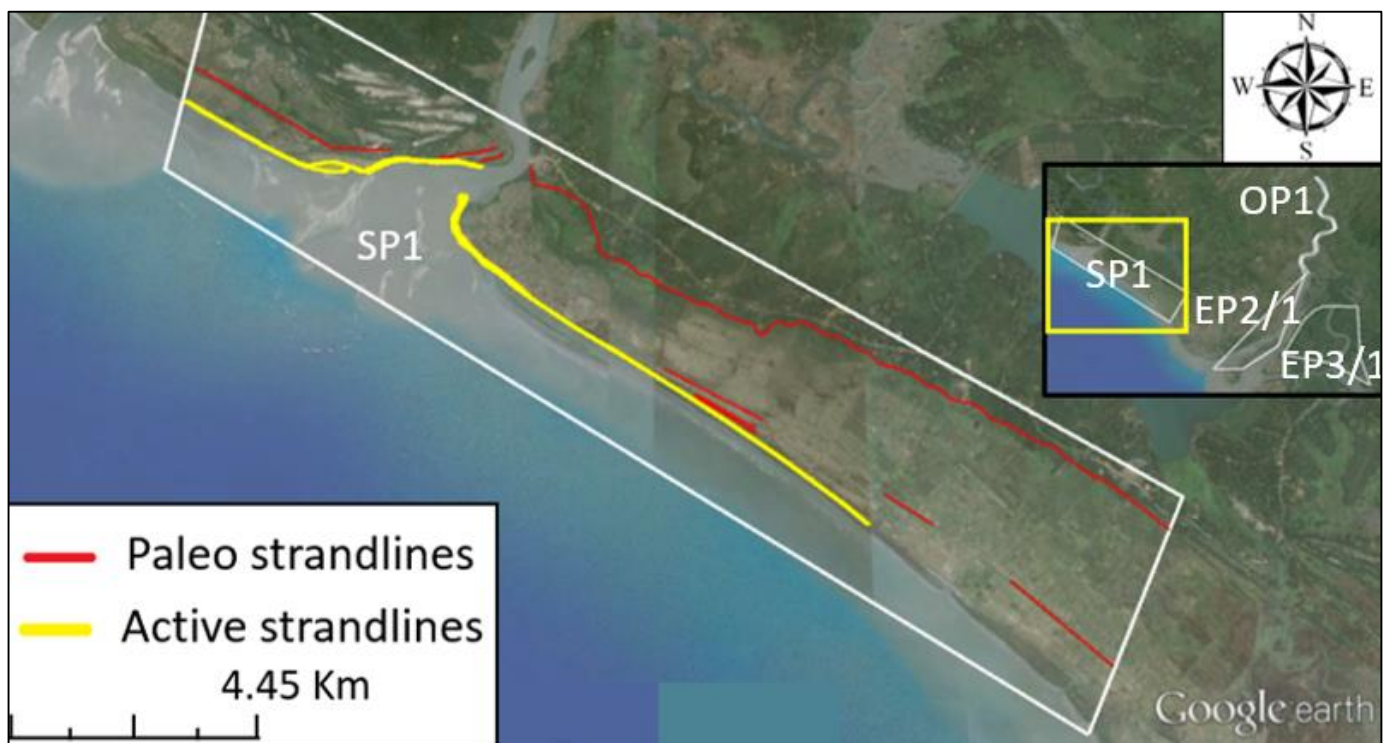


Figure 51: Interpretation of the locations of the active and paleo strandlines by Siegfried (2013) in concession SP1 by interpreting the satellite images from Landsat 7 (2008), RADARSAT (2010) and Google Earth (2015). The paleo strandlines (red) can be noted running parallel to the present day coast (yellow) (Siegfried, 2013). Base modified from Google Earth (2015).

5.6.2.2 Concession EP2/1

Concession EP2/1 contains shoals and sand-mud banks. But through interpretation of the Google Earth images it can clearly be seen that the rim of the barrier island also contains a sandy coastline. Land inwards and along the river the landscape is dominated by mangroves (1A as shown in Figure 48). The coastal drift is in a south easterly direction (Goussard, 2010). The active and paleo strandlines are interpreted to be the main areas of prospectivity in concession area EP2/1 (Siegfried, 2013).

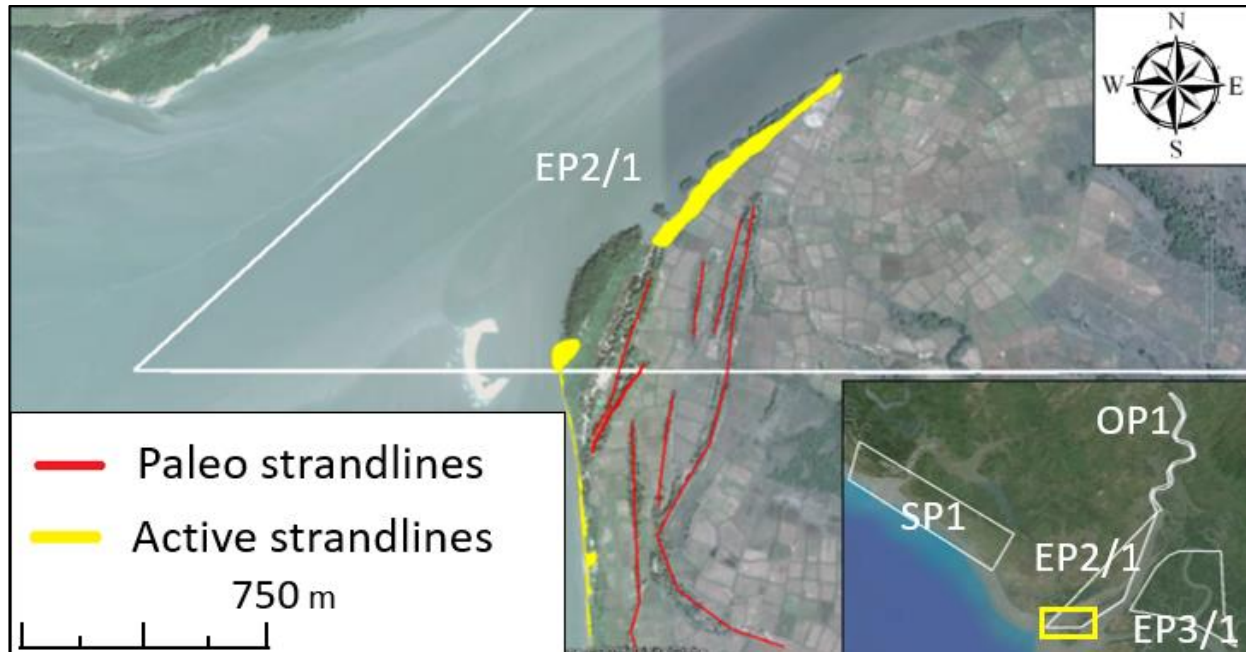


Figure 52: Interpretation of the locations of the active and paleo strandlines by Siegfried (2013) in concession EP2/1 by interpreting the satellite images from Landsat 7 (2008), RADARSAT (2010) and Google Earth (2015). The paleo strandlines (red) can be noted running parallel to the present day coast (yellow) (Siegfried, 2013). Base modified from Google Earth (2015).

5.6.2.3 Concession EP3/1

Along the coastline Concession EP3/1 is dominated by mangroves materialized by continuous barrier of trees (1A). Land inwards mangroves are also dominant (Goussard, 2010). Therefore, this concession area is not prospective.



Figure 53: Shows concession EP3/1. Base modified from Google Earth (2015).

5.6.2.4 Concession OP1

Concession OP1 is mainly situated within the fluvial stream of the Konkouré River. Therefore, this concession area is not prospective.

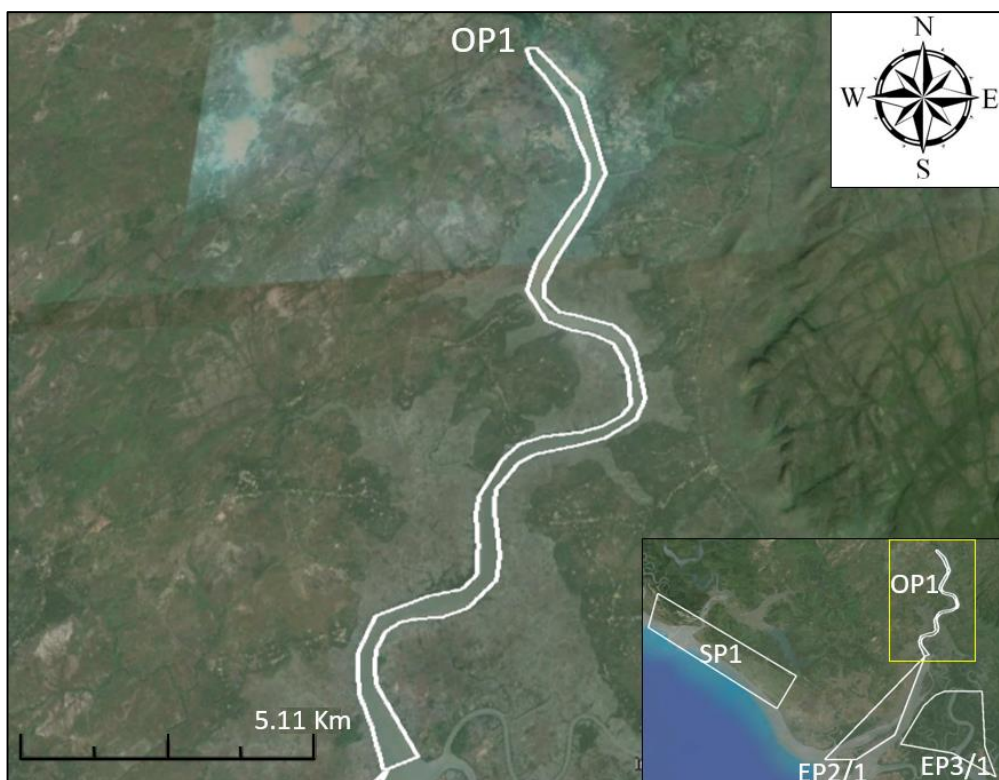


Figure 54: Shows concession OP1. Base modified from Google Earth (2015).

5.7 Summary and conclusion

The risks associated with the development of a HMS exploration project are not only geological. Changes in the political regime or local laws and regulations can affect the viability of the development of the GAM project. An overall Investment Attractiveness Index constructed by Wilson and Cervantes (2014) shows that Guinea was ranked 78 out of 112 countries surveyed. This indicates that the investment risk is relatively high compared to other countries.

Currently the main project risk comes from the outbreak of Ebola in the country. This outbreak occurred one month after the exploration in Guinea, in February 2013. Due to the health risks, (associated with Ebola) it is not safe to travel to Guinea. The Guinean mining law requires an exploration report to be submitted every 6 months. Due to the health risk of Ebola situation this is not possible. If the permits are revoked by the Guinean mining authority's investment in the HMS exploration project will be lost.

Through literature research the following favourable parameters for HMS deposit formation have been summarized for the GAM project:

- The source rocks for ilmenite, rutile and zircon (highly metamorphic rocks) are present within the Konkouré drainage basin.
- The enrichment processes wind, surf and wave action in the swash zone, marine longshore drift and leucoxenation are possibly present within the concession areas, but this needs to be validated during exploration.
- The Konkouré estuary has a regressive strandline (for the past 4000 years). The HMS could potentially be preserved in the form of paleo strandlines within the littoral environment.

Through satellite imagery the location of active sandy strandlines and paleo strandlines have been interpreted by P. Siegfried (2013). These active (and paleo) strandlines are expected to have the most potential to contain HMS. EP2/1 and SP1 contain these active and paleo strandlines and have therefore been explored. Concessions OP1 and EP3/1 do not contain these geological structures and have therefore not been explored.

6

Exploration

In the previous chapter the main target areas within the concessions have been determined. These target areas have been explored in February 2014. This chapter explains how these areas have been explored, which analysis techniques have been used and the results of exploration are summarized per geological domain.

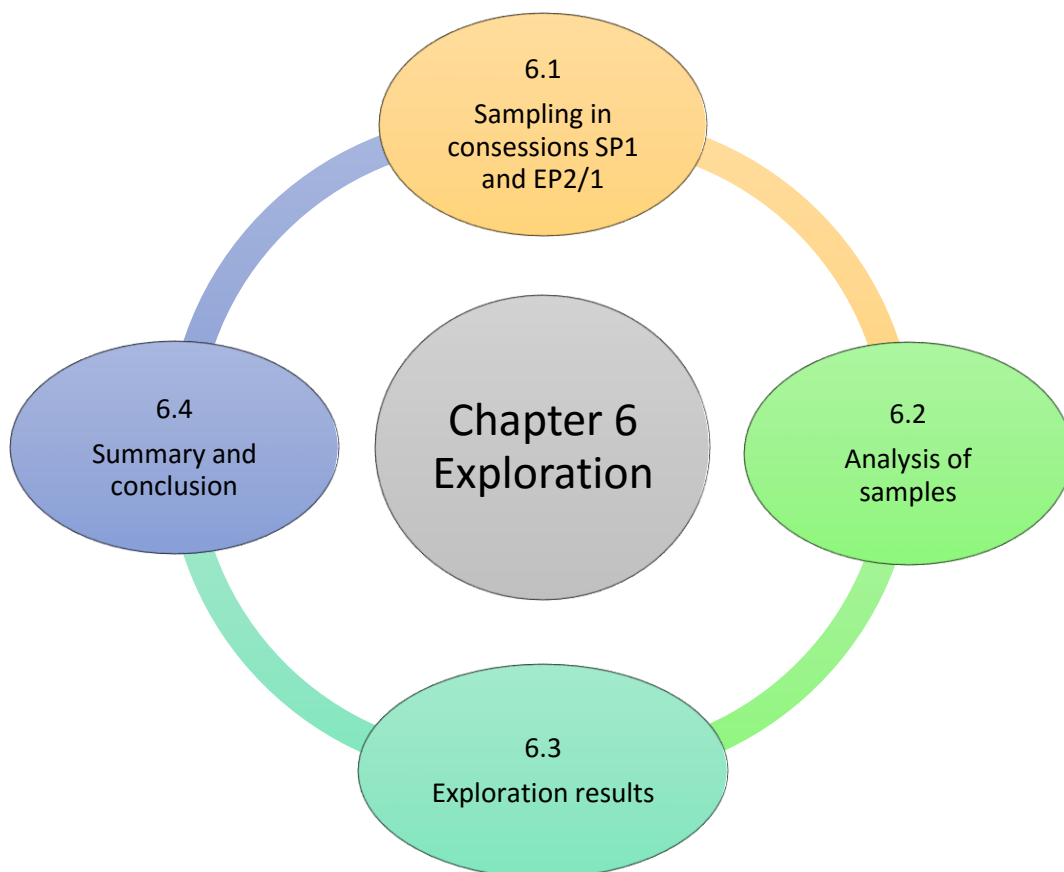


Figure 55: Overview of chapter 6

6.1 Sampling in concessions SP1 and EP2/1

Due to the relatively high costs and insufficient knowledge on the characteristics of the HMS the remote sensing methods discussed in paragraph 4.6.1.1 have not been used for primary exploration. Because the style of HMS mineralization is generally shallow, extensive and flat lying pitting is preferred to trenching at this stage of the exploration. The pitting technique requires manual labour and the geochemical analysis of the samples. The proposed and sampled locations using this pitting method are discussed in this paragraph.

6.1.1 Proposed sampling locations

Paleo and active strandlines (Sc and 3C indicated in table 14) have been identified through remote sensing techniques discussed in paragraph 5.6.3. It is expected that intersections with active (location 1 in Figure 56) and paleo (locations 2, 3 and 6 in figure 56) strandlines will be encountered. These strandlines are expected to contain ilmenite, rutile and zircon because the source rocks, within the drainage basin of the Konkouré river, contain these minerals (paragraph 5.3).

Location 5 (in figure 56) is chosen just before the ancient terrace (Sct). Location 4 is chosen on the hydromorphic terrace (Sh) to investigate the regional geology and is not directly aimed at intersecting a HMS deposit.

Below in Figure 56 the proposed sampling locations for concession SP1 are shown. The potential deposits are formed in a regressive manner and therefore the strike of the potential HMS follows the shoreline. The sampling locations are chosen perpendicular to the active strandline.

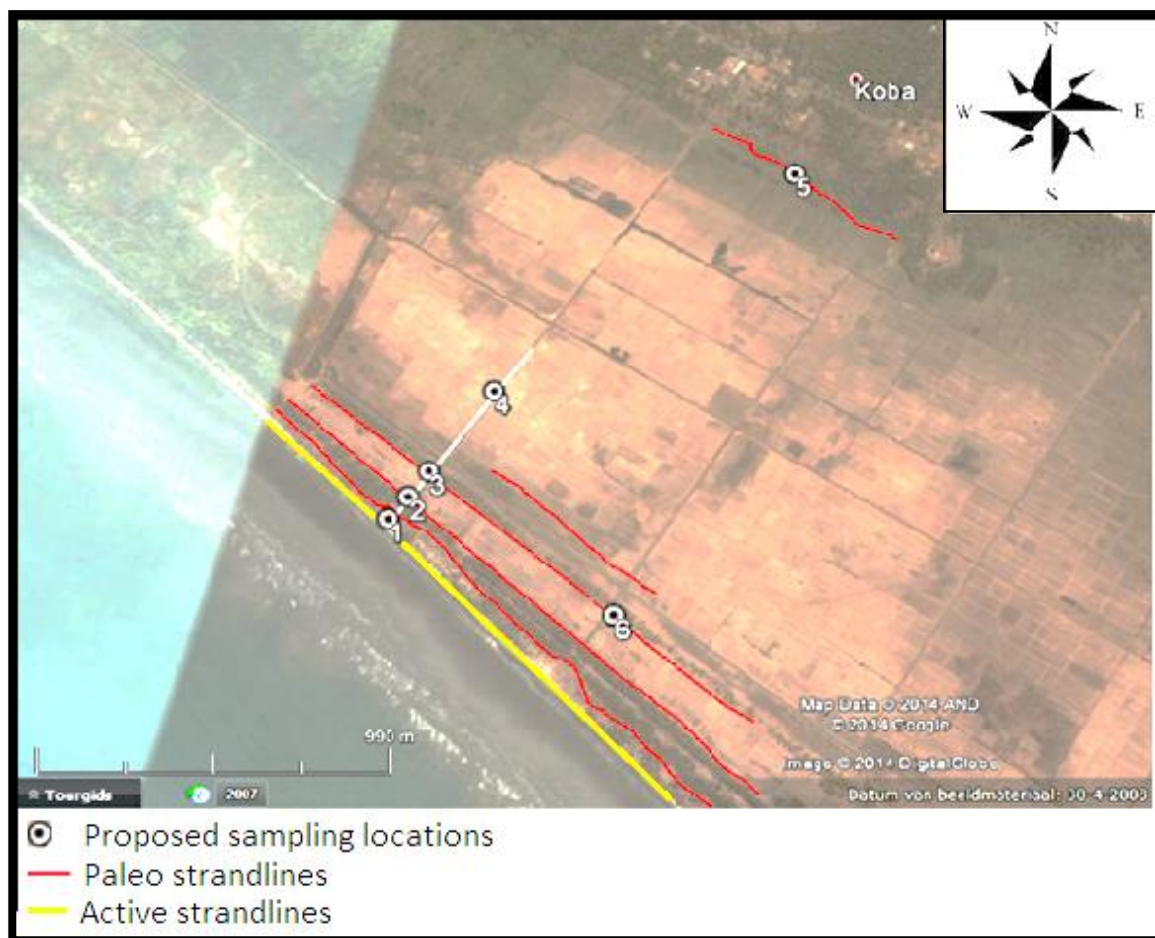


Figure 56: Shows the proposed sampling locations in concession SP1 by Siegfried (2013) along the active and paleo strandlines. Base modified from Google Earth (2015).

Below in figure 57 the proposed sampling locations for concession EP2/1 are shown. The sampling locations are chosen in the same manner as in concession SP1 perpendicular to the active strandline.

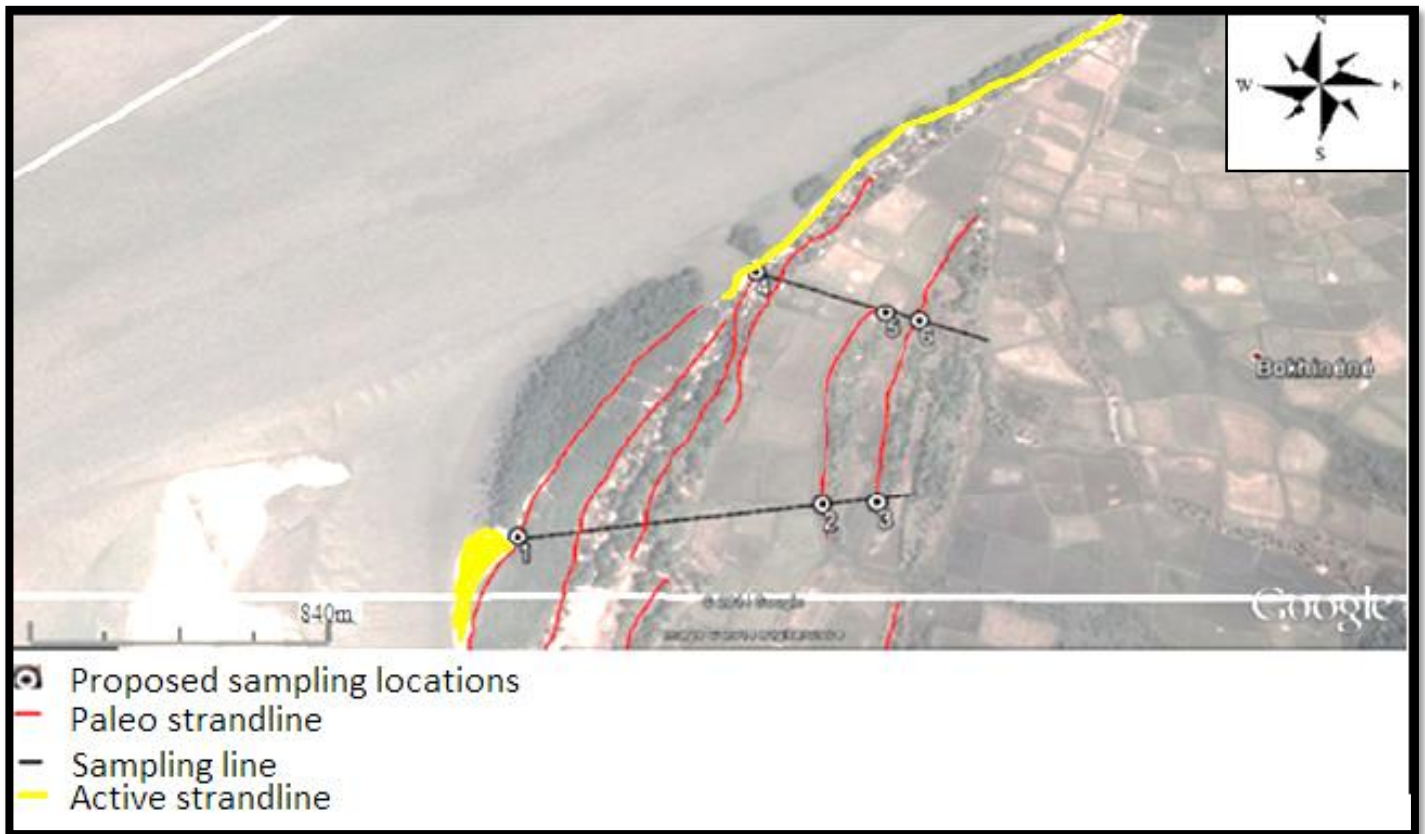


Figure 57: Shows the proposed sampling locations in concession EP2/1 by Siegfried (2013) along the active and paleo strandlines. Base modified from Google Earth (2015).

6.1.2 Sampled locations

The sampled locations as proposed in the previous paragraph 5.3.1 were not all sampled due to inaccessibility, inability to dig pits due to hard (laterized) sedimentary cover and a lack of time to reach the locations. During the exploration outcropping sediment was found because the local population were using the sand to build bricks. It was chosen to sample these locations first because it was interpreted that HMS was present at these locations.

During the exploration survey performed in February 2014, 28 locations were sampled in Dubreka during 5 days of exploration. 3 of these locations are located on the island of Bokhinene EP2/1 and 25 in SP1 area. On average the sample depth was 2.3 meters per sampling location. In total 72 samples were collected. The log sheets (Appendix B) have been constructed in compliance with JORC table 1 (Appendix E), which specifies the necessary reporting and sampling requirements.

Table 15: Summary of pitting

Concession area	Year	Total holes	Total depth (m)	Method
SP1	2014	25	55	Pitting
EP2/1	2014	3	3	Pitting

Of each sampled meter 2 Kg of sample was collected for analysis. This was done by first digging the pit and then spooning a homogenous (1m) sample into the bucket. This was done twice to obtain the 2 Kg's of sample.



Figure 58: Shows an example of sampled location ST1/L013/X01-X03.

6.1.2.1 Sampled locations in SP1

A GPS was used to determine the pitting locations. The GPS device used was a GPSMAP 60CSx. The horizontal accuracy of this device is typically less than 10 meters (Garmin, 2015). The numbering used to label these locations is the concession area (then called ST1) following the number of the location (L001-L028). In figure 59 the only the location numbers are shown (not the individual sample numbers).

Sample locations 7,8,9,10,24 and 28 were sampled following the proposed sample locations in the previous paragraph (6.1.1). The locations were not exactly the same because it was easier to reach the sampled locations by vehicle. Another sampling line following locations 11,12 and 25 was also chosen perpendicular to the active strandline.

Locations 1,2,3,4,5,6,13,14,15,16,18 and 19 were sampled because there was outcropping sediment. At the time of exploration, it was interpreted by the local geologist that these locations contained HMS mineralization. Locations 26 and 27 were sampled to interpret the regional geology between the other sample locations and were not targeted at locating HMS.

