MAKERERE UNIVERSITY

COLLEGE OF NATURAL SCIENCES
SCHOOL OF PHYSICAL SCIENCES
DEPARTMENT OF GEOLOGY AND PETROLEUM STUDIES

A REPORT ON THE GEOLOGIC MAPPING OF AREA C, IGAYAZA, ISINGIRO DISTRICT, WESTERN UGANDA

BY
MIREMBE PRISCILLAH

19/U/19788/PS

1900719788

SUBMITTED TO THE DEPARTMENT OF GEOLOGY AND PETROLEUM STUDIES MAKERERE UNIVERSITY IN PARTIAL FULFILMENT OF THE AWARD OF BACHELOR OF SCIENCE – PHYSICAL

ABSTRACT

The geological mapping exercise was carried out in Gayaza, Isingiro district in western Uganda with the main objective of acquiring skills in geological mapping where acquisition, processing and interpretation of field data were the major steps undertaken. The mapping exercise lasted a period of 8 days. The methods used in acquiring data for the project involved; making groups of 6 students, standardizing pace lengths to measure size of large structures, establishment of stations on out crops, taking GPS readings and measurements of strikes and dips of structures in each of those established stations. After the field work, samples were sorted and taken to the laboratory for further analysis. The mapped area C is situated on the NE limb of the Gayaza synclinorium and is part of the Karagwe-Ankolean system which belongs to the Meso-Neo Proterozoic cover formations. It lies on a rugged topography with intervening valleys, steep gorges and rounded hills. The lithology of the area comprises of ridges that are predominated by quartzites on the peaks and thick argillaceous formations constituting shales (ferruginous & grey) and phyllitic shales along the slopes and in low lands. The rocks were deposited in the order of shales followed by sandstones that later metamorphosed to quartzites that occupy the top of ridges which were later intruded by granites. Long-term episodes of erosion and weathering of the granites formed arena structures which predominate much of the Karagwe-Ankolean system. Metamorphism of these rocks was mainly low-grade regional metamorphism evidenced by foliation and some index minerals such as chlorite. Sandstones and shales were metamorphosed to quartzites and phyllites respectively. The major structures in the area include: beddings, faults, folds and joints all exhibiting two major trends; NW-SE trend which is similar to that of the regional folds and NE-SW direction similar to that of the cross folds whereas the minor ones include: micro-folds, micro-faults, quartz veins, foliation, laminations and mud cracks.

The drainage pattern of the area is essentially structurally controlled.

It was concluded from the findings that the study area belongs to the lower part of the Karagwe Ankolean system basing on the lithology, that is presence of thin quarzitic bands which are frequently boudinaged and sheared.

The economic potential of the area is low since no economic minerals have been discovered. However, some of the economic activities carried out include; farming, cattle keeping, quarrying and brick making.

DECLARATION

I **MIREMBE PRISCILLAH** pursuing Bachelor of Science in **Geology** (Major) declare that this work contained in the report, is entirely and truly my own observations based on the knowledge and information acquired throughout the mapping period and has never been submitted.

SIGNATURE: ....

DATE: ......6th / November / 2022

Project coordinator

Dr. Naguddj Betty

.... 6th / Nov / 2022

3

DEDICATION

I dedicate this report to my dear parents **MR. Mukisa Disan and Mrs. Mukisa Agnes,** relatives and close friends. Great thanks also go to Lecturers, Group C members and other students basically for their great support; financially, socially, morally and spiritually during field mapping period and during preparing the project presentations and report.

