SOUTH EASTERN KENYA UNIVERSITY

SCHOOL OF ENVIRONMENT, WATER AND NATURAL RESOURCES
DEPARTMENT OF GEOLOGY AND METEOROLOGY

GEOLOGY AND ECONOMIC MINERALIZATION OF THE NEOPROTEROZOIC MOZAMBIQUE BELT ROCKS OF THE MWITIKA-MAKONGO AREA, KITUI COUNTY, SOUTH EASTERN KENYA.

BY

GITHENYA K. LINCOLN

F426/KIT/20715/2016

THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF THE MASTER OF SCIENCE DEGREE IN MINERAL EXPLORATION AND MINING OF SOUTH EASTERN KENYA UNIVERSITY.

2020

DECLARATION

I understand that plagiarism is an offence and I, therefore, declare that this thesis is my original work and has not been presented to any other institution for any other award.

Signature……………………………………. Date……………………………….

Githenya K. Lincoln

F426/KIT/20715/2016

This thesis has been submitted for examination with our approval as University Supervisors.

Signature………………………………………. Date……………………………..

Prof. Eliud M. Mathu,

Department of Geology and Meteorology,
South Eastern Kenya University.

Signature……………………………………….. Date……………………………...

Dr. Aaron K. Waswa,

Department of Geology,

University of Nairobi.

Signature………………………………… Date………………………………..

Dr. Patrick C. Kariuki,

Department of Geology and Meteorology,
South Eastern Kenya University.

DEDICATION

This study is dedicated to my parents, Mr Richard Githenya, Mrs Regina Githenya, my wife Metrine and daughter Tamika. It is from them that I derive my motivation every day of my life.

ACKNOWLEDGEMENT

This study was carried out at the South Eastern Kenya University (SEKU), with the full education scholarship from the Graduate Teaching Assistant (GTA) program of the university. The study was also made possible through the financial support from the ASALI project under the leadership of Professor Mary Mburu (SEKU). I am sincerely grateful to the University for the scholarship and many opportunities accorded to me while undertaking my studies. In particular, I want to thank the Department of Geology and Meteorology, through the Chairman of Department, where the study was undertaken.

I am greatly indebted to my supervisors; Professor Eliud M. Mathu, Dr Aaron K. Waswa and Dr Patrick Kariuki who have worked with me tirelessly to ensure the completion of this study. Their support, invaluable advice and constructive criticism are highly appreciated. I wish to express my profound gratitude to them for their committed guidance during the study and for having to read this thesis and help me polish it.

Special thanks go to Mr John Waita, a senior Kenya Government geologist, who participated in the fieldwork and greatly assisted me in the field activities. His instructive and constructive critiques in this study are greatly appreciated. My thanks also go to Mr Mboga, of The Mines and Geological Department in the Ministry of Mining and Petroleum for his input in lapidary work including preparation of petrographic thin sections and analyses of the rock and mineral samples. I also wish to thank the staff in the geochemical section in the Mines and Geological Department who assisted me in the geochemical analyses of rock and mineral samples.

I highly appreciate Mr Mutua, the village administrator in Makongo area and the entire Mwitika-Makongo community, for their cooperation during my stay during the fieldwork.

Lastly, I acknowledge the support received from my entire family especially their encouragement, finances and spiritual guidance. To others who supported me and have not been mentioned, you are still highly appreciated.

Above all, I thank the Almighty God for the care, protection, knowledge and wisdom He has granted me, my family and my supervisors during the entire period of this research work.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF PLATES

ABBREVIATIONS AND ACRONYMS

AAS	Atomic Absorption Spectrophotometer
ANS	Arabian Nubian Shield
DEM	Digital Elevation Model
DN	Digital Number
EMBS	Eastern Mozambique Belt Segment
ENVI	Environment for Visualizing Images
FCC	False Colour Composite
GIS	Geographic Information System
ILWIS	Integrated Land and Water Information System
Landsat	Land Soil and Terrain Satellite
Ma	Million years
NE	North East
NWMBS	Northwestern Mozambique Belt Segment
OIF	Optimum Index Factor
OLI	Operational Land Imaging Sensor
PC1	Principle Component Analysis 1
PCA	Principal Component Analysis
PPL	Plane Polarized Light
PPM	Parts Per Million
RGB	Red Green and Blue
SWMBS	Southwestern Mozambique Belt Segment
USGS	United States Geological Survey
UTM	Universal Traverse Mercator
XPL	Cross Polarized Light
XRD	X-Ray Diffraction
XRF	X-Ray Fluorescence

DEFINITION OF TERMS

Environment for Visualizing Images (ENVI): is a software application used to process and analyze remote sensed imagery.

Geographic Information System (GIS): is a system designed to capture, store, manipulate, analyze, manage, and present spatial or geographic data (Bakker et al., 2001).

Optimum Index Factor (OIF): is a statistical method used to select the most informative colour composite images for any given RGB colour composite.

PCI Geomatica: is a remote sensing desktop software package for processing earth observation data (Waswa, 2015).

Rockworks: is a software program for creating 2D and 3D maps used for mining, petroleum and environmental industry for subsurface visualization (Waswa, et al., 2015).

ABSTRACT

The Mwitika-Makongo research area occurs within the Neoproterozoic Mozambique metamorphic belt in Kenya and is located in Kitui East sub-county of Kitui County. The area is bounded by longitudes 38° 18'E and 38° 26'E and latitudes 1° 22'S and 1° 32'S. This area is easily accessed from the Nairobi-Thika-Kitui-Zombe road or the Nairobi –Machakos-Kitui-Zombe road. From previous geological works, it had been established that several mineral resources of economic potential like iron ore, magnesite, and various gemstones were present in the area. However, despite this possible mineral richness, an enigmatic problem exists where their occurrence, genesis and related mineralization are not satisfactorily understood including their economic potential. To address the aforementioned problem, this study integrated geological, geochemical and remote sensing investigations to establish economic mineralization in the area. The first objectives of this study were to identify lithological units and geological structures related to potential economic minerals. The other objectives were to establish economic minerals formation history and their probable quantity in the study area. Geological methods consisted of, field mapping and geochemical analysis. The remote sensing methods included; band combinations, principal component analysis and lineament extraction. Investigations using remotely sensed data established widespread previously undocumented geological structures, new lithological units and undiscovered mineral alteration zones. Through this study, it was established that the project area lies within a medium to a high-grade metamorphic zone of the Neoproterozoic Mozambique belt. Structurally, the rocks of the project area have a NE trend with westerly or easterly dips. This study identified that the intrusives rock units in the project area were associated with economic mineralization of iron ore, magnesite and heavy mineral sands. Geochemical and petrographic evidence ascertained that the study area is rich in mineral resources that can boost its economic status. For example, the iron ore in Kalima Kathei area contained above 86% Fe_2O_3 which corresponds to acceptable levels of commercial iron ores. From an economic geological point of view, the area has the potential to produce economic rocks like marbles and ornamental rocks, economic minerals like iron ore, Magnesite and heavy mineral sands with traces of titanium. Surface estimation of the resources in the Mwitika-Makongo area was as follows; Marble at 22, 748 tons, iron ore at 172.5 tons and Magnesite at 620 tons. This study, therefore, recommends exploitation of these resources, to bring great economic growth in Kitui County as a whole. This study recommends drilling works to establish the actual tonnage and quality of the established deposits.

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background information of the study

Impact of mining on economic development and growth can be locally or nationally leveraged to build new infrastructure, new technologies and working opportunities for the population. According to Africa Mining Vision, most of the African countries like Kenya, still struggle with making the mineral resources work for them in uplifting the lives of their people (United Nations Economic Commission for Africa, 2009). This can be attributed to the fact that the mining sector in Kenya is relatively small in comparison to its Gross Domestic Product contributions (KPMG, 2016).

Kenya currently relies heavily on importation of manufactured goods especially those whose raw materials are iron and steel. This significantly dims her hopes of providing a high-quality life for all her citizens by 2030. According to Kenya’s Vision 2030 (Government of the Republic of Kenya, 2007), industrialization is one of the economic pillars of this Vision. The country’s new development blueprint is the “Big Four Agenda” that comprise; manufacturing, universal healthcare, affordable housing and food security. For the country to achieve the aforementioned two economic Visions, economic mineral resources are planned to be among those that will play a major role in the process.

The rock and mineral resources in Kenya are many and variable. They include industrial materials like iron to building materials like tuffs and limestone. The country’s mining industry has been touted as a critical anchor in the development or economic growth to alleviate poverty. Despite this, many counties in Kenya especially those with mineral richness exhibit low levels of development and poor standards of living. This negatively affects the reputation of the country given that the Constitution has stipulated bill of rights for every person to the highest attainable standard of health, adequate food and housing (Government of the Republic of Kenya, 2010).

The country is also lagging behind on eradicating extreme poverty for all people by 2030, following its commitment to Sustainable Development Goals (United Nations Development Programme, 2015). Mineral resources in the country can impact positively in achieving the Sustainable Development Goal number nine that aims at promoting inclusive and sustainable industrialization and significantly raise the industry's share of employment and gross domestic product by 2030. Sustainable industrialization can be significantly scaled up through exploration for economic rocks and minerals in the country. Currently, the country is not experiencing good practices in the mining industry since the existing knowledge on mineral resources and geology is old and can only be reviewed through up to date mineral exploration.

The Kenyan Government has realized this challenge and dedicated a ministry to deal with the development of the mining sector. Acts like the Mining Act of 2016 were also enacted to strengthen articles of the Constitution that apply to mineral resources.

To realize this visions of hope and growth in the country like Kenya's Vision 2030 (Government of the Republic of Kenya, 2007) and Sustainable Development Goals (United Nations Development Programme, 2015), exploration works for new economic deposits is necessary. A number of the economic geological deposits (iron ore, titanium, gold, fluorite, soda ash, graphite, limestones and marbles, gemstones, among others) are located within the Kenyan Neoproterozoic (900-500 Ma), Mozambique Belt (Ministry of Mining, 2015).

The segment of the Neoproterozoic Mozambique Belt which transects the Kitui County has been well known following the discovery of massive quantities of marbles, coal and iron ores. Rocks of economic value in the County include; Granites, Trachytes, Phonolites, and Quartzites. Economic mineral resources also present in the County include; Clays, Feldspars, Iron ore, Copper, Magnesite, Gemstones and Heavy Mineral Sands. Through several semi-detailed county geological surveys in the last five years, the Kitui County Government has realized her great potential of mineral wealth and has shown a lot of interest in promoting mining to her population.

The main aim of this research project was therefore to undertake a detailed investigation of the geology and economic mineral resources occurring in the Neoproterozoic Mozambique Belt rocks of Mwitika-Makongo area, Kitui County. The outcome of this research work is expected to be of great importance to the County and National governments, mineral prospectors, developers, scientists, and investors who might have an interest in the Kenya mining industry, particularly in Kitui County.

1.2 Problem statement

There is increased growth in global population than at any time in history, accompanied by a faster mineral consumption than the population as more consumers enter the market for minerals and as the global standard of living increases (Kesler, 2007). The increase in global population has heightened demand for economic rock and mineral resources that are used in various industries like the steel industry, manufacturing, energy resources, aesthetic, medicine, besides others. Rocks and minerals used in manufacturing industries like iron ore, limestones and those used in fertilizers are also on high demand to enhance productivity on existing agricultural lands for future food security given the increasing population.

Mineral resources are non-renewable assets. This finite resources especially those essential as building blocks for technologies, infrastructure, energy and agriculture are in high demand due to population growth and technology advancements. Currently, Kenya relies on the importation of manufactured goods especially those whose raw materials are iron and steel (Aaron Kutukhulu Waswa, 2015). There has been concern about the resources that will support a growing human population, given that the Kenya population exceeds her mineral resources extraction. We can solve this mineral supply crisis by increased mineral exploration.

Realization of viable deposits through exploration will open up the mining industry that will foster economic development by providing opportunities for decent employment for Kenyans. As a step towards finding a solution to this mineral demand, this research work was developed to investigate possible economic mineralization in Makongo area and ascertain if any viable deposits can be realized and utilized for the development of the Mwitika-Makongo Community and the benefit of the nation of Kenya at large.

1.3 Objective of the study

1.3.1 Main Objective

The main objective of this research work was to geologically investigate in detail the geology, geological structures and minerals of the Mwitika-Makongo area, to understand their petrogenesis, economic status and mineral resources present in the study area.

1.3.2 Specific Objectives

(i) To identify lithological units in the project area, especially those that could be hosting potential economic minerals.

(ii) To delineate the geological structures of the Mwitika-Makongo area that may be related to possible economic mineral resource occurrences.

(iii) To establish the petrogenesis of potential economic minerals in the study area and their formation history.

(iv) To establish the quality and quantity of potential economic minerals in different rock units, in the study area, which can be exploited for economic gain.

1.4 Research questions

The following were the questions that the researcher aimed at answering through this research work.

(i) Which lithological units in the project area host potential economic minerals?

(ii) What are the geological structures of the Mwitika-Makongo area that might be hosting economic mineral resources?

(iii) What is the petrogenesis and formation history of the potential economic minerals in the study area?

(iv) What is the quality and quantity of the potential economic minerals in different rock units the project area which can be exploited for economic gain?

1.5 Justification and significance of the study

Economic mineral resources form the structural basis of modern civilization. Minerals appear in many forms in modern civilization, either obvious or concealed. The technological advancements of the 21st century are heightening demand for mineral as new materials and applications are found. This expands the market for mineral commodities stimulating extensive exploration and discovery of new mineral resources.

Minerals play an important role in the Kenyan economy, hence there is a need to carry out scientific research to understand their mode of occurrence, quality and economic potential in Neoproterozoic Mozambique belt rocks. According to Vision 2030, Kenya aims to become the provider of choice for basic manufactured goods in eastern and central Africa. This can only be achieved through improved competitiveness in manufacturing to promote efficiencies. Exploiting of economic rock and mineral resources in Kenya will secure and sustain local industries, raising market share in the regional market and attracting large strategic investors in key industries.

Locally, the study area is classified as semi-arid, where no adequate farming activities can be carried out. Its population is marginalized with a high dependency on animal rearing which is hampered by lack of enough water and inadequate pasture. It is aimed that achievements of this project work through its objectives will greatly help in the realization of the economic mineral resource potential, which would then open up the area for mineral investors. As a result, this would lead to the development of the local community.

Furthermore, it should be noted that the last documented geological mapping in the study area was done by Sanders (1954) and was largely a reconnaissance study. Hence, it may not have established in detail the lithological and mineral resources of this area. Since then, no major geological works have ever been done in the area. It was, therefore, appropriate to review in details the geology of this area to evaluate any potential economic mineral resources.

1.6 Limitation

During the geological fieldwork investigations, it was important to use appropriate geological equipment and machinery. Lack of some of these equipment such as those used in the geochemical analysis in the Geology and Meteorology Department at the university hampered satisfactory progress of this research work. The study area is also remotely located with a limited public transport system and accessing the field for geological investigations was a challenge.

1.7 Delimitation

This research work presents a study of the geological mapping of the Mwitika-Makongo area and the investigated economic status of the possible mineral resources in the area. The study was confined to an area of 100 km^2 of the Mwitika-Makongo area in Kitui County.

This research involved three multi-disciplinary investigations. The first investigation involved remote sensing where satellite imagery of the study area was analysed to delineate target areas for exploration. The second investigation involved geological field mapping where rock and mineral samples were collected from the study area. The last investigation involved the geochemical analysis of collected samples to indicate the quality of potential economic resources.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Geology of Neoproterozoic Mozambique belt rocks

The Mozambique Belt is a major North-South (N-S) trending metamorphic and lithotectonic domain that extends from the Middle East to Mozambique. The belt was formed approximately between 900 and 550 million years (Ma) ago. This belt is interpreted to be an Orogen resulting from a continent-continent plate collision between the east and west Gondwanalands (Key *et al.*, 1989). The Mozambique belt name was proposed by Arthur Holmes in 1948 at the 18th International Geological Congress. The name Mozambique belt has been used throughout since then until Stern (1994) proposed it to be changed to the East African Orogen (EAO). Stern (1994), also suggested that this belt comprises of the Arabian-Nubian Shield (ANS) in the north and the Mozambique belt in the south (Figure 2.1).

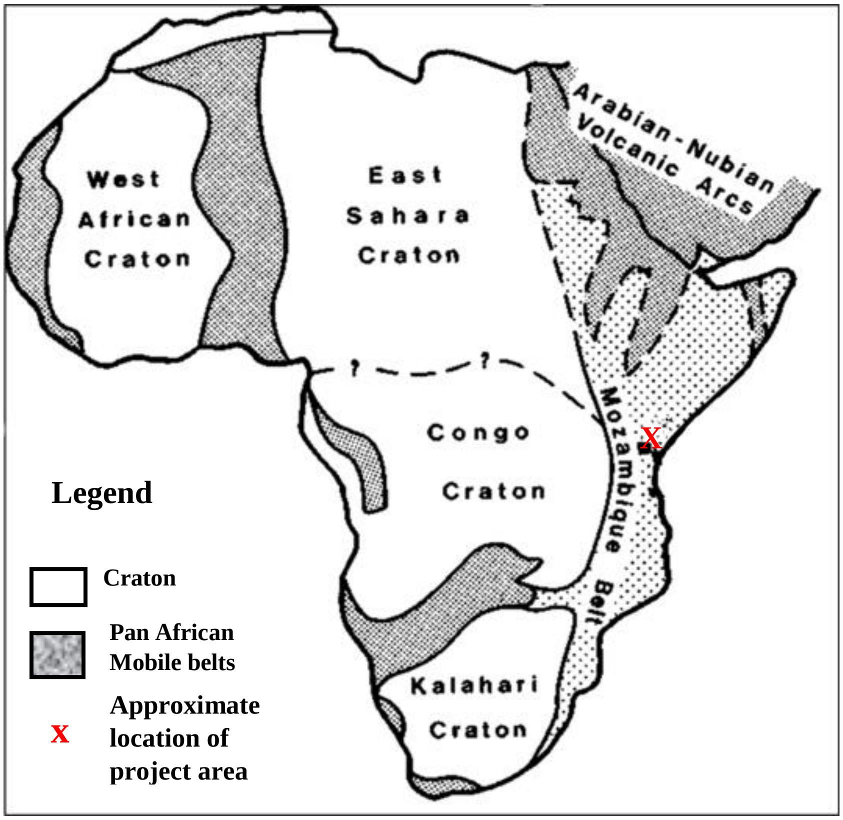


Figure 2. 1: Location of the Mozambique mobile belt in Africa (Modified from Pohl et al., 1980).

According to Sanders (1963), the Mozambique belt is a mobile belt that cuts through cratons and older mobile belts. The rocks of this belt, therefore, have a complex history of superimposed deformation and metamorphism which consists of a high grade reworked or reactivated Precambrian rocks (Nyamai, 1999). The arm of the Mozambique belt in Kenya is divided into four segments where the study area lies within the central part of the middle segment (figure 2.2).

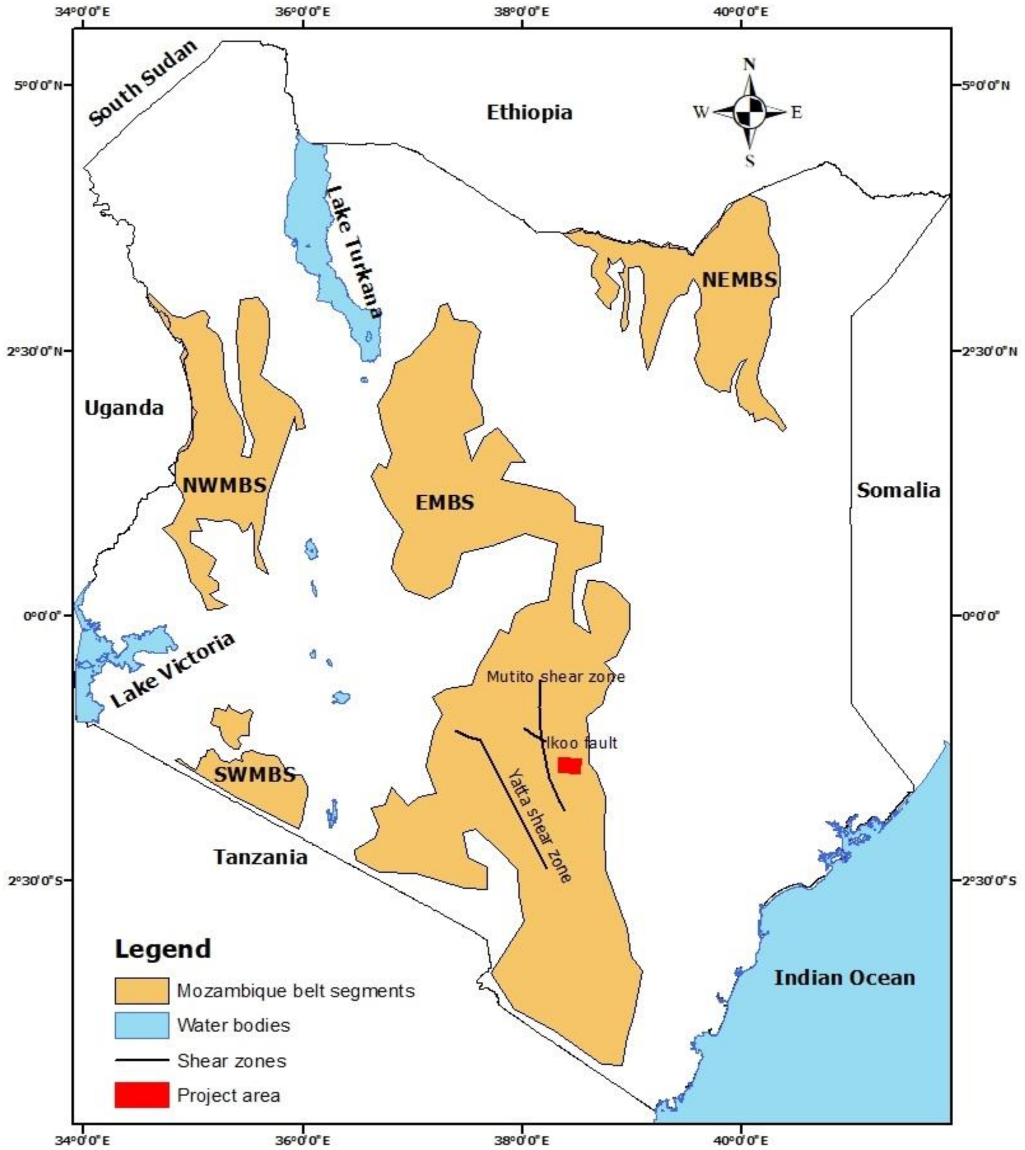


Figure 2. 2: Map of Kenya showing the location of Mozambique Belt Segments (Modified from Nyamai et al., 2003). **SWMBS** = South West Mozambique Belt Segment, **NWMBS**= North West Mozambique Belt Segment, **NEMBS** = North East Mozambique Belt Segment and **EMBS** = Eastern Mozambique Belt Segment.

Previous geological works in the central segment (EMBS), interpreted it to consist of pelitic and semi-pelitic schists and gneisses, migmatites and amphibolites. New rock units like widespread granitoid gneisses, anorthositic, gabbroic to ultramafic intrusions and limited andesitic volcanics have been established by various researchers that have reviewed the geology and tectonic history of this segment of the belt in Kenya, (Biyajima *et al.*,1975; Opiyo-Aketch and Nyambok, 1984; Mathu and Tole, 1984; Key *et al.,* 1989*;* Mathu *et al.,* 1991; Mathu, 1992; Gaciri *et al.*,1993; Mosley, 1993; Nyamai *et al*., 1999, 2003; Waswa, 2015; Waswa *et al.*, 2015). Findings of these new lithological units, most of them basic and ultrabasic rocks, demands a thorough economic mineral potential investigation through the present study.

2.2 Past geological studies in the study area

Among the earliest geologists to conduct geological mapping and assessment of the mineral resources in Kitui County was Schoeman (1951). During his reconnaissance survey and mapping work of the area west of Kitui Township, he described the rocks in this area as having undergone high-grade metamorphism. He did geology and petrography of the rocks and described the area to be widely occupied by migmatites and granitoid gneisses. Previous geological works near the study area were done by Thompson (1948), where he carried out resistivity tests around Mui market when attempting to choose a well site for coal exploration. Later, Thompson was accompanied by Hamilton in the year 1950 to investigate lignite prospect at the Mui basin.