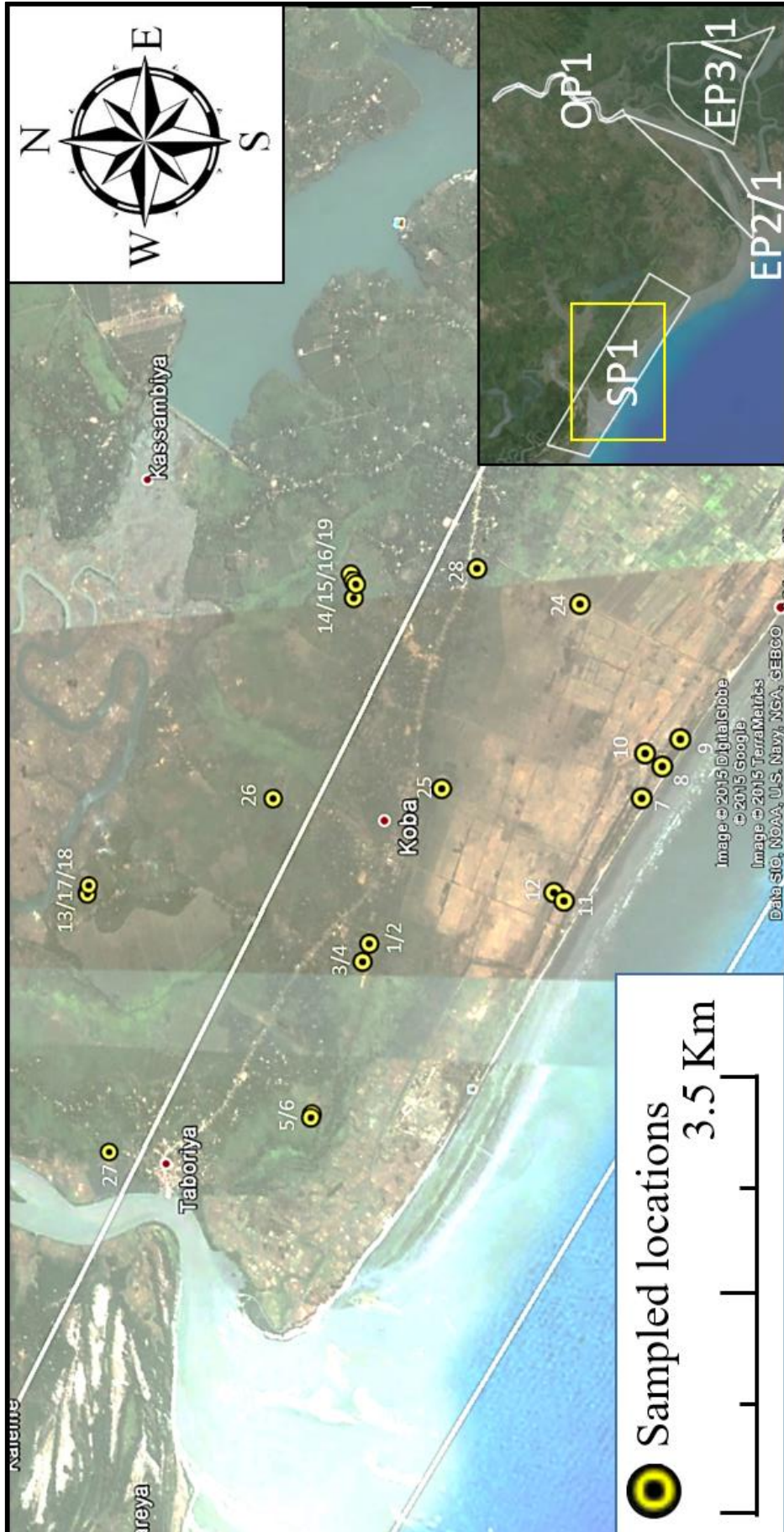


Figure 59: Shows the sampled locations concession SP1. Base modified from Google Earth (2015).

6.1.2.2 Sampled locations in EP2/1

In concession EP2/1 three locations were sampled. At sampling location EXP1/L023 only an image was taken due to insufficient time to sample. At location EXP1/L020 HMS was encountered on the surface of the sandy beach (3C). Following this discovery, the active strandline to the south was explored but no similar HMS mineralization on the surface was found. EXP1/L021 and EXP1/L022 were then sampled to explore the paleo strandlines.

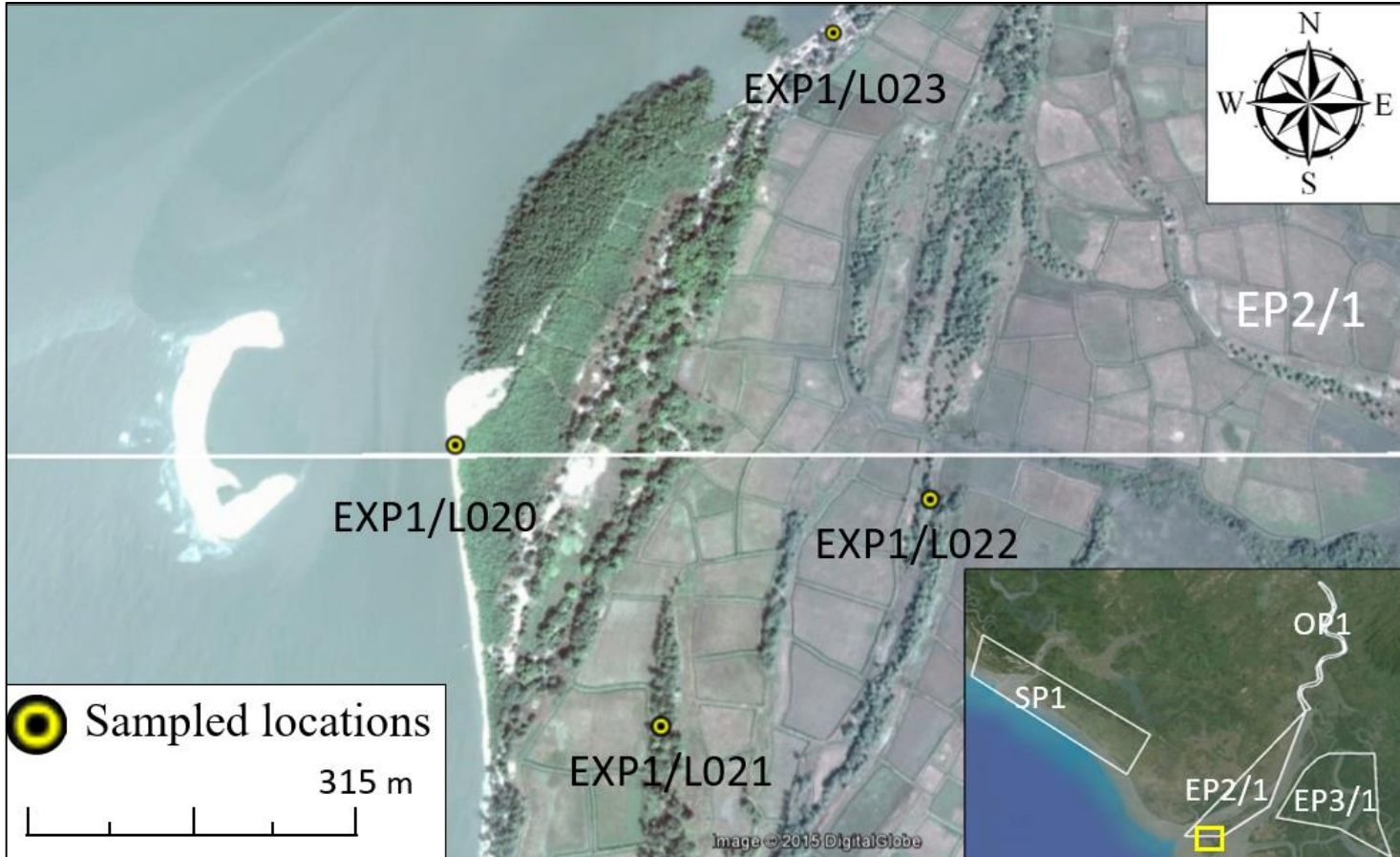


Figure 60: Shows the sampled locations concession EP2/1. Base modified from Google Earth (2015).

6.2 Analysis of samples

Of every sample taken in Guinea a duplicate was made. This was done by using the cone and quartering method²⁹. Of the two samples collected in Guinea one (approximately 1 kg) was sent to Scientific Services in South Africa and the other was stored in Guinea. Scientific Services have an ISO 9001:2008 certification and are part of an inter lab standards verification scheme. ISO 9001:2008 sets out the criteria for a quality management system. ISO 9001:2008 is implemented by over one million companies and organizations in over 170 countries (ISO, 2014). The most promising samples were analysed at the TU Delft.

The samples which were submitted to Scientific Services laboratory were analysed on the grain size, THM, magnetic composition and the elemental composition. The analysis performed on the samples is shown in Figure 61. The full experimental procedures are explained in Appendix C.

²⁹ The process of reducing a representative sample to a convenient size, or of dividing a sample into two or more smaller samples for testing, is called cone and quartering.

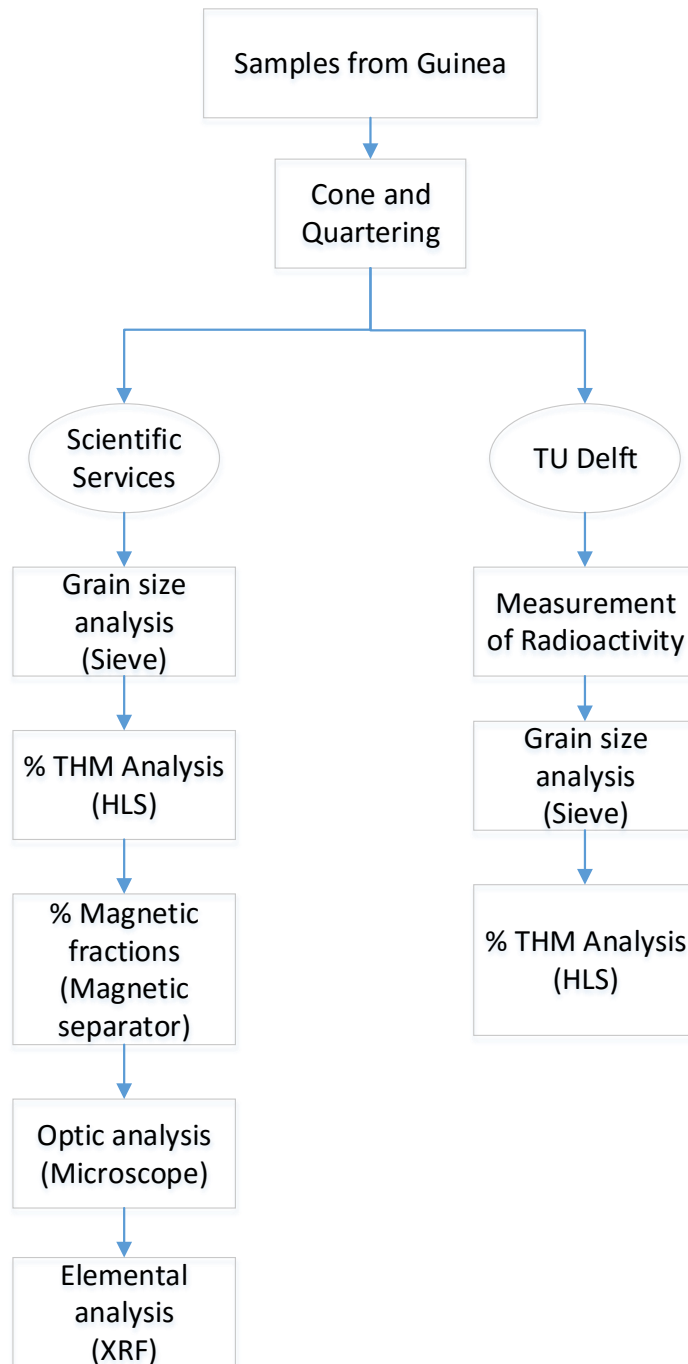


Figure 61: Shows the laboratory analysis methods used at scientific services and at the TU Delft.

At Scientific Services first the samples were sieved to determine the relative amounts of oversize ($>1\text{mm}$) and undersize ($<45\ \mu\text{m}$). The remainder ($-1\text{mm} +45\ \mu\text{m}$) was subjected to tetra-bromoform heavy liquid separation for the determination of the amount of material with a density (SG) greater than $2.9\ \text{t/m}^3$. This is an effective determinant of the content of total heavy minerals present (% THM). The results of this analysis are shown in Appendix C1.

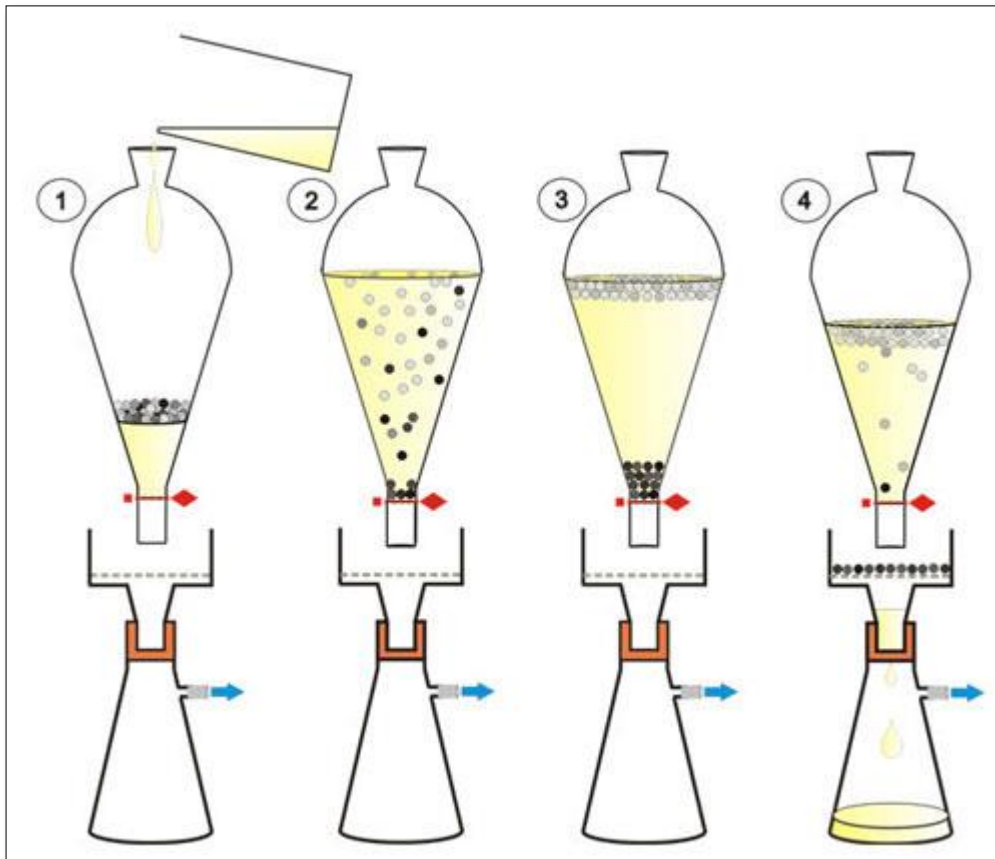


Figure 62: Shows the simplified heavy liquid separation method. 1: Insert sample 2: Insert heavy liquid 3: Lights float heavier material sinks 4: Open red valve to catch the heavy material (BGS, 2014)

After the HLS the samples containing the highest %THM content were further analysed by magnetic separation. The samples were subjected to magnetic separation at various degrees of intensity using a Carpcio induced roll magnetic separator. The Carpcio machine divides the THM into four electrostatically different fractions:

- Magnetic: The first fraction is the high susceptibility magnetic fraction, which consists mainly of magnetite.
- Weakly magnetic (0.8Amp): The second fraction consists mainly of ilmenite.
- Magnetic others: The third fraction is 'waste' material such as garnet, epidote and tourmaline.
- Non – magnetic: The final fraction consists mainly of zircon, rutile and leucoxene.

The results of this analysis are shown in Appendix C2.



Figure 63: Shows the Carpco® - high-intensity induced-roll magnetic separator (Boekhoud, 2011).

After the magnetic separation of the samples the mineralogy of the most promising samples were analysed with an optical microscope. This was conducted by geologist P. Siegfried at the laboratory using a binocular microscope. The results of this analysis are shown in Appendix C4 (Siegfried, 2013).

After this analysis the samples which showed the most promising results (highest % VHM) were analysed on their elemental composition by using XRF (X-ray fluorescence). The full results of the analysis are shown in Appendix C3.

At the Reactor Institute Delft (RID) the samples were analysed on their radioactivity. This was done by measuring the background values of the alpha particles, beta particles and gamma rays by using a Geiger counter³⁰. Then the samples were held closely to the Geiger counter to assess the influence of the samples on the radioactivity. The samples did not significantly change the reading of the Geiger counter from the background values. Therefore, it was concluded that the samples are not radioactive and it was possible to analyse the samples at the TU Delft.

After the radioactive analysis, the samples were further analysed on grain size and % THM by using a similar procedure as conducted at Scientific Services. This was done to compare with the results of Scientific Services (Appendix C2).

³⁰ A Geiger counter is an instrument for detecting the presence and intensity of radiations (as cosmic rays or particles from a radioactive substance) by means of their ionizing effect on an enclosed gas which results in a pulse that is amplified and fed to a device giving a visible or audible indication (Encyclopedia, 2015).

6.3 Exploration results and interpretation of local geology

In this section the results of the pitting survey, the regional geology described by Goussard (2010) (paragraph 5.4) and the interpretation of the remote sensing data (paragraph 5.6.2) are combined to obtain a more detailed geological description of the geological domains present in the explored concession areas. The concessions SP1 and EP2/1 are described separately below.

6.3.1 Sampling results and interpretation of local geology of concession SP1

The groundwater level varies between 1,5 and 4,60 meters from the surface in concession area SP1. This data has been obtained through the encountered water in the sampled locations, as shown in the log sheets (Appendix B) and Figure 64 below.

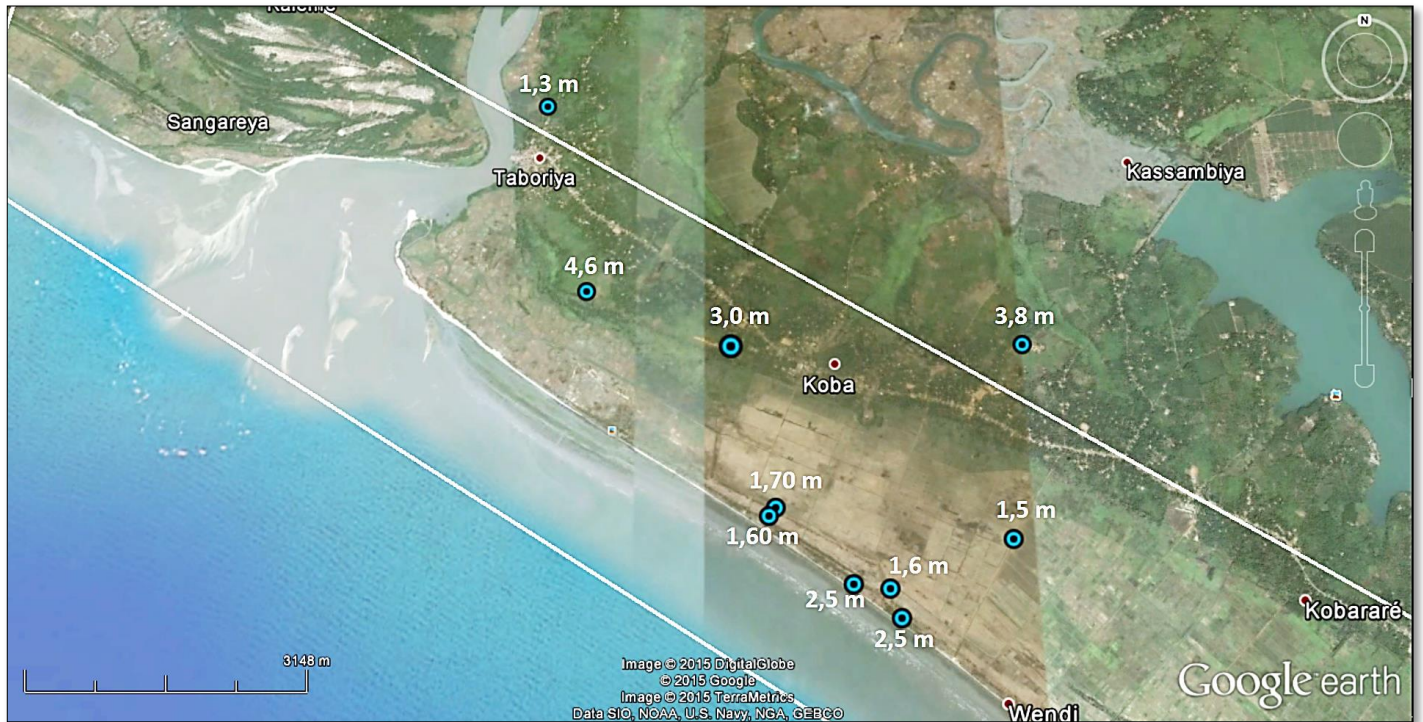


Figure 64: Shows the measured groundwater level (indicated in meters below the surface) in concession SP1. Base modified from Google Earth (2015).

The different geological domains discussed in this paragraph are summarized in table 14 and described in paragraph 5.4. In figure 65 a schematic interpretation of the geological surface map of SP1 is constructed based on the results of the remote sensing survey (paragraph 5.6.2) and the local geological description (paragraph 5.4) using Google Earth (2014) and the results from the exploration.

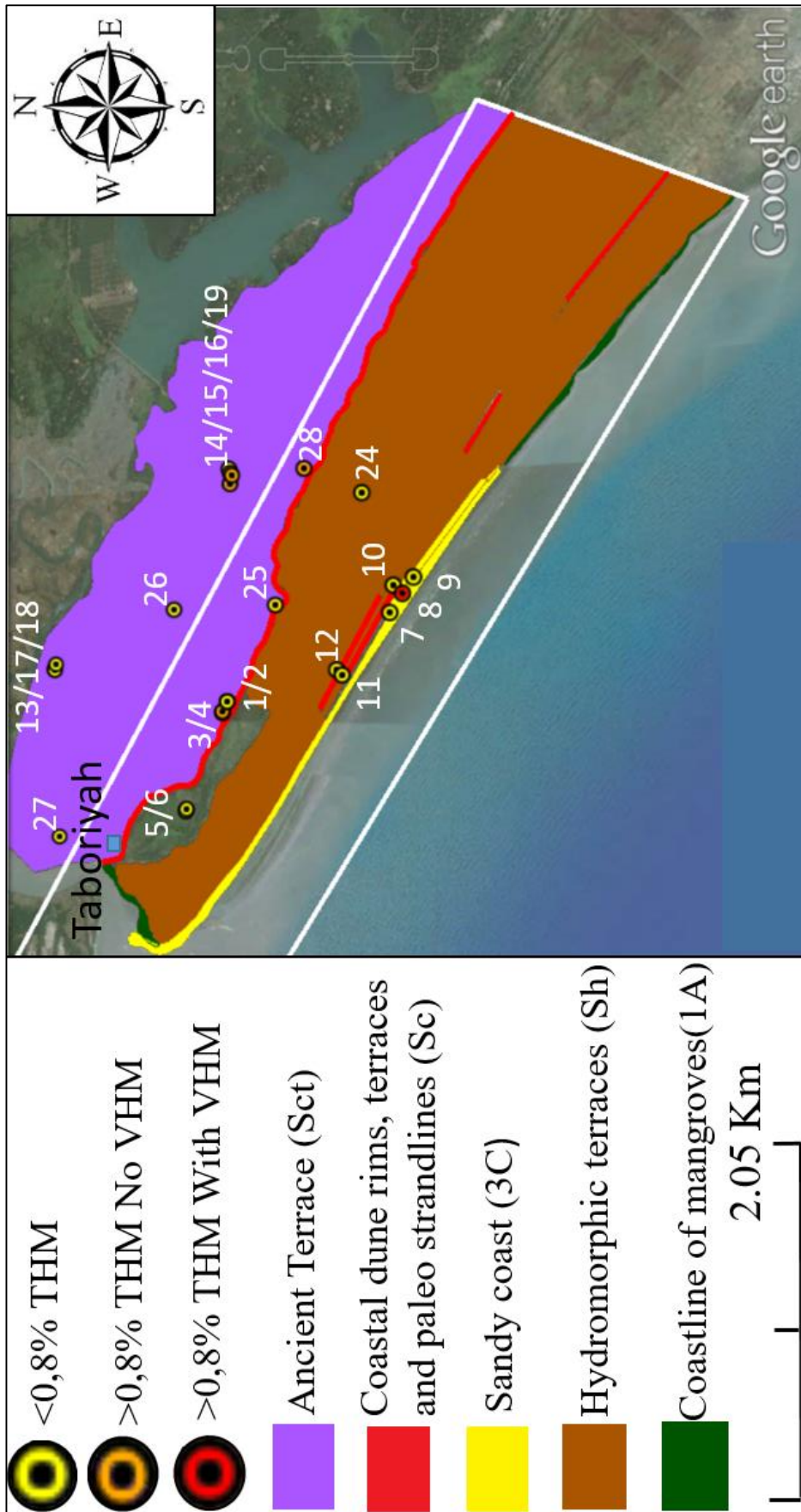


Figure 65: Shows the interpretation of the surface lithology (<2m) in concession SP1. The interpretation of the surface lithology has been compiled from the exploration results (2014), the local geology described by Goussard (2010) and through interpretation of Google Earth satellite imagery (2015). Sample site locations are indicated by the numbers. Base modified from Google Earth (2015).

Sandy coast (3C)

The numbering of the sampled locations is described as: concession/site location number/sample number from the top of pit. For example, ST1/L008/X02 means the sample is located in concession area SP1 (ST1), at location 8 (L008) and is the second sampled meter (X02) from the top of the pit. In the past the concession area was called ST1 instead of SP1.

Site locations ST1/L007, ST1/L008, ST1/L009 and ST1/L010 are situated in the sandy coast domain (3C). First a layer of humus and sand covers the marine sand. The sandy coast consists of unconsolidated sediment. As an example site location for this geological domain ST1/L008 is shown below.

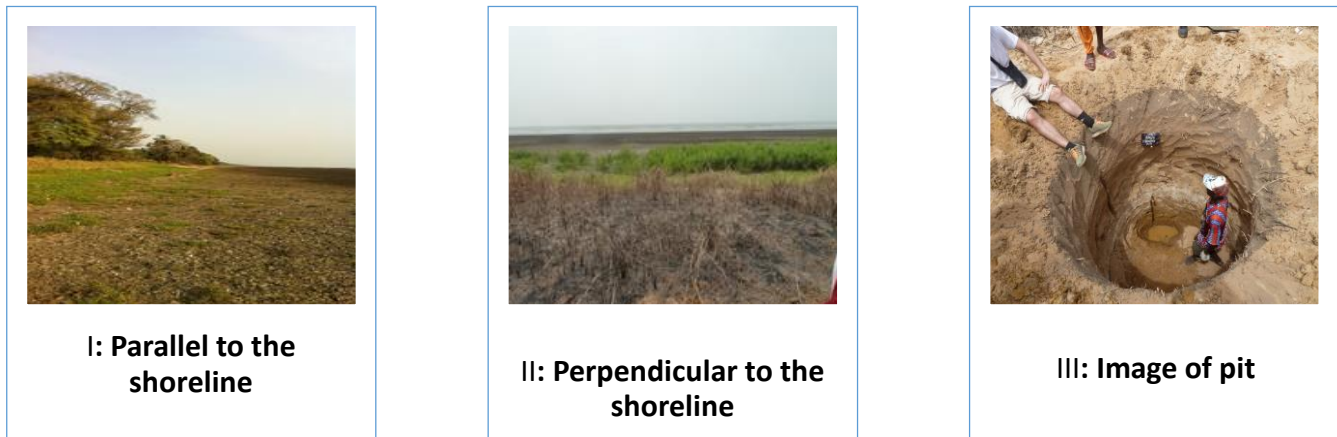


Figure 66: I: Shows an image taken from ST1/L008 parallel to the shoreline. II: Shows an image taken from ST1/L008 perpendicular to the shoreline. III: Shows the pit of location ST1/L008.