God richly bless you

TABLE OF CONTENTS

CHAPTER ONE: INTRODUCTION ... 7
1.1 Background ... 7
1.1.1 back ground ... 7
1.1.2 Location and Accessibility ... 7
1.1.3 Drainage and vegetation ... 8
1.1.4 Physiography ... 9
1.1.5 Land use ... 9
1.1.6 Settlement ... 10
1.1.6 Climate ... 10
1.2 Objectives of the field study ... 10
1.2 REGIONAL GEOLOGY ... 10
1.2.1 Regional geology ... 10
1.2.2 Economic Geology ... 14
1.2.3 Stratigraphy and Geochronology ... 15
1.2.5 A map of AREA C ... 21
Figure 6: A map of AREA C ... 21
1.2.6 CROSS SECTION ... 21
1.2.7 Stratigraphic column ... 22
1.2GEOLOGIC HISTORY ... 27
1.3.1 Depositional history ... 28
1.3.2 Depositional environment ... 29
1.4 Stratigraphic rock succession ... 30
1.4.1 Tectonic Evolution ... 31
1.4.2 Geochronology and Age Dating ... 32
CHAPTER THREE: STRUCTURES ... 32
3.3.1 Stereographic analysis of bedding planes ... 34
3.3.3 Other stereographic analyses. ... 38
3.4.1 Major Structures ... 40
3.4.2 Minor Structures ... 46
3.5 Discussion ... 49
3.5.2 Tectonic history/deformation history of the area ... 50
CHAPTER FOUR: PETROGRAPHY AND METAMORPHISM ... 50

4.1.3 Macroscopic description. 51
4.2 METAMORPHISM 57
4.2.1 Types of Metamorphism 58
4.2.2 Types of Metamorphism in the mapped area C 58
CHAPTER 5: REGIONAL SYNTHESIS 59
5.2 HOT SPOT PRESENTATIONS 60
5.2.1 Discussion and interpretation of all the information gained. 61
CHAPTER SIX: CONCLUSIONS AND RECOMMENDATIONS 65
6.2 OBSERVATIONS 66
6.2.3 Materials used 70
6.3 Recommendations 70
REFERENCES 72

CHAPTER ONE: INTRODUCTION

1.1 Background

1.1.1 back ground

This report contains detailed information for the field mapping exercise, with more emphasis on area C, in Gayaza, Isingiro district, which is about 30km from Mbarara Town, South-western Uganda. The area mapped lies in the Karagwe-Ankolean System which is the third oldest system after the Basement complex and Buganda –Toro systems in Uganda.

This project report is a compilation of the activities that were carried out during the 14 days of field geological mapping details in the Gayaza synclinorium in Karagwe-Ankolean system, two days of hotspot presentations and two days of geologic excursions to the other very important areas in the region to as far as Uganda – Tanzania boarder to the south of the region and to Kyambura in Bunyaruguru, along the western arm of the East African Rift System escarpments, north of the region mapped. The mapping project was completed by compiling the detailed report of the findings from the measurements taken in the field in addition to both macroscopic and microscopic observations of the thin sections made from the hand sized samples collected from the field.

1.1.2 Location and Accessibility

Area C is found in Gayaza Parish Kabingo sub- county in Isingiro District, South-western Uganda. It is located about 30km South of Mbarara town along Mbarara-Isingiro road. The area borders Mbarara district to the North, Ntungamo district to the West, Rakai district to the East, and the Republic of Tanzania to the South as shown by the map of Uganda.

The mapped area C, lies between UTM coordinates of Eastings (**256000E to 258000E**) and Northings (**991700S to 991900**S) in Gayaza sub county, Isingiro district.