Sanders (1954) carried out a geological survey in the area and explained the complexity of the structural geology and the state of economic geology at the time. In his report, he documented occurrences of several minerals within the metamorphic rocks including sillimanite, iron ore, graphite, magnesite, besides others. His report described occurrences of dyke intrusions between Endau and Magongo, which he classified as fine-grained lamprophyres. Minerals of economic potential in his report include titanium-bearing iron ores, which are widely distributed in the area and are found even in river sands. Another possible economic mineral documentation was magnesite occurring as thin reticulate veins at a small hillock called Kathai (interpreted by the author to be the present day Kalima Kathei), (Sanders, 1954). Despite their mentioning, these possible economic mineral resources were never investigated in detail to ascertain their potential.

Saggerson(1957), carried out an extensive geological survey in the South Kitui area, which includes the current Kitui South Sub-county. He mapped both the Precambrian Neoproterozoic

Mozambique belt rocks as well as the Tertiary phonolites of the Yatta plateau. He reported the presence of iron ores, marbles, graphite and gemstones besides others (Saggerson, 1957). He also gave an exhaustive evaluation of graphite deposits in Kanziku area and attempted to compute the iron ore reserve estimate in the area to be about 107,500 tonnes, based on a depth of 50 feet (Saggerson, 1957). His report documented the occurrence of basic and ultra-basic intrusive rocks such as; Kapoponi, Magongo, Mukono and Kenze. He associated the occurrence of vermiculite deposits with these intrusive rock bodies (Saggerson, 1957).

Walsh (1963), mapped Ikutha area and mentioned that graphite, limestone, vermiculite and sillimanite as possible minerals of economic significance. He indicated that graphite occurs in workable quantities which was later supported by the production records in the Mines and Geology Department of the Geological Survey of Kenya since 1952. It was recorded that a total of 1760 tonnes of ore with an estimated current value of euros 73,351 were exported between the year 1952 and 1957 (Walsh, 1963). It is possible that the manganese and magnesite mineralization in Kitui County is of metamorphosed calcareous sediments origin as earlier stated by Walsh (1963) in his classification of rocks on this region. The ultramafic and mafic intrusions observed on Makongo area could also be related to igneous rocks that Walsh (1963) described to have intruded into the Mozambique mobile belt. Baker (1963), surveyed the geology of Endau area which is to the northeastern side of Mwitika-Makongo area. His work documented the folding in a North-South trend in the rocks of the area. Lack of Neoproterozoic Mozambique Belt rocks exposures and the level of technological knowledge at the time hindered him from interpreting these fold patterns. However, this folding pattern is still present and has been encountered by other researchers in the area.

The most notable geological works close to the study area was done by Mathu (1980), in which he deduced that the migmatites and granitoid gneisses commonly found in the area represented portions of highly granitized core. He described the events of regional metamorphism to have caused multiple foliations and cataclasis of distinctive textures in these rocks. Mathu (1992), mapped Mutito and Ikoo faults, and deduced that these faults were formed in the high-grade metamorphic rocks of the Neoproterozoic Mozambique belt and were reactivated in Tertiary to have the current steep Mutito fault scarp and the elevated Kitui chain of hills. He postulated that within the regions of the faults, the rocks are mainly migmatites and gneisses formed at the amphibolite and granulite facies of metamorphism. He noted that the Kitui chain of hills occupy a tectonic 5 to 7 km wide shear zone with high iron ore enrichment. However, a detailed investigation of the shear zone is yet to be carried out.

Waswa et al., (2015)successfully delineated the iron ore deposits in Ikutha area using ground magnetic survey method and developed a contour map showing the boundary of iron-rich rocks. He also defined the rocks that existed in the area and updated its geological map. His project study displayed that a lot still needs to be investigated about the Mozambique belt in Kenya, in terms of mineral resources, geology and tectonics.

A closely related research methodology to the work of Waswa was adopted in evaluating the geology and economic mineralization of the Neoproterozoic Mozambique belt rocks in this study. Documentation of various minerals with economic potential from past geological reports by Sanders (1954) and Saggerson (1957), also suggests that such geological formations may be extending beyond what is presently available. This needs to be investigated considering the advanced technology in mineral exploration to date.

2.3 Economic mineralization in Mozambique belt rocks.

The Neoproterozoic Mozambique belt in Kenya has complex geology, structures and tectonics with high economic potential from mineralization to geotourism, especially from its scenic physiographic features resulting from folding, faulting and erosional inselbergs. The lithological units which are widespread within the belt including that of mafic to ultramafic intrusions which are potential sources of economic minerals like base metals, industrial rocks and minerals, and gemstones. Exploration works within the belt have revealed a relatively high concentration of copper, zinc, tin chromite, nickel and manganese in the mafic and ultramafic rocks of this belt (Nyamai, 1999). Rocks of Neoproterozoic Mozambique belt in Kenya have also been found to be of economic use, for example, limestone and marbles are used for cement manufacture; granites and diorites are used in the construction industry as ballast, aggregates or ornamental stones.

The Mozambique belt rocks in Machakos region are potential for economic minerals as they may be tectonically fragmented and scattered ophiolites, while others are possible fragments of the subcontinental mantle (Nyamai, 1999). The thermobarometric conditions that prevailed during the formation of the Mozambique belt are important in determining the economic potential of minerals like high-quality gemstones that form part of the mineral wealth in the Kenyan segment of the

Mozambique belt (Nyamai *et al.*, 1993). Coloured gemstones like tourmaline, aquamarine, rose quartz, amazonite, emerald, ruby, sapphires, and others have been reported to occur in both host rocks as well as in veins and pegmatites in Embu, Meru, Baringo, Taita Taveta and Kitui as documented by various researchers (Opiyo-Aketch and Nyambok, 1984; Mathu and Tole, 1984; Key *et al.*, 1989*;* Mathu *et al.*, 1991; Mathu, 1992; Gaciri *et al.*,1993; Mosley, 1993; Nyamai *et al.*, 1999, 2003)

Important potential mineralization within mafic and ultramafic rocks of the Mozambique Belt in Kenya include; copper mineralization (Pulfrey and Walsh, 1969) in Tsavo East and Voi, chromite mineralization occurring as chromite pods in ultramafic rocks in west Pokot (Vearncombe, 1983). Ultramafic and mafic rocks elsewhere across the world are known to host most of the world's economic concentrations of Platinum-group elements (PGE) like the PGE reef deposits in the Bushveld Igneous Complex of South Africa. This complex hosts magmatic ore deposits containing primarily platinum, palladium and rhodium, with copper, nickel, gold and others recovered as by-products.

Geological structures in the Mozambique belt control some economic mineralization especially those of iron ore and gemstones. These geological structures include faults and folds. For example, the Mutito fault is known to have been formed during the Precambrian period and reactivated during the Tertiary period (Mathu, 1992). The reactivation of the fault is considered to have caused the deposition of sediments within the Mui basin. Sanders (1954), postulated that the sediments of the Mui basin were deposited from the waters of a Lake which was formed during a tectonic movement in the area. Other minor tectonic structures within the area like tensional joints, shear zones and veins also control mineralization and are evidence of tectonic evolution.

According to geochemical evidence, the rocks in Matuu-Masinga area had a high content of chromium (160 ppm) and nickel (55 ppm) compared with the averages (Nyamai, 1999). This has also been supported by Waswa (2015). The geochemical evidence indicates that iron ore deposit of Mutomo-Ikutha area contained P_2O_5 (0.2-5.9%) and TiO_2 (0.05-1.9%) elements. There was a positive correlation of iron ore and P_2O_5 and a negative correlation with other elements found within the host rock. This evidence indicated that the mode of delivery of iron ore and P_2O_5 were similar hence originating from a hydrothermal/magmatic fluid.

The evidence based on the aforementioned publication shows that the Neoproterozoic Mozambique belt rocks in the project area and Kenya at large are endowed with numerous economic minerals like iron ore, magnesite and various gemstones. The full economic potential of these minerals especially in Makongo area of Kitui East Sub-county has not been satisfactorily investigated and realized. The presence of lineaments in Makongo area can also be used as a vital clue for geotechnical and hydrogeological target surveys for groundwater resources considering that Kitui County is a semi-arid area with a serious need of water, especially in the study area. Makongo hill also has a good elevation of about 1500 metres that can be used for geotourism besides acting as a good trap for relief rainfall.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Study Area

The Mwitika-Makongo study area occurs in the Neoproterozoic Mozambique Belt rocks of Kitui sub-county in Kitui County. The county shown in figure 3.1, is located in Southern Eastern Kenya, about 160 km east of Nairobi City, with Kitui town being its administrative capital. The county covers an area of 30,496.5 km^2 including 6,302.7 km^2 occupied by Tsavo East National park, making it the sixth-largest county in Kenya. It shares borders with Tharaka-Nithi and Meru counties to the north, Embu to the northeast, Makueni and Machakos counties to the west, Tana River to the east and southeast, while Taita-Taveta county borders it to the south (County Government of Kitui, 2014).

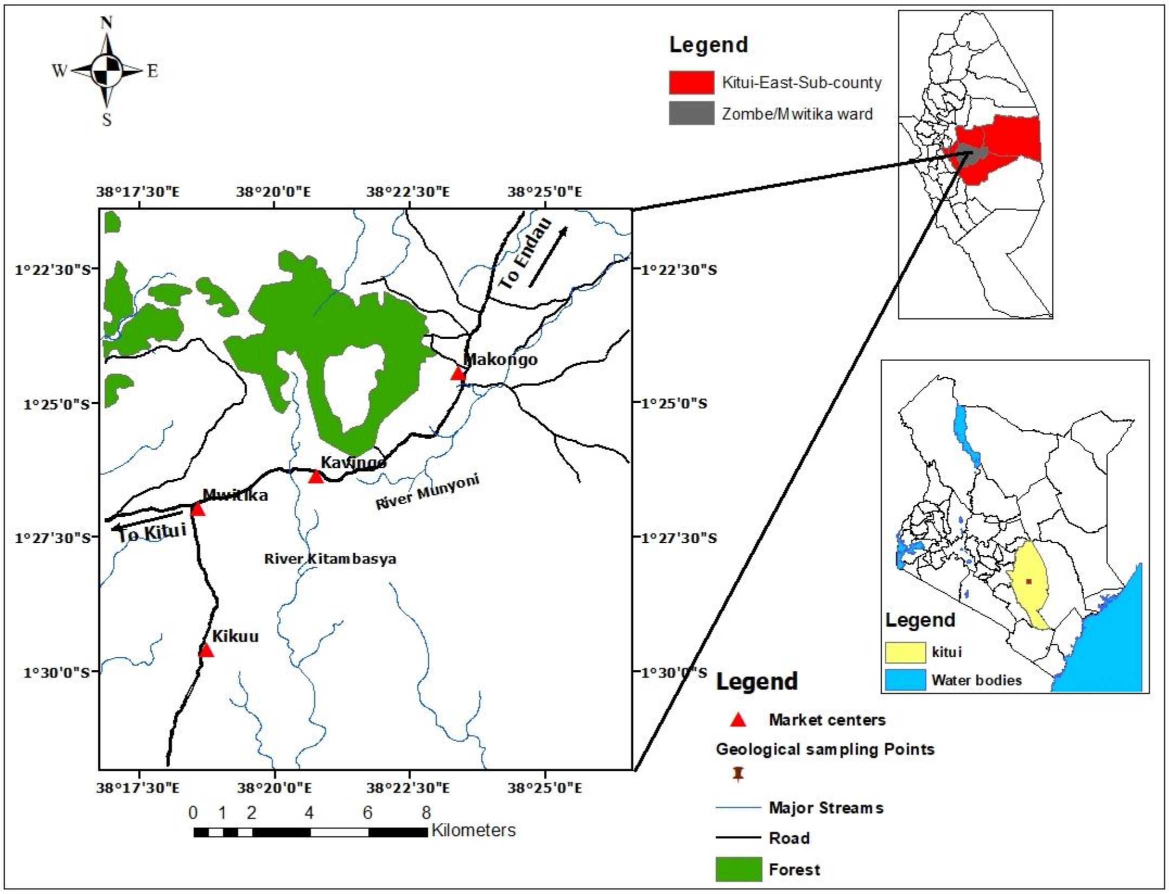


Figure 3. 1: The map of the study area with major towns within the area and its location within Kenya (shaded in yellow in the inset map).

3.1.1 Geographical Location

The Mwitika-Makongo study area is bounded by longitudes 38° 18' E to 38° 26' E and latitudes 1° 22' S to 1° 32' S, covering an approximate area of 100 Km^2. This area can be accessed from Nairobi through the Thika-Kitui-Zombe road or through the Machakos-Kitui-Zombe road. The study area is located on the eastern side of Zombe town and is easily accessed through a murram road that is regularly graded by the Kitui County Government.

3.1.2 Climate

The Mwitika-Makongo study area, like many other parts of Kitui county, is generally hot and dry with low unreliable rainfall. It experiences high temperatures throughout the year, ranging from 14° C to 34° C, with September and October to January and February being the hot months. The highest temperatures are experienced in months of January-March and September-October. This project area has a bi-modal rainfall pattern, with two rainy seasons annually. The long rains come in the months of March to May and the short rains, between October and December. Rainfall in the study area varies from an average of 250 mm to 1050 mm per year and its climatic condition can be classified as arid to semi-arid, similar to most parts of Kitui County (County Government of Kitui, 2014).

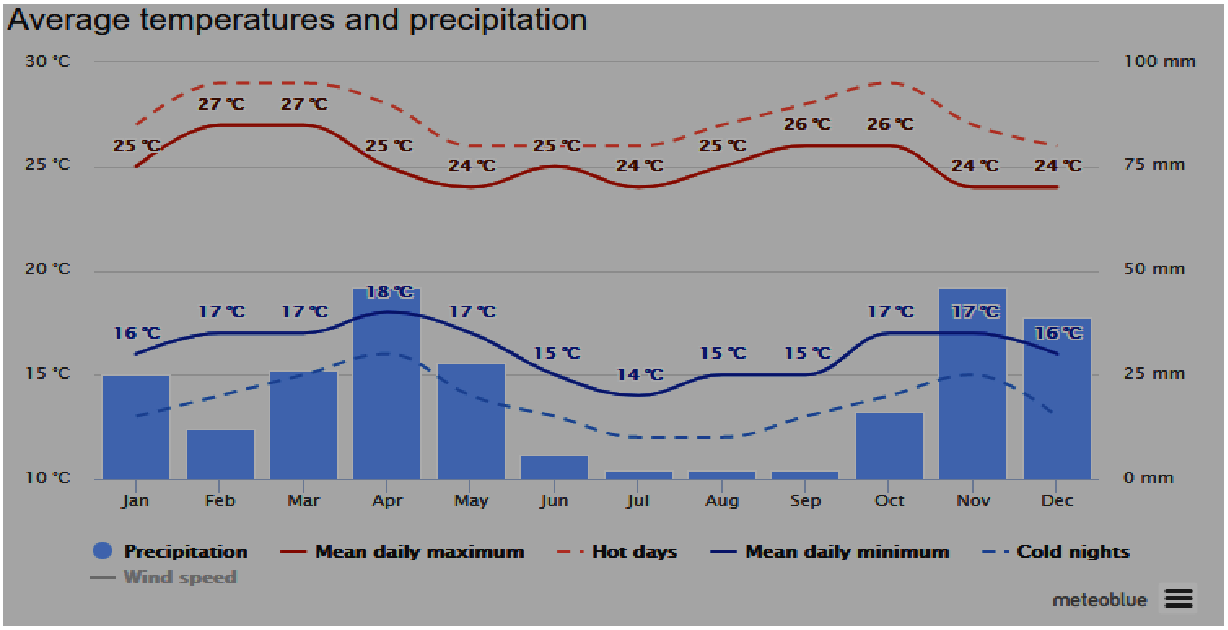


Figure 3. 2: Climate of Kitui County. Source: http://www.meteoblue.com/en/weather.

3.1.3 Vegetation and Soils

Vegetation in the study area mainly consists of scattered thorny shrubs with tall trees occurring around high-altitude areas such as the Makongo hill forming a forest around it. Common tree species found in the area include the baobab and whistling thorn acacia (Plate 3.1). There is limited grass cover on most parts of the area. Red-brown sandy soils consisting of quartz and iron oxide pebbles form the predominant soil cover, although black cotton soils were encountered in some few places.

Plate 3. 1: Dry shrubs and baobab tree indicating typical vegetation in the study area (UTM: 433729/9844323).

3.1.4 Land Use

There are limited land use activities in Mwitika-Makongo area which are governed by factors such as climate, altitude and type of soil. The land in the area is mostly used for grazing and crop farming. Due to the arid climatic conditions, crop farming is mainly for subsistence purposes. Pigeon peas, cowpeas, sorghum and maize are the main food crops grown in the area (County Government of Kitui, 2014). Livestock rearing includes goats, sheep cattle and poultry, while other commercial activities in the project area include beekeeping, charcoal burning and brick making.

3.1.5 Physiography and Drainage

The general topography of the study area is of moderate relief with two major hills Makongo and Kalima Kathei forming areas of high altitudes. The elevations of the hills range from 700 meters to 1500 meters. Ikoo river which is the only major river in the area is located far away from the study area between Zombe and Mwitika. Local people rely on River Munyoni which is seasonal and few water dams like Kalima Kathei dam. The seasonal rivers and streams flow from areas of higher relief into areas of low relief (Figure 3.1).

3.2 Methodology

The following methodological approach was used to achieve the objectives of this research work.

3.2.1 Geological Investigation

Geological field studies involving fieldwork and geological mapping were carried out to elucidate on the geology and structures of the study area.

3.2.1.1 Fieldwork and Geological Mapping

To identify lithological units that are potential hosts of economic minerals, geological field mapping and sample collection of rocks and minerals in the Mwitika-Makongo area were carried out. Traverses of 20 meters by 20 meters were created forming a grid on the study area. Samples were collected along these traverses in the grid on foot. Fresh rock and mineral samples were collected by the use of a geological hammer to avoid collecting weathered samples (e.g. Plate 3.2).

Sample sizes were determined depending on the type of analyses to be performed. For thin-sections, rock samples of about 10 cm thick by 5 cm by 5 cm were sufficient for producing one or two thin-sections. Samples for geochemical analysis were 1 kg each for major and minor element analyses. Care was taken to ensure that the samples were fresh. Field mapping and sampling sites were determined by physical features and by the aid of a handheld GPS receiver in every location. These locations and samples collected were noted in a field notebook detailing the outcrop characteristics.

Plate 3. 2: Measurement of joint structures in Meta-pyroxenite rocks of Mwitika area.

3.2.1.2 Petrographic Studies

Rock thin sections were largely prepared from rock samples that showed the potential of hosting economic mineral resources. This was done to minimize the cost of preparing thin sections for all the rock samples collected. Petrographic analyses deal with the microscopy and mineralogy of samples of fresh rocks.

Rock samples were cut using a diamond saw to sizes that could be handheld during polishing and grinding. During the grinding stage, samples were washed with running water to remove the grinded chips. Finer polishing was attained through the use of an electrically powered polishing machine. Polishing and grinding reduce the size of the rock samples to recommended sizes of about 30 microns, for microscope analyses. After polishing, samples were mounted on a glass slide for analysis under plane-polarized light and under crossed nicols to identify the mineralogical composition of the host rocks in the study area. Microphotographs of mineralogical textures in the thin sections were captured using a computer connected to the light microscope.

This activity was carried out in the Ministry of Mining and Petroleum laboratory (Madini house), Kenya. The characterization of the mineralogical composition facilitated the identification of the host rocks in the project area. Petrographic information also supplemented the field data and facilitated the establishment of the iron ore origin and history of deposition.

3.2.3 Geochemical Investigation

To indicate the quality of potential economic rocks and minerals in the study area, samples were collected from selected areas for geochemical analyses. The geochemical analysis was either through X-ray fluorescence (XRF) or X-ray Diffraction (XRD) depending on the samples collected. This was done in the laboratory of the Ministry of Mining and Petroleum in Kenya. For every analysis, samples were prepared by pulverizing using a pulverizing machine (laboratory pulverizer) to grains of 100 microns in diameter. After pulverization, the samples were packed, sealed and taken through chemical analyses.

3.2.3.1 X-Ray Fluorescence (XRF) Analysis

This analysis was done to find out the presence and concentration of major and trace elements of the pulverized samples. This was carried out by the Bruker XRF, S1 Titan model, at the Ministry of Mining and Petroleum (Madini house). Thirteen powdered and pulverized samples were geochemically analyzed using that equipment. The concentration of elements measured from each sample was recorded in terms of their percentages. Since trace elements are usually presented in parts per million (ppm), their concentration was converted to ppm by multiplying each of the recorded percentages by 10^4.

3.2.3.2 X-Ray Diffraction (XRD) Analysis

The XRD machine works on the principle of irradiation. An irradiated sample emits X-rays which are diffracted in a way that is characteristic of the analyzed compound. The machine provides spectra patterns whose pick angles and intensities are measured. The sample constituent is determined by the pick angles, while the intensities of the picks determine the sample constituent's compounds.

These analyses were performed at the Ministry of Mining and Petroleum (Madini house), using Bruker X-ray Diffractometer. The analyses were necessary for determining the bulk mineralogical composition of the samples. The results were recorded as spectra of elements, as well as in percentages.

3.2.3 Remote Sensing Investigations

Remote sensing is the collection of information about an object or area without being in physical contact with it. Satellite remote sensing remains one of the best techniques for mapping not only the geology of a place but also the associated structures (Chasia, 2014). Remote sensing offers a fast method of geological mapping in defining potential exploration targets before intensive field exploration activities.

To delineate the geological structures of the study area, digital satellite imagery (Landsat 8/OLI) from USGS (http:/www.earthexplorer.gov) was used for structural analysis and mapping of hydrothermally altered outcrops. Image analysis was done using ENVI 5.3 and ArcGIS 10.5. Extraction of lineaments was done using PCI geomatic 2016 while a Rose diagram was generated using Rockworks 16.

3.2.3.1 Data Sources

The satellite imagery used for structural analysis and mapping of hydrothermally altered outcrops was Landsat 8/OLI year 2019. This digital imagery was downloaded from the USGS website for scenes LC81670612019025 LGN00.

3.2.3.2 Processing Method

Based on the metadata from the downloaded Landsat 8/OLI satellite imagery, georeferencing of the digital imagery was not necessary since the images were (L1T images). These images are usually terrain corrected and georeferenced by the data provider. The first step, therefore, involved clipping the imagery using a shapefile of the size of the study. This ensured that the researcher only worked with the data that was necessary for this study. The next step involved the application of ENVI 5.3 and ArcGIS software in the interpretation of spectral signatures in the colour composite band and band ratio combinations. This was done to create a map for depicting hydrothermally altered areas as zones for economic mineralization. To detect faults and lineaments in the study area, digital image processing technique such as principal component analysis was used. During geological field mapping, ground verification, analysis and interpretation were done on faults and lineaments.

CHAPTER FOUR

4.0 RESULTS

This chapter presents the results of the research carried out in the Mwitika-Makongo area. These results are on the petrology, stratigraphy, geological structures, petrochemistry and remote sensing investigations. They are presented in the following sections.

4.1 Results of Lithological Mapping

Geological field mapping was carried out to achieve the first and second objectives. Lithological and structural gaps, missed out by the previous geologists were identified during this research work. Missing lithology in some sections from the reports produced by Saggerson (1957) and Sanders (1954) was updated. These missing lithologies were identified as Meta-pyroxenites.

From the geological investigations, rock units of Mwitika-Makongo area have been classified based on field relations and lithology. They were assigned different colours and grouped according to their relative age of formation. Stratigraphically, these rock units were grouped into four categories (Table 4.1) as follows: (1) Metamorphosed semi-pelitic sediments, (2) Metamorphosed psammitic sediments, (3) Metamorphosed calcareous sediments, and (4) Metamorphosed and unmetamorphosed igneous intrusives. The rock units have been subsequently discussed in the following sections of this thesis and a new geological map of the Mwitika-Makongo area produced (Figure 4.1).