In the table below the results of the size analysis and HLS are shown.

Table 16: Results of size and HLS separation of samples present in Sandy coast (3C)

Sample Number	% Oversize (>1mm)	% Undersize (<45 μ)	THM (%)
ST1/L007/X01	0,3	1,9	0,2
ST1/L007/X02	1,5	2,3	0,6
ST1/L008/X01	0,1	0,8	0,2
ST1/L008/X02	0,0	1,8	2,0
ST1/L009/X01	0,2	0,3	0,2
ST1/L009/X02	0,6	2,3	0,3
ST1/L010/X01	0,0	1,8	0,2

The results of the size separation show that the sizes fall within the standards discussed in paragraph 4.7 (max. 10% smaller than 45 microns and 20% larger than 1mm). At site location ST1/L008/X02 up to 2.0 % THM has been encountered, which is above the industry standard discussed in paragraph 4.5 (0,8 % THM). This sample was further analysed. The other samples show THM mineralization between the 0,2 and 0,6% which is below the industry standard of 0,8% THM. Therefore, these samples were not further analysed. In Table 17 the results of the magnetic separation are shown. The samples were analysed with an optical microscope by P. Siegfried (2013). The results of this analysis are also shown in Table 17.

Table 17: Results of magnetic separation ST1/L008/X02

Magnetic Fraction	THM (%)	Comments Siegfried (2013)
Magnetic	1,42	
Weakly magnetic	39,26	Very dark steel grey, shiny and often platy ilmenite. No limonite or maroon coloured material. Occasional rod like, light orange, well rounded monazite grains.
Magnetic- Others	34,8	Contains of only light orange, well-polished monazite grains.
Non- magnetic	24,06	Quartz, occasional zircons, often dark
Total	99,54	

The magnetic analysis shows that the largest fraction is the weakly magnetic fraction (39.26% THM) which contains ilmenite. An amount of 0.56% of the THM content is not accounted for. This is due to the loss of mass during the magnetic separation. In the table below the XRF analysis is shown.

Table 18: Results of magnetic and XRF analysis of sample ST1/L008/X02

Magnetic fraction	Elemental composition (%)																
	La ₂ O ₃	CeO ₂	P ₂ O ₅	BaO	ZrO ₂	SrO	Fe ₂ O ₃	MnO	Cr ₂ O ₃	V ₂ O ₅	TiO ₂	CaO	K ₂ O	SiO ₂	Al ₂ O ₃	MgO	Na ₂ O
Magnetic (%)	0,03	0,04	0,13	0,4	1,52	0	38,55	0,65	2,89	0,28	44,6	0,03	0,26	4,1	3,37	0,81	0
Weakly magnetic (%)	0	0,05	0,13	0,48	0,33	0	38,04	0,82	0,5	0,26	51,26	0,02	0,01	2,31	2,35	0,58	0
Magnetic Others (%)	0,02	0,07	0,31	0,34	0,36	0	32,28	0,44	0,41	0,19	37,78	0,12	0,09	10,35	8,58	0,86	0,16
Non-magnetic (%)	0,02	0,05	0,22	0,43	23,1	0,07	1,72	0,03	0,11	0,18	46,34	0,04	0,02	18,55	4,44	0,05	0,76

From the XRF and magnetic analysis the following conclusions have been made:

- 39,26% of the THM fraction is weakly magnetic. This weakly magnetic material consist mainly of ilmenite as the TiO₂ content of the whole weakly magnetic fraction contains 51,26% TiO₂.
- The weakly magnetic fraction (51,26%) falls above the minimum industry standards determined in paragraph 4.5 (50% TiO₂). This is in line with the observations made by Siegfried (2013) that this fraction contained mainly ilmenite.
- The XRF analysis does not show that monazite is present in the weakly magnetic fraction as stated by Siegfried as the elemental composition of the La₂CO₃, CeO₂ and P₂O₅ are not above the margin of error of the XRF analysis.
- The high P₂O₅ could indicate the presence of monazite in the magnetic others and non-magnetic fractions.
- In the non-magnetic fraction the high TiO₂ content (46,34 % TiO₂) can be explained by the presence of rutile.
- The non-magnetic portion hosts significant ZrO₂ as supported by the observed presence of pink zircon. This ZrO₂ content (23,1% ZrO₂) is below the industry standards determined in paragraph 4.5 (66% ZrO₂).
- In the magnetic fraction the high TiO₂ (44,6% TiO₂) content can be explained by the presence of titanomagnetite (Fe²⁺(Fe³⁺,Ti)₂O₄).

Hydromorphic terraces (Sh)

Sampled location ST1/L024 is located within this geological domain. The surrounding landscape consists of grassland and appears to be continuous surrounding the site location ST1/L024, as shown in Figure 67 below.



Figure 67: I: Shows an image taken from ST1/L024 in a southerly (coastally) direction. II: Shows an image taken from ST1/L024 in a Northerly direction. III: Shows an image taken of pit ST1/L024

Table 20: Results of Samples present in Hydromorphic terraces (Sh)

Sample Number	% Oversize (>1mm)	% Undersize (<45 μ)	THM (%)
ST1/L024/X01	2,7	86,2	0,1
ST1/L024/X02	0,0	99,5	0,0

The sample sizes are well outside the ranges discussed in paragraph 4.7. Also the THM falls well outside of the minimum industry requirements (0,8% THM) and therefore this geological domain (1st two meters) has no further exploration potential.

Ancient sandy terraces (Sct)

Based on the results of the analysis the sample locations can be divided into two areas. The first area consists of an area ferruginisation and ferricrete formations and the second area consists of fluvial and/or lateritic material which is greatly enriched in iron though tropical weathering processes.

Ferruginisation and ferricrete formations

The surface sediment of the sample sites is consolidated with a first layer of laterized material. Laterites are soil types rich in iron and aluminium, formed in hot and wet tropical areas. Nearly all laterites are rusty-red because of iron oxides. They develop by intensive and long-lasting weathering of the underlying parent rock.

It is interpreted that the samples group into an area of extensive ferruginisation and ferricrete formations. Ferruginous crusts are either developed from the weathering of underlying rocks (lateritic residuum) or by ferruginisation of sediments (ferricrete).

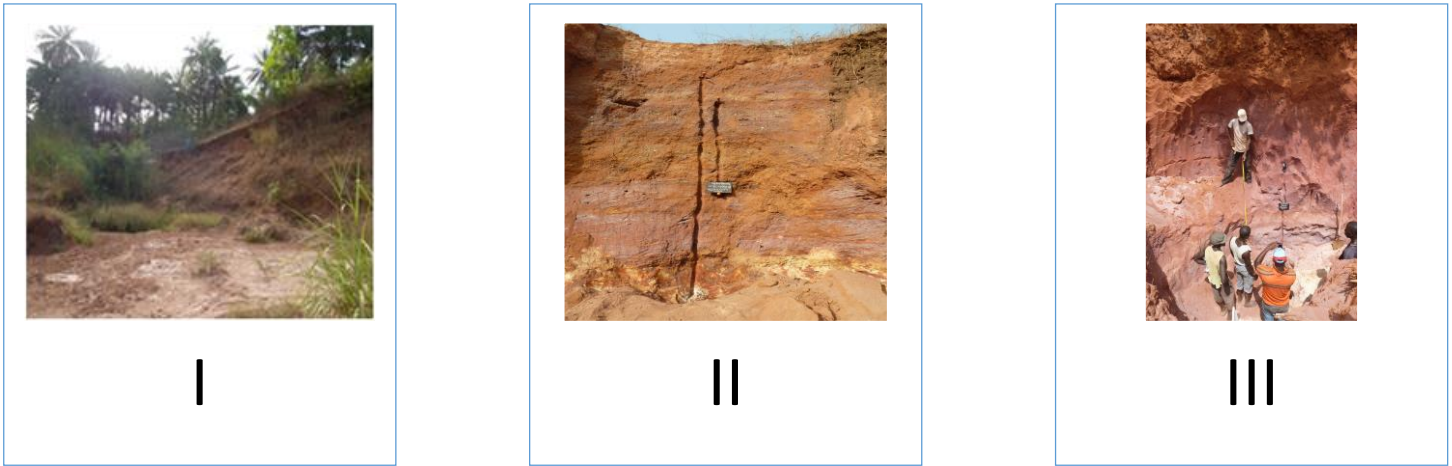


Figure 68: I: Shows an image of location ST1/L028 taken in a westerly direction, II: Shows an image of pit ST1/L028; III: Shows an image of location ST1/L005.

Table 19: Results of size and HLS separation of ancient terrace samples (Sct) (Scientific Services 2014; Siegfried 2013).

Sample Number	Oversize (>1mm) (%)	Undersize (<45 μ) (%)	THM (%)
ST1/L001/X01	3,0	5,8	0,1
ST1/L001/X02	0,9	7,9	0,4
ST1/L002/X01	9,5	9,2	0,1
ST1/L002/X02	8,9	7,9	0,4
ST1/L002/X03	0,0	14,4	0,1
ST1/L003/X01	34,9	9,4	2,5
ST1/L003/X02	24,2	7,5	0,7
ST1/L003/X03	0,4	7,0	0,4
ST1/L004/X01	12,1	10,5	1,7
ST1/L004/X02	20,0	5,4	0,7
ST1/L005/X01	9,6	6,6	0,2
ST1/L005/X02	2,6	6,4	0,4
ST1/L005/X03	7,7	3,8	0,4
ST1/L005/X04	1,7	4,0	0,4
ST1/L006/X01	3,3	6,8	0,5
ST1/L006/X02	2,5	5,7	0,3
ST1/L006/X03	8,7	3,8	0,3
ST1/L006/X04	2,6	3,1	0,2
ST1/L028/X01	58,9	13,2	2,5
ST1/L028/X02	23,6	14,2	1,6
ST1/L028/X03	4,0	6,5	0,5

The results of the size separation show that most of the sizes fall within the standards discussed in paragraph 4.7 (max. 10% smaller than 45 microns and 20% larger than 1mm).

The results of the HLS separation show that there is significant THM mineralization within the samples as there are 4 samples with a THM content larger than 0.8% (minimum industry standard discussed in paragraph 4.5). Sample ST1/L003/X01 showed the highest THM content so this sample was magnetically separated. The results are presented in table 20.

Table 20: Magnetic separation of sample ST1/L003/X01

Magnetic Fraction	THM (%)	Comments Siegfried (2013)
Magnetic	1,65	
Weakly magnetic	42,74	Generally maroon and dark maroon stained, irregular platy and capsule like limonite (as shown in Figure 69 image I)
Magnetic- Others	52,09	
Non- magnetic	3,02	Dominated by quartz and limonite (as shown in Figure 69 image II).
Total	99,50	

42,74% of the THM are weakly magnetic. This weakly magnetic material consists mainly of limonite. An amount of 0,50% of the THM content is not accounted for. This is due to the loss of mass during the magnetic separation.

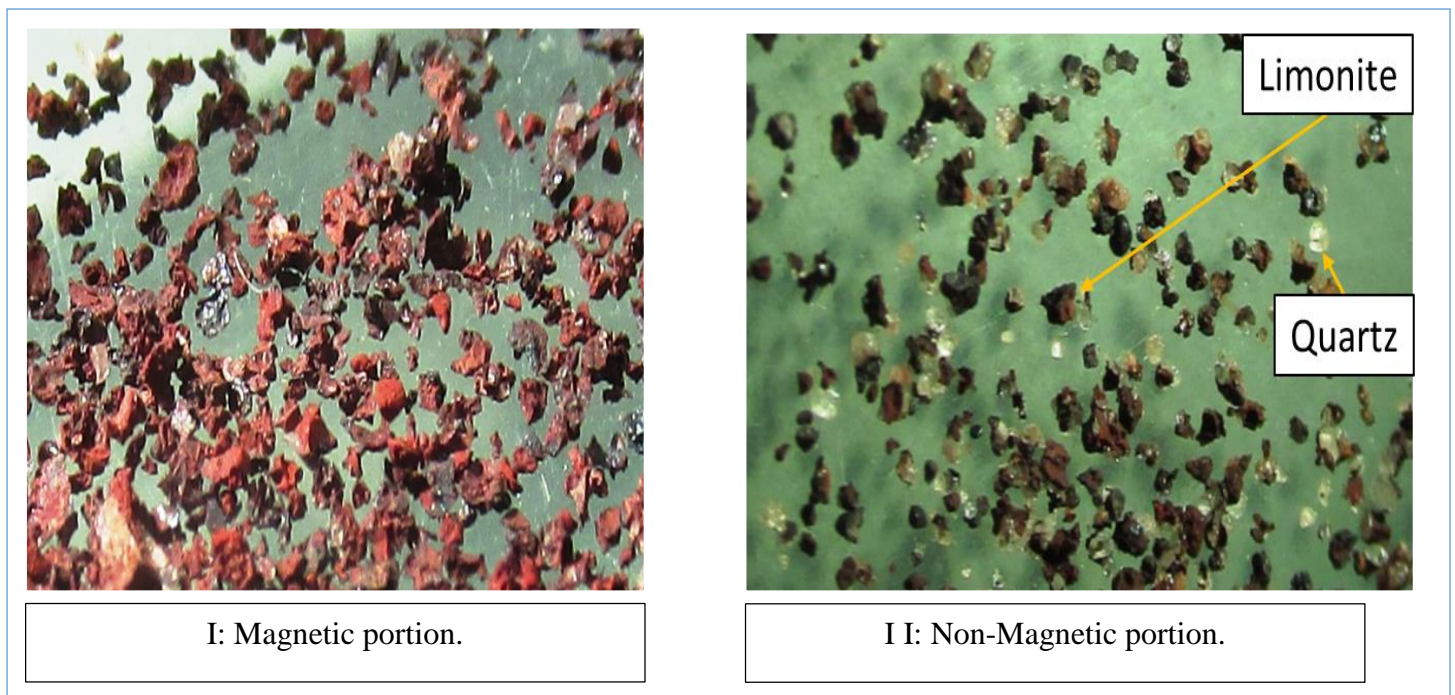


Figure 69: Shows the interpretation of sample ST1/L003/X01 by microscopic imagery by Siegfried (2013).

Sample ST1/L003/X01 has a similar split to samples ST1/L001 and ST1/L002 suggesting similar origin and setting. The ability of limonite to be magnetic, variably magnetic or non-magnetic has caused limonite to be distributed throughout the various sample splits. Limonite usually forms from the hydration of hematite and magnetite, from the oxidation and hydration of iron rich sulphide minerals, and chemical weathering of other iron rich minerals such as olivine, pyroxene, amphibole, and biotite. It is often the major iron component in lateritic soils (Siegfried, 2013).

The sample sites do show HMS mineralization (0,1 -2,5% HMS) but this mineralization is due to the process of ferricretization and consists mainly of limonite and do not contain mineralization of the VHM. Although no VHM mineralization has occurred within this area, marine sands have been discovered at these site locations in the deepest samples (ST1/L002/ X03, ST1/L003/ X03, ST1/L005/ X04, ST1/L006/ X04 and ST1/L028/ X03). These samples do not show significant HMS mineralization (0,1-0,7 % THM) but it is expected that in further exploration these sites could contain HMS mineralization which comply with the industry standards discussed in paragraph 4.5 (0.8% THM).

Fluvial and lateritic sediment



Figure 70: I: Shows image of location ST1/L014, II: Shows image of location ST1/L015, III: Shows image of location ST1/L019

Table 21: Results of size and HLS separation of ancient terrace (Sct)

Sample Number	Oversize (>1mm) (%)	Undersize (<45 μ) (%)	THM (%)
ST1/L013/X01	15,4	5,3	0,3
ST1/L013/X02	7,1	6,2	0,3
ST1/L013/X03	5,8	3,3	0,2
ST1/L017/X01	7,3	7,3	0,3
ST1/L017/X02	3,8	6,6	0,1
ST1/L018/X01	29,0	12,8	0,3
ST1/L018/X02	23,2	9,5	0,4
ST1/L018/X03	4,9	4,3	0,2
ST1/L026/X01-03	6,6	36,5	0,1
ST1/L014/X01	45,2	7,4	3,3
ST1/L014/X02	17,2	5,0	0,7
ST1/L014/X03	16,1	2,7	0,6
ST1/L015/X01	44,8	8,3	1,6
ST1/L015/X02	25,8	6,8	2,5
ST1/L015/X03	12,8	4,2	2,2
ST1/L016/X01	19,2	6,3	0,3
ST1/L016/X02	22,0	7,2	0,3
ST1/L016/X03	33,8	2,8	0,5
ST1/L019/X01	63,8	4,7	1,8
ST1/L019/X02	25,4	8,4	0,5

The results of the size separation show that most of the sizes fall within the standards discussed in paragraph 4.7 (max. 10% smaller than 45 microns and 20% larger than 1mm).

The results of the HLS separation show that there is significant THM mineralization within the samples as there are 5 samples with a THM content larger than 0.8% (minimum industry standard discussed in paragraph 4.7). Locations ST1/L014, ST1/L015 and ST1/L019 showed the highest THM content and therefore from these locations the samples with the highest THM content samples were also magnetically separated. The results are presented in table 23.

Table 22: Magnetic separation results for the ancient terrace (Sct)

Magnetic fraction	Sample number		
	ST1/L014/X01	ST1/L015/X02	ST1/L019/X01
Magnetic	1,54	1,97	5,47
Weakly magnetic	44,68	47,24	27,36
Magnetic- Others	49,82	46,46	42,12
Non- magnetic	3,23	3,94	23,51
Total	99,27	98,97	98,46

With an optical microscope the following information has been obtained of these spate magnetic fractions (Siegfried, 2013):

Sample ST1/L014/X03

Weakly magnetic fraction

Maroon stained blacks and reds, irregular and porous appearing limonite clusters. Many irregular platy grains possibly as original concretionary surfaces around clasts, often with cavities.

Non-magnetic portion

Mainly composed of shardy and irregular transparent grains of quartz. Many are occluded with coverings of limonite. Trace clear zircons noted.

Sample ST1/L015/X02

Weakly magnetic fraction

Dark purple and maroon grains, shardy and often porous. All appear as limonite.

Magnetic others fraction

Dark purple and maroon grains, shardy and often porous. All appear as limonite.

Non-magnetic fraction

Very fine grained well rounded light pink and white zircons, but dominated by shardy quartz grains with limonite coverings and occlusions.

Sample ST1/L019/X01

Weakly magnetic fraction

Generally, very pink and maroon coloured limonite with fine limonite dust covering all grains. As can be noted by the magnetic splits the samples ST1/L014, L015 and L019 all have similar splits and under microscope can be seen to be largely identical representing weathered fluvial and/or lateritic material which is now greatly enriched in iron though the process of tropical weathering.

Coastal dune rims, recent terraces and paleo strandlines (Sc)

Samples ST1/L011 and ST1/L012 are located within this geological domain. The marine sands consist of a layer of humus then sandy coast and then mud.



Figure 71: I: Shows an image of landscape in a southerly direction from ST1/L012, II: Shows an image of site location ST1/L011. III: Shows an image of site location ST1/L012

Table 23: Results de-sliming and HLS separation of samples present the coastal dune rims, recent terraces and paleo strandlines

Sample Number	Oversize (>1mm) (%)	Undersize (<45µm) (%)	THM (%)
ST1/L010/X01	0,0	1,8	0,2
ST1/L011/X01	6,8	3,5	0,3
ST1/L012/X01	0,7	2,0	0,2

The results of the size separation show that the sizes fall within the standards discussed in paragraph 4.7 (max. 10% smaller than 45 microns and 20% larger than 1mm).

The results of the HLS separation show that the samples did not contain THM mineralization above the minimum industry stand discussed in paragraph 4.5 (0,8 % THM) and therefore these samples were not further analysed.

6.3.2 Sampling results and interpretation of local geology of concession EP2/1

The groundwater level in concession area EP2/1 varies between 0,6 and 1.5 meters from the surface, as shown in the log sheets (Appendix B) and Figure 72 below.



Figure 72: Shows the measured groundwater level (indicated in meters below the surface) in concession EP2/1. Base modified from Google Earth (2015).

The schematic interpretation of the surface lithology has been constructed in the same manner as in the previous paragraph and is shown in Figure 73.

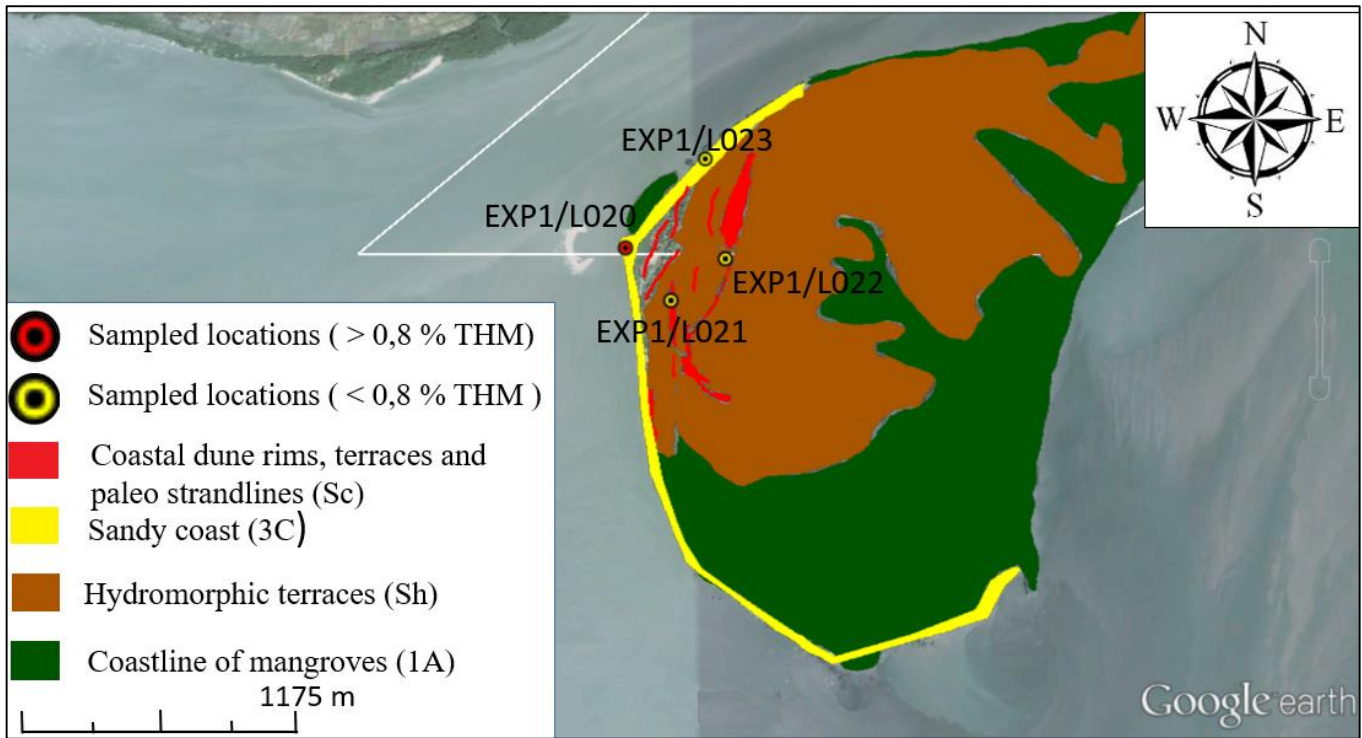


Figure 73: Shows the surface lithology (<2m) in concession EP2/1. The interpretation of the surface lithology has been compiled from the exploration results (2014), the local geology described by Goussard (2010) in subsection 5.4 and through interpretation of Google Earth satellite imagery (2015). Base modified from Google Earth (2015).

Sandy coast (3C)

The numbering of the sampled locations is described as concession/site location number/ sample number from the top of pit. For example, EXP1/L020/X01 means the sample is located in concession area EXP1 (EP2/1), at location 20 (L020) and is the first sampled meter (X01) from the top of the pit. In the past the concession area was called EXP1 instead of EP2/1.

Sample site EXP1/L020 is located within this geological domain (3C). In figure 74 a site description of site EXP1/L020 is shown. Sample EXP1/L020 is located in this region along the coastline (strandline) of Bokhinene. Towards the sea the sediment becomes very muddy. Next to the location the first dune starts (as shown by the green vegetation in figure II below).



Figure 74: I: Shows an image of the HMS on the sandy beach (3C) near pit location EXP1/L020. Image taken parallel to shoreline in a westerly direction. II: Image of pit location EXP1/L020 perpendicular to shoreline. III: Image of pit location EXP1/L020.

This results of the size and HLS separation are shown in the table below.

Table 24: Results of De-sliming and HLS separation

Sample Number	Oversize (>1mm) (%)	Undersize (<45µ) (%)	THM (%)
EXP1/L020/X01	0,3	0,6	18,1

The results of the size separation show that the sizes fall within the standards discussed in paragraph 4.7 (max. 10% smaller than 45 microns and 20% larger than 1mm).

The results of the HLS separation show that the sample contains significant THM mineralization which is above the minimum industry standards discussed in paragraph 4.5 (0.8 % THM). Therefore, the sample was further analysed on its magnetic composition. The results are shown in the table below.

Table 20: Results of magnetic separation of sample ST1/L020/X01

Magnetic fraction	% of THM	Comments Siegfried (2013)
Magnetic	3,38	This sample was mono-mineralised, very dark black, very shiny with irregular edges characteristic of magnetite.
Weakly magnetic	76,55	Ilmenite grains are dark grey, polished and metallic, no alteration or rusting noted. Appear very fresh, with some occasional angular quartz grains.
Magnetic Others	6,92	This sample is dominated by a shardy transparent white mineral which is sometimes slightly yellowed (stained) mineral. Looks like quartz, sometimes has a distinctive cleavage (pyroxene).
Non- magnetic	12,8	Shown in figure 75, where approximately: <ul style="list-style-type: none"> • 60% of the material is composed of white and pink zircons. • 20% of the sample is composed of shiny black mineral sometimes rod like and usually with a shiny yet irregular surface. This material represents possibly staurolite or metamict zircon. • 10% of the sample is monazite grains which are well rounded and light orange in colour • 10% of the sample is composed of rutile which has an orange-red colour
Total	99,65	

An amount of 0,35% of the THM content is not accounted for. This is due to the loss of mass during the magnetic separation. In figure 75 the non-magnetic fraction of sample ST1/L020/X01 is shown.