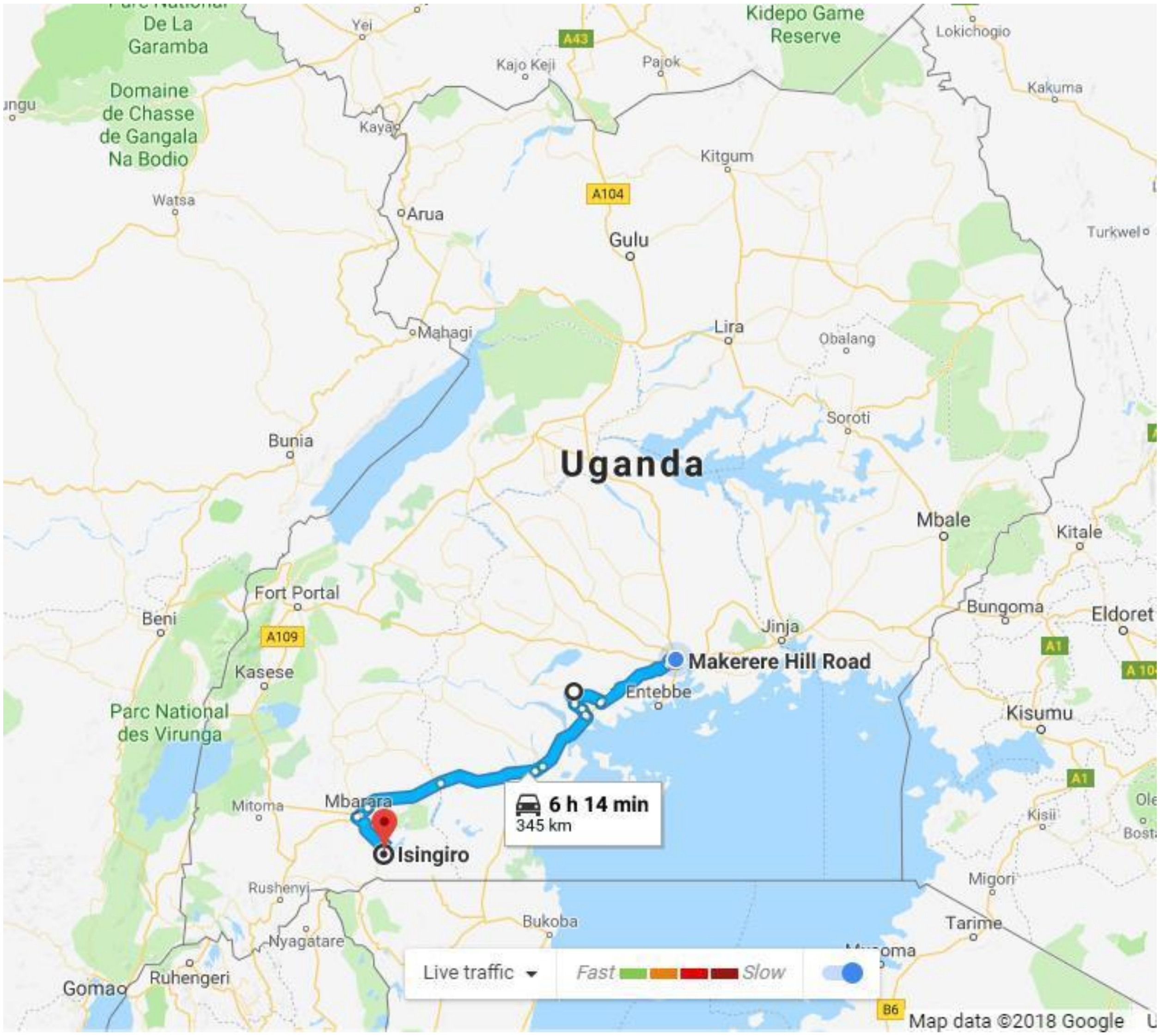


Figure 1: location and accessibility to Isingiro

1.1.3 Drainage and vegetation

The vegetation of the area is mainly of savannah type, with the hill tops mainly occupied by quartzite ridges having short grass and thin thorny shrubs. Most of the hilltops also have scanty vegetation and isolated trees. Scattered short grasses dominated the slopes of the hills but are being degraded by human activities like animal grazing. Vegetation thickness and abundance increases downslope, and in the valleys, there are mainly banana plantations and thick shrubs. Agriculture is mainly in the low land areas due to silty roam soils formed from the weathering and deposition of the rocks in the hills and the slopes. The deposited sediments form the soil that supports agriculture. There exists tree planting especially along the slopes of the hill, and the trees are mainly eucalyptus and pine plus the natural indigenous trees that are mainly used as a source of firewood timber and construction purposes.