Table 4. 1: Stratigraphic classification of rocks in the study area.

Lithology Classification	**Rock Formation**
1. Metamorphosed semi-pelitic sediments	(i) Biotite gneiss
2. Metamorphosed psammitic sediments	(i) Granitoid gneiss (ii) Migmatites
3. Metamorphosed calcareous sediments	(i) Calc-silicate granulite (ii) Marbles
4. Metamorphosed and unmetamorphosed igneous intrusives	(i) Amphibolite (ii)Meta-gabbro (iii) Norite (iv) Meta-pyroxenite (v) Peridotite

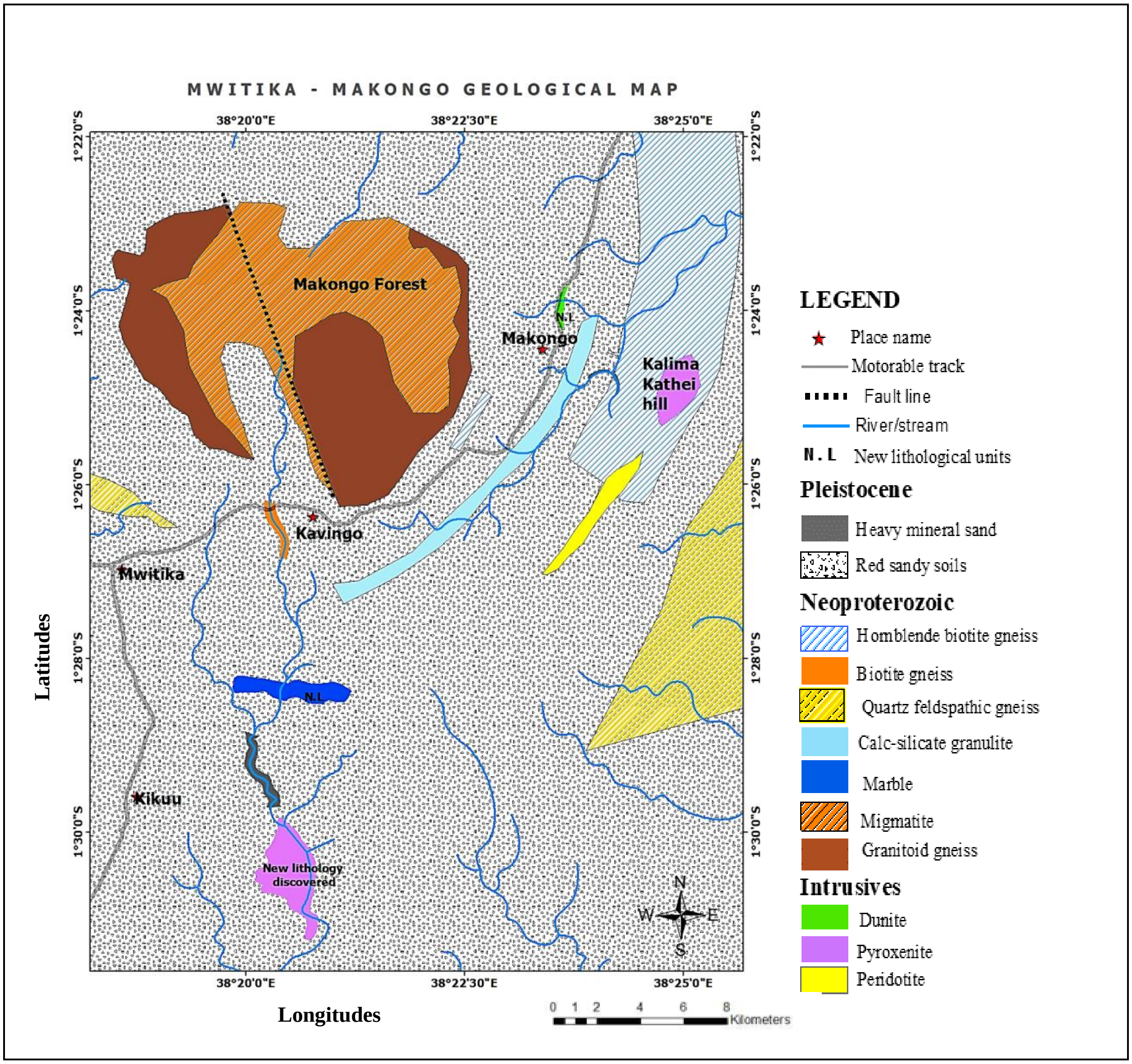


Figure 4. 1: Geological map of the Makongo-Mwitika study area improved and modified from Sanders (1954) and Saggerson (1957).

4.1.1 Metamorphosed semi-pelitic Rocks

These include the following rocks in the study area;

4.1.1.1 Biotite gneisses

These rocks occur as pale grey coloured outcrops exposed at a dry stream bed. The rocks are composed of biotite (15%), feldspars (65%) and quartz (20%). Although the rocks are heavily weathered due to the nature of their location, very well foliated bands rich in biotite can be observed. There are concordant inclusive pegmatite veins with coarse-grained feldspar augens measuring about 2 cm. The veins measure about 25 cm wide and have augens of K-feldspars. They are layered with the main rock (Plate 4.1) and the contact between the host rock and the pegmatite veins is sharp. The K-feldspars inside the pegmatites plunges 25° to the SE while the host rock trends in an N-S direction and dips 30° to the east.

Plate 4. 1: Biotite gneiss with composition layering near Makongo hill indicated by dotted red and yellow lines (UTM: 425246/9840716).

4.1.2 Metamorphosed Psammitic rocks

These include the following rocks;

4.1.2.1 Granitoid gneisses

Granitoid gneisses are high grade regional metamorphic rocks, coarse-grained and vary in colour from cream-white to pink. The rocks are formed from pre-existing formations (originally igneous or sedimentary) that were deeply buried and granitized through subsurface melting. Through burial, there is an increase in temperature and pressure making the rock to become plastic and buoyant (decrease in density). The plastic material gets injected into existing joints in the overlying rocks and crystallizes into massive rocks that are relatively harder and more resistant to weathering.

The Mozambique Neoproterozoic mobile belt where the study area lies consists predominantly of this rock type and this was evidenced especially around Makongo hill. Here, the granitoid gneisses are highly folded, faulted and jointed. Majority of the Makongo hill is dominated by granitoid gneisses associated with migmatites, forming a boundary that is difficult to place as they merge imperceptibly.

Major minerals in terms of composition within the rocks are Quartz, Plagioclase and K-Feldspars. Minor accessory minerals include magnetite, hornblende, biotite, garnet and muscovite. In some instances, the rock contained pegmatites and quartz veins that have been stretched, pinched, swelled out or folded. The dominant K-feldspar in the rock is microcline hence the pinkish-grey colour of most outcrops. The K-feldspar occurred as well-developed phenocryst that has sometimes been sheared to form augens (Plate 4.2). Magnetite grains were found only in pink coloured granitoid gneisses with massive pegmatites on the eastern side of Makongo hill. It was absent in the sugary textured weathered varieties especially on the slopes of the hill.

Plate 4. 2: Lensoidal quartz-feldspar vein in granitoid gneiss below the handle of the hammer (UTM: 430410/9843667).

4.1.2.2 Migmatites

A typical migmatite consists of darker and lighter parts and is a product of high-grade metamorphism that record crustal flow especially plastic flow in an area. Migmatites are both igneous and metamorphic in nature hence behaving as two-phase material. This enhances strain localization in the liquid (magma) phase and promotes strain hardening in the solid (host rock) phase. Migmatite outcrops are characterized by a mixed appearance of granite or older rocks that have recrystallized between igneous and metamorphic states. The minerals in them seem to have been intermixed with occasional folds and sheared veins indicating plastic flow in the rock. Some migmatites are mylonitized but most seem to have undergone plastic flow and hence very resistant to erosion even on-stream beds. Dark compact ultrabasic intrusions sometimes occur within the rocks as lenticular bodies or dark streaky schlieren drawn parallel to foliations and not of great extent.

In Makongo area especially the hill, there are highly granitized gneisses that could have been in the late stage of migmatization. On top of the granitoid gneisses are the migmatites that form part Makongo hill cap or summit. In some localities, they were found to have pink pegmatite mineralized with magnetite grains. Migmatites in the study area can be classified based on field observations as follows;

A) Agmatite migmatite: They are also called Breccia migmatite because of the breccia-like structures in the rock. These migmatites have dark compact intrusions occurring as lenticular bodies parallel to the rock (plate 4.3). The term agmatite is derived from the word Agma meaning fragments. The fragments of paleosome are surrounded by narrow veins of the neosome. In some instances, fragments occur as linear structures on the migmatite. In the study area, these migmatites were observed in the northeastern side of Makongo hill at a normal fault floor near Makongo primary school.

Plate 4. 3: Agmatite migmatite rock at Makongo valley (UTM: 430410/9843667).

B) Snake-like structure migmatite: They are also called Phlebitic migmatite. The rock has veins sheared and folded to take the shape of a snake in motion. Veins of light coloured neosome traverse dark coloured paleosome resulting in veined structure migmatite (plate 4.4). These migmatites were observed in Makongo valley occurring close to raft-like migmatites.

Plate 4. 4: Snake-like structures in migmatites (UTM: 429934/9843952).

C) Raft-like Migmatite: They are also called Schollen migmatite. They are migmatite with rafts of paleosome within the neosome. The rock has similar structures to agmatite migmatite but here they appear as a surface run often by water due to shearing. The paleosome occur as raft-like fragments partially dissolved in the neosome and showing distinct borders (plate 4.5). The neosome is more abundant so that the disrupted blocks of paleosome float in it like rafts. This rock was observed in the northeastern side of Makongo hill about 200 metres from Makongo secondary school.

Plate 4. 5: Raft-like structure migmatite (UTM: 429872/9844022).

D) Banded migmatite: They are also called folded structure migmatite. They are formed by compressional pressure acting on a rock. The incompetent layers are bent in contrast to the competent layers resulting in buckling and bending of layers. The compressional pressure is not equally distributed within the rock, resulting in an unequal distribution of the bands. The final product is a dark strongly banded homogeneous rock with a visible wavy foliation (plate 4.6). This rock was observed in the western slopes of Makongo hill facing Mwitika.

Plate 4. 6: Banded migmatite on the western slope of Makongo hill (UTM: 427899/9841988).

4.1.3 Metamorphosed calcareous sediments

These rocks include the calc-silicate granulites and the marbles.

4.1.3.1 Calc-silicate granulites

Well exposed outcrops are observed towards Kavingo market. The rocks appear pale grey in colour, coarse-grained, have greenish-grey minerals (30%) and weathers to pale brown sandy soil (plate 4.7). The rocks could have been formed from metamorphosed calcareous sediments that are suspected to be the parent material of the gneisses, marbles and migmatites in the area.

Plate 4. 7: Calc-silicate granulite outcrop at Kavingo market (UTM: 431530/9842188).

4.1.3.2 Marbles

In the study area, marble outcrops were observed behind Ngaaka Yakwa market. The marble band has a width of 71 metres and an observed length of 100 metres. Its colour ranges from pure to creamy white with shades of blue-grey. The band has redepositions of fine-grained kunkar limestone overlying the marble band (plate 4.8). The portions where kunkar limestone has been deposited, are pinkish and contain coarser patches. Quartz pebbles are cemented within the rock showing patches of clear shinny grains in the band. Grains of quartz are about 10% of the rock matrix in composition. Where the marble band has been weathered to creamy white soils, the local people dig it out for cows to lick for calcium benefits.

Plate 4. 8: Weathered marble band outcrop at Ngaaka Yakwa market (UTM: 427768/9836899).

4.1.4 Metamorphosed and unmetamorphosed igneous intrusive rocks

4.1.4.1 Amphibolites

Amphibolite rocks are coarse-grained, dark grey, highly jointed and have occasional thin white plagioclase bands crisscrossing the rock. They occur close or near meta-gabbro at Mweiga stream. They are non-foliated and their association with meta-gabbro at Mweiga could be interpreted as the megabbro being their parent rocks. They were also found on the way to Kaliku at the eastern side of Makongo hill. The rocks here had hornblende plagioclase feldspars and minor amounts of biotite. They weather to pale brown coloured soils (Plate 4.9) below. In thin sections, these rocks had plagioclase and pyroxene minerals with few intercalations of quartz grains. Under the microscope, the dominant mineral was pyroxene with two directional cleavages close to 90° (plate 4.10).

Plate 4. 9: Amphibolite rock with thin white bands at Mweiga stream (UTM: 426492/9834250).

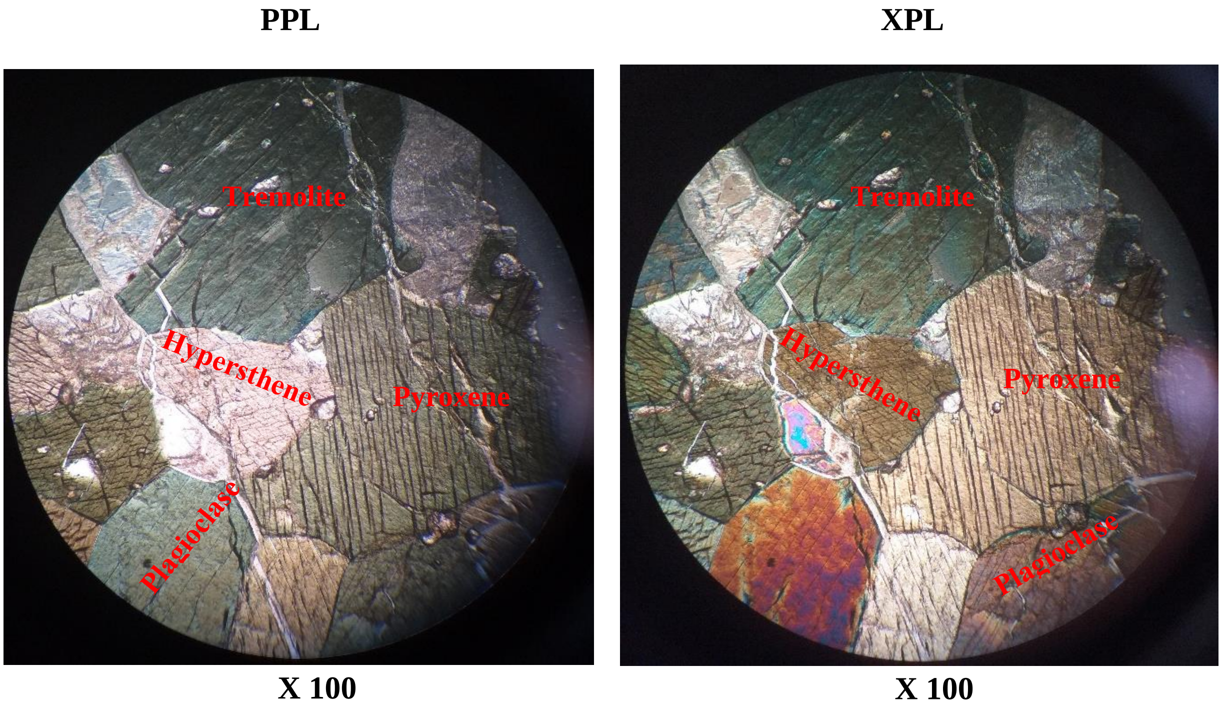


Plate 4. 10: Mineral composition of Amphibolite rock from the study area.

4.1.4.2 Meta-pyroxenites

The Meta-pyroxenite rocks were observed in two localities in the study area, at Kalima Kathei hill and Mweiga stream. At Kalima Kathei hill, the outcrops were dark blue-grey in colour, non-foliated and medium-sized grained. The rocks cover most parts of the hill displaying an unvegetated ground on the slopes of the hill (plate 4.11). This is attributed to their highly interlocking grain matrix which makes them difficult to fracture even through weathering, hence limiting vegetation growth. The rocks have a high density and have turned yellowish or brownish a few inches on the surface due to weathering of the iron ore mineral into limonite. Many outcrops around the hill consist of boulders that have been rounded by exfoliation due to their compact nature. Sanders (1954) had classified these rocks in this hill as Charnockitic and the largest single body forming the hill.

On the southern part of the study area, massive outcrops of these rocks were observed at Mweiga stream. The outcrops were dark grey in colour and highly jointed. In thin sections, the rocks are rich in clinopyroxene with minor amounts of diopside (plate 4.12). When the sample was observed under the light microscope, the dominant minerals were pyroxenes (60 %) and magnetite (10%). Plagioclase feldspar with a strong albite twinning was also present (30 %), (Table 4.2). Under crossed polars (XPL) in (plate 4.12), dark green pyroxene of Aegirine was found to be intruded by magnetite. The other minerals observed in the rock were orthopyroxene.

In some localities along the stream, the rocks are highly deformed and mylonitized. Deformation structures like boudinages and mylonites are absent in the highly jointed varieties. The undeformed outcrops have a series of joints striking concordant to the rock strike and dipping 65° W. At both localities where the rocks were observed, the local people break and transport them for foundation aggregates or road aggregates.

Plate 4. 11: Round shaped meta-pyroxenite at Kalima Kathei (UTM: 435925/9843455).

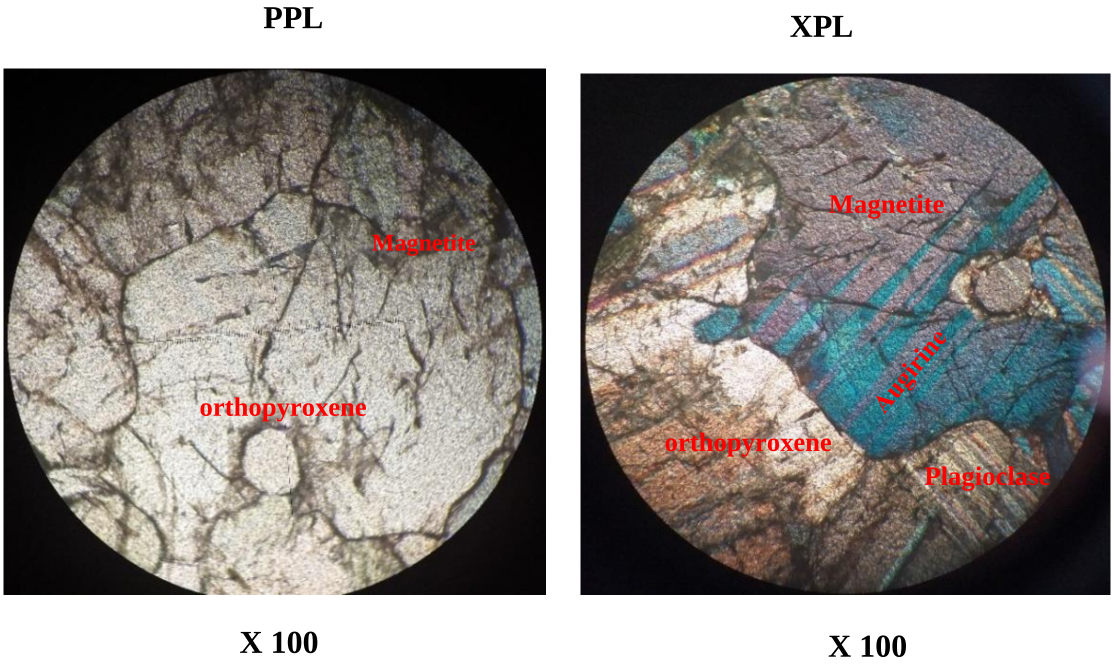


Plate 4. 12: Mineral composition of meta-pyroxenite rock from the study area.

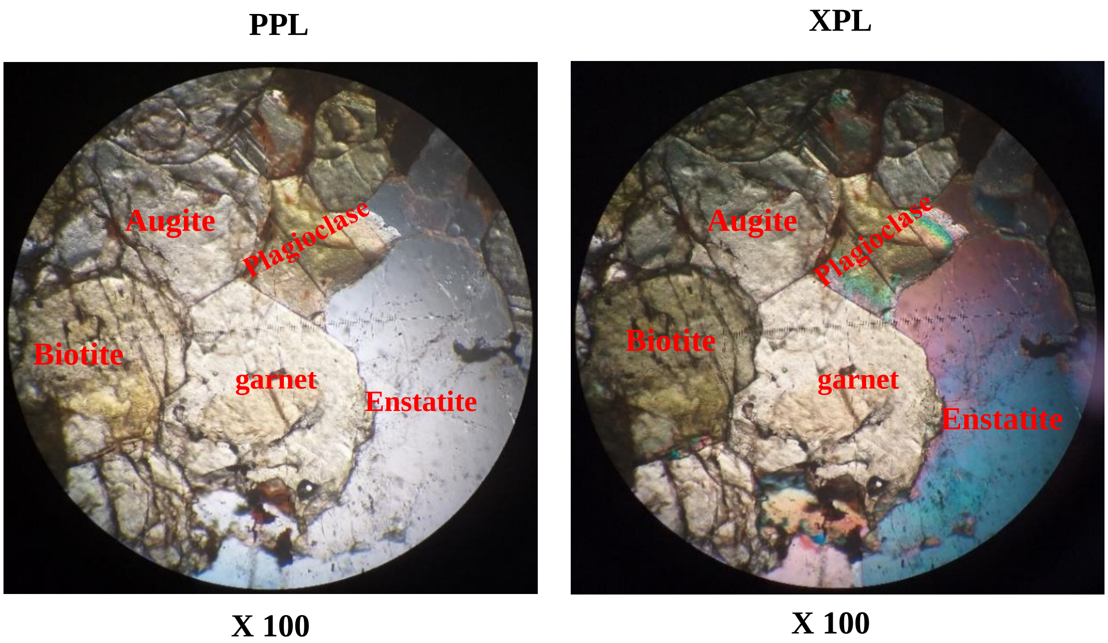
Table 4. 2: Modal composition of Meta-pyroxenite

Mineral Type	Percentage by volume
Plagioclase	30
Pyroxene	60
Magnetite	10
Total	100

4.1.4.3 Meta-gabbros

These rocks are rare but occur in Kalima Kathei hill and on the way to Mweiga stream (plate 4.13). They are associated with intrusive rocks especially at Kalima Kathei where they occur as exposures of coarse-grained black, unfoliated rocks. They are heavy, compact, have a hackly fracture and weather to dark brown soils. The rocks have biotite at 25%, plagioclase feldspar at 35%, pyroxene (enstatite) at 37% and garnets at 3% (Table 4.3). When the sample was viewed under the light microscope, a large grain of enstatite was observed with secondary inclusions of garnets. Under plane-polarized light (PPL), biotite appeared brown with a weak relief. Under crossed polars (XPL), enstatite appeared as grey but was colourless in PPL (plate 4.14).

Plate 4. 13: Meta-gabbroic rock on the way to Mweiga stream (UTM: 422165/9839707).



PPL **XPL**

X 100 **X 100**

Plate 4. 14: Mineral composition of meta-gabbro rock under a light microscope.