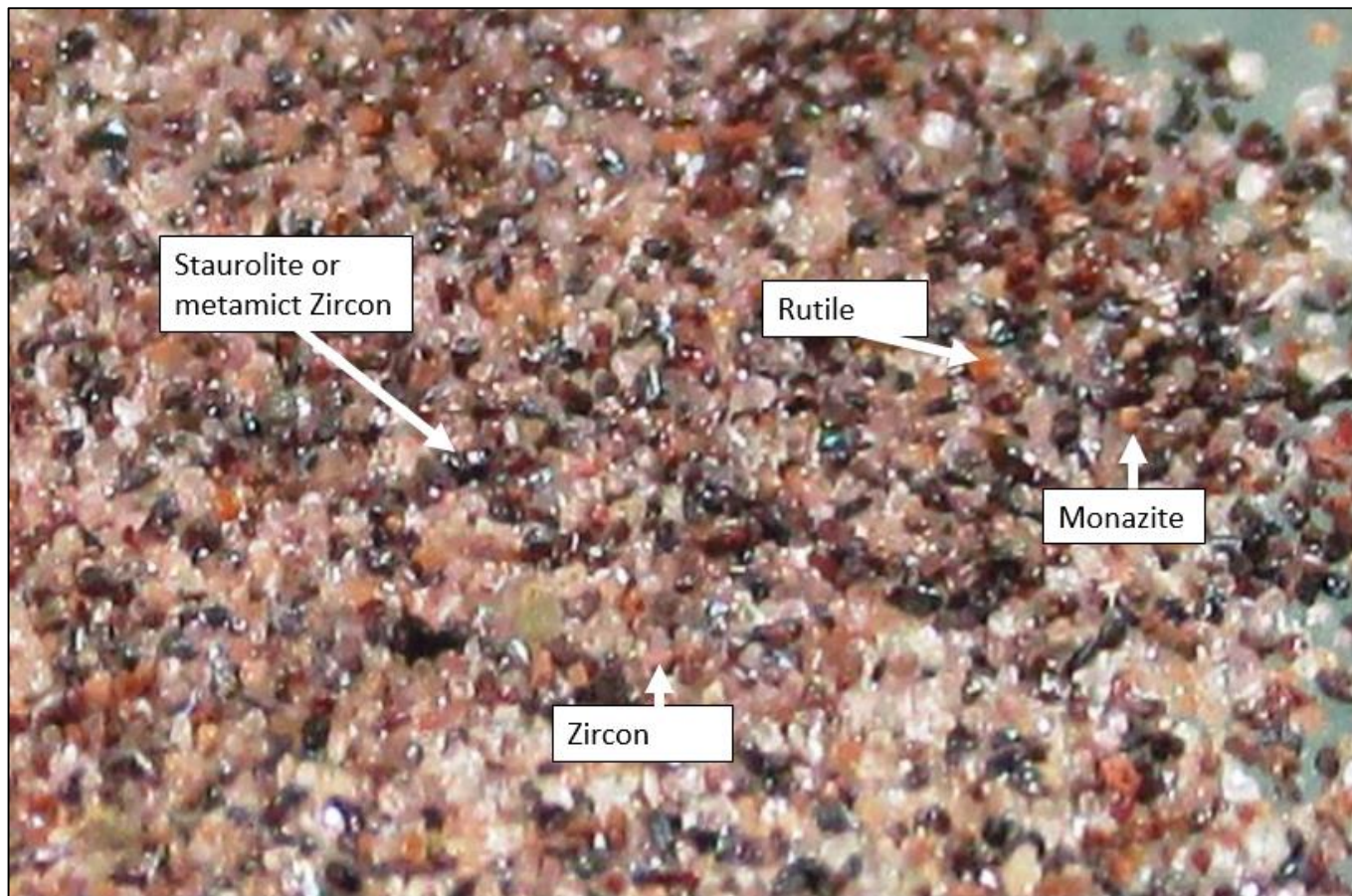


Figure 75: Shows the interpretation of the non- magnetic portion of sample EXP1/L020/X01 by microscopic imagery by Siegfried (2013). The image shows a high content of zircons (light pink and white grains).

The results of the XRF analysis are shown in the table below.

Table 25: Results of magnetic separation sample EXP1/L020/X01

Magnetic fraction	Elemental composition (%)																
	La ₂ O ₃	CeO ₂	P ₂ O ₅	BaO	ZrO ₂	SrO	Fe ₂ O ₃	MnO	Cr ₂ O ₃	V ₂ O ₅	TiO ₂	CaO	K ₂ O	SiO ₂	Al ₂ O ₃	MgO	Na ₂ O
Magnetic (%)	0	0,1	0,06	0,39	2,09	0	48,07	0,66	2,56	0,3	43,75	0,04	0	1,1	0,65	1,58	0,07
Weakly magnetic (%)	0,01	0,1	0,05	0,45	1,22	0	48,05	0,85	0,28	0,27	48,88	0,06	0	1,09	0,12	1,03	0,01
Magnetic Others (%)	0,04	0,12	0,21	0,26	0,92	0	25,8	0,51	0,66	0,16	28,2	1,75	0,01	25,02	4,94	10,9	0,26
Non-magnetic (%)	0,02	0,8	0,23	0,28	38,89	0,09	0,63	0,03	0,04	0,14	29,31	0,12	0,01	23,66	0,96	0,21	1,24

From the XRF and magnetic analysis the following conclusions have been made:

- 76,55% of the THM fraction is weakly magnetic. This weakly magnetic material consists mainly of ilmenite as the TiO₂ content of the whole weakly magnetic fraction contains 48,88% TiO₂.
- The weakly magnetic fraction (48,88% TiO₂) falls just below the minimum industry standards determined in paragraph 4.5 (50% TiO₂).
- The non-magnetic portion hosts significant ZrO₂ as supported by the observed presence of pink zircon. This ZrO₂ content (38,89 ZrO₂) is below the industry standards determined in paragraph 4.5 (66% ZrO₂).
- The high (29,31%) TiO₂ content of the non- magnetic fraction with no iron indicates the presence of rutile.

- The high (43,75%) TiO₂ of the magnetic portion indicates the presence of titano-magnetite (Fe²⁺(Fe³⁺,Ti)₂O₄).
- The high relatively high P₂O₅ could indicate the presence of monazite in the magnetic others and non-magnetic fractions as observed in the microscopic analysis shown in Table 20.
- The magnetic others showed a mineral present similar to quartz but with a cleavage. XRF results show a very high MgO and SiO₂ content and it is suggested that this mineral is enstatite (Mg pyroxene).

Coastal dune rims, recent terraces and paleo strandlines (Sc)

Sample EXP1/L021 is located in this geological domain and is located in the second tree line from the coast. The topography is flat.



Figure 76: Shows an image of EXP1/L021, A: Humus and sand B: marine sand, C: Mud

Table 26: Results size and HLS separation dune rims, recent terraces and paleo strandlines (Sc) in EP2/1

Sample Number	Oversize (>1mm) (%)	Undersize (<45µ) (%)	THM (%)
EXP1/L021/X01	0,1	3,6	0,4

The results of the size separation show that the sizes fall within the standards discussed in paragraph 4.7 (max. 10% smaller than 45 microns and 20% larger than 1mm). No significant HMS mineralization has occurred within this sample, so no further analysis was performed.

Hydromorphic terraces (Sh)

Sample EXP1/L022 is located within this geological domain. EXP1/L022 is located just behind a tree line (4th tree line from the coast) of palm trees.

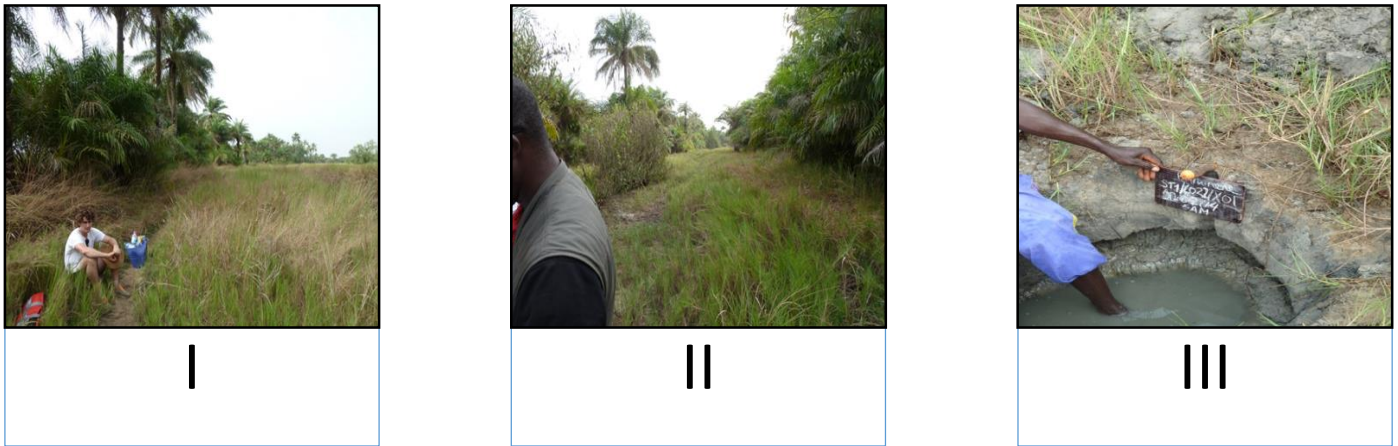


Figure 77: I: Shows an image taken of sample site EXP1/L021 in a westerly direction. II: Image taken from sample site EXP1/L022 in an easterly direction. III: Image of sample site EXP1/L021.

Table 27: Results analysis SH in EP2/1

Sample Number	Oversize (>1mm) (%)	Undersize (<45 μ) (%)	THM (%)
EXP1/L022/X01	0,1	3,6	0,4

The results of the size separation show that the sizes fall within the standards discussed in paragraph 4.7 (max. 10% smaller than 45 microns and 20% larger than 1mm). No significant HMS mineralization has occurred within this sample, so no further analysis was performed.

6.4 Summary and conclusion

The primary aim of the exploration was to locate HMS within the concession areas; the secondary aim was to obtain more insight in the geological domains within the concession areas. Different exploration techniques exist to meet these aims. Insufficient knowledge on the HMS properties was available to justify the costlier exploration remote sensing and drilling methods. Because the style of HMS mineralization is generally shallow, extensive and flat lying pitting is preferred to trenching at this stage of the exploration. The pitting technique required manual labour and the geochemical analysis of the samples.

Besides the HMS, VHM mineralization was expected to be present in the sandy coast (3C), coastal dune rims, recent terraces and paleo strandlines (Sc) and ancient terraces (Sct). Anomalous quantities of HMS have only been discovered in the sandy coast (3C) in concessions SP1 and EP2/1. The results from the samples obtained in the ancient terraces (Sct) show that these areas contain extensive ferruginisation and ferricrete formations and thus far no VHM (potential) has been detected in these geological domains.

The two samples EXP1/L020/X01 (in concession EP2/1) and ST1/L008/X02 (in concession SP1) have shown the most promising results. These samples were both located in the sandy coastline (3C). Sample EXP1/L020/X01 complies with the industry standards summarized in paragraph 4.8 on sample size and THM content. The TiO₂ content (48.88% TiO₂) is a bit lower than the industry standard (50% TiO₂). The ZrO₂ content (38.89% ZrO₂) is well below the industry standards discussed in paragraph 4.8 (66% ZrO₂). The high (29.31%) TiO₂ content of the non- magnetic fraction with no iron indicates the presence of rutile.

Sample ST1/L008/X02 complies with the industry standards summarized in paragraph 4.8 on sample size and THM content. The TiO₂ content (51.26% TiO₂) is a bit higher than the industry standard (50% TiO₂).

The ZrO_2 content (23.1% ZrO_2) is well below the industry standards summarized in paragraph 4.8 (66% ZrO_2). The high (46.34 %) TiO_2 content of the non- magnetic fraction with no iron indicates the presence of rutile.

The five other samples encountered in the sandy coast (3C) do not meet these industry standards due to limited THM and VHM mineralization.

Magnetic, optic and elementary analysis showed that in addition to the VHM's ilmenite, rutile and zircon monazite was also present.

The samples have been examined on their radioactivity and have shown not to exceed background values. Therefore, the radioactivity is expected to comply with industry standards (<500ppm U+Th) and were safe to test at the TU laboratory.

Exploration target prospectivity

Based on the exploration results discussed in the previous chapter the exploration target prospectivity for the concession areas is estimated. The estimation of the prospectivity is based on a renewed pitting survey as insufficient data is available to advise on a drilling or remote sensing survey. The exploration results are insufficient to estimate a HMS resource which has reasonable prospects for economic extraction. Therefore, an exploration target is estimated following the JORC code (2011) in the most promising concession areas (SP1 and EP2/1).

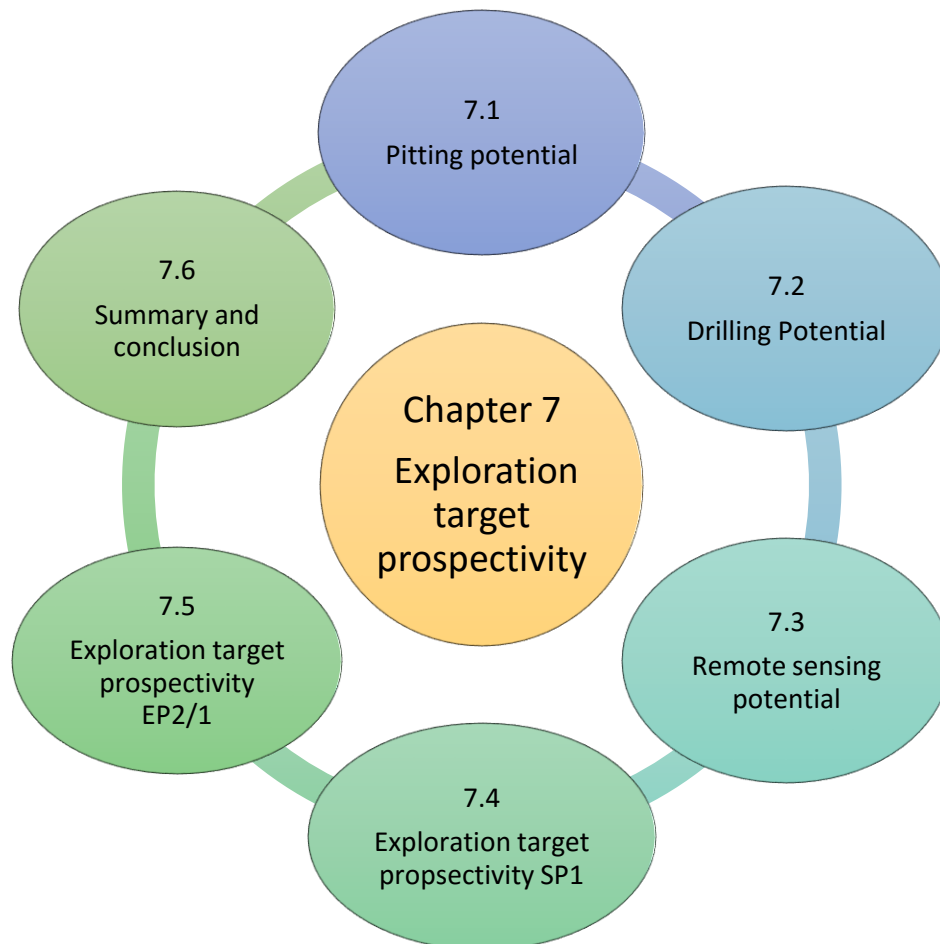


Figure 78: Overview of chapter 7

7.1 Pitting potential

In this paragraph the exploration prospectivity of the different geological domains within the concession areas are discussed.

7.1.1 SP1 East of Taboriyah

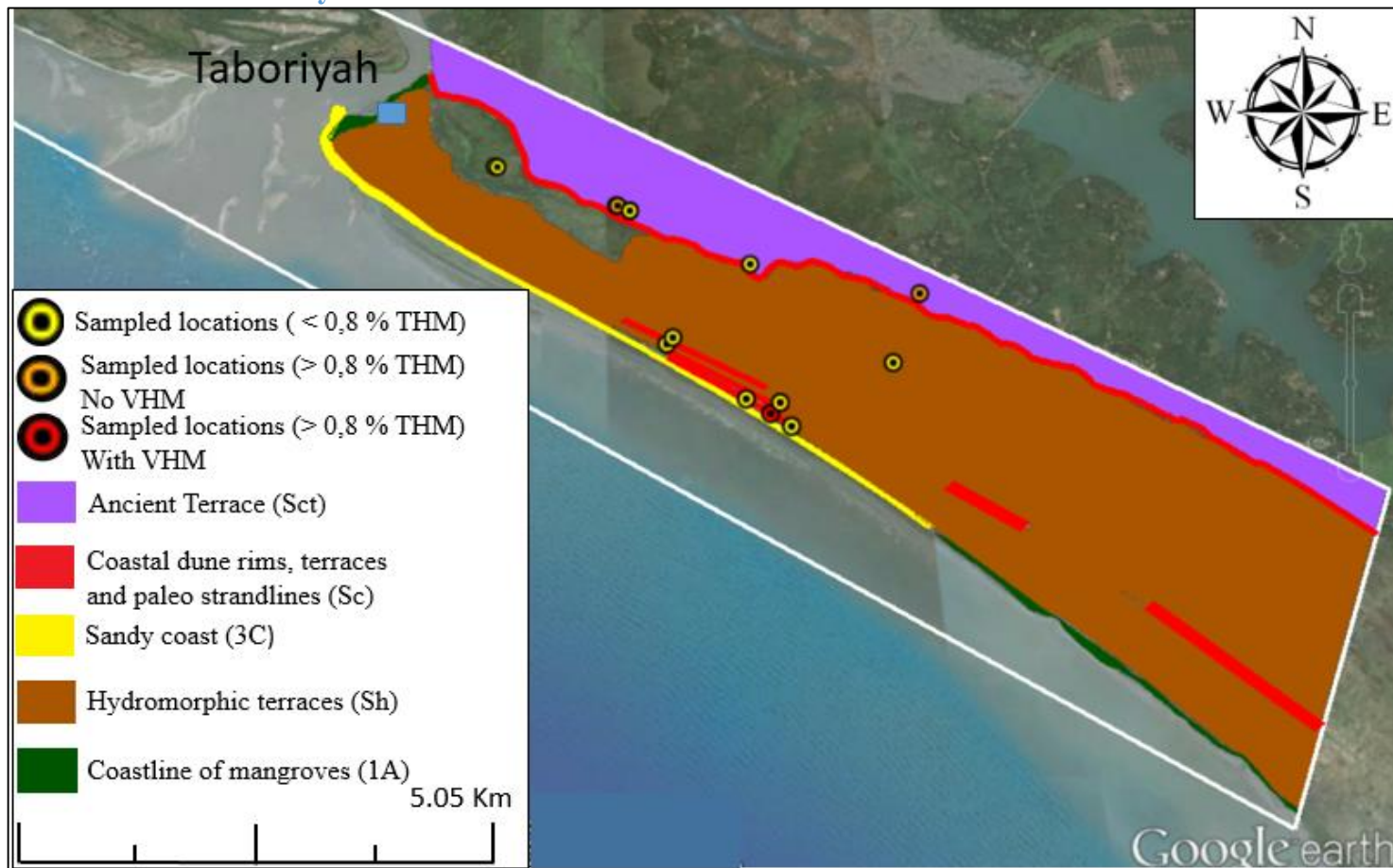


Figure 79: Shows the interpretation of the surface lithology (<2m) and the sampled locations in concession SP1. The interpretation of the surface lithology has been compiled from the exploration results (2014), the local geology described by Goussard (2010) in subsection 5.4 and through interpretation of Google Earth satellite imagery (2015). Base modified from Google Earth (2015).

Sandy coast (3C)

As indicated in paragraph 6.3 the sandy coast contained HMS (ST1/L008/X02 contained 2% THM) but the continuity and homogeneity of the HMS within the sandy coast is unknown. At locations ST1/L007, ST1/L009 and ST1/L0010 the samples contained a THM content of 0,2 up to 0,6 %. It is interpreted that the strike of the mineralogy follows the curvature of the shoreline. Because HMS mineralization has been encountered in this domain further pitting in this area is advised.

Coastal dune rims, recent terraces and paleo strandlines (Sc)

Site locations ST1/L011 and 12 are located within this zone. No significant amount of THM mineralization has been encountered in these samples (0,3 and 0,4 % THM).

Three paleo strandlines have been identified in the region East of Taboriyah. It is interpreted that the strike follows the curvature of the dune rims. Based on site locations ST1/L11 and ST1/L012 it is expected that 1-2 meters of sample can be collected until groundwater or mud is reached. More pitting is required in this geologic domain to evaluate if significant amounts of HMS are present.

Hydromorphic terraces (Sh)

Based on sample ST1/L024/X01 and X02 it is interpreted that in this zone no HMS mineralization will be encountered in the first two meters as it is expected that this zone will consist predominantly of clay. It is expected that beneath this clay groundwater will be discovered. Therefore, it is not recommended that further pitting is performed in this geological domain.

Ancient terraces (Sct)

It is concluded from paragraph 6.3.1 that this zone does not contain VHM mineralization in the first meters (4m). It is expected that in this geological domain the top layer will consist of laterized sediment and below this layer ferruginous and ferricrete sediment will be discovered. Sample locations ST1/L001,2,3,4,5,6 and 28 indicated that beneath the layers of ferruginous and ferricrete sediment marine sands (sandy coast 3C) are present. Although marine sand has been discovered no significant amounts of HMS have been encountered within these sandy coastal layers (up to 0,4% THM). Therefore, it is not recommended that further pitting is performed in this area.

7.1.2 SP1 West of Taboriyah

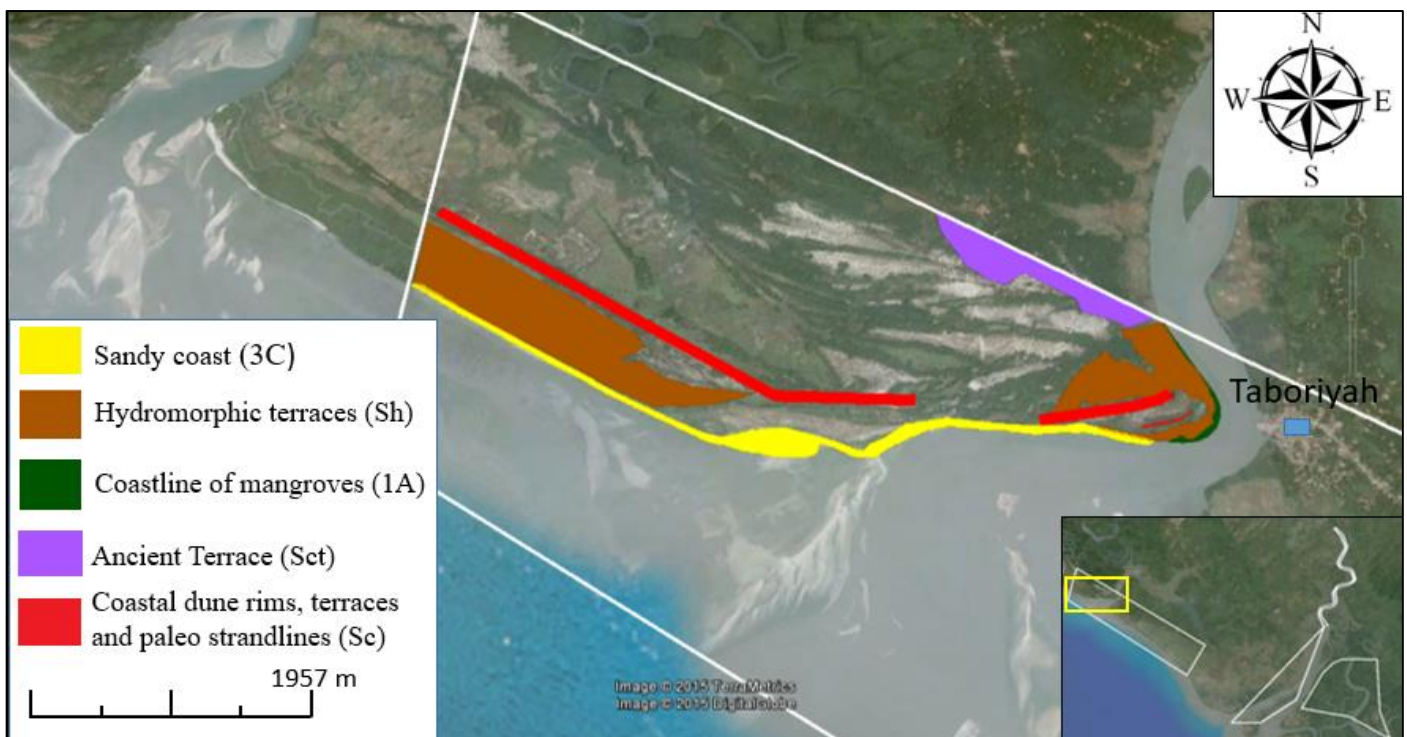


Figure 80: Shows the interpretation of the surface lithology (<2m) of the area west of Taboriyah in concession SP1. The interpretation of the surface lithology has been compiled from the local geology described by Goussard (2010) in subsection 5.4 and through interpretation of Google Earth satellite imagery (2015). Base modified from Google Earth (2015).

Exploration has not yet been performed within this region. Through the remote sensing data (5.6.2) and the local geology described in paragraph 5.4, the geological domains regions 3C, Sc and Sct and Sh are expected to be present as indicated in Figure 80.

Sandy coast (3C)

In this region the same style of mineralization is expected as the sampled locations ST1/L007, 8 and 9. It is recommended that pits are dug in this geological domain for the first 2 meters. It is expected that deeper pits cannot be dug due to the groundwater level.

Hydromorphic terraces (Sh)

It is expected that this geological domain does not contain HMS mineralization. It is expected that the first two meters will consist of clay and below this layer groundwater will be discovered (Similar to ST1/L024/X01 and X02). It is not recommended that pitting is performed in this region.

Coastal dune rims, recent terraces and paleo strandlines (Sc)

Within this region at least 2 of these geological structures are expected to be present, as shown in Figure 80. It is expected that these geological structures could contain HMS mineralization and therefore these areas should be sampled.

Ancient terraces (Sct)

This geological domain covers a small amount of the concession area. It is expected that the sediment will contain similar mineralogy as the samples ST1/L001,2,3,4,5,6 and 28. As these samples did not contain VHM's it is recommended that this area is not pitted.