Figure 2: drainage and vegetation

1.1.4 Physiography

Topographically, the mapped area was generally hilly with numerous ridges and valleys. The ridges are capped by Quartzites while the slopes and valleys are mainly composed of shales which vary from Ferruginous shale to gray shales and phyllites. There exist two parallel quartzite ridges that are oriented in the north east south west direction in the mapped area. There exists a low land area in the North West of the mapped area which is composed of the weathered granite and all that could be seen in the area were gray clays, and brown sand grains rich in quartz. This area is known as the Arena which physiologically looks like a stadium with steep sides. It was formed due to intensive differential weathering of the intruded Masha granite, relative to the neighboring lithologies, that is shales and Quartzites (Barnes, 1956)

1.1.5 Land use

The main use of land in the study area is for agriculture, which is mainly subsistence. This is carried out in the slopes and low lands of the mapped area dominated by the fertile soils of weathered quartzites mixed with weathered shales along the slopes and in low lands. The crops are mainly bananas, maize, cassava, sweet potatoes, beans, gnuts, fruits like pawpaws, oranges, mangoes, passion fruits.

There exist animals rearing, especially cattle, goats, sheep, chicken and pigs. The cattle are the source of milk that they consume for nutritional nourishment and the rest sold for income. The cattle are mainly grazed in the hilly areas covered by grass growing in the fractured quartzites. Another land use activity in the mapped area was brick laying from which they build houses and sell the rest for income, however this is carried out on a small scale. Stone quarrying is another activity carried out.

1.1.6 Settlement

The population in Isingiro district is generally sparse, with a population distribution of about 99-115 persons per km2 (*Uganda Bureau of Statistics, 2010*). The settlement is sparsely distributed, with most people concentrated in lowland areas. The settlement pattern is also linear, with most people concentrated along the main Isingiro-Kikagati road and trading centers. The trading centers are mainly in the low-lying areas

1.1.6 Climate

Gayaza lies in region that experiences tropical type of climate which is influenced by the relief and topography of the area of up to 1600-2400m (*Ucakuwun, 1989*). There are two rainy seasons, one from April to May and the other from October to November with the wettest month being April. The hottest months (as told by the natives), are from December to February then June to September.
The amount of rainfall received in a year moderately ranges from 750 to 1250mm annually, and the remaining periods are dry with an almost semiarid climate. Based on data from the Directorate of Geological Survey and Mines Uganda (DGSM, 1973), the mean annual temperature of region is minimum at 12.5 to 150C and maximum of around 25 to 27.50C

1.2 Objectives of the field study

Main objective

- To learn all skills involved in geological mapping and other geological related projects.

Specific objectives

- To develop the basic field observation techniques of different geological structures and materials
- To learn how to collect geological data using different geological materials.
- To learn how to relate the geological features and the conditions of the area of study.

1.2 REGIONAL GEOLOGY

1.2.1 Regional geology

The rocks of Isingiro are non-fossiliferous of Precambrian. Therefore, K-A system consists of a folded and metamorphosed succession of arenites and argillites over 26,000 feet in thickness which contains numerous quartzites interbedded with cleaved mudstones, slates, phyllites and schists. Quartzite conglomerates occur sporadically and siliceous limestones now represented by calc-silicate rocks are found at the base of the succession (Ucakuwun, 1989).

Elliot (1893) made the first geological report on the Karagwe-Ankolean system in southwestern and western Ankole and together with Gregory, proposed the term ‘Karagwe-Ankolean’. Phillips (1959) identified quarzitic horizons q1 to q4 and he noted the q4 as being the thickest underlying the Rugaga plateau and comprising numerous quartzite layers interspersed with thin argillaceous bands.