Table 4. 3: Modal composition of meta-gabbro

Mineral Type	Percentage by volume
Biotite	25
Plagioclase	35
Enstatite	37
Garnet	3
Total	100

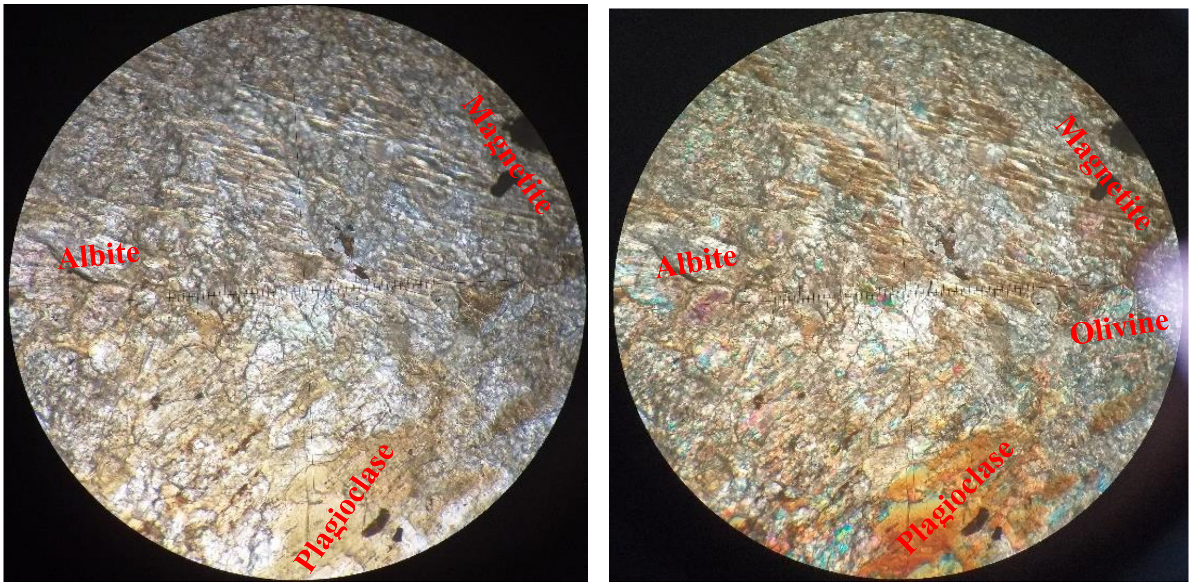
4.1.4.4 Olivine Norite

Several exposures of dark grey, coarse-grained and hard to break rocks were observed on the slopes of Kalima Kathei (plate 4.15). The minerals in the rocks have no preferred orientation and the rocks are compact. The boulders measure about 1m by 40 cm. Albite twinning is observed in plagioclase grains in hand specimen. Olivine and pyroxene minerals dominate the rock at 50 % and 30 % respectively (Table 4.4). Under crossed polars (plate 4.16), Olivine appears altered with secondary inclusions of albite, magnetite and biotite in small grains scattered in the rock.

Table 4. 4: Modal composition of Olivine Norite

Mineral Type	Percentage by volume
Olivine	50
Plagioclase	12
Pyroxene	30
Magnetite	8
Total	100

Plate 4. 15: Plagioclase feldspar displayed in Kalima Kathei Norite (UTM: 434815/9843222).



PPL **XPL**

X 100 **X 100**

Plate 4. 16: Mineral composition of Norite rock from the study area.

4.1.4.5 Peridotite

A coarse-grained, compact dark greenish rock occurs on the way to Endau, about one kilometer past Makongo shopping centre. The rock is tough to break and has no alterations (plate 4.17). It occurs close to some few outcrops of weathered dunites. The association with dunite could be interpreted to be of the ophiolitic suite. The grains in the rock have phaneritic texture implying slow cooling hence an intrusive rock. The sample consists of pyroxene at 60%, plagioclase at 20%, olivine at 15% and magnetite at 5 % (Table 4.5). Under the light microscope, accessory minerals of magnetite and garnets were observed. When observed under plane-polarized light (PPL) in (plate 4.18), enstatite was pale in colour with greenish to pinkish pleochroism. Under crossed polars (XPL) in (plate 4.18), the enstatite was pink in colour. Grains of magnetite were observed to be intruded inside those of pyroxene.

Plate 4. 17: Coarse-grained peridotite outcrop near Makongo market (UTM: 432501/9844694).

Table 4. 5: Modal composition of peridotite

Mineral Type	Percentage by volume
Olivine	15
Plagioclase	20
Pyroxene	60
Magnetite	5
Total	100

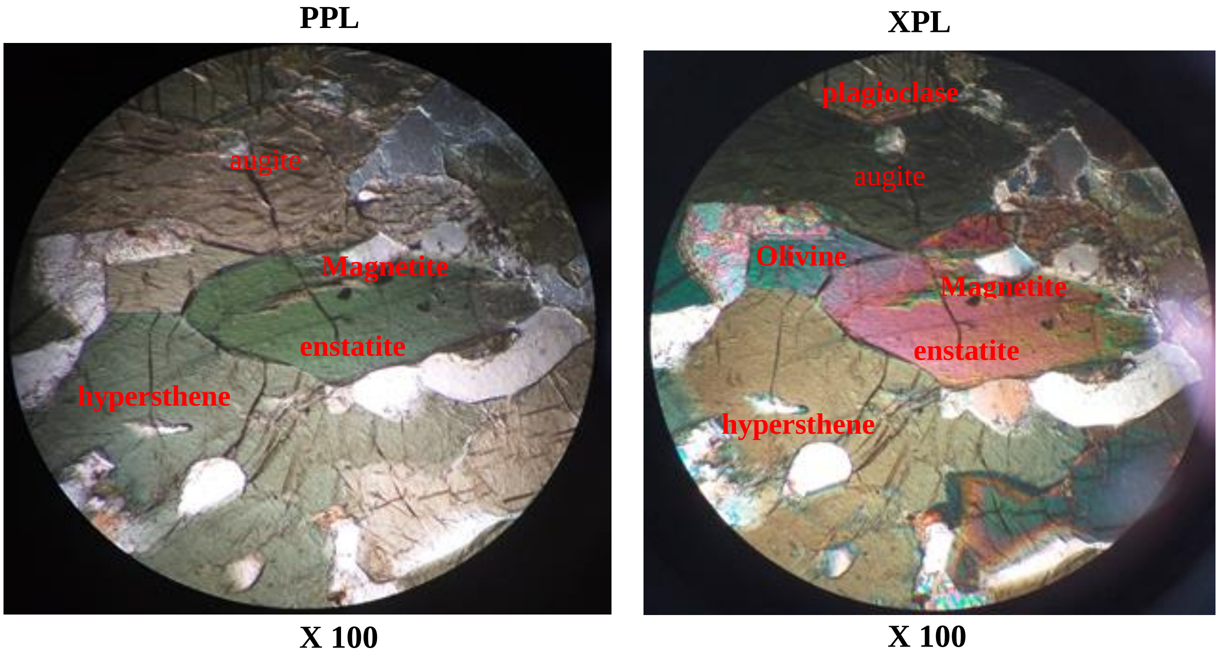


Plate 4. 18: Mineral composition of peridotite under the light microscope

4.2 Results of Geological Structures of Mwitika-Makongo Area

The geological structures of Mwitika-Makongo area can be grouped as either metamorphic or igneous structures. Metamorphic structures are associated with the Pan-African tectonothermal events of about 650 Ma in age which led to deformation and metamorphism of the Neoproterozoic Mozambique belt rocks in eastern Africa. They include structures like foliation planes, lineations, folds, faults, pegmatites, veins and joints (Figure 4.2). The igneous structures include the intrusive bodies found in the study area. They were intrusive into the Neoproterozoic rocks in the area as either dykes or sills before metamorphism. After metamorphism, they formed foliated and lineated metamorphic rocks like amphibolites in the area.

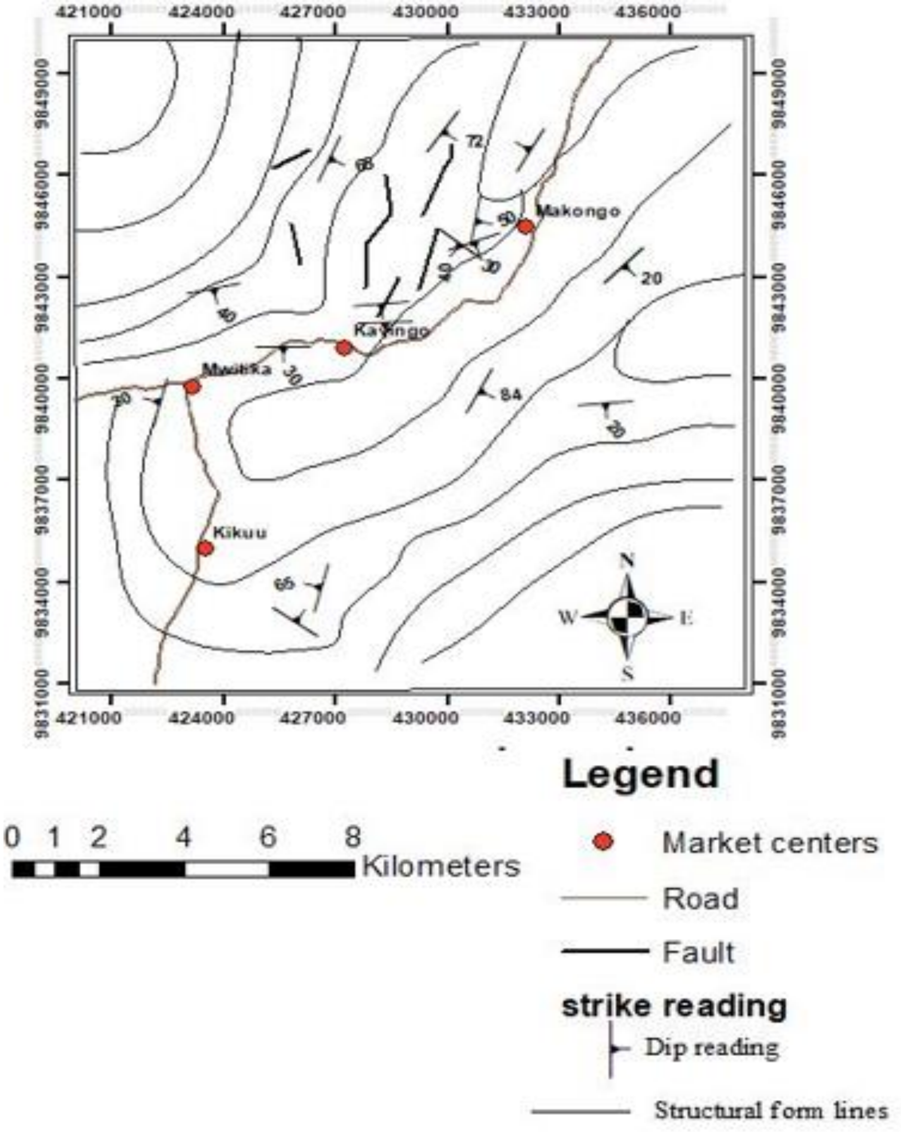


Figure 4. 2: Structural map of Mwitika-Makongo area

4.2.1 Metamorphic structures

These structures can be grouped into minor or micro-structures and major structures as described in this section. The minor geological structures include; foliation and lineation structures, micro-folds and shear indicator structures. The major geological structures include; faults and joints.

4.2.1.1 Foliation structures

The parallel arrangement or distribution of minerals in a rock is called foliation. It can include compositional layering like that observed in gneisses. In the study area, foliation was observed as a medium to coarse-grained minerals that formed compositional banding with a preferred planar orientation of minerals in a concordant K-feldspar pegmatite. The compositional banding occurs at all sizes varying in thickness from millimeter to centimeter scale. In rocks like migmatites, the bands had pinch and swell structures. Foliation planes in biotite gneiss in the area is an indicator of boundaries between the host rock and the pegmatites (plate 4.19). Strike and dip readings (Table 4.6), were used for the stereographic projection of 17 poles of foliation planes, drawn on an equal area net (fig 4.3). From the stereographic plot, the foliation in the area lack any plane of symmetry and are therefore triclinic. The fold axis plunges at 20° in a direction of 250° (figure 4.3).

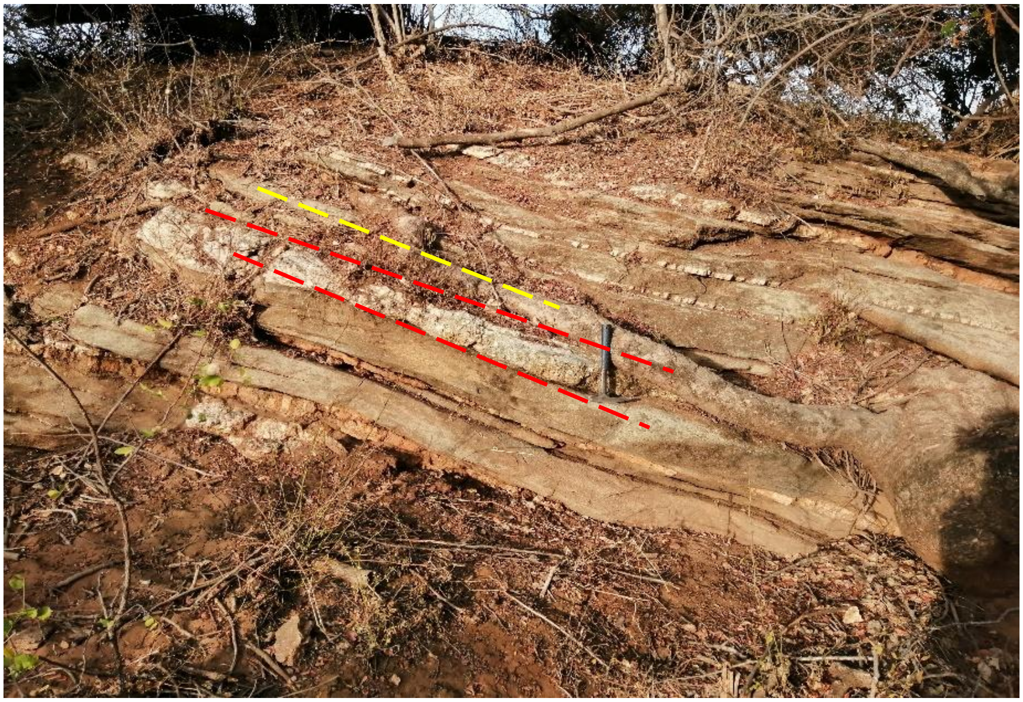


Plate 4. 19: Foliation planes in biotite gneiss (UTM: 425246/9840716).

Table 4. 6: Strike and dip readings used for stereographic projection.

ID	UTM Easting	UTM Northing	Strike	Dip	Direction
1	425246	9840716	90	30	W
2	425240	9840700	90	44	E
3	425246	9840716	20	25	W
4	422165	9839707	15	30	W
5	422175	9839707	15	25	W
6	426492	9834250	25	65	W
7	430874	9844238	10	50	W
8	430697	9843916	65	30	E
9	430410	9843667	70	30	E
10	429934	9843952	65	40	E
11	429872	9844022	76	34	W
12	432462	9845459	45	20	W
13	427888	9841285	5	35	W
14	427827	9841366	15	25	W
15	427899	9841948	5	25	W
16	427936	9841960	30	60	E
17	428002	9842083	15	40	W

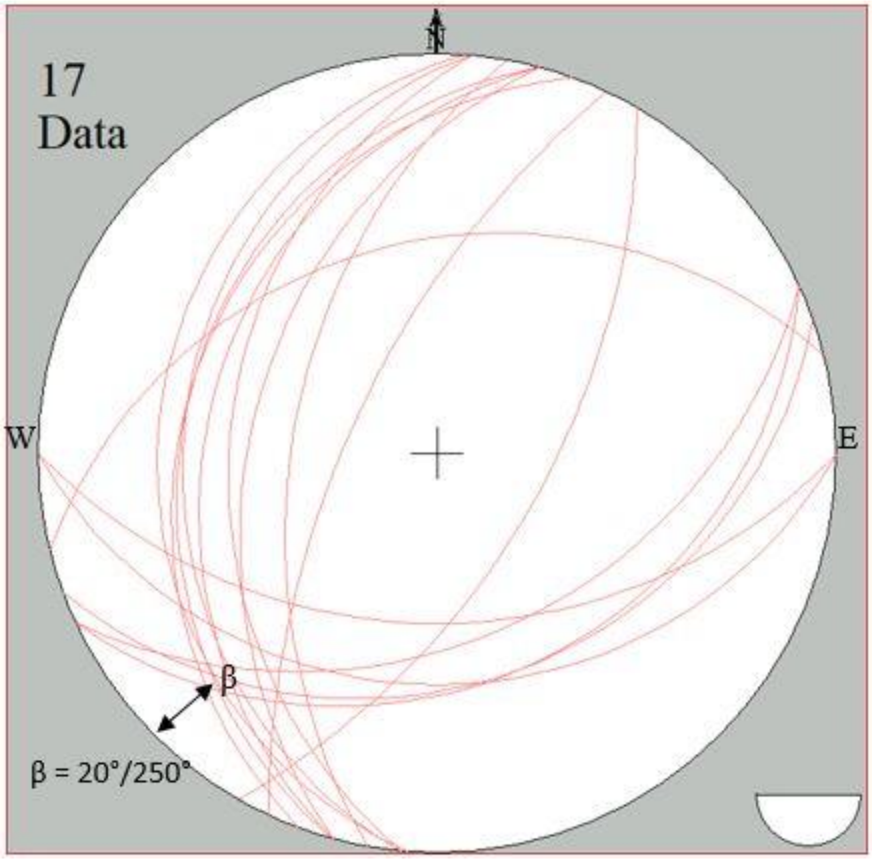


Figure 4. 3: Stereographic projection of 17 poles of foliation planes of the study area on equal area net.

4.2.1.2 Lineation

It is the alignment of linear elements in the rock such as the aligned prismatic grains of hornblende or any preferred orientation of mineral grains in a rock. In the study area, linear structures like mineral Lineations and boudin Lineations are well developed and found nearly in all rock types. They are best displayed in biotite gneiss and migmatites. Few structures like macroscopic folds were observed in granitoid gneiss. Lineations were measured and recorded (Table 4.7) for stereographic projection. The general trend of lineation is 250° SW with a plunge of 20° which almost coincides with the fold axes as seen in figure 4.4.

Boudins display a wide variety of shapes in the area. In most cases, mega crystals of potash feldspar are found at the middle of the boudinage surrounded in a matrix of quartz and biotite grains. Presence of pinch and swell structures within the rocks in the study area are signs that the area experienced strong non-linear shearing. This is also displayed where some boudins have been rotated in a sinistral manner. Mineral lineations in the area are composed of aligned crystals of hornblende, feldspars and quartz grains in a rock matrix. In the mylonitized meta-pyroxenites of Mweiga stream, the meta-pyroxenes show a preferred parallel orientation (plate 4.20).

Table 4. 7: Lineation readings used for stereographic projection

ID	UTM Eastings	UTM Northings	Strike	Plunge
1	425246	9840716	90	30
2	422165	9839707	195	30
3	426317	9832830	29	50
4	426370	9832860	305	70
5	426492	9834250	195	65
6	430874	9844238	10	50
7	430410	9843667	70	30
8	429934	9843952	65	40
9	429954	9844052	128	40
10	427888	9841285	85	35
11	427988	9841385	88	78
12	427827	9841366	75	25
13	427899	9841948	85	25
14	432098	9847093	335	35
15	432198	9847113	210	80
16	432128	9847013	330	80
17	434606	9843118	18	52
18	434695	9843019	30	49
19	434633	9842919	45	20
20	423385	9842351	78	40
21	426963	9846046	24	65
22	429866	9846838	35	72
23	433913	9839037	85	20
24	430864	9839272	28	84

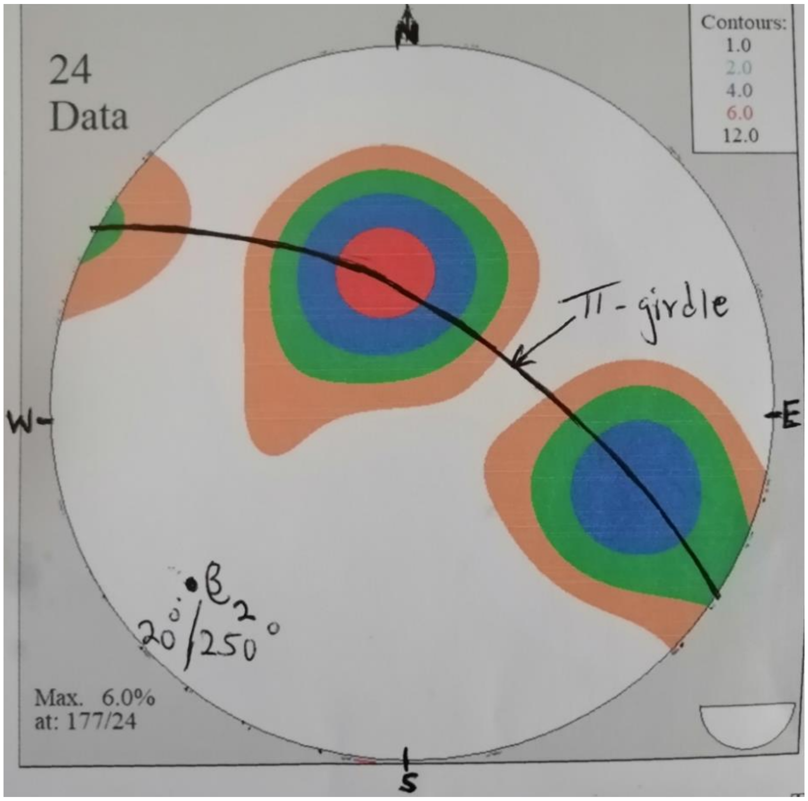


Figure 4. 4: Stereographic projection of twenty-four lineation readings collected from the study areas. These readings were projected on the stereo net at 6% area.

Plate 4. 20: A lineated and protomylonitized Meta-pyroxenite occurring in Mavia mailu area showing a preferred parallel orientation (UTM: 426317/9832830). The lineation trend at 29° NE and plunges at 50°.

4.2.1.3 Folds

Although no big folding patterns were observed in the rocks of the study area, the majority of mesoscopic folds were best observed in migmatites and granitoid gneisses. Their distribution is limited to certain outcrops and can rarely occupy large areas of an outcrop. These folds had in some instances been sheared forming S and Z structures within the various rock outcrops (plate 4.21). Their fold limbs were in millimetre scale especially on the western scarps of Makongo hill but those on the eastern slopes were large with limbs in centimetre scales. They were best observed on faulted surfaces with their fold plunges at 20° to the direction of the Faultline and trending at 250°.

Plate 4. 21: S-shaped mesofolds on granitoid gneiss at Makongo hill (UTM: 427899/9841948).

4.2.1.4 Strain and shear indicator structures

These are secondary structures formed in the solid rock as a result of crustal deformation. In the study area, it was observed that sinistral shearing took place though it was limited to certain types of rocks. The indicators of the type and zone of shearing were observed in the following deformed features; Sheared veins and folds, mylonites, kink bands, boudins and sheared K-feldspar blob.

a) Sheared veins and folds

These sheared veins were observed on the western slopes and fault surfaces of Makongo hill. They were composed of quartz and K-feldspar grains. They are lensoidal in shape and sigmatilly folded. Bigger folded veins were observed in migmatites around the hilltop. In granitoid gneiss, these folded veins took various shapes from S-shaped veins to snake-like veins (plate 4.22).

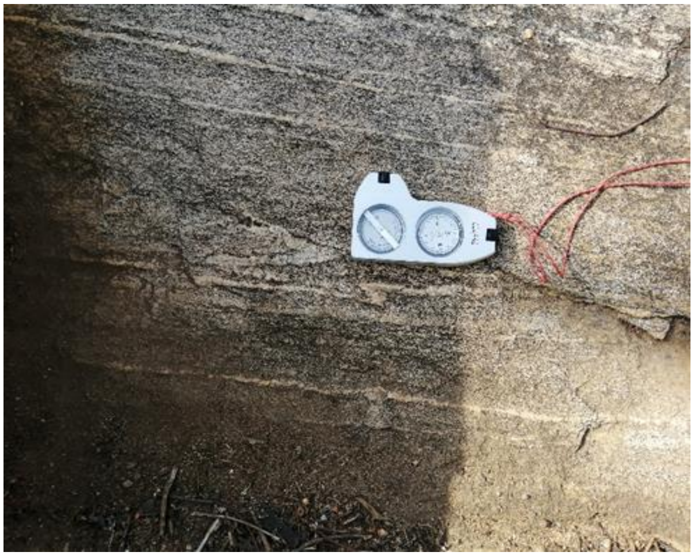


Plate 4. 22: S-shaped quartz-feldspar vein in granitoid gneiss (UTM: 428002/9842083).

b) Mylonites

It is a compact rock characterized by a well-developed lineation resulting from the tectonic reduction of grain size. In some instances, the rock can contain rounded porphyroblasts and lithic fragments of the same mineral composition as the one in the rock matrix. In the study area, mylonitized meta-pyroxenites were observed at Mweiga stream where they have been highly jointed. The rock was characterized with sheared augen like grains oriented trending at 30°. These grains resembled nodes sinistrally sheared (plate 4.23). The type of mylonitization was observed as protomylonite resembling cataclasite.