7.1.3 EP2/1 Island of Bokhinene

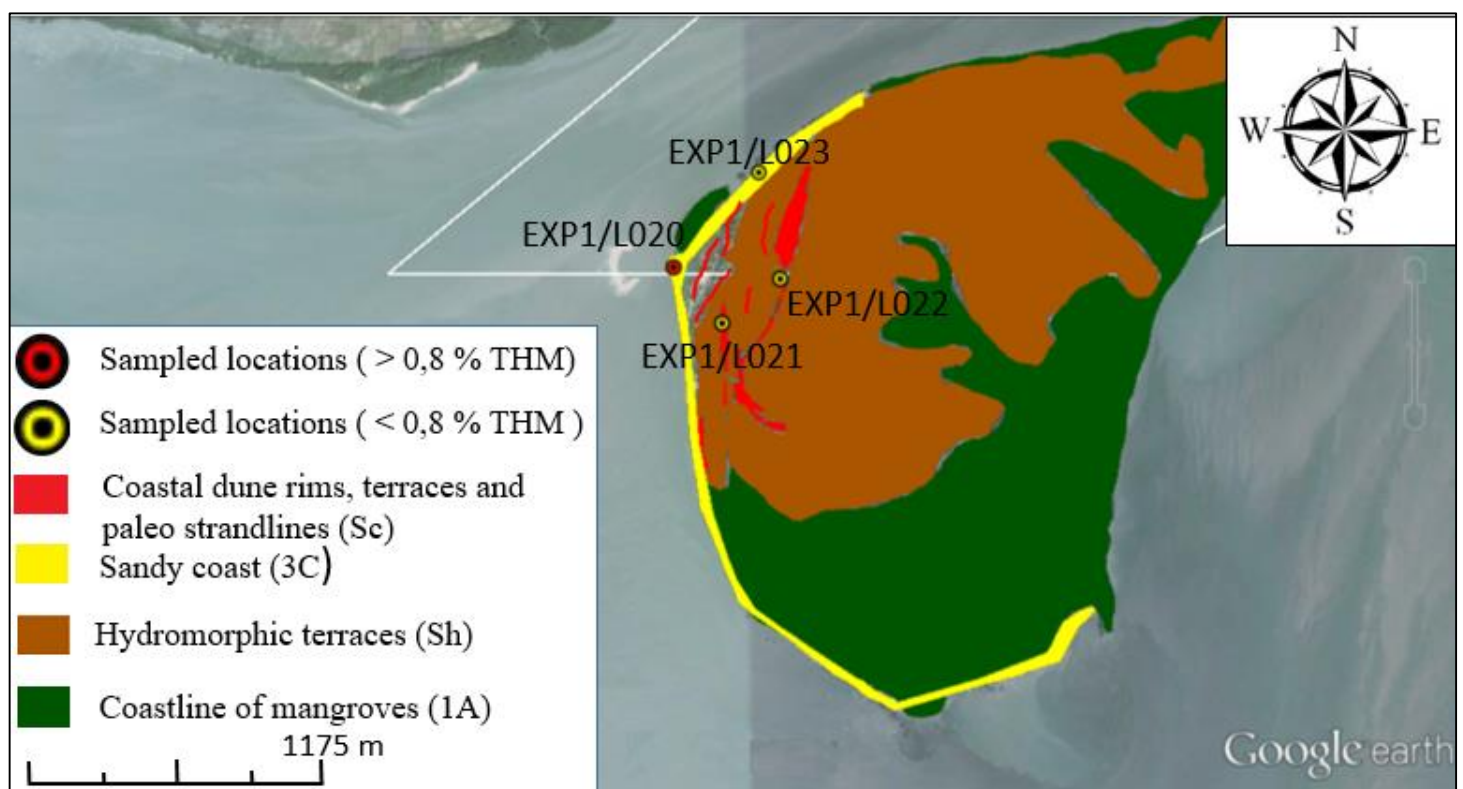


Figure 81: Shows the interpretation of the surface lithology (<2m) of the island of Bokhinene in concession EP2/1. The interpretation of the surface lithology has been compiled from the local geology described by Goussard (2010), exploration results (2014), in subsection 5.4 and through interpretation of Google Earth satellite imagery (2015). Base modified from Google Earth (2015).

Sandy coast (3C)

As indicated in paragraph 6.1.2 the sandy coast (3C) contained HMS (EXP/L020/X01 contained 18,1% THM). The grade continuity of the HMS is unknown. It is recommended that pitting is performed to evaluate the continuity and homogeneity of the grade of the sandy coastline (3C). The mineralization is expected to follow the curvature of the shoreline. Because HMS mineralization has been encountered in this geological zone further pitting is advised.

Coastal dune rims, recent terraces and paleo strandlines (Sc)

More pitting is required to determine if this geological domain contains significant amounts of HMS. EXP1/L021/X01 did show minor HMS mineralization (0,4% THM). It is recommended that the paleo

strandlines indicated in Figure 81 are sampled through pitting. Based on the results of the groundwater level (Figure 72) it is expected that first 2 meters can be sampled before the groundwater is encountered and no further pitting is possible.

Hydromorphic terraces (Sh)

Based on sample EXP1/L022 it is expected that this geological domain does not contain HMS. It is expected that this layer consists predominantly of clay. Beneath this layer of clay groundwater is expected to be encountered (similar to sample EXP1/L022). Therefore, it is not recommended that further pitting is performed in this area.

7.2 Drilling potential

Insufficient data is currently available to advise on the locations, depth and amount of drillings. It is expected that to be able to comply with the minimal size of a HMS operating mine drilling will need to be included into the exploration program to be able to estimate a HMS resource.

The following recommendations are made of a drilling survey is considered:

- 1) It is expected that the strike follows the curvature of the active and paleo strandlines. The drilling should therefore perpendicular to these structures.
- 2) Accessibility in the rainy season will be difficult within concession SP1 and EP2/1 as a large part of the estuary is flooded. Therefore it is advised that a drilling survey should be conducted in the dry season (December to April).
- 3) Within the concession areas there are narrow bridges. Dependent on the size of the drilling equipment it needs to be assessed if the shoreline is accessible. If this shoreline is not accessible the bridges need to be widened.
- 4) To reach the area West of Taboriyah or the Bokhinene Island the drilling equipment will need to be transported by boat.
- 5) It is expected that groundwater will be encountered below approximately 2 meters of drilling depth. Therefore, the drill must be able to handle groundwater.

7.3 Remote sensing potential

Through exploration ilmenite has proven to be the predominant heavy mineral within the THM fraction. In the same samples magnetite has also been identified. Because ilmenite and magnetite are magnetic minerals (aerial) magnetic surveys could be considered within the concession areas to detect magnetic anomalies (as discussed in paragraph 4.6.1.1). However, at this stage more information on the bulk magnetic characters should be obtained before such a survey is performed.

As discussed in paragraph 6.3 monazite and zircon have been discovered within the HMS in samples EXP1/L020/X01 and SP1/L008/X02. Therefore potentially an (aero) radiometric geophysical survey can be performed to detect radiometric anomalies of these minerals (as discussed in paragraph 4.6.1.1). However, at this stage more information on the bulk radiometric characters should be obtained before such a survey is performed.

The results of these surveys could potentially determine anomalies and thus determine the locations for further drilling/pitting surveys. But these exploration techniques are very costly (as explained in paragraph 4.6.2) and it is uncertain if an anomaly can be detected due to the weakness of the signal and therefore the results are uncertain.

Therefore it is advised that when the recommended pitting survey is performed, the samples are assessed on their bulk physical properties (density, radiometry and magnetics).

7.4 SP1 Exploration target prospectivity

In this paragraph an exploration target is estimated based on the exploration results and on the potential of a renewed pitting survey. The exploration target for SP1 is based on the exploration results of the sandy coast (3C) where a HMS anomaly was encountered in sample location SP1/L008/X02. Also 3 other sampled locations (ST1/L007, ST1/L009 and ST1/L010) were sampled up to 2 meters within this sandy coast.

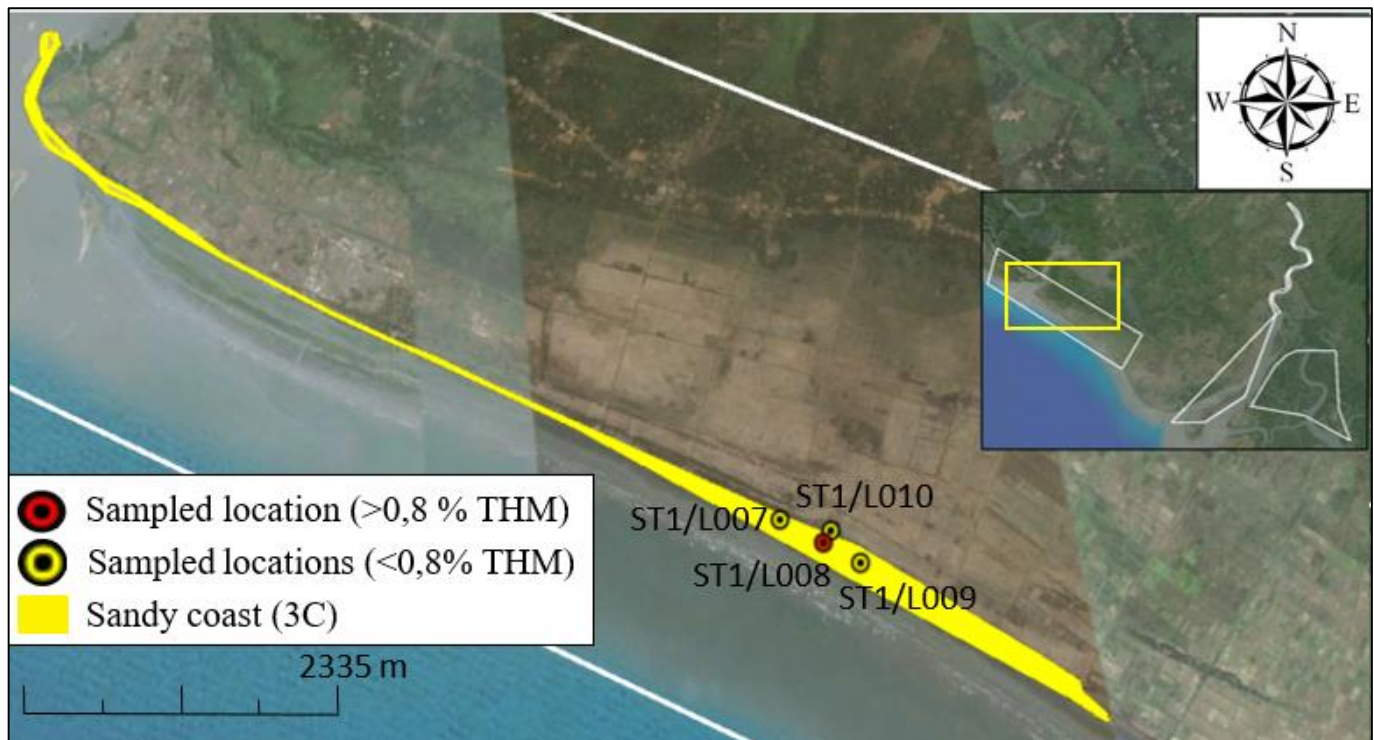


Figure 82: Shows the interpretation of the sandy coast (3C) and the sampled locations in this lithological domain in concession SP1. The interpretation of the surface lithology has been compiled from the exploration results (2014), the local geology described by Goussard (2010) in subsection 5.4 and through interpretation of Google Earth satellite imagery (2015). Base modified from Google Earth (2015).

For the sandy coastline (3C) the exploration target is estimated using the following formula:

$$\text{Exploration Target} = \text{Area} * \text{Thickness} * \text{Average THM content} * \text{Bulk density} \quad (1)$$

Where,

- Exploration target: Expected mass of HMS to be present (tons).
- Area: The sandy coast (3C) has been interpreted through google earth and the exploration program. The strike and width have been estimated using google earth (km²)
- Thickness: The thickness is based on the exploration program where groundwater or clay was discovered beneath geological units limiting the pitting depth at 2 meters from the surface (m).
- Average THM content: The average discovered THM per site location (%).
- Bulk density: Volume to tonnage conversion factors are facilitated by dry bulk density (BD) algorithms. Often for low grade HM dune deposits, a simple BD of quartz sand (1.60 g/cm³) is used for volume to tonnage conversion (Baxter, 1977; Iluka 2008). Therefore, in this case GAM has also used 1.60 g/cm³ for the volume to tonnage conversion (g/cm³).

To be able to quantify a mineral resource the spatial data needs to be extrapolated with a calculated measure of certainty. As too little data points are available within the sandy coast (3C) to extrapolate and calculate a measure of certainty an alternative method (best and worst case scenario) is used to evaluate the exploration results and estimate an exploration target. When the concession area is further explored the result of the exploration will result in between one of 2 outcomes:

1) A worst case scenario

In this scenario sampled locations ST1/L007, 8, 9 and 10 represent the only mineralized zone within the sandy coast (3C) in concession area SP1. Outside of this area the sandy coast (3C) does not contain any HMS mineralization.

2) A best case scenario

In this scenario the area covered by locations ST1/L007, 8, 9 and 10 is representative for the whole sandy coast (3C) in concession area SP1.

7.4.1 Worst case scenario exploration target prospectivity (mass)

Using the block method, the sampled sites within the sandy coast (3C), are divided into blocks (of equal area). In the worst case scenario, the only HMS mineralization present within the sandy coast (3C), is the local mineralization sampled within the area covered by the sample sites ST1/L007-10. The total mass of the in the worst case scenario is calculated by using formula (1) on 97.

Table 28: Shows exploration prospectivity in the worst case scenario SP1.

Block	Length (m)	Width (m)	Thickness (m)	Density (ton/m ³)	Mass (1.000 tons)	Average grade (%THM)	Total mass of HMS (1.000 tons)
7	328	206	2	1,6	216,2	0,4	0,9
8	328	206	2	1,6	216,2	1,1	2,4
9	328	206	2	1,6	216,2	0,3	0,6
10	328	206	1	1,6	108,1	0,2	0,2
Total worst case scenario				1,6	756,8	0,54	4,1

7.4.2 Best case scenario exploration target prospectivity (mass)

In the best case scenario, it is assumed that the total block calculated in the worst case scenario above is continuous along the sandy coast (3C). The total mass of the in the worst case scenario is calculated by using formula (1) on 97.

Table 29: Best case scenario SP1

Block	Length (m)	Width (m)	Average thickness (m)	Density (ton/m ³)	Mass (1.000 tons)	Average grade (%THM)	Total mass of HMS (1.000 tons)
Full sandy coast (3C)	11.500	400	1,75	1,6	14720,0	0,54	69,9

7.4.3 In situ value of VHM SP1

The only data present on the relative amount of valuable heavy minerals and the elemental composition of the HMS are the results obtained through magnetic separation and XRF analysis of sample ST1/L008/X02. To be able to estimate the amount of weakly magnetic material (consisting mainly of ilmenite as the weakly magnetic fraction contained 51% TiO₂) it has been assumed that the HMS within concession area SP1 has the same composition as ST1/L008/X02. This assumption needs to be further researched in future exploration. The estimated amount of weakly magnetic material and the value of this fraction is used to approximate the in situ value of the best and worst case scenarios by using the following formula:

$$In\ situ\ value = Mass\ of\ HMS * VHM\ fraction\ of\ HMS * Value\ of\ VHM \tag{2}$$

Table 30: Potential in situ value VHM's for best and worst case scenario in SP1 (Bedinger, 2014; MiningBulletin, 2015).

VHM	Fraction of VHM (by weight %)	Mass of VHM worst case scenario (1.000 tons)	Mass of VHM best case scenario (1.000 tons)	Value VHM (USD/ton)	Total in situ value worst case scenario (Million USD)	Total in situ value best case scenario (Million USD)
Ilmenite	39	1,6	27,3	95	0,2	2,6

7.5 EP2/1 Exploration target prospectivity

In the concession EP2/1 the sandy coast (3C) contained HMS mineralization within in sample EXP/L021/X01. This was the only sample taken within this geological domain in this concession. Again a worst case and best case scenario exploration target are estimated.

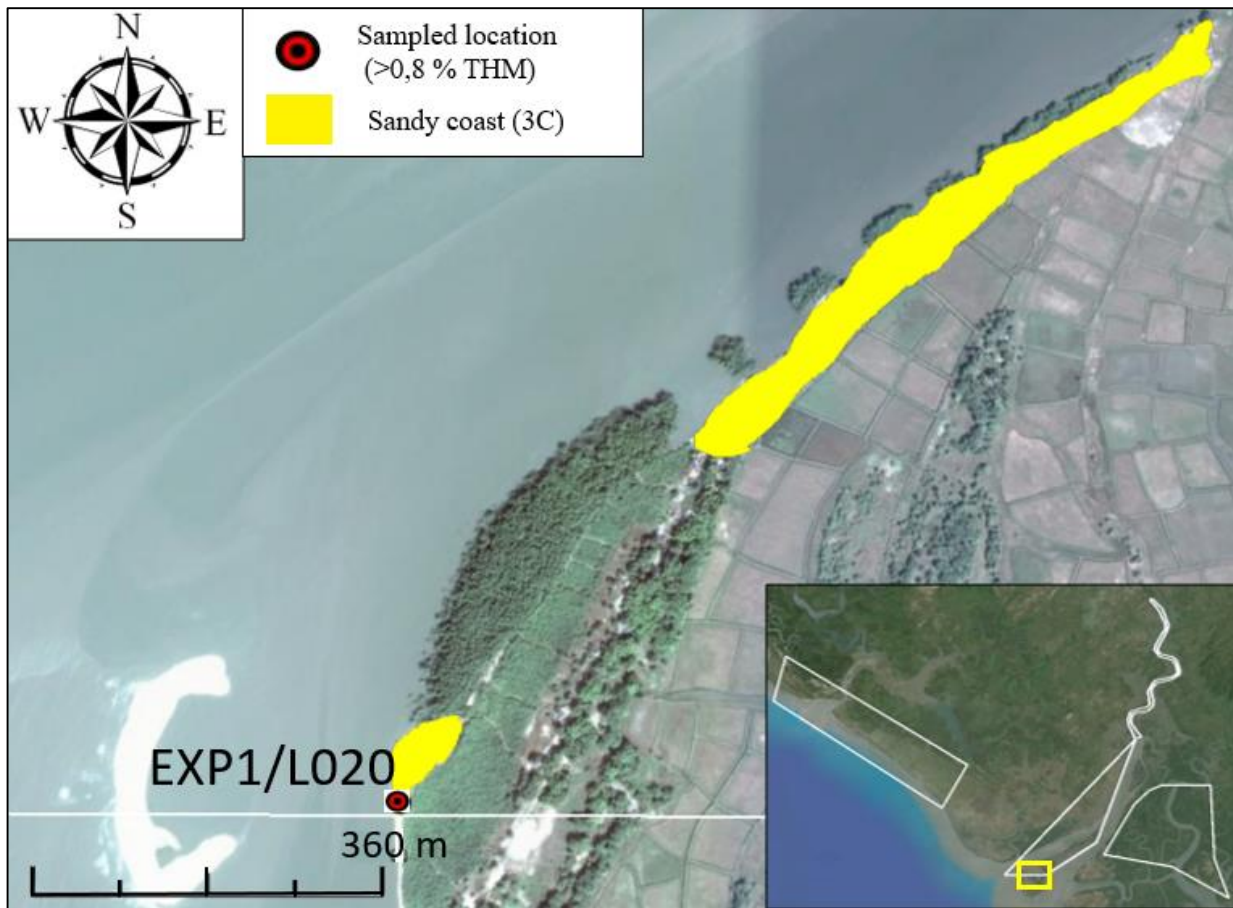


Figure 83: Shows the interpretation of the sandy coast (3C) and the sampled locations in this lithological domain in concession EP2/1. The interpretation of the surface lithology has been compiled from the exploration results (2014), the local geology described by Goussard (2010) in subsection 5.4 and through interpretation of Google Earth satellite imagery (2015). Base modified from Google Earth (2015).

7.5.1 Worst case scenario exploration target prospectivity (mass)

In the worst case scenario, the mineralization encountered within sample EXP/L021/X01 was local and is not continuous within the sandy coast (3C). The dimensions are chosen based on the visual estimation that the HMS (black) mineralization could be seen on the surface for 10 by 10 meters. The thickness is of the sample is based on sample EXP/L021/X01, where groundwater was found under this 1 meter below the surface. The total mass of the in the worst case scenario is calculated by using formula (1) on 97.

Table 31: Worst case scenario EP2/1

Block	Length (m)	Width (m)	Thickness (m)	Density (ton/m ³)	Mass (tons)	Average grade (%THM)	Total mass of HMS (tons)
3C	10	10	1	1,6	160	18,1	29

7.5.2 Best case scenario exploration target prospectivity (mass)

In the best case scenario it is assumed that the mineralization occurred which occurred at sample site location EXP/L021/X01 is continuous in the sandy coast (3C) within the concession area EP2/1. The total mass of the in the worst case scenario is calculated by using formula (1) on 97.

Table 32: Best case scenario EP2/1

Block	Length (m)	Width (m)	Thickness (m)	Density (ton/m ³)	Mass (1.000 tons)	Average grade (%THM)	Total mass of HMS (1.000 tons)
3C	1300	800	1	1,6	1664	18,1	301,2

7.5.3 In situ value of VHM EP2/1

As the weakly magnetic fraction contained 49% TiO₂ it is interpreted that this fraction can be classified as ilmenite. Based on the magnetic separation, when assumed that the VHM content of the HMS is the same as in sample EXP/L020/X01, the following amount estimation of the in situ value of the VHM's are present in the best and worst case scenario in the HMS. To calculate the in situ value formula (2) on page 103 has been used.

Table: Potential in situ value VHM's for best and worst case scenario in EP2/1 (Bedinger, 2014; MiningBulletin, 2015).

VHM	Fraction of HMS (by weight %)	Mass VHM in worst case scenario (tons)	Mass VHM in best case scenario (1.000 tons)	Value (USD/ton)	Total in situ value worst case scenario (USD)	Total in situ value best case scenario (Million USD)
Ilmenite	77	22,3	232	95	2118	22,0
Rutile	1	0,3	3	800	231	2,4
Zircon	8	2,4	24	1000	2316	24,1
Total in situ value					4666	48,5

7.6 Summary and Conclusion

In this chapter the exploration target of a renewed pitting survey has been estimated based on the exploration results. In the best case scenario this exploration target is insufficient to have reasonable prospects for economic extraction and can therefore not be defined as an inferred mineral resource (2011). Therefore, the estimated amount of HMS and VHM are defined as exploration targets following the JORC code (2011).

The exploration targets are estimated following the JORC code (2011) in the most promising concessions SP1 and EP2/1 within the sandy coast (3C). The explorations targets have been estimated using the block model method to estimate the exploration potential in the best and worst case scenario. The estimated HMS within the sandy coast (3C) for both scenarios are summarized below:

- SP1
 - Worst case scenario : 756.800 tons of sediment at 0,5 % THM at 39% ilmenite, 1 % rutile and 7% zircon
 - Best case scenario : 12.880.000 tons of sediment tons at 0,5% THM at 39% ilmenite, 1 % rutile and 7% zircon
- EP2/1
 - Worst case scenario : 160 tons of sediment, at 18,1% and THM at 77% ilmenite
 - Best case scenario : 1.664.000 tons of sediment, at 18,1% and THM at 77% ilmenite

In the best case scenario, the total heavy minerals (THM) which have been found within the first two meters of the concession areas are assumed to be continuous throughout the sandy coastline (3C). In the worst case scenario, the found HMS locations are the only locations within the concession areas which contain HMS and thus the HMS is assumed to be discontinuous throughout the sandy coast (3C).

When compared to the industry standards (2008) the best case scenario (in total 259.200 tons of ilmenite) and worst case scenario (1.624 tons of ilmenite) do not meet the minimal deposit size of 700.000 tons (as explained in paragraph 4.8).

Although this is the case there still remains exploration potential within the concession areas. The sandy coast (3C) has not been sampled deeper than 2 meters, due to a shallow water table, and is therefore not included in the exploration target. In addition to this, the sandy coast (3C) west of Taboriyah has not been explored and has therefor also not been included in the exploration target.

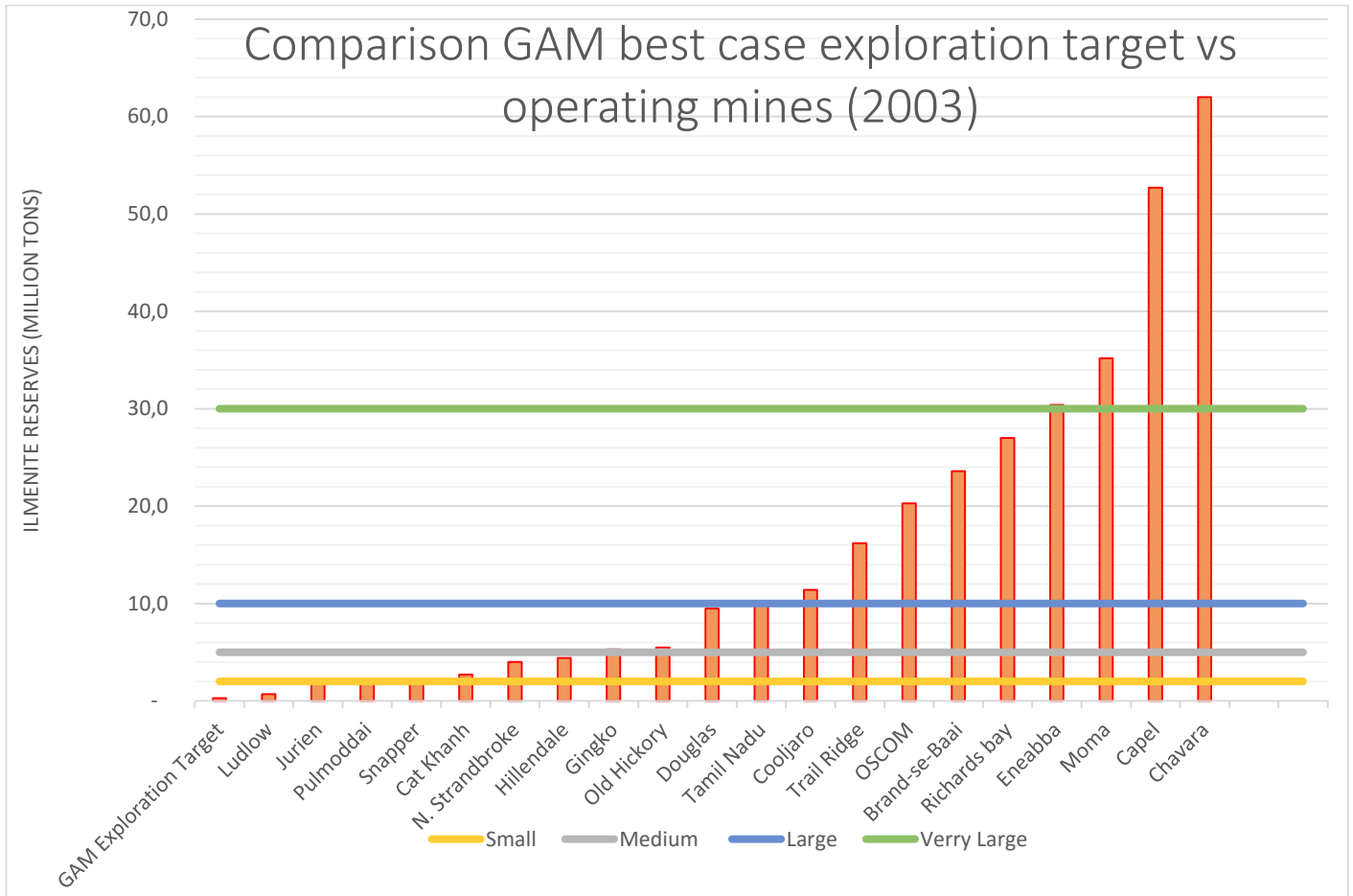


Figure 84: Comparison GAM exploration target versus operating mines (2003). Data modified from Elsner (2011).