Plumber (1960) described thinning of the quartzites on the northwestern limb of the Igayaza syncline east of the Mbarara-Kikagati road. Tissot et al (1980) described the Kibaran as an extensive tin-tungsten metallogenic province of East and Central Africa with Sn, W, Nb, Ta, Be, and Li mineralization in the zones of metasomatic alteration around granites.
Biryabarema (1995) noted that to the north and west of the area underlain by the Gayaza syncline, the rocks of the K-A system are largely argillaceous with quartzites attenuating fairly abruptly. These argillaceous rocks of the K-A system showed a progressive increase in metamorphism towards the base from shales and slates through phyllites to muscovite or sericite schist. This progressive trend in metamorphism also corresponds with their proximity to granites in anticlinal cores.
However, besides those early workers, many students and lecturers from the department of geology and petroleum studies, Makerere university have also made study and research in this area. The lithologies in all areas are similar, therefore a three-fold subdivision was established and is generally accepted.

Division	**Lithology**
lower division (4000-6000 m)	pelitic rocks, sometimes graphitic, with intercalation of quartzites, calcareous and itabiritic formations. Greywacke layers underwent metamorphism of different grades to produce phyllites, micaschists, gneisses, migmatites and kinzigites.
middle division (2000-3000 m)	characterized by a large quartzitic body, which comprises intercalations of pelitic rocks and some conglomerates. It is followed by schists and quartzoschists with calcareous sediments and itabiritic layers in its upper part. Rarely leucogranites with tourmaline and tin minerals intrude this unit.
upper division (3000-5500m)	includes mudstones, siltstones, sandy mudstones, sandstones, grits, and occasional conglomerates which are intercalating with the quarzitic horizons.

Geochronology tells us of the age dating of the Kibaran belt. Several geochronological methods such as radiometric methods have been used to determine the relative ages. It was reported from Kibaran rocks in north western Tanzania and south western Uganda by different scientists including; (Vernon-Chamberlain, 1967; Lowenstein, 1969; Vernon-Chamberlain and Snelling, 1972; Bugrow et al., 1982; Cahen et al.; 1984; Cahen and Snelling, 1988; Ikingura et al., 1990). It was related to the Pan-African cycle showing that the post-orogenic G4 granites with most important mineralization being spatially restricted thus belonging to the Kibaran belt. Basing on pegmatite and hydrothermal fluids analysis, the following interpretations were generally agreed; the synorogenic granites (G1 and G2) yield ages of 1370 ± 25 Ma and 1310 ± 25 Ma respectively. The G3 granites provided a whole rock Rb: Sr isochron at 1094 ± 13 Ma, and the

G4 granite ages were clustering at about 976 ±13 Ma (Pohl, 1994). Two major fold trends have been established and described by Barnes et al. (1956) and these are the regional set of folds which are generally trending in NW-SE, and are assumed to be the dominant fold set. The other set is the cross folds that trends NE-SW, and hence perpendicular to
the regional fold as shown in figure 1.4 below