Plate 4. 23: Weakly deformed Meta-pyroxenite at Mweiga stream (UTM: 426317/9832830).

c) Boudins

Boudins are geological structures formed by extension, where a tabular body in a rock is stretched and deformed amidst less competent surrounding rock matrix. Boudinage in a rock can be formed through either brittle, plastic or a combination of both deformation mechanisms.

In the rocks of the study area, lensoidal shaped feldspar boudins of about 2 cm length were observed in granitoid gneisses of Makongo hill. The lenticular shaped boudins were sinistral sheared (plate 4.24). These boudins were interpreted to have been formed during shearing of the ductile/plastic rock of the area. Where the rock was brittle, rectangular-shaped boudins are formed. No rectangular-shaped boudins were observed in the study area.

Plate 4. 24: Sinistral sheared quartz-feldspar boudins (red dotted lines) in granitoid gneisses of Makongo hill (UTM: 430410/9843667).

d) Sheared feldspar blob

Sheared feldspar blobs were observed in a pegmatite vein hosted in a weathered biotite gneiss near Ngaaka yakwa area. The K-feldspar porphyroblast shows that the pegmatite vein has undergone shearing resulting in sheared feldspar blob through squeezing of the pegmatite vein. The pegmatite veins show compositional layering concordant to the host biotite gneiss, implying that they could be as a result of injection metamorphism. Formation of these veins was followed by compression and rotational forces which led to sinistral shearing of K-feldspar grains indicated by the cross in the plate 4.25.

Plate 4. 25: Sinistral sheared K-feldspar forming a spherical body in biotite gneiss (UTM: 425246/9840716).

e) Kink bands and orbicule

Kink bands are deformational bands characterized by bends and twists within some minerals. They develop in pre-tectonic minerals. These bands were observed in a granitoid gneiss near Kathiini spring at Makongo hill. The bands were formed when a K-feldspar aplite dyke was injected vertically into the rock resulting in folded cleavage.

The intrusion of this K-feldspar aplite dyke may have resulted in the formation of circular-shaped K-feldspar porphyroblast in the gneiss. This porphyroblast was interpreted to have formed from high normal stress caused by the dyke on the feldspar vein. This disc-shaped feature was formed in a high metamorphic grade rock as the temperature for crystal plastic behaviour of the feldspar vein was considerably higher. The disc-shaped orientation of the feature can be attributed to the transformation of the K-feldspar grains into a fish-like feature by recrystallization at the rims of the crystals. The circular-shaped K-feldspar (plate 4.26), is pointed by a pen while the kink bands are pointed by the edge of the geological hammer.

Circular-shaped K-feldspar.

Kink bands features in a feldspar dyke

Plate 4. 26: Kink band in granitoid gneiss at Kathiini spring (428012/9842093).

4.2.1.5 Faults

Majority of the faults observed were confined within Makongo hill. The hill is highly faulted in all sides but major fault lines were observed on the western and eastern parts. The hill is characterized by a thick vegetation capping, especially indigenous trees and thorn shrubs that are seldom sufficiently open to allow free penetration on foot. However, few footpaths that the local people use for grazing give reasonable access to the hill. The series of faults within and around the hill gives a linear trend in the drainage pattern of the area from NW to SE.

The faults on the western side of Makongo hill from Mwitika side, are suspected to be normal faults which have caused vertical movement of rocks forming hanging walls conspicuously seen as fault scarps. From geological observations, the first fault seemed to have been a mega normal fault on the western side of the hill with a huge downthrow facing Mwitika. This was followed by a mega trans-tensional fault that cuts the normal fault on the western side separating the two parallel normal faults. The normal faults are deeply inclined with angles close to 50° and a vertical movement of fewer than 200 metres of the downthrow to produce two separate fault scarps (plate 4.27). The trans-tensional fault extends to the middle of the hill and can best be observed from Ngaaka Yakwa shopping centre.

Plate 4. 27: A view of Makongo hill showing the eastern side. Noted are steep step faults with fault scarps exposing creamy white granitoid gneiss rocks (UTM: 425246/9840716).

On the eastern side of the Makongo hill, a vertical fault has created a graben/valley inside the forest. The graben can easily be seen from Makongo secondary school's main gate (plate 4.28 B). On the floor of this valley, a dam was constructed by the local people to collect water during the rainy season. The downthrow of this fault has formed the floor of the graben which is composed of migmatites and magnetite rich pegmatites.

Plate 4. 28: **A)** Normal fault observed at Ngaaka yakwa with a dipping hanging wall, **B)** Graben formed from faulting on the eastern side of Makongo hill (UTM: 430874/9844238).

On the northern side of the hill towards Kawala shopping centre, only one major normal fault can be observed from Kawala secondary school. This normal fault has created a valley with the downthrow facing Kawala market. The number of normal faults around Makongo hill could be an indication that the hill is an anticline of a major fold in the area, as many faults occur where maximum folding of rocks takes place, especially at anticlines. On the western side, the major fault planes are aligned parallel to the direction of the hill's fold. There are S-shaped folds on some scarp surfaces and the rocks here have strong jointing.

The major faults are accompanied by minor faults that can be measured on foot using a tape measure. One such fault was measured on the western side of the hill. This fault was striking in an N-S direction with a 10 metres wide displacement of the rocks (plate 4.29 A). Huge joints occurred on the surface of the displaced rock mass on both sides of this fault. Green vegetation was observed to grow in the fault opening perhaps due to the stream water that flows in it during the rainy season. Major streams from the hill were observed to flow through the fault opening cutting the murram road near Ngaaka yakwa flowing to the SE of the study area. A small spring was also observed on a faultline in an impermeable rock where locals fetch water even in the dry season (plate 4.29 B).

Plate 4. 29: A 10 metres wide fault scarp opening with thick vegetation in **(A), (B)** a fault-controlled spring at Makongo hill (UTM: 427936/9841960).

4.2.1.6 Gaping tectonic joints

Joints or a set of joints can be related to other geological structures such as major faults or broad upwarps of the crust in an area. The joints observed and measured in the Neoproterozoic Mozambique belt rocks of Makongo area vary in number and orientation from one rock type to the other. The joint numbers increase from migmatites through amphibolites, Meta-pyroxenites to granitoid gneisses in the area. However, the increase in number was inverse to the size of displacement in a rock. In the granitoid gneisses of Makongo hill, joints were observed to occur near veins and pegmatites. The orientation trends of the joints were measured in degrees using a Bruton portable compass in the field.

Most granitoid gneisses of Makongo hill are well jointed and consist of individual master strike joints with a vertical angle of between 70° to 85° (plate 4.30). The vertically inclined joints had a slight movement normal to the fracture plane and were best observed near Makongo hill fault lines. Other joints observed in the rocks of Makongo hill were those contained in the migmatites. Majority of those found in migmatites had no displacements and occurred as a series of fractures close to veins. However, around the hill especially on the eastern slopes, two sets of joints were observed in amphibolite rocks with angles of 210° and 330°.

Plate 4. 30: Tectonic joints (A&B) in the granitoid gneiss of Makongo hill (UTM: 427642/9841734).

Jointing in the southern part of the study area especially in Mweiga stream area is entirely developed in the meta-pyroxenite rocks. These joints comprise of longitudinal joints, cross joints and oblique joints. The longitudinal joints are best observed in the massive boulders along the banks of Mweiga stream while the cross joints are dominant on the dry stream bed. Some vertical and horizontal joints were observed in the boulders along the banks and few mylonitized rocks forming H and T intersection patterns. The cross joints strike at angles of 030° and 305°. In some instances, a vertical and a horizontal joint had intercepted to form an L shaped joint with a hinge angle of 95°.

In the north-eastern side of the study area especially around Kalima Kathei area, no major joints were observed. Only joints due to exfoliation and weathering were observed in the rocks here. A rose diagram of 24 data sets was plotted indicating that the majority of the joints are oriented along 15° to 30° in the NE direction in the study area (Figure 4.5).

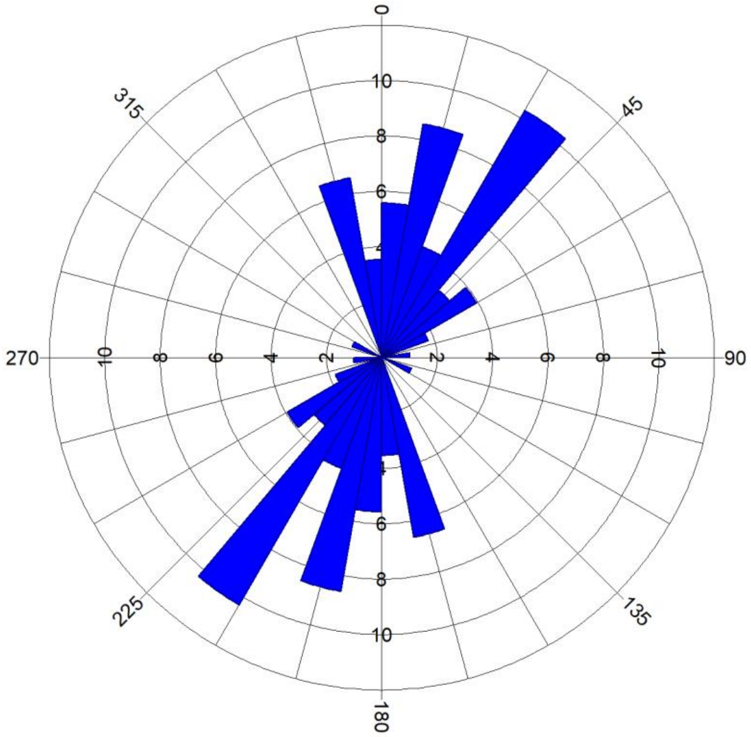


Figure 4. 5: A rose diagram for 24 data sets collected on joints within the rocks of the study area. This shows that the majority of the joints are longitudinal joints with a mean ray trend of 21.6°. Few cross joints and oblique joints are also present.

4.3 Results of Geochemical Analyses

This section gives results of the geochemistry of heavy mineral sands and rock units collected from the Mwitika-Makongo area. The purpose of these analyses was to figure out the degree of concentration of elements in these geological units, to determine their mineral potential, quality and petrogenesis.

The samples used in geochemical analyses were collected from the geochemical grid (figure 4.6) below. A total of 13 samples are plotted in their respective locations. The geochemical diagrams and graphs were plotted using geochemistry extension of Oasis Montaj software and Microsoft Excel.

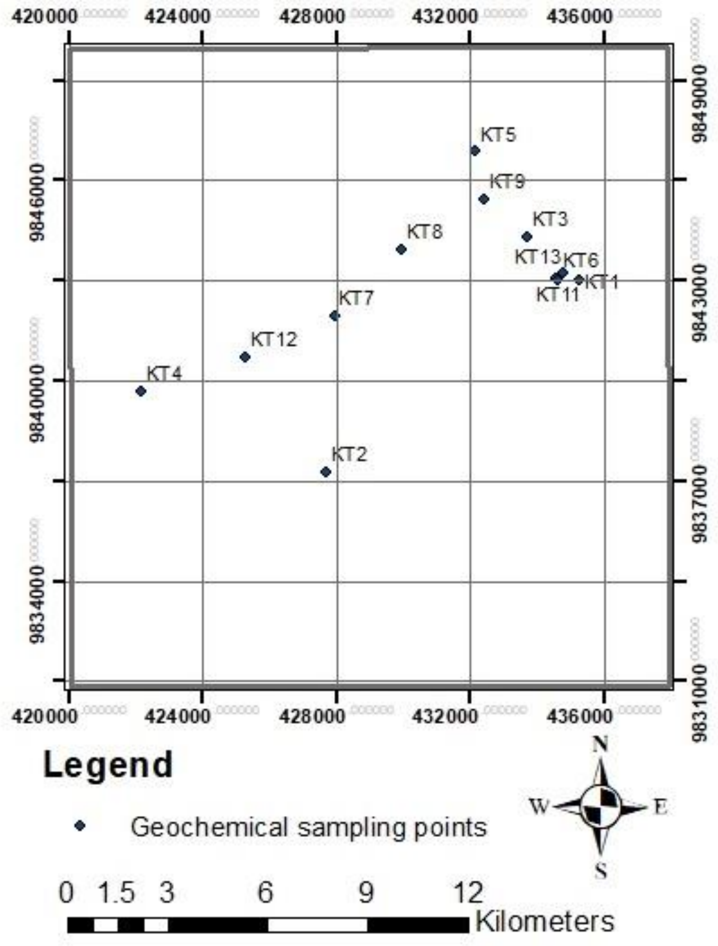


Figure 4. 6: Geochemical sample collection grid map of the Mwitika-Makongo area.

4.3.1 Major and Trace elements analysis

X-Ray Fluorescence method was used to analyze major, minor and trace elements from the rock samples at the Ministry of Mining and Petroleum (Madini house). The results are presented in Table 4.8. The major elements are given in weight per cent. Due to the limitation of the XRF equipment, some elements like sodium and magnesium were not determined in some samples by this method. This necessitated the use of X-Ray Diffraction method to supplement on these analyses.

Since trace elements are usually presented in parts per million (ppm), their concentrations were converted from weight per cent to ppm by multiplying their weight per cent concentration by 10^4.

Table 4. 8: Results of chemical analysis of rock samples of Mwitika-Makongo area (major elements in %WT, minor elements in ppm).

	KT1	KT2	KT3	KT4	KT5	KT6	KT7	KT8	KT9	KT10	KT11	KT12	KT13
SiO_2	**56.211**	0.276	18.177	44.826	48.173	**77.119**	**76.667**	78.768	51.100	4.467	2.278	**76.562**	48.678
Al_2O_3	11.347	2.826	4.130	10.659	19.647	8.682	7.532	0.233	7.343	2.515	3.320	9.192	4.365
Fe_2O_3 (Total iron)	8.693	1.596	2.424	**13.185**	5.731	2.429	4.547	16.701	13.108	**58.851**	**86.162**	2.443	8.379
CaO	8.158	**86.076**	**73.166**	10.797	21.154	1.321	3.144	0.511	24.191	0.415	0.000	1.355	15.855
MgO	7.793	7.948	0.000	13.197	4.296	0.00	0.00	0.000	0.000	0.000	0.000	0.000	21.215
MnO	0.201	0.115	0.231	0.191	0.183	0.068	0.162	0.418	1.245	0.411	0.216	0.071	0.183
Na_2O	1.045	0.154	0.133	0.241	0.207	0.406	2.399	0.682	0.000	0.635	0.000	0.000	0.069
K_2O	3.872	0.000	0.412	0.564	0.061	8.441	5.682	0.153	0.000	0.144	0.000	8.359	0.058
TiO_2	1.536	0.115	0.613	**5.883**	0.389	0.226	0.357	1.362	1.085	**31.614**	**4.648**	0.227	0.628
P_2O_5	0.478	0.575	0.573	0.423	0.136	0.369	0.283	0.509	0.989	0.227	1.778	0.484	0.048
Total	99.334	99.681	99.859	99.966	99.977	99.061	100.773	99.337	99.061	99.279	98.402	98.693	99.430
Trace element in ppm													
Rb	320	-	40	-	-	330	80	-	-	100	380	360	-
Sr	**2390**	**3270**	620	**1570**	**1230**	120	950	-	550	-	-	130	270
Y	20	-	40	-	30	170	130	-	50	-	-	150	20
Zr	250	400	140	280	310	940	**1700**	970	220	680	200	950	90
Nb	110	-	-	-	30	140	100	390	80	220	-	120	50
Ba	**1190**	-	-	-	-	-	**2380**	-	-	-	-	-	-
La	-	-	-	-	-	-	-	-	-	-	-	-	-
Th	-	-	-	-	-	-	-	10	-	-	-	-	-
Sn	-	-	570	-	-	-	-	320	-	-	-	990	-

Key: magnesite (KT1), marble (KT2), limestone (KT3), heavy mineral sand (KT4), amphibolite (KT5), Meta-pyroxenite (KT6), granitoid gneiss (KT7), pegmatite (KT8), dunite (KT9), iron ore (KT10 & KT11), biotite gneiss (KT12), and norite (KT13) from Mwitika-Makongo area.

4.3.2 Major elements presentation

From table 4.8, major and trace elements concentration of samples collected in the study area are shown. One heavy mineral sand was analysed (KT4), the result showed that the sample was rich in iron (Fe_2O_3) and titanium oxide (TiO_2) giving values of 13.185 wt. % and 5.883 wt. % respectively. From the rock samples analysed, the results show that most of the samples have a wide range of composition and are rich in silica (SiO_2), iron (Fe_2O_3) and titanium oxide (TiO_2). The highest concentration of iron was observed in iron ore sample (KT11) at 86.166 wt. %, while the lowest was in marble (KT2) at 1.596 wt. %. Higher values of titanium were also recorded in samples number KT10 and KT11 collected at Kalima Kathei hill with values of 31.614 wt. %. Two samples of marble (KT2) and limestone (KT3), had the highest concentrations of CaO values of 86.076 wt.% and 73.166 wt.%, respectively.

4.3.2.1 Correlation Matrix for Major elements

Pearson correction coefficients were used to test the dependence between the ten major geochemical elements. The Pearson correlation matrix results were plotted using MS Excel (Table 4.9). From this matrix, a positive correlation between two elements means that their mode of delivery into the rocks of the study area is similar.

From these analyses, it is noted that SiO_2 correlates negatively with Fe_2O_{3Total}, CaO, MgO, MnO, TiO_2 and P_2O_5. This means that their delivery mode in the Mwitika-Makongo study area is not similar. This fact is true because the content of SiO_2 is low when the contents of these elements go higher. SiO_2 had a positive correlation with Al_2O_3, Na_2O and K_2O, meaning the three are delivered in similar ways in the study area.

Fe_2O_{3Total} correlates negatively with CaO, MgO, Na_2O and K_2O but correlated positively with MnO, TiO_2 and P_2O_5 (table 4.9 and figure 4.7 A to H). A strong correlation was noted between Fe_2O_{3Total}, TiO_2 and P_2O_5 indicating that their mode of delivery in the area could be similar, with a likely source from hydrothermal fluids whose source is magmatic intrusions in the area. MgO shows a positive correlation with CaO and Al_2O_3, but shows negative correlation with Fe_2O_{3Total}, TiO_2 and P_2O_5. This pattern suggests that Mg and Ca are hosted by carbonate minerals in Mwitika-Makongo area. The processes involved in supplying Fe_2O_3 to the rocks of the study area is unrelated to that of carbonate minerals due to the lack of positive correlation between them.

Table 4. 9: Pearson correlation matrix for major elements in Mwitika-Makongo area

	SiO_2	**Al_2O_3**	**Fe_2O_3 (Total iron)**	**CaO**	**MgO**	**MnO**	**Na_2O**	**K_2O**	**TiO_2**	**P_2O_5**
SiO_2	1									
Al_2O_3	0.32786	1								
Fe_2O_3 (Total iron)	-0.55858	-0.36281	1							
CaO	-0.5205	-0.15821	-0.35631	1						
MgO	-0.07202	0.107553	-0.23444	0.126113	1					
MnO	-0.01832	-0.14049	0.116652	-0.01427	-0.23471	1				
Na_2O	0.377893	0.023848	-0.13613	-0.28784	-0.18946	-0.15498	1			
K2O	0.641682	0.250939	-0.35437	-0.37206	-0.2917	-0.38481	0.334699	1		
TiO_2	-0.45867	-0.26785	0.593449	-0.25174	-0.14293	0.124688	0.04161	-0.24784	1	
P_2O_5	-0.38166	-0.29787	0.632448	-0.00187	-0.37353	0.29494	-0.29441	-0.19746	-0.09908	1

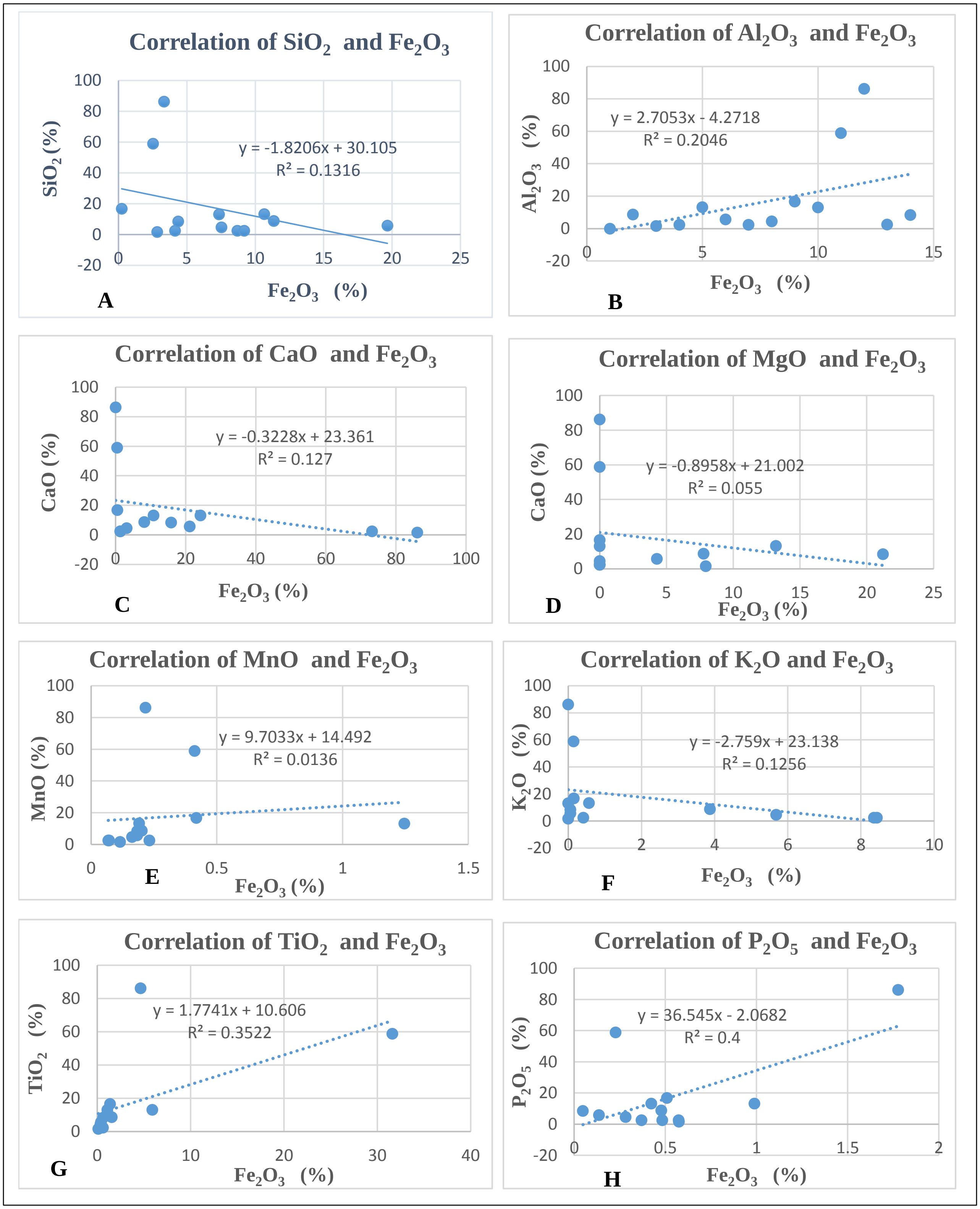


Figure 4. 7: Correlation of Fe_2O_3 with SiO_2, Al_2O_3, CaO, MgO, MnO, K_2O, TiO_2 and P_2O_5 in rocks of the study area.

4.3.3 Trace elements presentation

These are metals or minerals that are hosted in the rocks but occur in small amounts. Most of the trace elements like niobium, barium and zirconium, are of economic importance in many industries. From the study area, the highest concentration of trace elements was noted in heavy mineral sand (sample KT4) and magnesite (sample KT1) in table 4.8. As trace elements are usually presented in parts per million (ppm), their concentrations in rocks of the study area were considered economically unviable due to their low concentrations.