All of the HMS mineralization which has satisfied the minimal industry standards has been discovered in the sandy coast (3C). Therefore, pitting is proposed within this geological zone in the concession areas SP1 and EP2/1. The amount of pits and the pit spacing is dependent on the confidence level GAM requires and on the available budget.

8

Discussion

Following the literature study it was expected that HMS mineralization would be present within the concession areas. It was expected that HMS would be found within the (active and paleo) strandlines and the ancient terraces. During exploration HMS mineralization was only encountered within the active strandlines (sandy coast 3C). Within the ancient terraces (Sct) HMS was found but due to the presence of limonite within the samples this HMS mineralization has been interpreted to be caused by the process of ferruginisation and no VHM are present within these samples. When exploration is performed in the future the focus of exploration should lie in the sampling of the sandy coastline (3C). More data within this geological domain can then be used to understand the continuity and homogeneity of the mineralization within this domain.

Based on the source rocks present in Guinea and the drainage basin of the Konkouré river it was expected that the VHM ilmenite would be the primary mineral in the concession areas. In concession EP2/1 the results showed that the HMS contained 76% weakly magnetic material (ilmenite) and that zircon and rutile were occasionally present. But in concession SP1 the HMS contained 39% weakly magnetic material and 24% non-magnetic material (containing zircon). This indicates that the ilmenite content is relatively low. In this case the rutile and zircon content could significantly contribute to the in situ exploration target value. In this case the ilmenite does not necessarily have to be the primary mineral (to be mined). To assess the prospectivity of the exploration target size only the ilmenite content has been considered. Further exploration could show that rutile and zircon contribute significantly to the possible prospectivity of the concession areas. Therefore, the distribution, continuity and homogeneity of each of these VHM minerals in the HMS needs to be further researched.

The different mineral compositions of the samples could be explained by the different depositional processes which have formed these HMS anomalies. The sample which contained a HMS and VHM anomaly in concession EP2/1 was discovered on the surface of the Bokhinene island. The sample which a HMS and VHM anomaly in concession area SP1 was found 1 meter below the surface in the sandy coast. It is expected that these two locations have different depositional mechanisms forming these HMS and VHM anomalies. If further research is performed, it is advised to obtain insight in the relations of the HMS depositional mechanisms and the concentrations of heavy mineral sand.

In concession area SP1 the sampled locations were randomly selected within the sandy coast (3C). In concession area EP2/1 the sample was not randomly selected as the black HMS could be seen on the surface. The approximation of the exploration target size in concession SP1 is based on seven samples of four (randomly) sampled locations. The approximation of the exploration target size in concession EP2/1 is only based on 1 sample and that the extent of mineralization could be seen in an area of 10 x 10 meters. This indicates that the size of the exploration target is estimated with more confidence in concession SP1 than in the concession EP2/1.

In order to provide a better of the approximation of the exploration target size of concession area EP2/1 more samples should have been taken in the sandy coast (3C). This was not done because the concession area was only accessible by boat and therefore the time we had to explore this concession area was limited.

When comparing the results of TU Delft and Scientific Services there is a large difference between the results. This is due to the inaccuracy of the method used. When the valve is opened also material lighter than the separation liquid ($2,95 \text{ kg/dm}^3$) passes through the valve due to a high flow rate. This process is quite difficult to regulate. Due to the experience and certification (ISO certified laboratory) of scientific services it is assumed that these values obtained were more accurate and therefore these values have been used in the estimation of the exploration target. When comparing the analysis at the TU Delft and scientific services it can be seen that the results from the TU Delft (all) show higher amounts of THM. The analysis method at the TU Delft or Scientific Services could not be repeated due to the limitation of funds (at the TU Delft the cost of the separation liquid was too expensive and could not be reused).

Summary and Conclusion

During this thesis the central question has been if the concession areas contain sufficient HMS mineralization to continue exploration and further invest in the GAM concession areas.

Literature research shows that the concession areas SP1 and EP2/1 potentially to contain a HMS deposit as the following requirements for a HMS deposit formation have been satisfied:

- The highly metamorphic rocks (Kassila, Babola, Mani Sub-series) are expected to be the source rocks for ilmenite and rutile. This source rock lies 10 km to the north of the concession areas. The potential source rocks for zircon in Guinea are the Proterozoic granites.
- A transport mechanism is present to transport the VHM from the source rocks into the concession areas. This transport mechanism, which captures the weathered sediment from the source rocks, is the drainage basin of the Konkouré river.
- The enrichment processes wind, surf and wave action in the swash zone, marine longshore drift, high energy surf and surge driven by turbulence during storm events and leucoxenation are potentially present within the concession areas, but this needs to be validated through further exploration.

Through interpretation of satellite imagery geological structures which are associated with HMS mineralization, such as active and paleo strandlines and ancient terraces, have been discovered in concession areas SP1 and EP2/1. The other concession areas (OP1 and EP3/1) are expected to be less prospective as these concessions do not contain these geological structures.

The concession areas were explored in February 2014. HMS was discovered in the sandy coast (in concession areas SP1 and EP2/1) and contained the expected VHM minerals ilmenite, rutile and zircon. Besides these VHM minerals monazite and staurolite have also been discovered.

Sample EXP1/L020/X01 in concession EP2/1 and sample ST1/L008/X02 in concession SP1 showed the highest concentrations of THM and VHM. Due to budget limitations these were the only samples fully analysed.

Sample EXP1/L020/X01 complies with the industry standards summarized in paragraph 4.8 on grain size and THM content. The TiO_2 content (48,88% TiO_2) is a bit lower than the industry standard (50% TiO_2). The ZrO_2 content (38,89% ZrO_2) is well below the industry standard summarized in paragraph 4.8 (66% ZrO_2). The high (29,31%) TiO_2 content of the non- magnetic fraction with no iron indicates the presence of rutile.

Sample ST1/L008/X02 complies with the industry standards summarized in paragraph 4.8 on grain size and THM content. The TiO_2 content (51,26% TiO_2) is a bit higher than the industry standard (50% TiO_2). The ZrO_2 content (23,1% ZrO_2) is well below the industry standard discussed in paragraph 4.7 (66% ZrO_2). The high (46,34 %) TiO_2 content of the non- magnetic fraction with no iron indicates the presence of rutile.

Based on the exploration results of the most promising concessions (SP1 and EP2/1 within the sandy coast) an exploration target size has been estimated for future exploration following the JORC code (2011). Insufficient data points are available to use an extrapolation method to calculate the (un)certainty of the potential HMS continuity and homogeneity. Therefore, an alternative method has been used to approximate an exploration target by estimating the amount of HMS present using the block model in a best and a worst case scenario. In the best case scenario, the THM which has been found in the first two meters of the concession areas is continuous throughout the sandy coast (3C). In the worst case scenario, the found HMS locations are the only locations within the concession areas which contain HMS and thus the HMS is discontinuous throughout the sandy coast (3C). For both these scenarios estimations have been made for the tonnage and grade of HMS present within the concessions SP1 and EP2/1:

- SP1
 - Worst case scenario : 756.800 tons of sediment at 0,5 % THM at 39% ilmenite, 1 % rutile and 7% zircon
 - Best case scenario : 12.880.000 tons of sediment tons at 0,5% THM at 39% ilmenite, 1 % rutile and 7% zircon
- EP2/1
 - Worst case scenario : 160 tons of sediment, at 18,1% and THM at 77% ilmenite
 - Best case scenario : 1.664.000 tons of sediment, at 18,1% and THM at 77% ilmenite

When compared to the industry standards (2008) the best case scenario (259.200 tons of ilmenite) and worst case scenario (1.624 tons of ilmenite) do not meet the minimal deposit size of 700.000 tons of ilmenite.

However, the estimation of the exploration target is only based on the sampled geological domains. The area west of Taboriyah contains a sandy coastline which has not been explored yet and has therefore not been taken into account when estimating the exploration target size. In addition, the exploration target is based on the first 2 meters of sediment in the sandy coast. If a drilling survey is conducted HMS could be found deeper than 2 meters. Therefore, sufficient exploration potential remains within the concession areas to discover a HMS deposit which could have reasonable prospects for economical extraction. From a geological point of view, it is therefore advised to continue with the exploration project. But GAM has to weigh the costs and the geological and non-geological risks of further exploration against the potential increase of the value when a HMS deposit or resource is discovered in the concession areas.

The main risk that GAM currently faces at this stage of the project is following the laws of the mining code. An exploration report is required every 6 months in accordance with the Guinean Mining (2011). Due to the Ebola outbreak exploration within the concession areas is unsafe and therefore the requirement of the Guinean mining code has not been fulfilled. This issue poses a threat to the ownership of the concession permits. When obligations of the Guinean Mining Code (2014) are not met the permits can be revoked and the exploration expenditures will be nullified.

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Recommendations

The following recommendations are made based on the results and experiences obtained through this thesis work:

- Exploration:
 - Conduct a pitting survey in the first 2 meters of sandy coast East of Taboriyah to validate the exploration target.
 - Conduct a pitting survey in the first 2 meters of sandy coast West of Taboriyah to increase the exploration target size.
 - Conduct a drilling survey to assess the HMS potential at larger depths (than 2 meters) to increase the exploration target size.
 - Conduct the exploration survey in the dry season (December – April). In wet season the concession areas are more difficult to access and are under water. Also the groundwater level will be higher which makes sampling more difficult.
 - A boat is necessary to access the concession areas East of Taboriyah and the island of Bokhinene. This will make the transport of drilling equipment difficult.
 - If sufficient funds are available purchase or rent a handheld XRF. This will enable the identification of HMS and VHM's while collecting samples. If there are insufficient funds for a handheld XRF, pan the samples to obtain insight in the presence of HMS.
 - It is expected that groundwater will be encountered below approximately a depth of 2 meters. This should be taken into consideration when choosing pitting or drilling method.
- Sample analysis:
 - The grain size analysis can be done more extensively. If sufficient funds are available more size fractions can be sieved to determine the distribution of the HMS over these size fractions.
 - To obtain insight in the accuracy of the sample analysis methods used and in the final confidence in the deposit size estimation it is recommended that at each stage multiple samples are taken to estimate the error at each stage of sample analysis.
 - It is recommended to also analyse the bulk properties of the samples to be able to assess the viability of using magnetic or other remote sensing methods to detect the HMS in the concession areas.
- Estimation of concession prospectivity:
 - To be able to estimate a HMS deposit size (resource) with sufficient amount of confidence more samples from the same geological domain should be sampled per concession area. In different concession areas different depositional mechanisms can be present. These different depositional mechanisms will concentrate the HMS in a different manner.

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Appendices

Appendices A: Site descriptions

ST1/L001



Figure 85: Image of ST1/L001 where A: Partially lateralized and weathered surface material, B: Fluvial River worked material (inclined layers) and C: Marine sands (horizontal layers)

ST1/L002

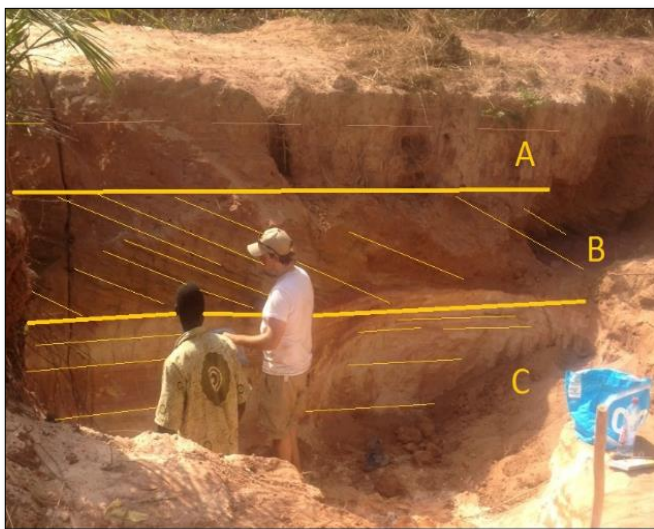


Figure 86: Image of ST1/L002, where A: Partially lateralized and weathered surface material, B: Fluvial River worked material (inclined layers) and C: Marine sands (horizontal layers)

ST1/L003

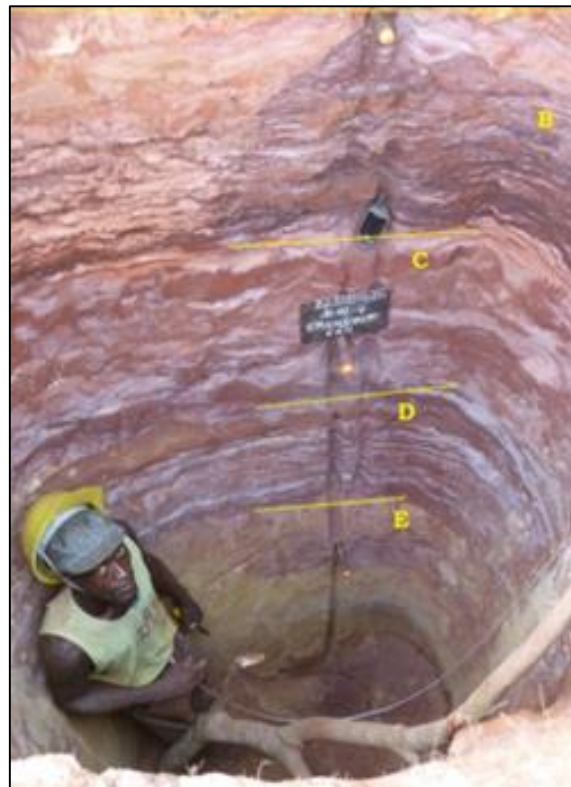


Figure 87: Figures of top and bottom of pit, where B: Red Sand (horizontal layers), C: Red sand, D: Red Sand (horizontal layers) and E: Marine sands

ST1/L004

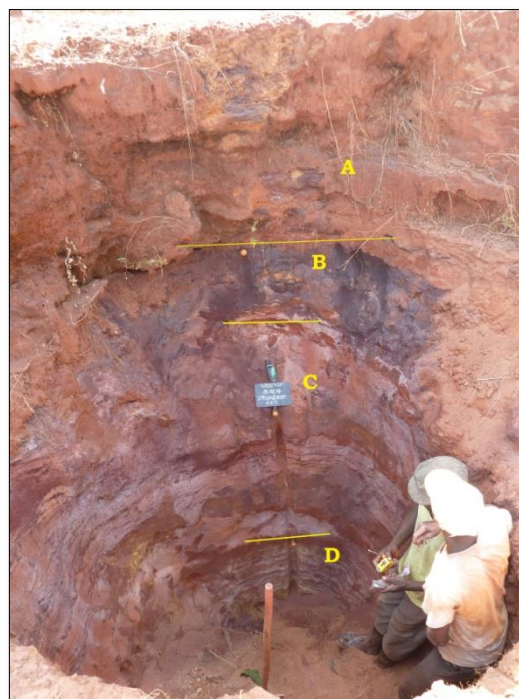


Figure 88: Image of ST1/L004. A: Mixture of rocks, sand and weathered surface material (Start of laterization process); B: Red sand; C: Red sand D: Red sand (horizontal layers)

ST1/L005



Figure 89: Image of ST1/L005, where A: Laterite and weathered surface material, B: Barren, C: Barren and D: Barren

ST1/L006



Figure 90: Image of ST1/L006, where A: Laterite, B: Barren, C: Barren and D: Marine sands

ST1/L007



Figure 91: Image of ST1/L007, where A: Mixture of humus and sand and B: Marine Sand

ST1/L008



Figure 92: Image of ST1/L008, where A: Mixture of humus and sand and B: Marine Sand

ST1/L009



Figure 93: Image of ST1/L09, where A: Mixture of humus and sand and B: Marine Sand.

ST1/L010



Figure 94: Image of ST1/L010, where A: Mixture of humus and sand and B: Marine Sand

ST1/L011



Figure 95: Image of ST1/L011, where A: Mixture of humus and sand and B: Marine Sand

ST1/L012



Figure 96: Image of pit ST1/L012, where A: Mixture of humus and sand, B: Sandy coast and C: Clay.

ST1/L013



Figure 97: Image of ST1/L013, where A: Laterite, B: Marine sands, C: Marine sands, D: Marine sands and E: Marine sands

ST1/L014



Figure 98: Image of ST1/L014, where A: Sand, B: Sand Inclined layers, C: Sandy coast horizontal layers and D: Sandy coast horizontal layers.

ST1/L015



Figure 99: Image of ST1/L015, where B: Red sand Inclined layers, C: Red sand Horizontal layers, D: Red sand Horizontal layers and E: Red sand Horizontal layers

ST1/L016



Figure 100: Image of ST1, where A: Mixture of humus and sand and B: Marine sand

ST1/L017

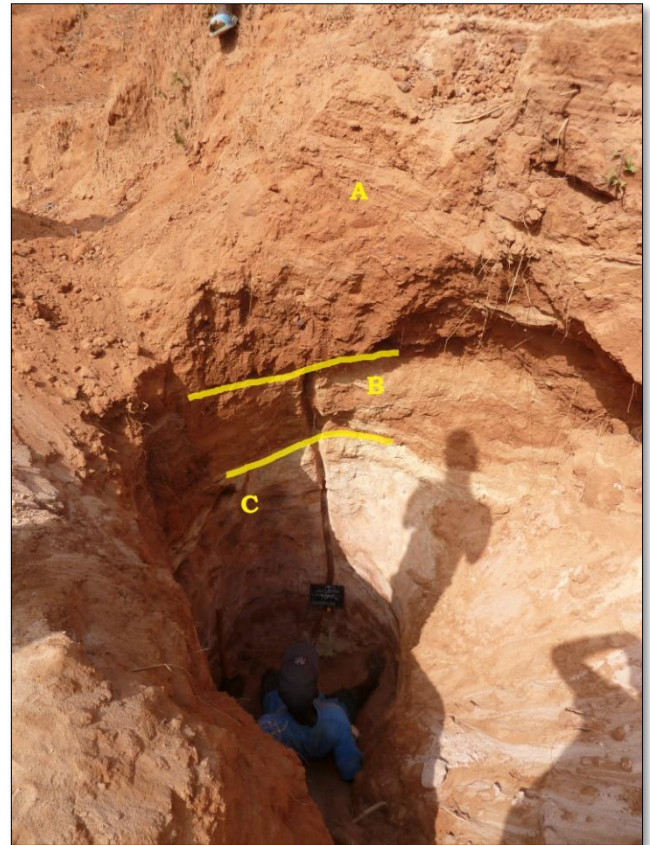


Figure 101: Image of ST1/L017, where A: Mixture of humus and sand, B: Sandy coast and C: Marine sand.

ST1/L018



Figure 102: Geology of ST1/L018,, where A: Mixture of humus and sand and B: Sand

ST1/L019



Figure 103: Image of ST1/L019, where A: Ferric sediment, B: Sand horizontally layered and C: Sandy coast (horizontally layered)

EXP1/L020



Figure 104: Image of EXP/L020, where A: Marine sand, B: Black sand and C: Marine sand

EXP1/L021



Figure 105: Image of location ST1/L021, where A: Mixture of humus and sand, B: Sandy coast and C: Mud

EXP1/L022



Figure 106: Image of ST1/L022, the site consists of mud.

ST1/L024



Figure 107: Image of ST1/L024, where A: Mixture of humus and sand and B: Clay

ST1/L025



Figure 108: Image of ST1/L025, where A: Mixture of humus and sand, B: Sand and C: Marine sand

ST1/L026



Figure 109: Image of ST1/L026, where A: Mixture of humus and sand and B: Sand

ST1/L027



Figure 110: Image of ST1/L027 which consist of sand and mud.

ST1/L028

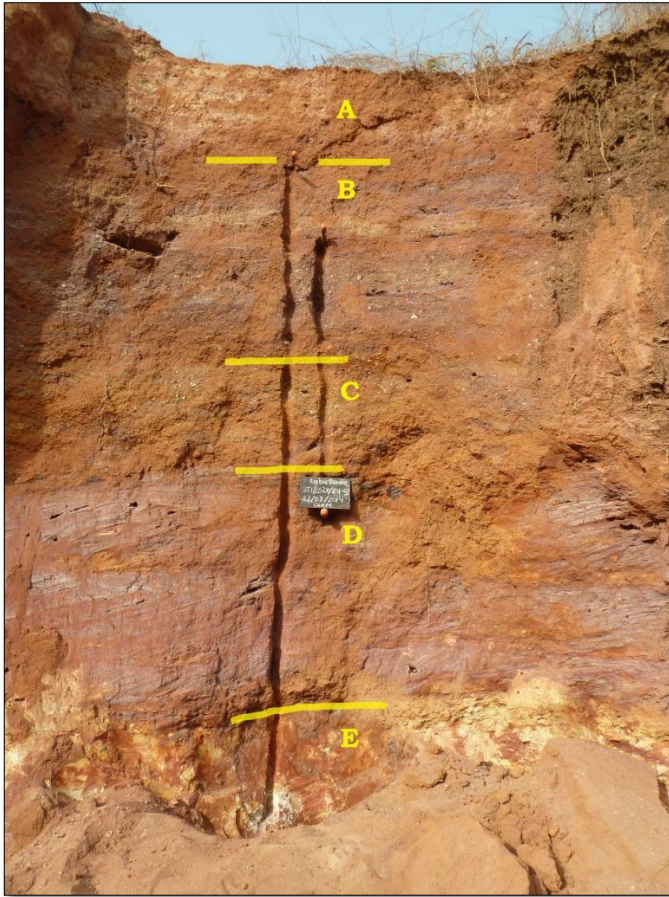


Figure 111: Image of ST1/L028, where A: Mixture of humus and sand, B: Horizontal layers, C and D: Red sand and E: marine sand