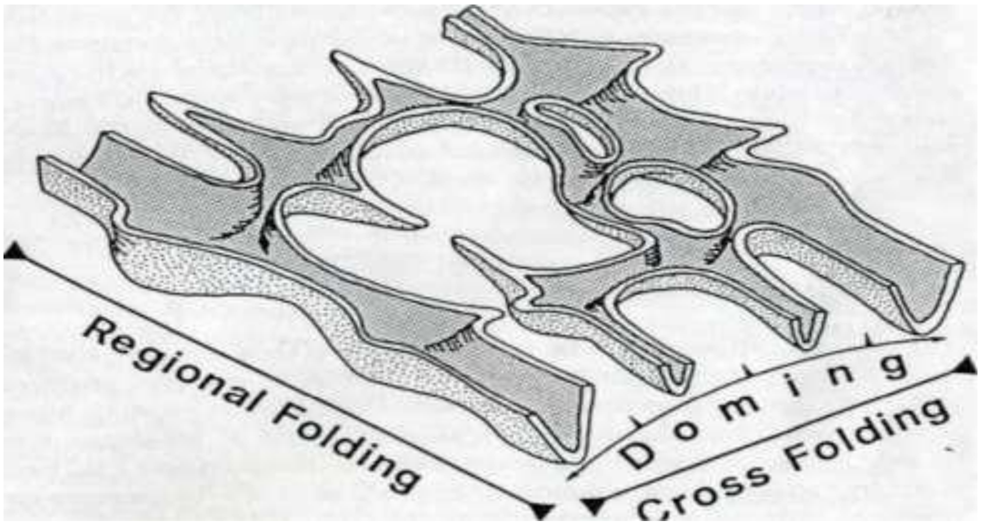


Figure 3: Patterns of folding in the Karagwe-Ankolean system

It has been observed that the folds have axial planar cleavage, schistosity, and crenulations which are common and could have played an important role as a plane of weakness for the subsequent development of certain faults which can be observed to strike parallel to these planes of weakness and also replace or even displace the limbs of some folds (King and DeSwardt, 1970). Also worth noting is that Barnes (1956) assumed an almost occurrent episode for the formation of the two-fold trends, but suggested two-fold mechanisms for their development.
The folds are generally open, having wavelengths of 8-16 km, but becoming tight within synclinal keels between adjacent arena granites. On a regional scale, these folds occur within a series of anticlinoria and synclinoria (Barnes, 1956).

Geotectonically, the geotectonic evolution occurred during the Kibaran tectogenesis and is thought to have begun around 1400 Ma *(Ucakuwun, 1989).* This is presumed to have been initiated by extensional tectonics that led to the shrinking of the crust with possible rifting. During further extension, there was active deposition of the K-A sediments concurrently with depression of lower crust, hence deepening the basin of deposition *(Ucakuwun, 1989)*. This was followed by a change in the stress field from extensional to compressional. Disharmonic folding of the sialic crust and the sedimentary pile led to the formation of synclinoria and anticlinoria structures. Tensional fractures were accentuated and faults developed in the sialic crust. General thickening of the crust then caused intrusion of the asthenosphere into the lower crust and triggered anatexis of the generation of mantle magma *(Ucakuwun, 1989).*
The absence of the volcanic sequence within metasediments of south-western Uganda suggests

that the rifting probably did not take place, although regional faulting may have occurred *(Ucakuwun, 1989).*

The sedimentary sequences and the underlying crust were subjected to different metamorphic conditions depending on the depth of burial, with low grade metamorphism being effective near the base of the sedimentary pile in the deepest regions. The major deformational phase which characterizes the K-A began with a change in regional stress situation from extensional to compressional both in the NW-SE direction, although the reason for the change in the stress situation is unknown *(Ucakuwun, 1989.*

The upright and overturned geometry of the folds and absence of associated regional thrusts indicate weak compressive stress caused by some distant collision event such as the second phase of deformation. During this stage, the sedimentary pile and the underlying sialic crust of the basin were disharmonically folded on the NW-SE axes.
The schistosity formed during stage (b) was folded, while crenulations and crenulation cleavages were formed in some places. Crustal thicken-ing in the basin occurred to accommodate shortening resulting into the coherence of the sialic crust, and folding with greater amplitude. The folds within the sialic crust explain the major anticlinoria and synclinoria structures of the Karagwe-Ankolean system of the study area.

According to Pohl and Gunter, (1991) the Karagwe-Ankolean system evolved as an intercontinental orogeny between about 1400 to 900Ma (Fig.1.5). Arrows indicate predominantly extensional or compressional regimes.