4.3.4 XRD mineralogical analyses

From XRD analysis, the results show that the majority of the rocks in the area are rich in iron minerals like hematite and magnetite. Other minerals present include pyroxene, titanium and rare earths. XRD mineralogical results are presented in two tables 4.10 and 4.11 showing the minerals identified through the analyses of each sample. The X-ray diffraction pattern of the minerals present in each sample is shown as spectra of abundance in the sample analysed on figures 4.8 and figure 4.11, circular distribution percentage diagram figures 4.9 and 4.10.

a) Meta-pyroxenite (sample MK4)

The mineralogy as given by XRD (Table 4.10), shows that the rock sample is very rich in pyroxenes (21 %), olivine (19.9 %), hematite (10.8 %) and magnetite (10.8 %). other minerals present in the sample include calcium thorium phosphate (11.5 %), titanium (4 %), tungsten (4.9 %) and zircon (2.7 %).

Table 4. 10: Mineralogical composition of sample MK4 from XRD analysis.

Mineral	Chemical formula	Vol. %
Calcium Thorium Phosphate	$Ca_{10.381}Th_{0.119}P_7O_{28}$	11.5
Hematite	Fe_2O_3	10.8
Magnetite	Fe_2O_4	10.8
Neltnerite	$Ca_{0.95}Mn_{6.05}SiO_{12}$	14.0
Olivine	$Fe_{0.2}Mg_{1.8}SiO_4$	19.9
Pyroxene	$Li_{0.3}Mg_{1.4}Si_2O_6$	21.0
Titanium	Ti	4.3
Tungsten	W	4.9
Zircon	$ZrSiO_4$	2.7
Total		**99.9**

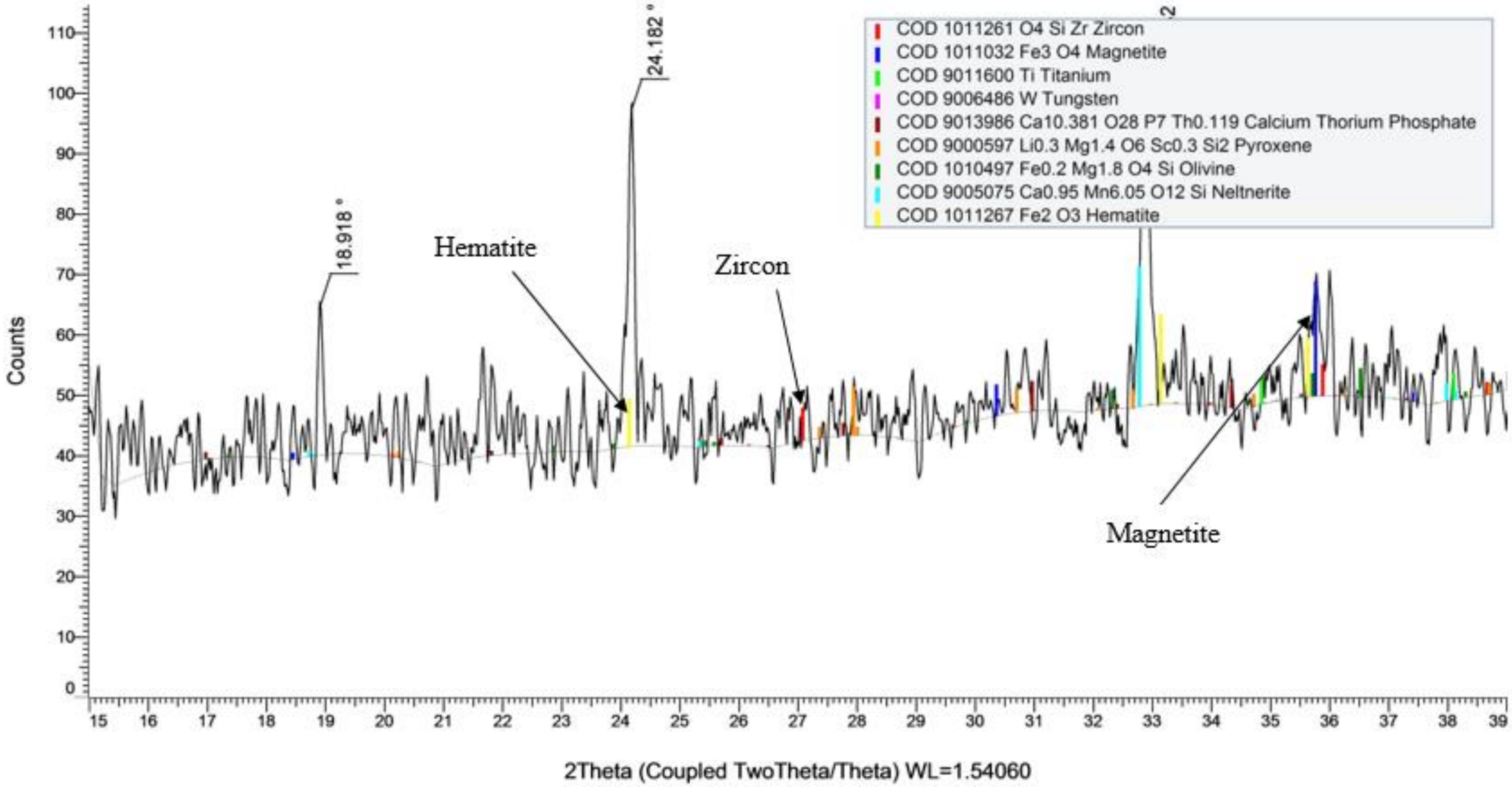


Figure 4. 8: X-ray diffraction pattern of sample MK4 showing the presence of zircon, magnetite, titanium, tungsten, pyroxenes, olivine and hematite.

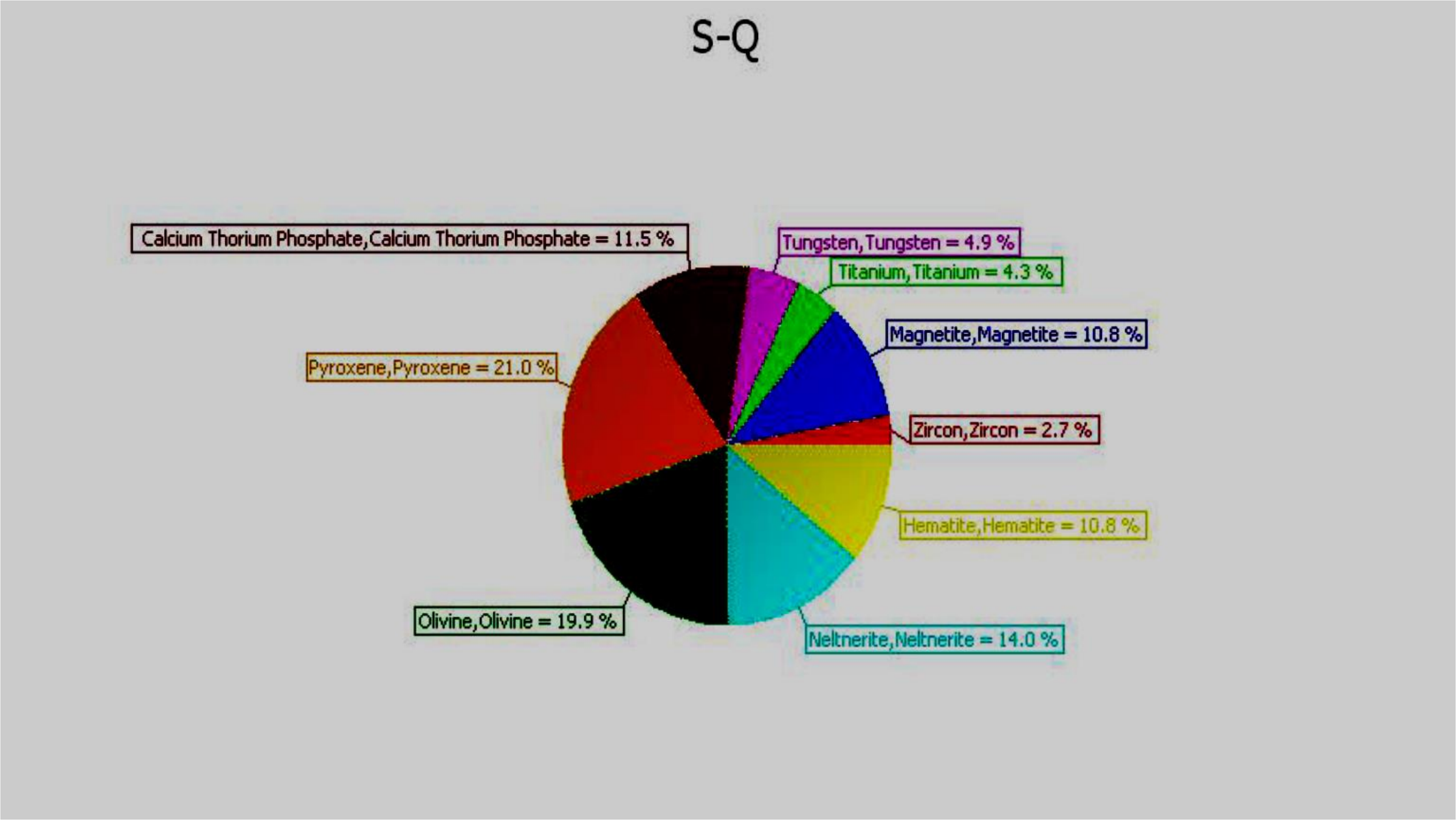


Figure 4. 9: Distribution diagram showing the percentage of each mineral in the sample MK4.

b) Heavy sand (MK12B)

Table 4.11 and figure 4.12 show the results of the XRD analysis of sample MK12B. The results obtained indicate that heavy sands in the study area are composed of silica (41.4 %), iron (20.9 %). Trace elements found within the sands include; Ruthenium and Lanthanum (13 %), gold and manganese (11.7 %), lead, cadmium and Tellurium (13 %), among others.

These results indicate that the heavy mineral sand in the area contains economic mineral potentials like iron and gold that can be extracted for economic gains.

Table 4. 11: Mineralogical composition of sample MK12B from XRD analysis.

Mineral	Vol. %
Silica	41.4
Iron	20.9
Ruthenium and Lanthanum	13
Gold and manganese	11.7
Lead, cadmium and tellurium	13
Total	**100**

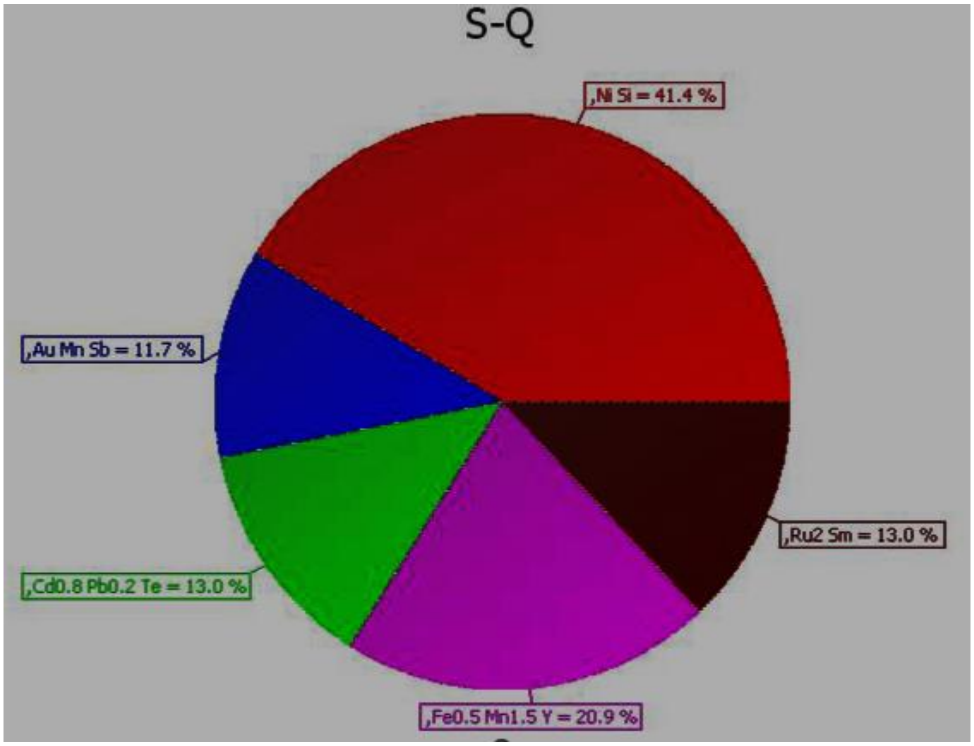


Figure 4. 10: Distribution diagram showing the percentage of each mineral in the sample MK12B.

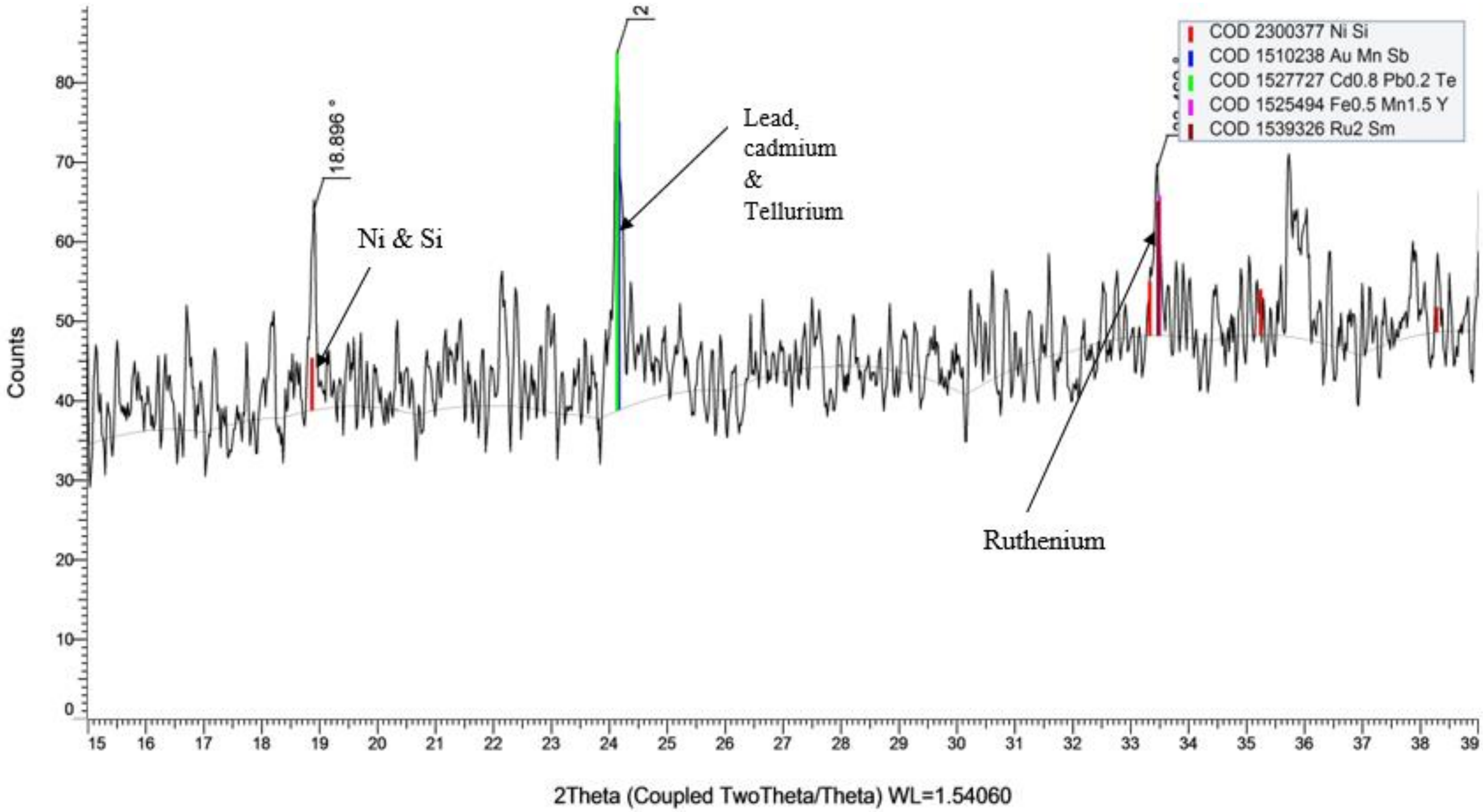


Figure 4. 11: X-ray diffraction pattern of sample MK12B showing the presence of silica, gold, manganese, lead, cadmium, ruthenium and iron.

4.4 Results of Potential Mineralization in Mwitika-Makongo Area

Different economic activities are carried in Mwitika-Makongo area, although more can be done to improve on the living standard of the local people. From this research work, economic mineralization in Mwitika-Makongo area was grouped into two categories as; (i) Mineral ores and (ii) economic rocks.

4.4.1 Mineral ores of the Mwitika-Makongo area.

Various mineral resources of economic potential are found in the study area. They include iron ore, magnesite, gemstones, and feldspars. Some minerals such as heavy mineral sands extend beyond the study area and can be easily found within the dry river beds of Kitui county. During dry periods, the local people excavate sands from river beds and sell it for building and construction activities.

4.4.1.1 Iron ore minerals

Iron ore in the study area was observed occurring as a band exposed on a footpath towards Kalima Kathei hill (plate 4.31). The iron ore band was estimated to be covering an area of 230 square meters of (2 m x 115 m). Since the iron ore depth can only be estimated by geophysical survey, the size of the boulders hammered from the band was used as an estimate of the band’s depth (30 cm).

Plate 4. 31: Hammered iron ore sample at Kalima Kathei (UTM: 434647/9843023).

In calculating the reserve potential for iron ore deposit, the formula below was used.

$$T = Th \times BD \times A$$

Where

T = Tonnage (in tonnes)

Th = Thickness of the deposit within the area of influence in meters

BD = bulk density (kg/m^3)

A = area of influence on a plan (m^2)

Using this formula, Tonnage of Kalima Kathei iron ore is

0.3 m x 2500 (kg/m^3) x 230 (m^2)

= 172,500 kg

= 172, 500/1000

= 172.5 tons.

4.4.1.2 Magnesite

Several magnesite prospecting pits were observed at the southern slopes of Kalima Kathei hill. The pits are owned by artisanal miners in the area (plate 4.32). The magnesite occurs intermixed with vermiculite and larger samples of the mineral are hard to extract. Good exposures of these minerals are difficult to find below 2 meters depth and they rarely develop to a width greater than half an inch. The prospecting pits were scattered in an area covering about 100 square meters. From the geochemical analysis of the samples collected, the magnesite contained 7.793 % Magnesium Oxide in weight percentage.

Using the reserve calculation formula ($T = Th \times BD \times A$), the tonnage of magnesite is

2 m x 3100 (kg/m^3) x 100 (m^2)

= 620, 000kg

= 620, 000/1000

= 620 tons.

Using the 7.793 % Magnesium Oxide in weight percentage to calculate the tonnage of Magnesium Oxide contained in the reserve estimate;

= (7.793/100) x 620 tons

= 48.3166 tons of MgO.

Plate 4. 32: **A)** Magnesite prospecting pit. **B)** Samples of magnesite and vermiculite from the pit (UTM: 435271/9843037).

4.4.1.3 Sands

Mineral sands exist in all sediments in the study area, especially along river and stream courses. The deposits form heavy mineral sands when the content of metallic minerals reach high concentrations. In general, there are two main types of mineral sands; light and heavy mineral sands. This classification is based on the specific gravity method of separation of these sands. The main component of light mineral sands is quartz and feldspar. Heavy mineral sand has a higher density and is characterized by dark colour due to its mineral content. It occurs mainly in rivers and the coastal environment when conditions are favourable.

A) Heavy mineral sands

Along the course of many dry streams in the area like Munyoni and Mweiga, black heavy mineral sands were observed. The black sands are strongly attracted by a magnet passed through them. Heavy mineral sands often occur in streams near iron ore deposits like those near Kalima Kathei.

Through geochemical analysis (table 4.8), the heavy mineral sand was found to contain iron (13.19%), titanium (5.88%) and zirconium (280 ppm). This resource is therefore important for commercial use due to its associated minerals. Titanium metal is used in corrosive chemical manufacturing industries due to its non-corrosive property. Zirconium is a raw material in ceramic industries for the manufacture of zirconium metals and zirconium chemicals. In this study, an estimate of the volume of these heavy mineral sand in Mwitika-Makongo area was calculated from Munyoni stream. The stream had the largest size of heavy mineral sand occurrence and was near Kalima Kathei hill where iron ore deposit was found. An area of 20 metres along the stream course was considered due to its best dark colour quality. The best samples were collected after sweeping the surface with twigs and collecting the dark heavy sand up to about 2 centimeters deep (plate 4.33).

Plate 4. 33: Black heavy mineral sands along Munyoni stream (UTM: 426017/9835483).

To calculate the surface volume estimate of the heavy mineral sand around Kalima Kathei area, the following formula was used;

(Volume of heavy mineral sand = occurrence area x depth of occurrence)

Area of occurrence = average width of stream (4 metres) x length (20 metres)

$$= 80\ m^2$$

$$\text{Volume} = 80\ m^2 \times 0.02m$$

$$= 1.6\ m^3$$

B) Ordinary/ light sands

These are sediments that are formed from weathering of parents rocks either through mechanical means or through chemical reactions. They are mostly formed along the rivers and streams through the settling down of sediments when the energy in the transport medium decreases. Due to scarce vegetation cover within the study area, large volumes of light sands can be spotted in footpaths and river channels. These sands have been used by locals in conserving water for use during dry seasons, especially along river courses. They have also been harvested for use in the construction industry as a source of income.

The mineral grains in these sands varied from 0.060 mm to 1 cm in length. The size of grains was determined by the parent material and the method of weathering. Where larger grain sizes were found, the method of weathering was presumed to be mechanical, although sediments mix when transported from the source. From the study area, light sand minerals consisted mainly of quartz and feldspar. Quartz is purely SiO_2 while feldspar is K_2O, Na_2O and Al_2O_3 rich minerals. This was proved through geochemical analysis of the mineral sand, showing high contents of silica (SiO_2) at 44.826% and Al_2O_3 (10.659%).

The surface area hosting ordinary sand deposit was estimated from the two main rivers (Munyoni and Kitambasya) in the area using ArcGIS 10.5 software to be about 4 km^2. The depth of ordinary sands in these rivers was estimated to be about one metre for better quality sands.

Using the reserve calculation formula ($T = Th \times BD \times A$), the tonnage of ordinary sand is

$$1 \text{ m} \times 1680 \text{ (kg/m}^3) \times 4{,}000{,}000 \text{ (m}^2)$$

$$= 6{,}720{,}000{,}000 \text{kg}$$

$$= 6{,}720{,}000{,}000/1000$$

$$= 6.72 \text{ million tons.}$$

4.4.1.4 Feldspars

They are the most important rock-forming silica minerals occurring in igneous, sedimentary and metamorphic rocks. There are two main groups of feldspars; alkali feldspars and plagioclase feldspars. Both groups are common in the study area. These minerals are a dominant constituent of the quartz-feldspathic gneisses and pegmatites in Mwitika-Makongo area. Feldspathic pegmatites are also common in migmatites and biotite gneisses (Plate 4.34).

Plate 4. 34: K-feldspar pegmatite in biotite gneisses (UTM: 425246/9840716).

4.4.1.5 Quartz

Quartz is the most abundant and common rock-forming mineral on earth. It occurs in several forms, as either crystalline or cryptocrystalline quartz. Quartz is widespread within the rocks of the study area, occurring as either vein intrusions or mineral components. This mineral form quartzite, a rock which is almost entirely composed of quartz minerals. Due to its close association with feldspars, local people extract them as decorative stones (plate 4.35) for landscaping of buildings.

Plate 4. 35: A heap of quartzites for sale (UTM: 422168/9839715).

The quartzite heap in plate 4.35 was estimated to be about 4 tons. The price per ton is Ksh 1500. However, quartzites have not been adequately exploited in the area. If utilized effectively, quartz has a variety of industrial uses. It can be used in the manufacture of glass, ceramics and refractories. It can also be used as ornamental or semi-precious stones or gemstones e.g., amethyst.