Appendix B: Log sheets

Table 33: Log sheets exploration

SAMPLE TAG	DATE	TIME	LATITUDE	LONGITUDE	ELEVATION (m)	LOCALITY	SAMPLE TOP (m)	SAMPLE BASE (m)	THICKNESS (m)	WATER TABLE (m)	QUALITY	GEOLOGY	COLOUR	Visual MINERALOGY
ST1/L001/X01	15-2-2014	1645	N 09°57.140'	W 013°54.403'	9	Bassingui	0,00	1,00	1,00		Friable	Sand and mud	pink, brown	-
ST1/L001/X02	15-2-2014	1645	N 09°57.140'	W 013°54.403'		Bassingui	1,00	2,00	1,00		Friable	Sand	yellow, pink, orange	-
ST1/L001/Xpure	15-2-2014	1645	N 09°57.140'	W 013°54.403'		Bassingui	0,26	0,88	0,62		Friable	Sand	brown	-
ST1/L002/X01	15-2-2014	1521	N 09°57.140'	W 013°54.403'	18	Bassingui	0	1	1,00		Friable	Sand and mud, laterite	orange, yellow	-
ST1/L002/X02	15-2-2014	1521	N 09°57.140'	W 013°54.403'		Bassingui	1	2	1,00		Friable	Sand	pink, yellow, black	-
ST1/L002/X03	15-2-2014	1521	N 09°57.140'	W 013°54.403'		Bassingui	2	3	1,00	3	Friable, humid	Argillite	pink, yellowish	-
ST1/L002/Xpure	15-2-2014	1521	N 09°57.140'	W 013°54.403'		Bassingui	0,43	1,24	0,81		Friable	Sand	black, yellow, pink, brown	-
ST1/L003/X01	16-2-2014	1424	N 09°57.274'	W 013°54.756'	24	Bassingui	2,2	3,2	1,00		Friable	Sand	Purple, brown, orange	-
ST1/L003/X02	16-2-2014	1424	N 09°57.274'	W 013°54.756'		Bassingui	3,2	4,2	1,00		Friable	Sand	Orange	-
ST1/L003/X03	16-2-2014	1424	N 09°57.274'	W 013°54.756'		Bassingui	4,2	5,2	1,00		Friable	Sand	Crème, yellow	-
ST1/L003/Xpure	16-2-2014	1424	N 09°57.274'	W 013°54.756'		Bassingui	2,2	3,92	1,72		Friable	Sand	Black, red	-
ST1/L004/X01	16-2-2014	1542	N 09°57.274'	W 013°54.769'	23	Bassingui	1,2	2,2	1,00		Friable	Sand	Purple, brown, orange	Heavy minerals, mica
ST1/L004/X02	16-2-2014	1542	N 09°57.274'	W 013°54.769'		Bassingui	2,2	3,2	1,00		Friable	Sand	Orange	Quartz, silica
ST1/L004/Xpure	16-2-2014	1542	N 09°57.274'	W 013°54.769'		Sabendet	1,2	1,7	0,50		Friable	Sand	Purple, brown, orange	Heavy minerals, mica
ST1/L005/X01	16-2-2014	1330	N 09°57.166'	W 013°54.462'		Sabendet	3	4	1,00		Friable	Sand	Red	-
ST1/L005/X02	16-2-2014	1330	N 09°57.166'	W 013°54.462'		Sabendet	4	5	1,00		Friable	Sand	Red, brown	-
ST1/L005/X03	16-2-2014	1330	N 09°57.166'	W 013°54.462'		Sabendet	5	6	1,00		Friable	Sand	Pink, brown	-
ST1/L005/X04	16-2-2014	1330	N 09°57.166'	W 013°54.462'		Sabendet	6	7	1,00		Humid, mrollable	Sand	Brown, crème	-
ST1/L005/Xpure	16-2-2014	1330	N 09°57.166'	W 013°54.462'		Sabendet	5,23	5,75	0,52		Friable	Sand	Pink	Zircon
ST1/L006/X01	16-2-2014	1624	N 09°57.618'	W 013°55.635'	19	Sabendet	0,6	1,6	1,00		Friable	Sand	Pink, brown	-
ST1/L006/X02	16-2-2014	1624	N 09°57.618'	W 013°55.635'		Sabendet	1,6	2,6	1,00		Friable	Sand	Pink, brown	-
ST1/L006/X03	16-2-2014	1624	N 09°57.618'	W 013°55.635'		Sabendet	2,6	3,6	1,00		Friable	Sand	Pink creme	-
ST1/L006/X04	16-2-2014	1624	N 09°57.618'	W 013°55.635'		Sabendet	3,6	4,6	1,00	4,6	Humid, mrollable	Sand	Orange, creme	-
ST1/L006/Xpure	16-2-2014	1624	N 09°57.618'	W 013°55.635'		Sabendet	0,6	1,67	1,07		Friable	Sand	Bron, pink	Zircon
ST1/L007/X01	17-2-2014	1735	N 09°55.703'	W 013°53.909'	13	Santi	0,54	1,54	1,00		Humid, friable	Marine Sand	Lemon, Orange	-
ST1/L007/X02	17-2-2014	1735	N 09°55.703'	W 013°53.909'		Santi	1,54	2,54	1,00	2,54	Humid, friable	Marine Sand	Yellow, Lemon	-
ST1/L008/X01	18-2-2014	1255	N 09°55.594'	W 013°53.751'	12	Santi	0,7	1,7	1,00		Humid, Friable	Marine Sand	Orange	-
ST1/L008/X02	18-2-2014	1255	N 09°55.594'	W 013°53.751'		Santi	1,7	2,7	1,00	2,45	Humid, Mollable	Marine Sand	Orange	-
ST1/L009/X01	18-2-2014	1147	N 09°55.498'	W 013°53.617'	12	Santi	0,57	1,57	1,00		Humid, Friable	Marine Sand	Grey	-
ST1/L009/X02	18-2-2014	1147	N 09°55.498'	W 013°53.617'		Santi	1,57	2,17	0,80		Humid, Mollable	Marine Sand	Grey	-
ST1/L010/X01	18-2-2014	1232	N 09°55.677'	W 013°53.681'	11	Santi	0,61	1,61	1,00	1,61	Humid, Mollable	Marine Sand	Orange	-
ST1/L011/X01	18-2-2014	1300	N 09°56.678'	W 013°54.434'	19	Santi	0,07	1,07	1,00	1,64	Friable, humid	Marine Sand	Orange, Grey	silica, quartz, ilmenite
ST1/L012/X01	18-2-2014	1330	N 09°56.179'	W 013°54.389'	20	Santi	0,74	1,74	1,00	1,74	Friable, humid	Marine Sand	Grey	Quartz
ST1/L013/X01	18-2-2014	1604	N 09°59.067'	W 013°54.386'	24	Kobarare	2,5	3,5	1,00		Friable	Sand	Orange, Crème	silica, quartz, ilmenite
ST1/L013/X02	18-2-2014	1604	N 09°59.067'	W 013°54.386'		Kobarare	3,5	4,5	1,00		Friable	Sand	Orange, Grey	Zircon, quartz, ilmenite
ST1/L013/X03	18-2-2014	1604	N 09°59.067'	W 013°54.386'		Kobarare	4,5	5,5	1,00		Friable	Sand	Crème, pink	silica, quartz
ST1/L014/X01	19-2-2014	1138	N 09°57.246'	W 013°52.647'		Toumbouya	0,3	1,3	1,00		Friable	Sand	Grey, Orange	Zircon, quartz, ilmenite
ST1/L014/X02	19-2-2014	1138	N 09°57.246'	W 013°52.647'		Toumbouya	1,3	2,3	1,00		Friable	Sand	Grey	Zircon, quartz, ilmenite
ST1/L014/X03	19-2-2014	1138	N 09°57.246'	W 013°52.647'		Toumbouya	2,3	3,3	1,00		Friable	Sand	Grey, Crème	Ilmenite, traces of copper
ST1/L014/Xpure	19-2-2014	1138	N 09°57.246'	W 013°52.647'		Toumbouya	0,3	2,13	1,83		Friable	Sand	Grey	Zircon
ST1/L015/X01	19-2-2014	1252	N 09°57.231'	W 13°52.668'	15	Koba	1	2	1,00		Friable	Sand	Orange	-
ST1/L015/X02	19-2-2014	1252	N 09°57.231'	W 13°52.668'		Koba	2	3	1,00		Friable	Sand	Pink	Feldspate, sulfur, silica
ST1/L015/X03	19-2-2014	1252	N 09°57.231'	W 13°52.668'		Koba	3	4	1,00		Friable, humid	Sand	Grey	Ilmenite, sulfur, quartz
ST1/L015/Xpure	19-2-2014	1252	N 09°57.231'	W 13°52.668'		Koba	1	3	2,00		Friable	Sand	Pink	Feldspate, sulfur, silica
ST1/L016/X01	19-2-2014	1345	N 09°57.262'	W 013°52.609'	19	Koba Tatema	0,8	1,8	1,00		Friable	Sand	Orange, light pink	Zircon, quartz, ilmenite
ST1/L016/X02	19-2-2014	1345	N 09°57.262'	W 013°52.609'		Koba Tatema	1,8	2,8	1,00		Friable	Sand	Reddish	Zircon, quartz, ilmenite
ST1/L016/X03	19-2-2014	1345	N 09°57.262'	W 013°52.609'		Koba Tatema	2,8	3,8	1,00	3,8	Humid, Friable	Sand	Orange	Ilmenite, traces of copper
ST1/L016/Xpure	19-2-2014	1345	N 09°57.262'	W 013°52.609'		Koba Tatema	0,8	2,4	1,60		Friable	Sand	Light pink	Zircon, quartz, ilmenite
ST1/L017/X01	19-2-2014	1551	N 09°59.071'	W 013°54.377'	14	Katzeb	1,6	2,6	1,00		Friable	Sand	Orange	Silica
ST1/L017/X02	19-2-2014	1551	N 09°59.071'	W 013°54.377'		Katzeb	2,6	3,6	1,00		Friable, humid	Sand	Light pink	Quartz, silica, sulfur
ST1/L018/X01	19-2-2014	1535	N 09°59.058'	W 013°54.335'	15	Katzeb	0,4	1,4	1,00		Friable	Sand	Chocolate	Quartz, silica
ST1/L018/X02	19-2-2014	1535	N 09°59.058'	W 013°54.335'		Katzeb	1,4	2,4	1,00		Friable	Sand	Chocolate	Silica
ST1/L018/X03	19-2-2014	1535	N 09°59.058'	W 013°54.335'		Katzeb	2,4	3,4	1,00		humid	Sand	Yellow, orange	Quartz, silica
ST1/L019/X01	19-2-2014	1455	N 09°57.248'	W 013°52.743'	24	Koba Tatema	0,9	1,9	1,00		Friable, humid	Sand	Chocolate	Zircon, quartz, silica, ilmenite
ST1/L019/X02	19-2-2014	1455	N 09°57.248'	W 013°52.743'		Koba Tatema	1,9	2,9	1,00		Friable, humid	Sand	Orange	silica, quartz, ilmenite
EXP1/L020/X01	20-2-2014	1450	N 09°49.699'	W 13°46.893'		Bokhinene	0	1,4	1,40	1,5	Humid	first 10 cm ilmenite	Black, white	First 10 cm ilmenite, then
EXP1/L020/Xpure	20-2-2014	1450	N 09°49.699'	W 13°46.893'		Bokhinene	0	0,1	0,10		Humid	ilmenite	Black	ilmenite
EXP1/L021/X01	20-2-2014	1500	N 09°49.536'	W 013°46.766'	21	Bokhinene	0	1	1,00	1,2	Humid, Friable	Sand	Grey	Ilmenite, zircon, quartz
EXP1/L022/X01	20-2-2014	1400	N 09°49.664'	W 13°46.616'	22	Bokhinene	0	0,6	0,60	0,6	Humid, Mollable	Sand and mud	Light green	quartz, silica
ST1/L024/X01	21-2-2014	1320	N 09°55.982'	W 013°52.889'	17	Tanene	0	1	1,00		Humid	Sand	Chocolate, Red, dark green	-
ST1/L024/X02	21-2-2014	1320	N 09°55.982'	W 013°52.889'		Tanene	1	1,5	0,50	1,5	Mollable, humid	Sand	Dark green	-
ST1/L025/X01	21-2-2014	1350	N 09°56.774'	W 013°53.823'	22	Tatema	2,85	3,85	1,00		Friable, humid	Sand	Orange	Quartz, ilmenite, silica
ST1/L025/X02	21-2-2014	1350	N 09°56.774'	W 013°53.823'		Tatema	3,85	4,85	1,00		Friable, humid	Sand	Crème	Ilmenite, silicium
ST1/L026/X01-03	21-2-2014	1450	N 09°57.791'	W 013°53.844'	21	Katiya	0,8	3,1	2,30		Friable	La couche arab (Sand	Yellow	Silica, quartz
ST1/L027/X01	21-2-2014	1543	N 09°58.984'	W 013°55.890'	23	Taboriya	0,4	1,3	0,90	1,3	Humid, Mollable	Sand	Grey	-
ST1/L028/X01	21-2-2014	1614	N 09°56.528'	W 13°52.650'	24	Koba Tanene	0,5	1,5	1,00		Friable	Sand	Light pink	Quartz, silica, zircon
ST1/L028/X02	21-2-2014	1614	N 09°56.528'	W 13°52.650'		Koba Tanene	1,5	2,5	1,00		Friable	Sand and pebbles	Light pink	Quartz, silica
ST1/L028/X03	21-2-2014	1614	N 09°56.528'	W 13°52.650'		Koba Tanene	2,5	3,5	1,00		Friable, little bit	Sand	Light Pink	Ilmenite, silica
ST1/L028/XPure	21-2-2014	1614	N 09°56.528'	W 13°52.650'		Koba Tanene	1	1,32	0,32		Friable	Sand	Pink	Zircon, silica

Appendix C: Lab Experimental procedure

Appendix C1: Size analysis (De-sliming)

Aim: Separating size fractions -45 μm , +45 μm and -1 mm and +1mm.

Samples are dried and weight recorded. Entire sample (usually about 1kg) is screened through 45 μm screen. Plus fraction recovered, dried and weighed to determine the % slimes (Scientific Services, 2014).

1. The sample once received and reviewed with paperwork is then weighed.
2. Water is added to the sample approximately 3:1 (H₂O: S). Attrition for 10minutes is adequate.
3. The sample is then wet screened with a 1mm and 45 μm screen.
4. Ensure the both screens are clean and free from any damage. If damage is evident - report this sieve to the QC.
5. Place the +1mm and +45 μm , -1mm sample into stainless steel pans with tags representing the sample number. These trays are then placed in an oven for drying. The -45 μm is discarded is the wet screening process.
6. Once dried these samples are weighed.
7. The sample (-1mm, +45 μm) is then sent through for THM

Appendix C2: HLS

Aim: Determination of % THM Samples concentration using tetra-bromo-ethane (TBE) at 2.95SG (Scientific Services, 2014).

1. TBE is placed into the glass flask up to the indicated mark.
2. Place approximately 1 scope of sample into the flask.
3. Wash down the sides of the container and inner pole with TBE to ensure all sediments are in the TBE.
4. Start the mixer for 10 seconds.
5. Wash down again to ensure sediments don't get lost.
6. Let lie for 5-10 minutes – until the bottom tube is clear.
Because TBE has a 2.95SG so the lights will float. Therefore, waste/lights/floats will stay at the top of the container. The concentrate sinks to the bottom. Once the tube water is clear release the tube and allowing the sediment to be captured in the filter paper placed below.
7. With the remaining sample – redo the process to ensure no concentrate is lost.
8. Finally, flush out the floats by opening the tube and allowing the sample to fall into another beaker with filter paper – allow this to stand capturing all the TBE which will be reused at a later stage.
9. When the sample is in the filter paper – wash through with acetone.
10. Take the filter paper of the concentrates and carefully pour into a bag – then open the filter paper ensuring nothing is lost.
11. Place the floats into the waste drums unless specified by the client to do otherwise.
And reuse the TBE.

Appendix C3: Magnetic and Para magnetic separation

Aim: Separating magnetic and non-magnetic fractions.

The magnetic/paramagnetic separations are undertaken using a Carpco High Intensity Lift magnet. This works by feeding the heavy mineral sand grains down a chute at an even and controlled rate where they come under influence of a rotating 'roll' magnet. The strength of the magnetic field can be varied by changing the current. The grains are separated by their magnetic susceptibility where the more magnetic grain are lifted over a gate while the non-mag grains drop into a receiver. By increasing the magnetic intensity, the grains are separated into the various components after multiple runs (Scientific Services, 2014).

Thus the 1st magnetic setting is at a very low strength which separates the very magnetic material (i.e. the Magnetite) off from the rest of the sample where it is recovered for weighing (Scientific Services, 2014).

The 2nd step is to increase the magnetic field strength and take off the "crude ilmenite" which mineral is para-magnetic due to it being roughly 50% Iron and 50% Titanium (Scientific Services, 2014).

The 3rd stage involves turning the magnet to full strength where the non-mag fraction is recovered. This is the important fraction where the Zircon and Rutile (leucoxene inclusive) are recovered as they are entirely non-magnetic. The other para-mag portion from this split is known as the 'Mag-others' and will contain things like incomplete leucoxene, iron rich garnets, monazite etc. (Scientific Services, 2014).

The whole process involves passing the sample 15 to 20 times through the instrument.

Appendix C4: Major and trace elements (XRF)

Aim: Trace major elements within magnetic fractions

The three fractions recovered by the process described above are pulverized in a swing mill prior to being analysed (Scientific Services, 2014).

1. Approximately 2 g of pulverized material is weighed into a pre-weighed crucible which is placed in a furnace at 1000°C for 4 hours and re-weighed. This determines the LOI (loss on Ignition).
2. 0.6500g of the fired material is added to 5.6000g of Lithium Borate flux and mixed well.
3. This sample / flux mixture is fused using a Claisse M4 gas fusion instrument where a fused disc is produced in a platinum mild.
4. This fused disc is analysed for the Major Elements on an analytical PW2400 WDXRF instrument using a specially developed Mineral Sands Application developed by Dr. Clive Feather.
5. The method is developed using specific CRM's (Certified Reference Material) to calibrate each element and to correct for inter-element interferences.

Appendix D: Exploration results

Appendix D1: Grain size and soil classification

Several classification systems exist for the grouping of soils using grain sizes. The system used in this thesis is the system set up by the United States Department of Agriculture (USDA).

Table 34: USDA soil classification system (University of Massachusetts Lowell, 2015).

Component	Grain Size Range USDA	
	Minimum (mm)	Maximum (mm)
Gravel	2	unlimited
Sand	0,05	2
Silt	0,002	0,05
Clay	0	0,002

The samples have been analysed using different lower limit for the gravel (1mm) than is specified by the USDA (2mm). For some samples it is therefore not conclusive to which class they belong and have therefore been described in the table below as Sand/Gravel.

Table 35: Grain size and soil classification. Red indicates Sand/Gravel, yellow indicates sand and green indicates silt/clay. (Siegfried, 2014; Scientific Services 2014)

Sample Number	Grain size (%)			Classification	Interpretation Siegfried (2014)
	+1 mm	-1 mm ; + 45µm	-45µm		
ST1/L001/X01	3	91,2	5,8	Sand	Partially laterized and weathered surface material/red sand
ST1/L001/X02	0,9	91,2	7,9	Sand	Red sand
ST1/L002/X01	9,5	81,3	9,2	Sand	Partially laterized and weathered surface material/red sand
ST1/L002/X02	8,9	83,2	7,9	Sand	Red sand
ST1/L002/X03	0	85,6	14,4	Sand	Marine sand
ST1/L003/X01	34,9	55,7	9,4	Sand	Red sand
ST1/L003/X02	24,2	68,3	7,5	Sand	Red sand
ST1/L003/X03	0,4	92,6	7	Sand	Red sand/marine sand
ST1/L004/X01	12,1	77,4	10,5	Sand	Red sand
ST1/L004/X02	20	74,6	5,4	Sand	Red sand
ST1/L005/X01	9,6	83,8	6,6	Sand	Red sand
ST1/L005/X02	2,6	91	6,4	Sand	Red sand
ST1/L005/X03	7,7	88,5	3,8	Sand	Red sand
ST1/L005/X04	1,7	94,3	4	Sand	Red sand/marine sand
ST1/L006/X01	3,3	89,9	6,8	Sand	Red sand
ST1/L006/X02	2,5	91,8	5,7	Sand	Red sand
ST1/L006/X03	8,7	87,5	3,8	Sand	Red sand
ST1/L006/X04	2,6	94,3	3,1	Sand	Marine sand
ST1/L007/X01	0,3	97,8	1,9	Sand	Marine sand
ST1/L007/X02	1,5	96,2	2,3	Sand	Marine sand
ST1/L008/X01	0,1	99,1	0,8	Sand	Marine sand
ST1/L008/X02	0	98,2	1,8	Sand	Marine sand
ST1/L009/X01	0,2	99,5	0,3	Sand	Marine sand
ST1/L009/X02	0,6	97,1	2,3	Sand	Marine sand
ST1/L010/X01	0	98,2	1,8	Sand	Marine sand
ST1/L011/X01	6,8	89,7	3,5	Sand	Marine sand
ST1/L012/X01	0,7	97,3	2	Sand	Marine sand
ST1/L013/X01	15,4	79,3	5,3	Sand	Fluvial red sand
ST1/L013/X02	7,1	86,7	6,2	Sand	Fluvial red sand
ST1/L013/X03	5,8	90,9	3,3	Sand	Fluvial red sand

ST1/L014/X01	45,2	47,4	7,4	Sand/ Gravel	Fluvial red sand
ST1/L014/X02	17,2	77,8	5	Sand	Fluvial red sand
ST1/L014/X03	16,1	81,2	2,7	Sand	Fluvial red sand
ST1/L015/X01	44,8	46,9	8,3	Sand/ Gravel	Fluvial red sand
ST1/L015/X02	25,8	67,4	6,8	Sand	Fluvial red sand
ST1/L015/X03	12,8	83	4,2	Sand	Fluvial red sand
ST1/L016/X01	19,2	74,5	6,3	Sand	Laterite sand
ST1/L016/X02	22	70,8	7,2	Sand	fluvial red sand
ST1/L016/X03	33,8	63,4	2,8	Sand	fluvial red sand
ST1/L017/X01	7,3	85,4	7,3	Sand	barren
ST1/L017/X02	3,8	89,6	6,6	Sand	Fluvial red sand
ST1/L018/X01	29	58,2	12,8	Sand	Fluvial red sand
ST1/L018/X02	23,2	67,3	9,5	Sand	Fluvial red sand
ST1/L018/X03	4,9	90,8	4,3	Sand	Fluvial red sand
ST1/L019/X01	63,8	31,5	4,7	Sand/ Gravel	Fluvial red sand
ST1/L019/X02	25,4	66,2	8,4	Sand	Fluvial red sand
EXP1/L020/X01	0,3	99,1	0,6	Sand	HMS
EXP1/L021/X01	0,2	99,5	0,3	Sand	Marine sand
EXP1/L022/X01	0,1	96,3	3,6	Sand	Sand
ST1/L024/X01	2,7	11,1	86,2	Silt/ Clay	Clay
ST1/L024/X02	0	0,5	99,5	Silt/ Clay	Clay
ST1/L025/X01	23,2	62,3	14,5	Sand	Barren
ST1/L025/X02	8,1	85,8	6,1	Sand	Barren
ST1/L026/X01-03	6,6	56,9	36,5	Sand	Barren
ST1/L027/X01	0,8	98,4	0,8	Sand	Barren
ST1/L028/X01	58,9	27,9	13,2	Sand/ Gravel	Fluvial
ST1/L028/X02	23,6	62,2	14,2	Sand/ Gravel	Fluvial
ST1/L028/X03	4	89,5	6,5	Sand	Fluvial
ST1/LOC14/Blank	35,7	58	6,3	Sand	

Appendix D2: Comparison exploration results with industry standards

In subsection 4.8 the industry standards for HMS have been summarized. In table 36 the results of the grain size analysis and the heavy liquid separation are compared with these standards.

- Minimum of 0,8% THM
- Maximum of 10% undersize (<45 microns)
- Maximum of 20% oversize (>1 mm)

The samples which comply with these industry standards have been highlighted in green. The samples which do not comply with the industry standards are highlighted in red.

Table 36: Shows grain size and Total Heavy Mineral content (THM). In red the samples have been highlighted which do not comply with the industry standards. In green the results are highlighted which do comply with the industry standards (Scientific Services, 2014).

Sample Number	Scientific Services			TU Delft		
	Grain size (%)		THM (%)	Grain size (%)		THM (%)
	Oversize (+1mm)	Undersize (- 45µm)		Oversize (+1mm)	Undersize (- 45µm)	
ST1/L001/X01	3	5,8	0,1			
ST1/L001/X02	0,9	7,9	0,4			
ST1/L002/X01	9,5	9,2	0,1			
ST1/L002/X02	8,9	7,9	0,4			
ST1/L002/X03	0	14,4	0,1			
ST1/L003/X01	34,9	9,4	2,5	30,1	1,2	8
ST1/L003/X02	24,2	7,5	0,7			
ST1/L003/X03	0,4	7	0,4			
ST1/L004/X01	12,1	10,5	1,7	11,1	1,3	7
ST1/L004/X02	20	5,4	0,7			
ST1/L005/X01	9,6	6,6	0,2			
ST1/L005/X02	2,6	6,4	0,4			
ST1/L005/X03	7,7	3,8	0,4			
ST1/L005/X04	1,7	4	0,4			
ST1/L006/X01	3,3	6,8	0,5			
ST1/L006/X02	2,5	5,7	0,3			
ST1/L006/X03	8,7	3,8	0,3			
ST1/L006/X04	2,6	3,1	0,2			
ST1/L007/X01	0,3	1,9	0,2			
ST1/L007/X02	1,5	2,3	0,6			
ST1/L008/X01	0,1	0,8	0,2			
ST1/L008/X02	0	1,8	2			
ST1/L009/X01	0,2	0,3	0,2			
ST1/L009/X02	0,6	2,3	0,3			
ST1/L010/X01	0	1,8	0,2			
ST1/L011/X01	6,8	3,5	0,3			
ST1/L012/X01	0,7	2	0,2			
ST1/L013/X01	15,4	5,3	0,3			
ST1/L013/X02	7,1	6,2	0,3			
ST1/L013/X03	5,8	3,3	0,2			
ST1/L014/X01	45,2	7,4	3,3	42	0,2	4
ST1/L014/X02	17,2	5	0,7			
ST1/L014/X03	16,1	2,7	0,6			
ST1/L015/X01	44,8	8,3	1,6	40,7	1,8	2
ST1/L015/X02	25,8	6,8	2,5			
ST1/L015/X03	12,8	4,2	2,2	13,6	1,4	4
ST1/L016/X01	19,2	6,3	0,3			
ST1/L016/X02	22	7,2	0,3			
ST1/L016/X03	33,8	2,8	0,5			
ST1/L017/X01	7,3	7,3	0,3			
ST1/L017/X02	3,8	6,6	0,1			
ST1/L018/X01	29	12,8	0,3			
ST1/L018/X02	23,2	9,5	0,4			
ST1/L018/X03	4,9	4,3	0,2			
ST1/L019/X01	63,8	4,7	1,8			
ST1/L019/X02	25,4	8,4	0,5			
EXP1/L020/X01	0,3	0,6	18,1	0,3	0,4	21
EXP1/L021/X01	0,2	0,3	0,4			
EXP1/L022/X01	0,1	3,6	0,4			
ST1/L024/X01	2,7	86,2	0,1			
ST1/L024/X02	0	99,5	0			
ST1/L025/X01	23,2	14,5	0,2			
ST1/L025/X02	8,1	6,1	0,1			
ST1/L026/X01-03	6,6	36,5	0,1			
ST1/L027/X01	0,8	0,8	0			
ST1/L028/X01	58,9	13,2	2,5			
ST1/L028/X02	23,6	14,2	1,6	53,1	11,8	3
ST1/L028/X03	4	6,5	0,5	2,2	0,7	6
ST1/LOC14/Blank	35,7	6,3	1,8			

In subsection 4.8 the industry standards for HMS have been summarized. The minimum specifications for the ilmenite are 50% TiO₂ and for zircon 66% ZrO₂. In the table below the results of the elemental composition are shown. The magnetic fractions which comply with the industry standards are highlighted in green. The magnetic fractions which do not comply with the industry standards are highlighted in red.

Table 37: Shows the XRF results analysed by Scientific Services (2014). The magnetic fractions which comply with the industry standards are highlighted in green. The magnetic fractions which don't comply with the industry standards are highlighted in red.

Sample	La ₂ O ₃ (%)	CeO ₂ (%)	P ₂ O ₅ (%)	ZrO ₂ (%)	Fe ₂ O ₃ (%)	TiO ₂ (%)	SiO ₂ (%)	Al ₂ O ₃ (%)	MgO (%)	Total (%)
ST1/L008/X02 Magnetic	0	0	0,13	1,55	38,64	44,47	4,16	3,37	0,78	99,28
ST1/L008/X02 Weakly magnetic	0	0,05	0,13	0,33	38,04	51,26	2,31	2,35	0,58	99,25
ST1/L008/X02 Magnetic Others	0,02	0,07	0,31	0,36	32,28	37,78	10,35	8,58	0,86	99,84
ST1/L008/X02 Non Magnetic	0,02	0,55	0,22	23,1	1,72	46,34	18,55	4,44	0,05	98,27

EXP1/L020/X01 Magnetic	0	0,1	0,06	2,09	48,07	43,75	1,1	0,65	1,58	98,67
EXP1/L020/X01 Weakly magnetic	0,01	0,1	0,05	1,22	48,05	48,88	1,09	0,12	1,03	99,41
EXP1/L020/X01 Mag Others	0,04	0,12	0,21	0,92	25,8	28,2	25,02	4,94	10,9	100,6
EXP1/L020/X01 Non Magnetic	0,02	0,8	0,23	38,89	0,63	29,31	23,66	0,96	0,21	96,99

Appendix E: JORC Table 1

Table 38: Compliance of exploration HMS (February 2014) Section 1: Sampling Techniques and Data.