4.4.2 Rocks of Economic Potential in Mwitika-Makongo area

Various rocks with potential for economical use were observed within the study area. These rocks have a wide range of economic application, especially in building and construction. They can also be extracted and sold for the construction of roads, sand dams and bridges, within Kitui county and beyond. Besides, other economic rocks like marbles have industrial importance and are used in cement manufacture. These economic rocks are described below;

4.4.2.1 Marbles

A marble outcrop band was observed behind Ngaaka Yakwa market. The marble band width was estimated to be 71 metres and an observed length of 100 metres. Since no drill core was available to determine the marble depth, a depth of 2 metres was estimated for reserve calculation. Its colour ranges from pure to creamy white with shades of blue-grey. Pink varieties of marbles, were also present although weathered. The pink varieties of marbles (non-foliated) are used in tiles and slabs. Marbles are widely used in industries for cement manufacture. Geochemical analysis of sample KT2 (marble) and KT3 (limestone), showed high content of lime of 86.076 % and 73.166 %, respectively (Table 4.8), that is good for industrial use.

Using the reserve calculation formula ($T = Th \times BD \times A$), the tonnage of marble is

$$2 \text{ m} \times 1602 \ (\text{kg/m}^3) \times 7100 \ (\text{m}^2)$$

$$= 22{,}748{,}400\text{kg}$$

$$= 22{,}748{,}400/1000$$

$$= 22{,}748 \text{ tons.}$$

Although this reserve is too little, the value might be very high given that geophysical survey or drilling has not been done on the area.

4.4.2.2 Gneisses

The Mwitika-Makongo area is extensively covered by a variety of biotite gneisses, quartzo-feldspathic gneisses and granitoid gneisses. These rocks have a wide application in the building and construction industry. They can be extracted and used in the construction of road bridges, especially between Zombe and Endau. They can also be crushed and used as an aggregate material for foundations in buildings by virtue of their great hardness.

4.4.2.3 Migmatites

In the study area, migmatite rocks occur mostly on Makongo hill near the granitoid gneisses. The local community have constructed a dam wall using these rocks (plate 4.36) below. Due to their compact and impermeable nature, they are good for dam construction, especially given the semi-arid state of the study area. The area is also covered by various types of migmatites, which if quarried effectively, can be shaped into decoration stones due to their various structures and colours. They are also useful for aggregates, ballast and concrete making.

Plate 4. 36: A dam constructed on a migmatite floor to collect rainwater

4.4.2.4 Pegmatites and veins

They are a widespread occurrence in Neoproterozoic Mozambique belt rocks and are conspicuously developed in zones of migmatites, granitoid gneisses and biotite gneisses in the study area. The pegmatites are milky white, pink or brown in colour and their texture is variable from medium to coarse-grained. The coarser grains are often of K-feldspars, quartz and some mafic minerals, while the finer grains are of sodic feldspars or biotite. Their composition also varies depending on the host rock. Where the pegmatites were found in granitoid gneiss and migmatites, magnetite-bearing quartz segregations occur scattered through the pegmatites. These pegmatites are pinkish-grey in colour, medium-grained and have few or no augen feldspars. The magnetite mineralization appears to be restricted to those pegmatites found in massive granitoid gneiss and migmatites especially at the slopes and top of Makongo hill. The estimated percentage of magnetite grains in the pegmatite was about 40% of the whole rock mass (plate 4.37). The biggest grains were averaging between 1- 2 cm.

Plate 4. 37: Pegmatite with magnetite grains in granitoid gneisses of Makongo hill (UTM: 429934/9843952).

Pegmatites can be cut and polished for architectural stones or tiles. They are also of economic importance as a source of iron ore and various gemstones. Other pegmatites found within the study area can also be mined for extraction of feldspars, mica and quartz.

4.5 Results of Remote Sensing Investigations

Application of satellite images helped in mapping hydrothermally altered outcrops of the study area, enhancing target exploration for economic minerals. This was achieved through the following remote sensing processing techniques;

4.5.1 Colour composite band combination

Several different spectral bands of Landsat-8/ OLI data were selected and combined in an RGB colour system. This was done to come up with the best colour composite Landsat-8 image for extracting useful information about the land surface. These combinations involved bands from each spectral region except for first spectral band 1 which is designed as a deep-blue band for coastal water and aerosol studies. Bands 5,6,7 (Figure 4.12) was used to discriminate hydrothermally altered zones. In false-colour image 5,6,7, red colour represents healthy vegetation, the light blue colour represents outcrops, bare land and sands, the dark blue colour represents hydrothermally altered rocks, and the light green represents unhealthy vegetation.

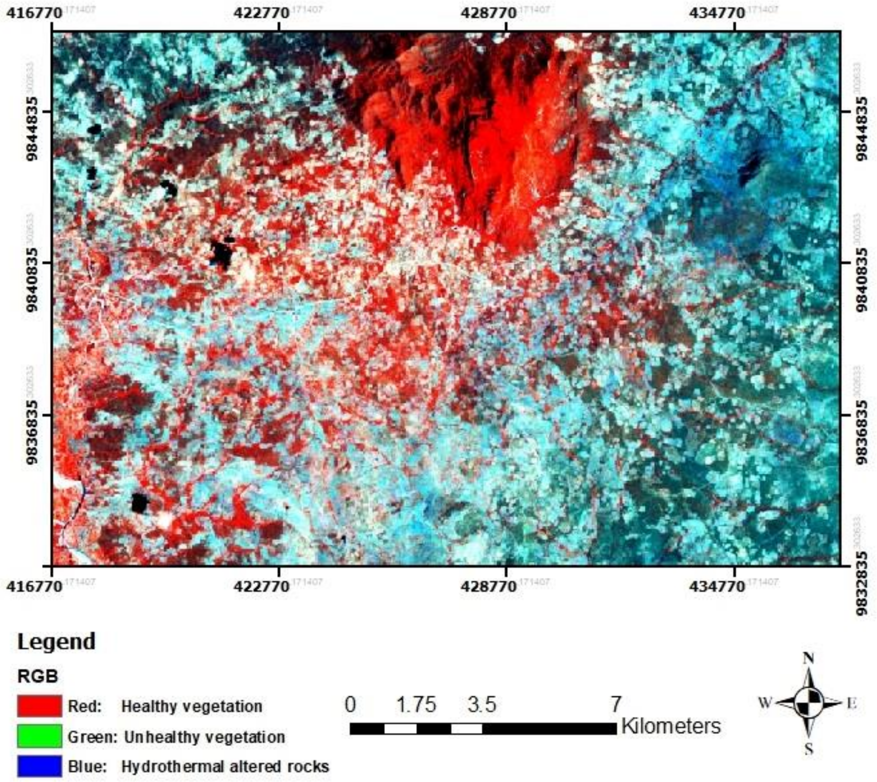


Figure 4. 12: FCC RGB bands (5,6,7) dark blue colour represents hydrothermally altered rocks

4.5.2 Band ratio combination

To enhance hydrothermally altered rocks in Neoproterozoic Mozambique rocks of the study area, band rationing was performed. Different band ratios were combined and assigned to RGB colour system. Band ratio combination (4/2, 6/7, 6/5) was found to be the most appropriate for delineating intrusive rocks useful in hydrothermal alteration mapping in the NE part of the study area. This was important as intrusive rocks are known to host economic minerals like iron from hydrothermal alteration. The band ratio (Figure 4.13), discriminated altered from unaltered outcrop and highlight areas where intrusive rocks occur. In Figure 4.13, olive green colour represents vegetation, purple colour represents sand/unaltered rock outcrops, and the blue colour represents altered rocks.

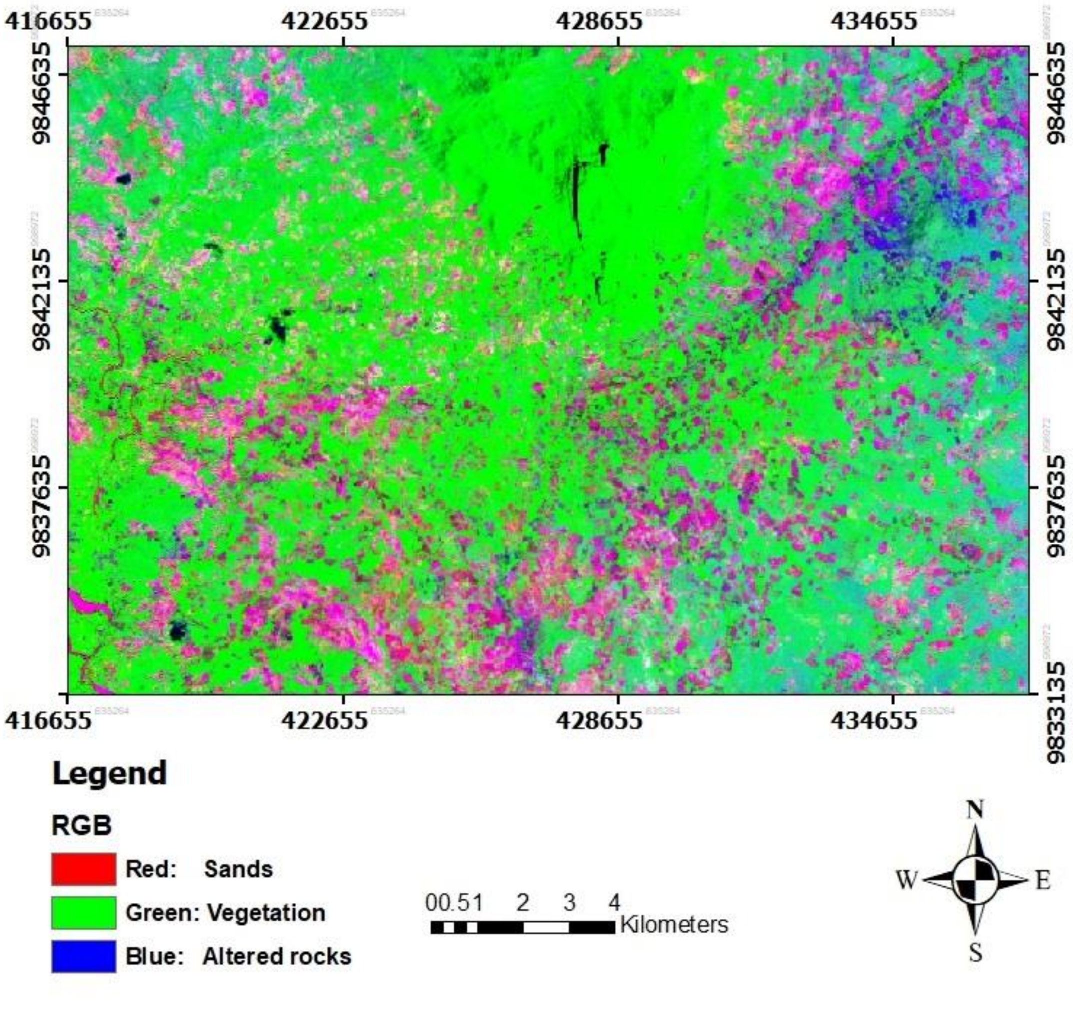


Figure 4. 13: FCC band ratio (4/2, 6/7 and 6/5) RGB, the blue colour represents altered rocks in the NE part of the satellite map.

4.5.3 Principal component analysis

The principal component analysis is used to display boundaries between terrain units. This is achieved by blending principal components in RGB colour composite images for all the bands used. In this study, the area is composed of several rock types among which quartzites, marbles and granitoid gneiss are light-coloured, and thus there is a plausible correlation of bands of image data. PCA technique was hence applied to reduce the number of correlated bands of an image to enhance on visual interpretation of ground features like alterations and lineaments. The following Landsat-8/OLI bands (1,2,3,4,5,6 and 7) were applied for this process.

The first three PCs with most data variance were combined in RGB composite (Figure 4.14). This was used for lineament and lithological mapping. Purple colours represent healthy vegetation, olive green colour represents outcrops, sands and bare-land, while the blue colour represents hydrothermally altered rocks that could be explored for potential economic mineral resources.

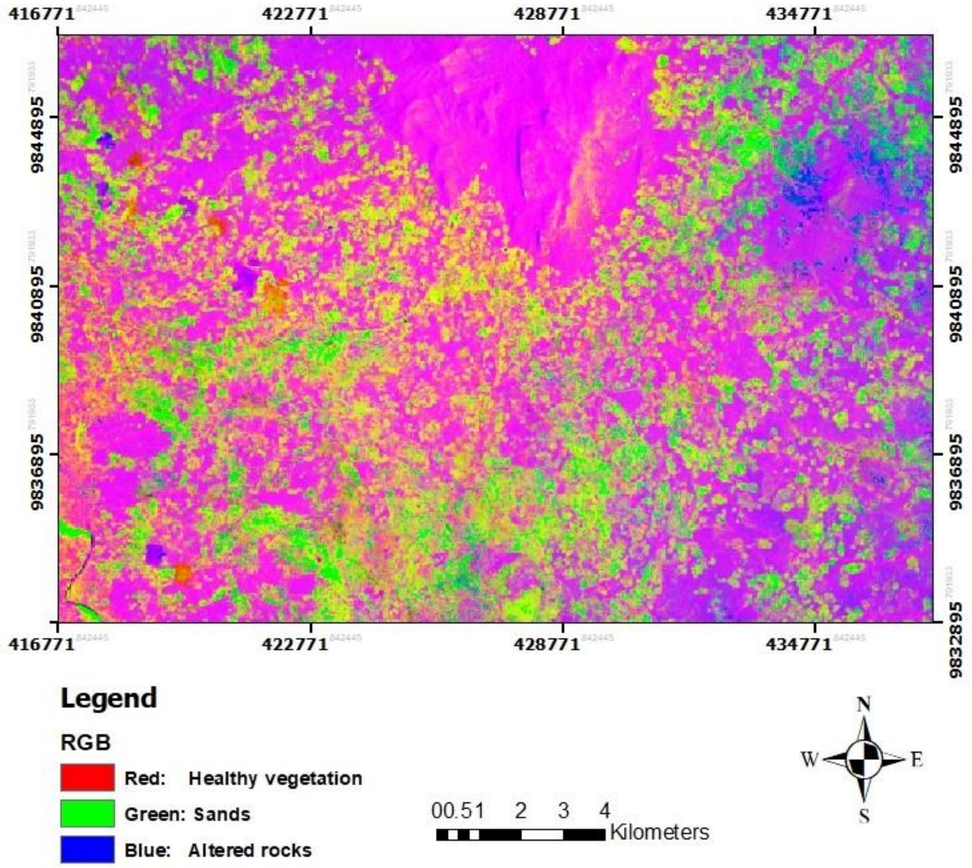


Figure 4. 14: RGB Composite PC3, PC2, PC1 best for displaying hydrothermally altered zones in blue on the NE part of the map**.**

4.5.4 Lineaments extraction

Lineaments have a strong topographic expression in the study area as detected on satellite images. A close relationship was observed between lineaments and the drainage pattern from satellite images, implying that the drainage pattern could be guided by lineaments. This was ascertained during geological field mapping as a majority of the streams in the area were observed to originate from areas of high elevation like Makongo hill and flowed downhill through fracture zones and faultlines.

Under line extraction parameters of PCI Geomatica 2016, automatic lineament extraction from Landsat 8/OLI bands of the study area was performed. The first principal component image (PC1) was good for visualization of linear features because it carried most information from all the bands and was preferred for lineament extraction (Figure 4.15).

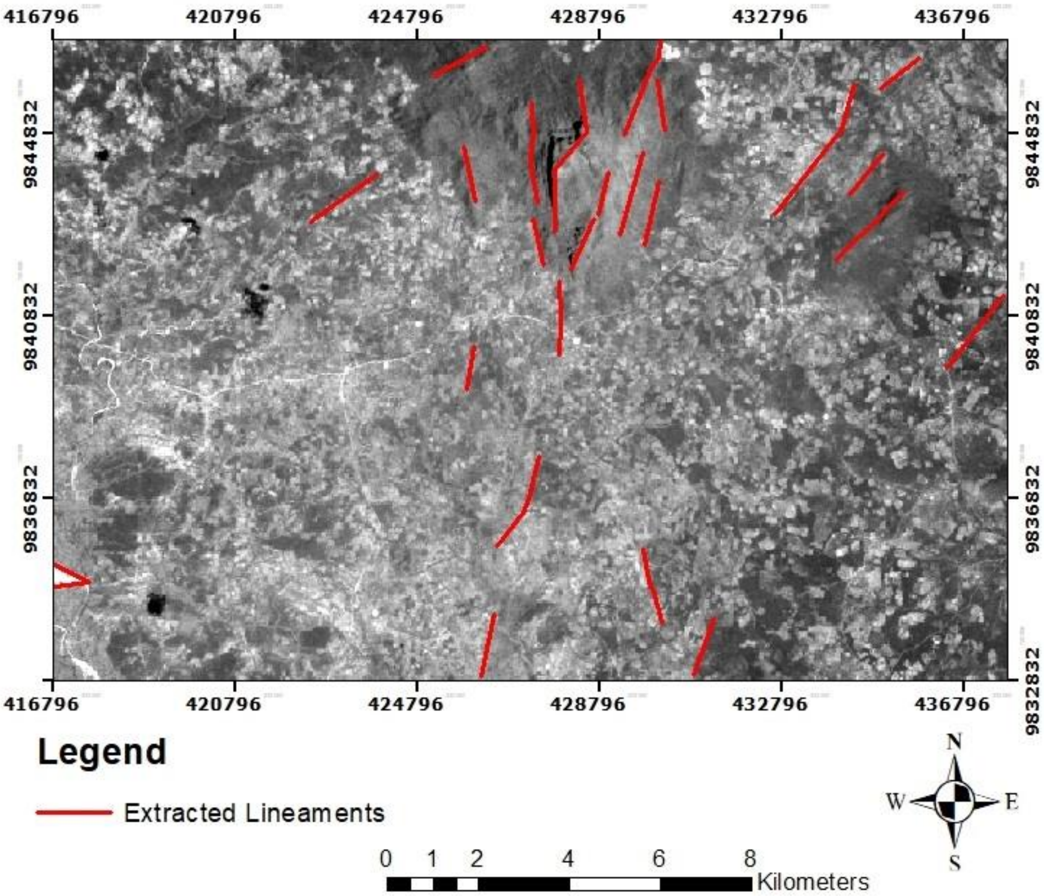


Figure 4. 15: Lineament map of Mwitika-Makongo area

The total lineaments obtained from automatic lineament extraction from PC1 were visually edited to extract only the structural lineaments. These structural lineaments were necessary for this study to delineate the geological structures in Mwitika-Makongo area, related to economic mineral occurrences. The predominant trend of lineaments in the study area, as observed in a rose diagram was in a NE direction (Figure 4.16).

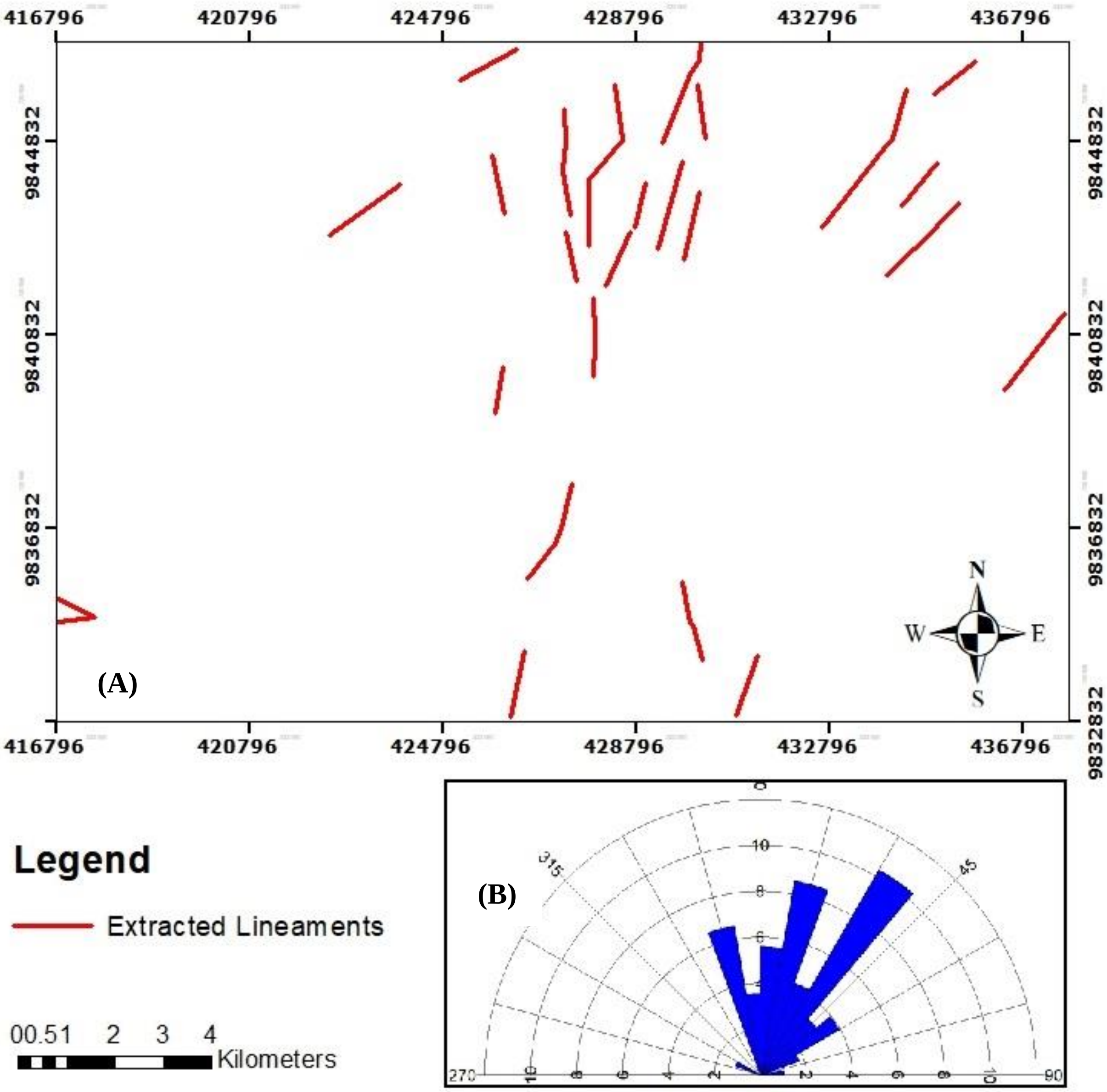


Figure 4. 16: Automatically extracted lineaments (A) and a rose diagram (B) of the study area.

CHAPTER FIVE

5.0 DISCUSSION OF THE RESULTS

This chapter presents a detailed explanation of the results obtained in the research carried out in the Mwitika-Makongo area. Explanations of the relations between geology and economic mineralization in the study area are discussed in this section. A comparison of how different or similar these research findings are, to those of other studies is also discussed.

5.1 Discussion on Lithological Units of Mwitika-Makongo Area.

The Mwitika-Makongo area was identified as a medium to high-grade metamorphic terrane with a North-South general structural trend, conforming to the general trend of Neoproterozoic Mozambique belt rock units. The rocks of the Makongo area are almost entirely of Neoproterozoic Mozambique Belt origin. They include the granitoid gneisses, metamorphosed psammitic rocks like quartzites and metamorphosed semi-pelitic like the biotite gneisses. Sandy soil deposits of Pleistocene and Recent Age, which include red and black soils are also found in various localities. On the local scale, granitoid gneisses and migmatites are the dominant rocks. Biotite gneisses, hornblende-biotite gneisses and quartz-feldspar- biotite gneisses occupy few areas. Intrusive rocks like gabbros and pyroxenites also occur as intercalations.

From geological field observations which include, banding of biotite gneisses and breccia-like structures in migmatites, it is concluded that the parent materials of these rocks were of sedimentary origin. The abundance of biotite and quartz in these rocks revealed that they were derived from parent sedimentary rocks, as biotite is abundant in argillaceous materials and quartz is arenaceous in origin. This was also strengthened by the close association between the granitoid gneisses and migmatites around Makongo hill.

The granitoid gneisses rocks are formed from pre-existing formations that were deeply buried and granitized through subsurface melting. Through burial metamorphism, there is an increase in temperature and pressure, making the rock to become plastic and buoyant (decrease in density). This explains the presence of migmatites capping on Makongo hill followed by granitoid gneisses. Saggerson (1957), had considered granitization in the area as being contributed by magmatic fluids, while Mathu (1980) deduced the close association between the granitoid gneisses and migmatite rocks, as representing portions of the highly granitized core formed at the peak of regional metamorphism within the granulite facies.

The presences of different types of migmatites in the study area are due to the changes in the parent rock compositions and the availability of high strain zones from high-grade metamorphism, enabling fluid movement. The presence of fragments of paleosome surrounded by narrow veins of neosome in Agmatite migmatites showed that they were formed from a melt that was constrained by pre-existing layering. The occurrence of magnetite grains in gneisses and migmatite rocks of the study area suggest that they are of igneous origin. This show that during the granitization phase, the melts were rich in iron that lead to mineralization of pegmatites.

Field observations of intrusive rocks like Meta-pyroxenite, Meta-gabbros and Peridotite showed that they occur close or near stream and faultlines. It was concluded that these rock bodies were tectonically intruded in areas of weaknesses like fracture zones. This information shows that intrusive bodies in the area contributed to iron ore mineralization through emplacement of the ore by the magmatic hydrothermal fluids in fractures during the intrusion phase.

The unvegetated ground on the slopes of the Kalima Kathei hill is attributed to the presence of Meta-pyroxenite with a high interlocking grain matrix which makes it difficult to fracture even through weathering, hence limiting vegetation growth. Many outcrops around the hill consist of boulders that have been rounded by exfoliation due to its compact nature.

5.2 Discussion on Geological Structures of Mwitika-Makongo Area.

The results show that the Mwitika-Makongo area experienced different tectonic events that lead to the formation of microstructures and major geological structures in the area. Presence of pinch and swell structures within the rocks in the study area are signs that the area experienced strong non-linear shearing. This is also displayed where some boudins have been rotated in a sinistral manner

Waswa (2015), ascertained that the Neoproterozoic Mozambique belt rocks of Ikutha area, Kitui County, have a complex folding pattern with at least three-fold generations. Major folds in Kitui area have been refolded to form major hills. Mesoscopic folds that can be measured in terms of various rock outcrops also occur in Neoproterozoic Mozambique rocks of Kitui area. Although no big folding pattern was observed in the rocks of the Mwitika-Makongo area, interpretation from stereonets indicates that the area has at least two-fold generations. From the projection of foliation in the area, the first folding pattern F1 was observed with a fold axes plunging at 20° in a direction of 250°. From lineation projection, the contour of lineations was spread along the pie girdle. This was interpreted to lie on a later folding pattern F2 meaning that they are from a second folding process. The beta lineation (β_2) of the second folding F2 coincided with those of the recent lineations.

Results from structures of strain and shear indicator gave the movement picture that took place during the formation and deformation of the rocks. The sheared veins and folds showed that the rocks were in a plastic state at the period of shearing. Presences of boudins and sheared K-feldspar porphyroblast show that the area underwent both plastic and brittle deformation. The mylonites in Meta-pyroxenite of Mweiga stream showed well-developed lineation from the tectonic reduction of grain size. This showed that the intrusive bodies were formed before the end of the metamorphic phase resulting in shearing of mineral grains.

Gaping tectonic joints in the rocks of the study area can be related to the numerous faults around Makongo hill. The joints vary in number and orientation from one rock type to the other depending on the level of strain experienced. In the granitoid gneisses of Makongo hill, joints were observed to occur near veins and pegmatites. This was an important factor during iron ore mineralization as the joints provided room for the deposition of magnetite.

5.3 Discussion on Geochemical Analyses.

From the rock samples analysed, the results show that most of the samples have a wide range of composition and are rich in silica (SiO_2), iron (Fe_2O_3) and titanium oxide (TiO_2). From these analyses, a strong correlation was noted between Fe_2O_{3Total}, TiO_2 and P_2O_5 indicating that their mode of delivery in the area could be similar, with a likely source from hydrothermal fluids. A negative correlation was noted between Fe_2O_{3Total} and CaO, MgO, Na_2O and K_2O. This showed that the material that formed the iron ore host rocks originated from clastic materials while Fe_2O_3 came from a hydrothermal source. These results were similar to findings of Waswa (2015), on iron ore deposit of Mutomo-Ikutha area.

Results from trace element analyses show that the rocks of the study area contain elements like niobium, barium and zirconium, which are of economic importance in many industries. These results indicate that the heavy mineral sand in the area contains economic mineral potentials like iron and gold that can be extracted for economic gains.

5.4 Discussion on Potential Mineralization in Rocks of the Study Area.

Geology has played a role in economic mineralization in rocks of the study area. Various economic mineral resources were found to occur in the study area. They include iron ore, magnesite, heavy mineral sands and feldspars. Magnetite is widely distributed in rocks of the study area and occurs as speckled grains in pegmatites and gneisses. In larger pegmatites, magnetite grains often occur conspicuously containing individual crystals measuring several centimeters in length. In stream sands, magnetite grains are heavily streaked and are easily collected when a magnet is passed across.

Although the tonnage of iron ore in the area is too little from the resource estimate calculation, it could be in thousands of tons because this value is just an estimate on the surface of less than one metre deep. Iron ore in the area can be mined and traded for great economic growth to the study area’s community. Iron ore is used in the production of iron and steel.

Magnesite was observed occurring as veins in ultramafic rocks of Kalima Kathei hill. Its formation can be attributed to secondary reactions with ultramafic rocks like dunites in the area. The olivine in dunite is metamorphosed to serpentinites, talc and finally to magnesite/sericite. The magnesite resource estimate was done on a small area through surface estimates, but its value may be high. Magnesite is used in various industries, especially as a source of magnesium for medicine as supplements. It is also used in the production of periclase for steel making. The estimated 48.32 tons of magnesium from the area can be mined and sold for a revenue stream.

Geochemical analysis of the heavy mineral sand showed that it contained iron (13.19%), titanium (5.88%) and zirconium (280 ppm). This resource is therefore important for commercial use due to its associated minerals. Titanium metal is used in corrosive chemical manufacturing industries due to its non-corrosive property. Zirconium is a raw material in ceramic industries for the manufacture of zirconium metals and zirconium chemicals. Although the estimated volume of heavy mineral sand in the area was little, high volumes can be obtained given that its deposition occurs mainly during the rainy season while this study was carried out during a dry season.

Rocks of economic potential observed in the study area include marble, gneisses, migmatites and pegmatite. These rocks have a wide range of economic application, in construction and industrial uses within Kitui County and beyond. The pink varieties of marbles in the area can be used in tiles and slabs. Marbles are widely used in industries for cement manufacture. Geochemical analysis of sample KT2 (marble) and KT3 (limestone), showed high content of lime of 86.076 % and 73.166 %, respectively, that is good for industrial use.

The mode of occurrence of pegmatites in Mwitika-Makongo area is highly variable. The larger bodies are sheets and veins averaging about 30 cm to half a meter in thickness. The sheet pegmatite has a sharp contact between them and the host rock, implying they could have been as a result of injection metamorphism. The vein pegmatites form small irregular segregations in granitoid gneisses or dyke-like bodies which often branch from the concordant sheets.

Pegmatite composition also varies depending on the host rocks. Where the pegmatites were found in granitoid gneiss and migmatites, magnetite-bearing quartz segregations occur scattered through the pegmatites. These pegmatites are pinkish-grey in colour, medium-grained and have few or no augen feldspars. The magnetite mineralization appears to be restricted to those pegmatites found in massive granitoid gneiss and migmatites especially at the slopes and top of Makongo hill. Pegmatites can be cut and polished for architectural stones or tiles. They are also of economic importance as a source of iron ore and various gemstones. Other pegmatites found within the study area can also be mined for extraction of feldspars, mica and quartz.

5.5 Discussion on Remote Sensing Investigations

Interpretation of the results from colour composite was compared with other research findings on hydrothermal alteration mapping. Frutuoso (2015), used colour composite bands 5,6,7 in mapping hydrothermal altered rocks. The altered rocks appeared as blue and were related to gold mineralization. Omwenga (2018), used bands 5,6 and 7 when mapping for hydrothermal alteration zones in Eburru. Githenya et al., (2019) used colour composite bands of Landsat 8/OLI to highlight areas of Neoproterozoic belt rocks as hydrothermally altered in blue colour. It is evident from this research work and others that have previously been carried out, that colour composite can be used to map hydrothermally altered zones and mineralized areas.

Band ratio has been successfully used in mapping hydrothermal alteration zones, Kujjo, (2010), Frutuoso, (2015), Achieng et al., (2017), Omwenga, (2018) and Githenya et al., (2019).

Lineaments can also be extracted from satellite images using both manual visualization and automatic lineament extraction through software such as PCI GeoAnalyst, Geomatica and Matlab. Waswa et al., (2015) used GeoAnalyst-PCI package to extract structural lineaments in Ikutha area.

This study aimed to use remote sensing techniques to delineate areas of hydrothermal alteration and their associated geological structures suitable for economic mineralization. This was achieved through various image processing techniques. The altered mineral recognized by Landsat 8/OLI imagery of the study area was iron ore occurring in intrusive bodies around Kalima Kathei hill. New lithological units of Pyroxenite were identified and associated with lineaments in the study area. This was ascertained through extensive geological field mapping, where Meta-pyroxenites were found occurring at Mweiga stream on the southern part of the study area. The results helped in updating the geological maps produced by Sander (1954) and Saggerson (1957) whose lithology was missing especially were the two maps merged (Figure 5.1). This was accomplished during this research work by using satellite imagery and geological field mapping.

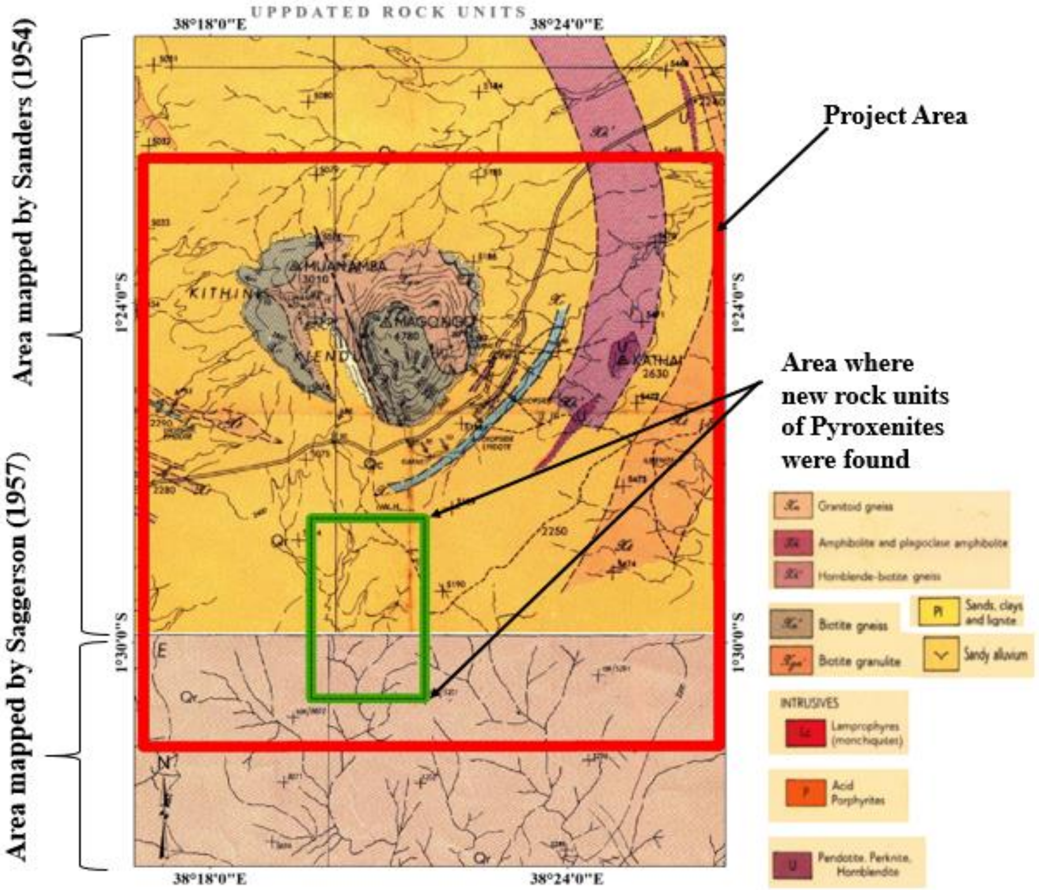


Figure 5. 1: Original rock units from areas mapped by Sanders (1954) and Saggerson (1957).

CHAPTER SIX

6.0 CONCLUSIONS AND RECOMMENDATIONS

Through this research work, evidence-based on geological field mapping, remote sensing data and geochemical analysis show that Neoproterozoic Mozambique belt rocks in Mwitika-Makongo area, are economically mineralized. Various economic mineralized units were delineated and their associated geological structures identified. Rocks of the study area were identified to have suffered polyphase tectonic deformation at varying degrees. This was exemplified by complex folds, depicted by several types of foliations and lineations, joints, and faulting. Several intrusions of granitic composition were observed crosscutting the Neoproterozoic Mozambique belt rocks. New lithological units discovered in this research work include Pyroxenite, dunite and marble. The general trend of rocks in the Mwitika-Makongo area is in a NE direction.

6.1 Conclusions

The conclusion of this research work is based on the four objectives of the study and explained as follows;

1) **The first objective of this study was to identify lithological units that host economic minerals occurring in Mwitika-Makongo area**.

   Geological field investigations found the following:

   a) Iron ore band on the south eastern slopes of Kalima Kathei hill.
   b) Magnesite on the southern slopes of Kalima Kathei hill, hosted in weathered veins of dunite.
   c) Granitoid gneiss and migmatites hosting magnetite rich pegmatites around Makongo hill.

2) **The second objective of this research was to delineate the geological structures of the study area that may be related to any possible economic mineral resource occurrences.**

   The following was found:

   a) Through remote sensing investigations, it was established that hydrothermally altered rocks occurred near intrusive rocks of Kalima Kathei area. The hydrothermally altered rocks hosted iron ore and magnesite as economic minerals.

b) Geological field investigations revealed that major pegmatites and quartz veins around Makongo hill had mineralization of magnetite at about 40%.

3) **The third objective of this research was to investigate the genesis of potential economic minerals in the study area.**

   a) Petrographic analyses of rock samples from the study area revealed that iron was an accessory mineral in almost all the rocks. It also revealed that iron replaced other minerals during the inclusion process. It can, therefore, be concluded that during the deformation and metamorphism phases in Mwitika-Makongo area, magmatic fluids deposited these economic minerals.

   b) Field observation of shearing and mylonites in Meta-pyroxenite rocks at Mweiga stream indicate that these intrusive rocks came before the end of the metamorphic period.

   c) Geochemical evidence indicates that Fe_2O_3 has a positive correlation of, $R = 0.632$ ($R^2 = 0.399$) with P_2O_5, $R = 0.593$ ($R^2 = 0.352$) with TiO_2, and a negative correlation with other elements. This shows that the mode of delivery of the two minerals into the area was similar, probably through hydrothermal fluids.

4) **The fourth objective of the study was to indicate the quality of economic minerals from different rocks in the area.**

   a) XRF studies revealed magnetite above (86%) as the major mineral in iron ore of Kalima Kathei area, which is of good quality for commercial iron ores.

   b) XRD analysis of heavy mineral sand samples indicates the presence of trace elements such as; Ruthenium and Lanthanum (13 %), gold and manganese (11.7 %), lead, cadmium and Tellurium (13 %), among others, which are of economic importance in various industries.

   c) The Mwitika-Makongo area is rich in mineral resources that can boost its economic status. These resources were estimated as follows; Marble at 22,748 tons, iron ore at 172.5 tons and magnesite at 620 tons. These resources can be mined for local use.

   d) All the reserves calculated might have a higher potential if depth investigations are done, this is because those calculated were only from surface investigations.

6.2 Recommendations

1. This research work recommends geophysical survey around Kalima Kathei area to establish the depth of iron ore mineralization and its reserve estimations.
2. It is recommended that drilling and assay work be done to establish the quality of iron ore and magnesite at Kalima Kathei area.
3. Radioactivity investigations should be carried out to gauge the heavy mineral sands in stream beds as they were found to contain high levels of rare earth elements like Lead (13%).
4. Further geological studies and investigations should be carried out around Makongo hill to establish the cause of the numerous amount of faults around the hill.
5. The Kitui County Government should encourage the local communities to invest in mining activities in the Mwitika-Makongo area due to economic resources in the area.
6. The Kitui County Government should enact laws governing the drafting and signing of local contracts in mineral exploration and mining to protect vulnerable communities from greedy investors.
7. Feasibility should be carried out on the extraction and utilization of the economic minerals and rocks established by this research like marbles, iron ore and magnesite.
8. The National Government should enact rules of engagement between the local people and mining investors to ensure that the County Governments do not miss huge investment opportunities due to local political intrigues and conflict of interests.

REFERENCES

Achieng, J., Mutua, J., Mibei, G., Olaka, L., & Waswa, A. K. (2017). Mapping of Hydrothermal Minerals Related to Geothermal Activities Using Remote Sensing and GIS: Case Study of Paka Volcano in Kenyan Rift Valley. *International Journal of Geosciences*, *08*(05), 711–725. https://doi.org/10.4236/ijg.2017.85039

Bakker, W. H., Janssen, L. L. F., Revees, C. V., Gorte, B. G. H., & Pohl, C. (2001). *Principles of Remote sensing* (Second). The International Institute for Aerospace Survey and Earth Sciences.

Biyajima, K., Suswa, K. and Miyakawa, K., (1975). Mantled gneiss dome in the Mozambique belt around Machakos area, Kenya, Preliminary Report. African Studies, Nagoya University, pp. 6-13.

Chasia, A. S. (2014). *Mapping Geological Structures in Western Mutomo, Kitui County: A Remote Sensing Approach* [Masters Thesis]. University of Nairobi.

County Government of Kitui. (2014). *First County Integrated Development Plan 2013- 2017*. Government of the Republic of Kenya.

Frutuoso, R. (2015). *Mapping hydrothermal gold mineralization using Landsat 8 data. A case of study in Chaves license, Portugal*. 85.

Gaciri, S.J., Altherr, R., Nyamai, C.M. and Mathu, E.M., (1993). Distribution of elements in mineral pairs from Mozambique belt rocks of Matuu area, central Kenya. In: Opiyo-Akech, N., 1984 edition, Proceedings of the 5th Conference on the Geology of Kenya - Geology for Sustainable Development, pp. 57-62. UNEP/ UNESCO, Nairobi

Githenya, L. K., Kariuki, P. C., & Waswa, A. K. (2019). Application of Remote Sensing in Mapping Hydrothermal Alteration Zones and Geological Structures as Areas of Economic Mineralization in Mwitika-Makongo Area, SE Kenya. *Journal of Environment and Earth Science*. https://doi.org/10.7176/JEES/9-11-03

Government of the Republic of Kenya. (2007). *Kenya Vision 2030*. National Economic and Social Council of Kenya.

Government of the Republic of Kenya. (2010). *The Constitution of Kenya*.

Kesler, S. E. (2007). Mineral Supply and Demand into the 21st Century. *In Proceedings for a Workshop on Deposit Modeling, Mineral Resource Assessment, and Their Role in Sustainable Development*, *1294*(US Geological Survey circular), 55–62.

Key, R., Charsley, T.J., Hackman, B.D., Wilkinson, A.F. and Rundle, C.C., (1989). Superimposed Upper Proterozoic Collision controlled Orogenies in the Mozambique Belt of Kenya. Precambrian Research 44, pp. 197-225

KPMG. (2016). *Analysis of the Mining Act 2016* (p. 14).

Kujjo, C. P. (2010). *Application of remote sensing for gold exploration in the Nuba Mountains, Sudan* [PhD Thesis]. Bowling Green State University.

Mathu, E. M., & Tole, M. P. (1984). Geology of the Ithanga Hills area. Journal of African Earth Sciences, 2(1), 1–16.

Mathu, E.M., Ngecu, W.M., Nyamai C.M. and Davies, T.C., (1991). Proterozoic island tectonism in the Kenyan Mozambique belt east of Nairobi. In: Muhongo, S. (Ed.) Proceedings of the International Geological Field Conference on the Mozambique belt in East Africa, Tanzania. 8, pp.59 UNESCO, Nairobi, Kenya.

Mathu, E. M. (1992). The Mutito and Ikoo faults in the Pan-African Mozambique Belt, Eastern Kenya. In *Basement Tectonics 7* (pp. 61–69). Springer.

Ministry of Mining. (2015). *Kenya Mining Investment Handbook 2015*. Government of the Republic of Kenya.

Mosley, P.N. (1993). Geological evolution of the late Proterozoic “Mozambique Belt “of Kenya. Tectonophysics, 221:223-355.

Nyamai, C. M. (1999). *Crustal Evolution of the Neoproterozoic Mozambique Belt Rocks in Matuu-Masinga Area, Central Kenya: An Implication to their Tectonic Setting and Potential Mineralization* [PhD Thesis]. University of Nairobi.

Nyamai, C. M., Mathu, E. M., Opiyo-Akech, N., &Wallbrecher, E. (2003). A Reappraisal of the Geology, Geochemistry, Structures and Tectonics of the Mozambique Belt in Kenya, East of The Rift System. African Journal of Science and Technology, 4(2), 51–71.

Nyamai, C.M., Mathu, E.M. and Ngecu, W.M. (1993). A review of the geology of the Mozambique Belt in Kenya. In: Peters, J.W., Kesse, G.O. and Acquah. P.C., (Eds.), Proceedings of the 9th International Geological Conference of the Geological Society of Africa - Regional Trends in African Geology, pp 334-347. Accra. Ghana

Omwenga, B. (2018). *Use of Space-borne imageries in Mapping of Hydrothermal Alteration Zones and Geological Structures in the Eburru Geothermal Complex, Kenya*. 14.

Opiyo-Akech, N. and Nyambok, I.O., 1984. Precambrian geology of the Ishiara area, Kenya. Journal of African Earth Sciences, 2, pp. 61-65.

Pohl, W., Horkel, A., Neubauer, W., Niedermayr, G., Okelo, R. E., Wachira, J. K., & Werneck, W. (1980). *Notes on the geology and mineral resources of the Mtito Andei-Taita area (southern Kenya)*. ÖGG.

Pulfrey, W. and Walsh, J. (1969). The geology and mineral resources of Kenya. Geological Survey of Kenya Bulletin, 9, 34 pp

Saggerson, E. P. (1957). *Geology of the South Kitui Area: Degree Sheet 53, SW Quarter, with Coloured Geological Map*. Geological Survey of Kenya.

Sanders, L. D. (1954). *Geology of the Kitui Area: Degree Sheet 53, NW Quadrant, with Coloured Geological Map*. Government Printer.

Sanders, L. D. (1963). *Geology of the Voi-South Yatta area: Degree Sheet 65, N.E. Quadrant, With Colored Geological Map*. Government Printer.

United Nations Development Programme. (2015). *Sustainable Development Goals*. United Nations.

United Nations Economic Commission for Africa. (2009). *Africa Mining Vision*. African Union.

Vearncombe, J.R. (1983). A dismembered ophiolite from the Mozambique belt. West Pokot. Journal on African Earth Sciences, 1, 133-143.

Walsh, J. (1963). *Geology of the Ikutha Area: Degree Sheet 60, NW Quarter, with Coloured Geological Map*. Government Printer.

Waswa, Aaron K., M. Nyamai, C., M. Mathu, E., & W. Ichang’i, D. (2015). Integration of Geological Mapping and Remote Sensed Studies for the Discovery of Iron–Ore

Mineralization in Mutomo–Ikutha Area, SE Kenya. *Universal Journal of Geoscience*, *3*(2), 39–50. https://doi.org/10.13189/ujg.2015.030201

Waswa, Aaron K., Nyamai, C. M., Mathu, E., & Ichang'i, D. W. (2015). Application of Magnetic Survey in the Investigation of Iron Ore Deposits and Shear Zone Delineation: Case Study of Mutomo-Ikutha Area, SE Kenya. *International Journal of Geosciences*, *6*, 729–740. https://doi.org/10.4236/ijg.2015.67059

Waswa, Aaron Kutukhulu. (2015). *Petrology And Iron Ore Mineralization In The Neoproterozoic Mozambique Belt Rocks Of Mutomo – Ikutha Area, Kitui County, S.E. Kenya.* [PhD Thesis]. University of Nairobi.