Criteria	JORC explanation	GAM
a) Sampling techniques	Nature and quality of sampling (e.g. cut channels, random chips, or specific specialized industry standard measurement tools appropriate to the minerals under investigation, such as down hole gamma sondes, or handheld XRF instruments, etc.). These examples should not be taken as limiting the broad meaning of sampling.	Pitting was used to obtain samples at 1m intervals. Approximately 2kg of homogenized sample was collected per meter pitted. One sample was analysed by scientific services and one at the TU delft university. All samples were either coned and quartered with approximately 1kg/sample/meter collected or all the material was collected per meter and transported to laboratory. Both procedures are appropriate for mineral sands sampling.
	Include reference to measures taken to ensure sample representability and the appropriate calibration of any measurement tools or systems used.	Samples were collected from pits by using a spoon and holding a bucket below to collect a sample at the specified interval (1m). It was ensured visually that the whole meter was sampled the same way. If this was not done correctly the sampling was performed again to obtain a represent sample and optimize pit sample recovery. As the bucket was held below the spoon recovery was very high for all samples (>90%). After the whole sample was quartered the sample was transferred into a sample bag
	Aspects of the determination of mineralization that are Material to the Public Report.	Total Heavy Minerals (THM) is defined as mineral grains within 43 to 1000 µm size range with an SG greater than 2.95 kg/dm ³ .
b) Drilling techniques	Drill type (e.g. core, reverse circulation, open-hole hammer, rotary air blast, auger, Bangka, sonic, etc.) and details (e.g. core diameter, triple or standard tube, depth of diamond tails, face-sampling bit or other type, whether core is oriented and if so, by what method, etc.).	Pits wells were dug vertically with an approximate diameter of 1,5 meter and sampled to the water table.
c) Drill sample recovery	Method of recording and assessing core and chip sample recoveries and results assessed.	Sample recovery was visually checked.
	Measures taken to maximize sample recovery and ensure representative nature of the samples.	Samples were collected from pits by using a spoon and holding a bucket below to collect a sample at the specified interval (1m). It was ensured visually that the whole meter was sampled the same way. If this was not done correctly the sampling was performed again to obtain a representative sample and optimize pit sample recovery. As the bucket was held below the spoon recovery was very high for all samples (>90%). After the whole sample was quartered the sample was transferred into a sample bag.
	Whether a relationship exists between sample recovery and grade and whether sample bias may have occurred due to preferential loss/gain of fine/coarse material.	No known relationship between recovery and grade exist. Sample bias might have occurred due to the difference due to preference loss/gain of fine /coarse material.
d) Logging	Whether core and chip samples have been geologically and geotechnical logged to a level of detail to support appropriate Mineral Resource estimation, mining studies and metallurgical studies.	Geological logging the majority of the samples was conducted in the field by the author of this thesis (Roosegaarde Bisschop). Lithological and mineral data was recorded onto a field handbook (Appendix C). All samples were systematically logged recording colour, hardness, composition and estimated HM% and mineralogy.
	Whether logging is qualitative or quantitative in nature. Core (or coast, channel, etc.) photography.	Photos were taken of the site location and analysed by geologist Pete Siegfried.

	The total length and percentage of the relevant intersections logged.	As shown in Appendix C.
e) Sub-sampling techniques and sample preparation	If core, whether cut or sawn and whether quarter, half or all core taken.	Non-core. Not appropriate for HMS.
	If non-core, whether riffled, tube sampled, rotary split, etc. and whether sampled wet or dry.	Samples were collected in their entirety on site. Samples were moist. Samples were cone and quartered with comprehensive mixing in between all stages of sampling (2 subsamples, Samples were moist).
	For all sample types, the nature, quality and appropriateness of the sample preparation technique.	Virtually all drill samples consist of sand, clayey sand or sandy clay. For these samples the sample preparation method is appropriate. <ul style="list-style-type: none"> • Dry for 5-8 hours in oven • De-slime through 45µm screen (minus 63µm fraction is “% slimes”) • Dry and weigh plus 45µm fraction • Split off and weigh plus 1.00mm fraction (“%oversize”) • Stir +1.00mm -45µm fraction into TBE (2,95 SG) liquid in separation funnels. • Sinks were drained, washed, dried and weighed to give “%THM”. The magnetic/paramagnetic separations are undertaken using a Carpco High Intensity Lift magnet. The whole process involves passing the sample 15 to 20 times through the instrument. Approximately 2 g of pulverized material is weighed into a pre-weighed crucible which is placed in a furnace at 1000°C for 4 hours and re-weighed. This determines the LOI (loss on Ignition). 0.6500g of the fired material is added to 5.6000g of Lithium Borate flux and mixed well. This sample / flux mixture is fused using a Claisse M4 gas fusion instrument where a fused disc is produced in a platinum mould. This fused disc is analysed for the Major Elements on an analytical PW2400 WDXRF instrument using a specially developed Mineral Sands Application developed by Dr. Clive Feather. The method is developed using specific CRM's (Certified Reference Material) to calibrate each element and to correct for inter-element interferences.
Quality control procedures adopted for all subsampling stages to maximize representivity of samples.	Quality control procedures adopted for all subsampling stages to maximize representivity of samples.	In the laboratory the samples were subsampled using a riffle splitter (dry).
	Measures taken to ensure that the sampling is representative of the in situ material collected, including for instance results for field duplicate/second-half sampling.	To obtain sample representivity for the 1m intervals it was aimed to obtain the same amount of sediment for each subsection of this interval. Field duplicates of each sample were taken. The results of this analysis of the duplicates are shown in appendix F.
	Whether sample sizes are appropriate to the grain size of the material being sampled.	Every sample consists of 1 meter (approximately 1 Kg) of the pit. It is expected that this sample size is appropriate for the sampling of HMS.
f) Quality of assay data and laboratory tests	The nature, quality and appropriateness of the assaying and laboratory procedures used and whether the technique is considered partial or total.	Laboratory analysis was performed at scientific services which is an ISO certified laboratory. Industry standard was used for particle size separation (+43 -1 mm). Industry standards used for HLS separation (TBE at 2,95 kg/m3).
	For geophysical tools, spectrometers, handheld XRF instruments, etc., the parameters used in determining the analysis including instrument make and model, reading times, calibrations factors applied and their derivation, etc.	NA

	Nature of quality control procedures adopted (e.g. standards, blanks, duplicates, external laboratory checks) and whether acceptable levels of accuracy (i.e. lack of bias) and precision have been established.	To verify the results obtained at scientific services, analysis of the samples was performed at the technical university of Delft.
g) Verification of sampling and assaying	The verification of significant intersections by either independent or alternative company personnel.	Verification between assay results and geologist THM% estimates of significant intersections (EXP1/L020) have not been performed yet.
	The use of twinned holes.	Not performed
	Documentation of primary data, data entry procedures, data verification, data storage (physical and electronic) protocols.	To verify the results obtained at scientific services, analysis of the samples was performed at the technical university of Delft. For sample EXP1/L020/X01 the THM was 18,1% at scientific services and 21% at the TU Delft.
	Discuss any adjustment to assay data.	NA
h) Location of data points	Accuracy and quality of surveys used to locate drill holes (collar and down-hole surveys), trenches, mine workings and other locations used in Mineral Resource estimation.	The location of the sampling locations is reported by using a handheld Garmin GPS Map 62st . All pits were pitted as vertical. Accuracy: Google earth was also used:
	Specification of the grid system used.	NA
	Quality and adequacy of topographic control.	For the topographic data points google earth was used.
i) Data spacing and distribution	Data spacing for reporting of Exploration Results.	All samples represent 1m of pitting
	Whether the data spacing and distribution is sufficient to establish the degree of geological and grade continuity appropriate for the Mineral Resource and Ore Reserve estimation procedure(s) and classifications applied.	Pit spacing and distribution is not sufficient to allow valid interpretation of geological and grade continuity appropriate to the estimation procedure and classification applied
	Whether sample compositing has been applied.	Sample compositing has not been applied.
j) Orientation of data in relation to geological structure	Whether the orientation of sampling achieves unbiased sampling of possible structures and the extent to which this is known, considering the deposit type.	The mineralisation is generally flat lying enabling vertical pitting to be appropriate.
	If the relationship between the drilling orientation and the orientation of key mineralised structures is considered to have introduced a sampling bias this should be assessed and reported if material.	
k) Sample security	The measures taken to ensure sample security.	The samples were under the security of the author of this thesis until delivered by the UPS to scientific services in South Africa.
l) Audits or reviews	The results of any audits or reviews of sampling techniques and data.	An experienced mineral sands geologist (Pete Siegfried) has been involved in generation of the exploration methods, procedures and geological database

Appendix F: Guinean mining code rights and obligations CPDM (2011)

Appendix F1: Right to carry out mine operations

The mining of HMS falls within the article category 3 (metallic substances) of article 13 (mines) in the Guinean mining code CPDM (2011). Mines are all other deposits of all Mineral Substances not classified as quarries, with the exception of liquid or gaseous hydrocarbons.

All individuals or legal entities with the necessary technical and financial capability to successfully complete the activities in question may undertake staking for indications, exploring for mine or Quarry Substances, subject to the conditions set out in this law.

Subject to the provisions of this law, Mine Substances may be exploited by the following:

Any individual or legal entity constituted as a public or private corporation under Guinean law, having the technical and financial capability to undertake the requested operation;

The right to carry out Mining or Quarry Activities can only be acquired by virtue of the following Mining Titles and Authorizations:

Mining titles:

- Exploration Permit;
- Industrial or Semi-Industrial Mining Operation Permit;
- Mining concession.
- Authorizations:
- Staking permits for Mine or Quarry Substances

The mining agreement a Mining Concession is issued for a maximum term of twenty-five (25) years and a Mining Operation Permit for a term of fifteen (15) years are issued in conjunction with a Mining Agreements the form of which is determined by decree. A Mining Agreement is valid for a maximum period corresponding to the term of the title to which it relates. It is renewable for periods of ten (10) years for a mining concession and five (5) years for an operating permit.

The Minister has the authority to sign the Mining Agreement upon receiving the National Mining Commission's approval and with the authorisation of the Council of ministers.

Within a period not exceeding seven (7) business days from the date of its signature, the signed Mining Agreement is then submitted to the Supreme Court for its legal opinion. Following the approval by the Supreme Court, the Mining Agreement is then forwarded to the National Assembly for ratification.

Once signed, the Mining Agreement will be published on the official Website of the Ministry in charge of Mines, or any other site designated by the Minister.

Once ratified, the Mining Agreement will be published in the Official Gazette and on the Official Website of the Ministry in charge of Mines, or any other site designated by the Minister.

The holder of a Mining Title or Authorisation is required to provide all reports to the Mining Administration in five (5) copies, three (3) copies of which are submitted to the MPDC, one copy of which is submitted to the Inspector General for Mines and Geology, one copy of which is submitted to the National Mining Authority and one copy of which is submitted to the National Geological Authority. Each report is submitted in hardcopy and electronic copy, must include all plans, drawings, cuts, tables, and photographs necessary for its understanding.

Reports and other attached documents shall be submitted in French. The Mining Administration will issue a receipt upon the filing of each report.

The content and frequency of these reports are specified in this Code and the implementing regulations of this Code, as well as in the granting laws.

Revocation of Mining Title and Authorisations Mining Title and Authorisations instituted by virtue of this Code may be revoked by the issuing authority for one of the following grounds:

- The exploration or mining activity is suspended or seriously restricted for more than six (6) months in the case of exploration, and more than twelve (12) months for mining operations, without legitimate grounds and in a manner detrimental to the public interest.
- The feasibility study produced demonstrates the existence of a Deposit which is economically and commercially exploitable within the perimeter of the exploration permit, but no mining operations follow within the timeframes set out in and in accordance with the modalities stipulated in Articles 34 and 41 of this Code.
- The violation of any of the provisions of this Code described below:

Appendix F2: Mining titles and obligations

Staking permit

Application method:

A Staking permit is granted to applicants for Exploration Permits in the zones set out in Article 42, with the exception of the zones set out in Articles 111 and 112 of this Code, by the National Director of Mines after obtaining the opinion from the National Geology Authority.

Table 39: Rights and obligations staking permit (CPDM, 2011).

Rights	Obligations
Confers on its holder the right to carry out staking work of Indications of one or several Mine Substances.	The holder of the Authorization is required to submit the results of its staking work to the State.
Renewable 6 months	

Exploration permit

Application method:

- For areas without geological information or with geological information which does not identify a Deposit: “the first applicant receives the title”.
- For areas that have already been prospected, containing a known Deposit or a Deposit that has attracted interest from several companies, the granting procedure will be by competitive and transparent tender offers and transparent call for tenders in accordance with the rules to be set out in regulations, and approved by the National Mining Commission. The call for tender offers must be completed within a maximum period of one (1) year from the effective date of the order of the Minister reserving the Deposit that is the subject of the call for tenders.

On the recommendation of the Minister in charge of Mines, a decree of the President of the Republic will launch the formal call for tender offers.

The instruments that establish the grant, expansion, renewal, transfer, the Lease, revocation or renunciation of Mining Titles must be published in the official gazette and on the official Website of the Ministry in charge of Mines, or any other site designated by the Minister.

The advertisement, by call for tenders, of already prospected Perimeters, with a view to the grant of an Exploration Permit must be published in at least two widely circulated newspapers and at least 45 days before the deadline for the submission of tenders.

Table 40: Rights and obligations exploration permit (CPDM, 2011)

Rights	Obligations
<p>An Exploration Permit confers on its holder the exclusive right to Prospect for the type of mining substance(s) for which the Permit is issued, within the limits of its area and without limitation as to depth.</p>	<p>The Exploration Permit’s granting order defines a minimum work program which the holder must carry out while the Permit is in effect, and the minimum financial outlay it is expected to devote to exploration each year during the term of the Permit and any renewals thereof. To this end, minimum expenditures per km² are instituted for Exploration Permits, the amounts of which are set out in the mining Regulations.</p> <p>The holder of an Exploration Permit must start Exploration work within the area of the Permit no later than six (6) months from the date of issuance of the Permit, and continue same diligently and according to generally accepted mining methods.</p> <p>During this period of six (6) months, the titleholder must complete the activities set forth in the granting order and including the following operations after confirming with the National Mines Authority that work has begun:</p> <ul style="list-style-type: none"> • Prepare activity reports and financial statements approved by the Administration following a period of work lasting at least three days within the exploration perimeter by at least one geologist hired by the titleholder or, alternatively, an aerial geophysical survey including at least three days of flights over the area • Submit copies of the environmental notice to the National Mining Authority and the Mining Promotion and Development Centre; • Provide local authorities, for information purposes, with the Environmental Notice and an explanation of the planned mitigation and rehabilitation measures
<p>During the term of the Exploration Permit, only its holder is entitled to an Operating Permit or Mining Concession for the Deposits found within the perimeter of the Exploration Permit.</p>	<p>This right comes into effect once the titleholder has submitted all the results from the date of the Exploration, surrendered half of the initial area to the State and produced the constitutes five file in accordance with Articles 30 and 37 of this Code.</p>
<p>The holder of an Exploration Permit can enter into a technical partnership enabling it to raise the necessary capital to finance the Exploration activities required for the discovery of a Deposit. This technical partnership will be submitted to the Minister for approval and must not, under any circumstances, consist of a direct or indirect transfer of the Exploration Permit concerned.</p>	
<p>A maximum of five (5) Permits for other substances within a maximum area of 500 km² for Industrial Operations.</p>	

<p>The Industrial Exploration Permit is granted for an initial period whose maximum term is three (3) years.</p>	
<p>The term of an Industrial Exploration Permit may be renewed two (2) times for a maximum period of two (2) years each time, at the request of the holder and on the same conditions as those on which the Permit was granted.</p>	<p>Each of these renewals occurs automatically if the holder has met all of the obligations contained in the granting order and in this Code and, if it so requests, in its application for renewal, a minimum work program adapted to the results of the preceding period and representing a financial outlay at least equal to that set out in the granting order.</p> <p>At each renewal, the Permit area covered by the exploration is reduced by half of its previous size. The area reverting to the applicant must include in the regular area the known deposits for the substances set out in the Exploration Permit. The area which is surrendered to the State must be available for subsequent development. The surface which is surrendered must, to the extent possible, form one or several compact blocks the sides of which are attached to a side of the area of the Mining Title.</p> <p>If at the end of this extension period, the holder of the Exploration Permit has still not submitted the feasibility study to the Mining Administration, the said Permit shall lapse and be cancelled.</p>
<p>1st renewal (2 years)</p>	<ul style="list-style-type: none"> • Copies of all quarterly reports, being twelve (12) reports for industrial permits all results of works and primarily geological, geophysical, geochemical and drilling results accompanied by corresponding map • Documents certifying compliance with the obligations contained in the granting order • The work program with a budget for the subsequent period; and a detailed schedule of work to be completed
<p>2nd renewal (2 years)</p>	<ul style="list-style-type: none"> • Copies of the eight (8) quarterly reports all work results and primarily geological, geophysical, geochemical and drilling results accompanied by corresponding maps • Documents certifying compliance with the obligations contained in the granting order; • The work program with a budget for the subsequent period; and a detailed schedule of work to be completed

Industrial Operating permit

Application method:

Permit is automatically granted to a Guinean company by Decree issued during Council of Ministers on the recommendation of the Minister in charge of Mines and following approval by the National Mining Commission, to the holder of an Exploration Permit who has met its obligations under the Mining Code and filed an application in accordance with the regulations, at least three months prior to the expiration of the validity period of the Exploration Permit under which the application is made.

The application for an Industrial Mining Operation Permit must be accompanied by supporting documentation, the details of which are set out in the mining regulation and must include each of the following:

- a copy of the valid Exploration Permit and proof of payment of all taxes and royalty's due
- A report on the exploration results regarding the nature, quality, volume and geographic location of the mineral resource identified.
- a plan in respect of the first or second surrender, as applicable, accompanied by the results of the exploration work and corresponding to half of the previous area
- a feasibility study including a plan for the development and operation of the Deposit, including, inter alia:
 - Detailed Environmental and Social Impact Study accompanied by a Social and Environmental Management Plan including an Emergency Plan; a Risk Management Plan; a Hygiene, Health and Safety Plan; a Rehabilitation Plan; a Resettlement Plan for the Population affected by the project and the measures to mitigate negative impacts and optimize positive impacts. an economic and financial analysis of the project and the plan for obtaining the requisite Permits and authorizations.
- plans and estimates for industrial infrastructures;
- a plan for supporting Guinean companies in creating and/or reinforcing the capacities of SMEs/SMIs or companies owned or controlled by Guinean nationals for the provision of goods and services generally used for their activities, as well as a plan to promote the employment of Guinean nationals, the minimum number of whom must conform to the quotas set out in this Code;
- a detailed schedule of the work to be done
- a community development plan annexed to the Local Development Agreement covering among others, aspects of training, medical, social, educational, roads, water supply, and electricity infrastructures (the Local Development Agreement will be signed upon delivery of the Title); and an architectural plan of the company's headquarters with an application for land allocation made to the competent Administration (the head office must be constructed within a maximum period of three years from the date an Operating Permit for iron ore, bauxite, gold and diamond is granted).

The grant of an Industrial Operation Permit will result in the cancellation of the Exploration Permit within the area of the Operating Permit.

Should a mineral substance other than the one for which the Operating Permit has been granted be discovered in the course of that exploration, the holder shall have a pre-emptive right in respect of its mining operations. This right must be exercised within a maximum of eighteen (18) months from the date of notification of the discovery to the State.

Table 41: Rights and obligations industrial operating permit (CPDM, 2011)

Rights	Obligations
<p>An Operating Permit confers on its holder the exclusive right to search, prospect, and develop and freely dispose of the mine substances which has been granted to it, within the limits of its area and without limitation as to depth.</p>	<p>The holder of a Semi-Industrial Mining Operation Permit must commence development and exploitation work within a maximum of six (6) months following the date of issuance of the Permit.</p> <p>As of one (1) year after the grant date, the titleholder is subject to a penalty for delay of ten million (10,000,000) GNF per month for the first three months. This penalty will increase by 10% per month over the previous month, effective from the fourth month of delay until the 12th month of delay.</p> <p>The holder of an Industrial Mining Operation Permit must begin development work within a maximum period of one year from the date of issuance of the Permit.</p> <p>As of one year after the grant date, the titleholder is subject to a penalty for delay of one hundred thousand (100,000) USD per month for the first three months. This penalty will increase by 10% per month over the previous month, effective from the fourth month of delay until the 6th month of delay.</p> <p>Eighteen (18) months from the grant date of the Industrial Mining Operation Permit, if the holder has still not started the work in accordance with the provisions of this Code, the granting decree, and the Mining Agreement, the State reserves the right to revoke or cancel the Title in question.</p>
<p>An Operating Permit confers on its holder the exclusive right to search, prospect, and develop and freely dispose of the mine substances which has been granted to it, within the limits of its area and without limitation as to depth.</p>	
<p>An Operating Permit creates, in favour of its holder, a moveable and divisible right that may be sub-leased. This right may be pledged in order to secure loans for Operations</p>	
<p>An Industrial Mining Operation Permit is granted for a maximum period of fifteen (15) years.</p>	
<p>For dredging of riverbeds, the authorized length of the watercourse may not exceed ten (10) km for industrial Permits.</p>	
<p>The term of an Industrial Operation Permit is renewed several times, upon application of its holder and under the same conditions as for its original grant, each time for a period lasting no more than five (5) years</p>	<p>When the holder has met its obligations stipulated upon the delivery or renewal of the Title and those arising under this Code, its Implementing regulations and the terms of reference, or the Mining Agreement.</p>

	<p>The holder of a mining Operating Permit is required to begin the Operating Phase, as defined in Article 168, within the timeframe stipulated in the feasibility study, and this within the grant a maximum period of four (4) years from date of the Mining Title for the Mining Operations Permit for the extraction and export of unprocessed ore and five (5) years for those dedicated to the processing of raw materials within Guinea. After this time period, a penalty for delay corresponding to the unused balance of expenditures contemplated for the calendar year will be applied. This penalty will not be due if the established unused balance of expenditures is less than 10% of the expenditure for the relevant calendar year and / or is the result of an adjustment to the works program validated by the Minister, following the approval by the National Mining Commission.</p>
	<p>The provisions of Article 88 of this Code will apply when the mining work or the expenditure of the titleholder constitutes less than 25% over a period of two consecutive years of the entire minimum work program, or of the total minimum expenditure provided for this period by the Mining Title, or by the terms of reference of the Operating Permit, except in duly justified cases of force majeure; such instances of force majeure not to exceed twelve (12) months.</p>
	<p>For the purposes of this Article, the “commencement of development work” is defined as undertaking preparatory, development and construction work amounting to a minimum sum representing between ten per cent (10%) and fifteen per cent (15%) of the total amount of the investment.</p>

Mining concessions

Requirements Application:

A Mining Concession is automatically granted to a Guinean company by decree issued in a Council of Ministers on the recommendation of the Minister in charge of Mines, following approval by the National Mining Commission, to the holder of an Exploration Permit who has met its obligations under the Mining Code. This application must be made at least three (3) months prior to the expiration of the validity period of the Exploration Permit under which the application is being made.

Investments of an amount equal to, or greater than five hundred million (500,000,000) USD for substances HMS mineral operations.

An application for a Mining Concession shall be accompanied by a file, the details of which are set out in the mining regulations. This file must include each of the following elements:

- a copy of the valid Exploration Permit and proof of payment of all fees and royalties due;
- a report on the exploration results, regarding the nature, quality, volume and geographic location of the mineral resource identified;
- a plan in respect of the first or second surrender, as applicable, accompanied by the results of the exploration work and corresponding to half of the previous area;
- a feasibility study including:
 - a detailed Environmental and Social Impact Study accompanied by a Social and Environmental Management Plan including an Emergency Plan, a Risk Management Plan, a Hygiene, Health and Safety Plan, a Rehabilitation Plan, a Resettlement Plan for the Population affected by the project and the measures to mitigate negative impacts and optimize positive impacts;
 - an economic and financial analysis of the project and the plan for obtaining the requisite permits and authorisations;
 - plans and estimates for industrial infrastructures;
 - a plan for supporting Guinean companies in relating and/or reinforcing the capacities of SMEs/SMIs or companies owned or controlled by Guinean nationals for the provision of goods and services necessary for their activities, and a plan to promote the employment of Guinean nationals, the minimum number of whom must conform to the quotas set out in this Code;
- a detailed schedule of the work to be done
- a community development plan annexed to the Local Development Agreement covering, among others, aspects of training, medical, social, educational, road, water supply, and electricity infrastructures (the Local Development Agreement will be signed upon delivery of the Permit).
- an architectural plan of the company's headquarters with an application for land allocation made to the competent administration (the head office must be constructed within a maximum period of three (3) years from the date of the grant of a Concession for iron ore, bauxite, gold and diamond).

Table 42: Rights and obligations mining permit (CPDM, 2011)

Rights	Obligations
<p>A Mining Concession confers on its holder the exclusive right to carry out all kinds of mining operations of Deposits for the mine substances for which the Concession is granted, within the limits of its perimeter, and without limitation as to depth.</p> <p>A Concession is an immovable, divisible, right which can be sub-leased; this right may be mortgaged in order to secure loans to finance mining operations.</p>	<p>The holder of a Mining Concession must begin development work within a maximum period of one (1) year from the date of the grant of the Mining Concession.</p> <p>As of one year after the date of the grant, the holder will be subject to a penalty for delay of two million (2,000,000) USD per month for the first three (3) months. This penalty will increase by 10% per month over the previous month, effective from the fourth month until the twelfth month of delay.</p> <p>Two (2) years from the grant date of the Mining Concession, if the holder has not commenced the development work in accordance with the provisions of this Code, the decree granting the Mining Concession, and the Mining Agreement, the State reserves the right to revoke or cancel the Title.</p> <p>The holder of a Mining Concession must begin the Operating Phase as defined in Article 168, within the timeframe stipulated in the feasibility study and within a maximum of five (5) years from the grant date of the grant of the Mining Title relating to the Concessions to extract and export unprocessed ore and six (6) years for those dedicated to the processing of raw materials in the territory of Guinea.</p> <p>After this deadline, a penalty for delay corresponding to the balance of unfulfilled investments scheduled for a given calendar year shall apply. This penalty will not be due if the established deficit of unfulfilled expenditures is less than 10% of the expenditure for the relevant calendar year and / or is the result of an adjustment to the works program validated by the Minister, following the approval of the National Mining Commission.</p> <p>The provisions of Article 88 will be applied when the mining work or the total expenditure of the titleholder is less than 25% for a period of two consecutive years of the entire minimum work program, or of the total minimum expenditure provided for this period by the Mining Title or by the terms of reference of the Concession, except in duly justified cases of force majeure; such instances of force majeure not to exceed twelve (12) months.</p> <p>For the purpose of this Article, the “commencement of the development work” is defined as undertaking preparatory, development and construction work amounting to a minimum sum of between ten percent (10%) and fifteen percent (15%) of the total amount of the investment.</p>
<p>The area for which a Concession is granted is defined in the granting decree. It must correspond, as closely as possible, to the boundaries of the Deposit(s), as defined in the feasibility study. The Concession’s perimeter must be the simplest polygon possible, with sides</p>	

aligned North-South and East-West.	
The Mining Concession is granted for a maximum period of twenty-five (25) years.	
The term of a Concession may be renewed, once or several times, each for a maximum period of ten (10) years, upon the application of the titleholder and under the same conditions as for its original grant, notably by filing a new feasibility study	When the holder has met its obligations stipulated upon the delivery or renewal of the Title and those arising under this Code, its implementing regulations and the terms of reference, or the Mining Agreement.