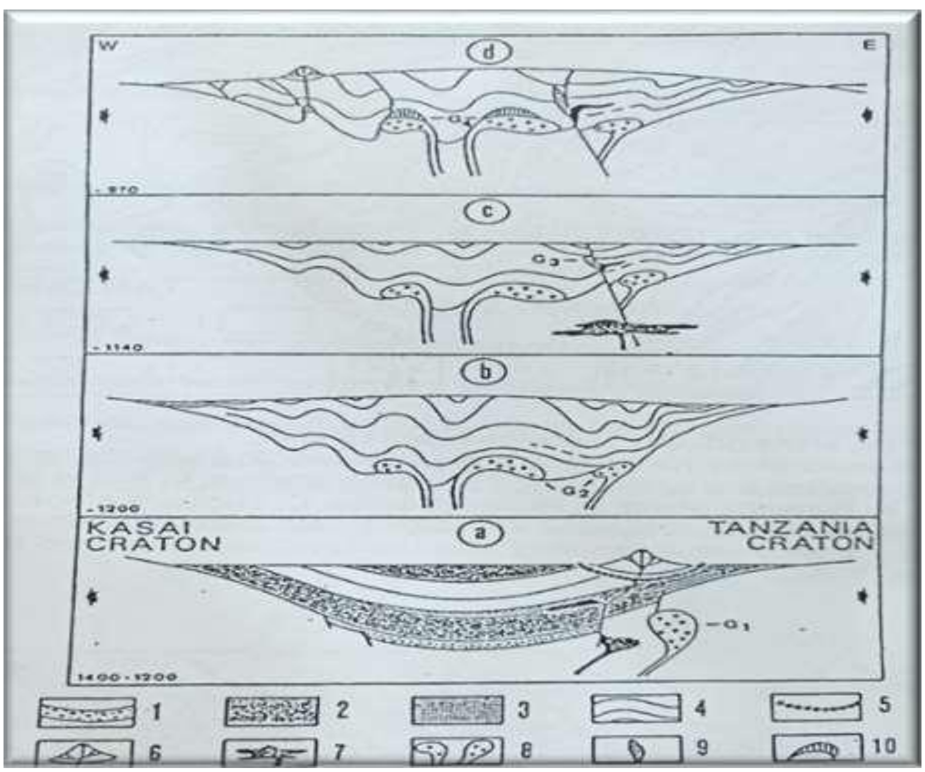


Figure 4: geotectonic evolution

1.Conglomerates	2. Sand and siltstones	3.Turbidites	4.Pelites.	5. Stromatolitic fringing reefs
6. Volcanic Island.	7. Mafic intrusions	8.G1 and G2 granites	9.G3 granites.	10.G4 granites

The description of the stages of evolution as shown in fig 1.5 above is summarized below;
a) Kibaran basin formation from about 1400-1300Ma.
b) Kibaran orogeny at about1300Ma, with the formation of the open folds of granite gneiss dome and haloes of thermal metamorphism.
c) Rifting affecting the Kibaran belt at about 1275Ma, with mantle magmas inducing crustal melting and rise along tensional faults to form layered mafic intrusions within the Kibaran meta-sediments.
d) The Lomamian orogeny at about 950Ma, inducing renewed compressive deformation, elevation and glaciations of the Kibaran Mountains, and intrusion of G4 granites.

1.2.2 Economic Geology

The economic potential in K-A system was first documented by J.S. and D.S Kargarotos at Kyerwa in NW Tanzania where cassiterite (tin ore, $SnO2$) was discovered in 1924, and became the first mineral to be exported in 1927 (Barnes 1961). Tin is widely distributed in small quartz, sericite and muscovite veins, also as accessories in pegmatites. The veins are derived from solidification of hydrothermal fluids containing tin, migrating from the Ibanda granite through a series of conduits. After a series of surveys, *Pohl (1994),* described the Kibaran belt as a tin tungsten metallogenic province of East to central Africa with Sn-W-Nb-Ta-Be-Li mineralization in metasomatic zones around granites. He noted four sub-groups of G4 granite-associated mineralization.

- Pegmatites with Sn and Nb/Ta, Li, Be, U/Th, muscovite, feldspar and kaolinite.
- Quartz veins with Sn and W, pyrite, siderite, bismuth, gold and uranium.
- Talc deposits developed by hydrothermal alteration of dolomites and magmatic mafic rocks.

Auriferous silicification zones with gold, pyrite, arsenopyrite, magnetite and specularite mineralization.
Currently Cassiterite is mainly obtained by small scale artisanal mining from quartz veins near Kikagati.
Modern geochemical and geophysical methods resulted in more mineral discoveries in parts of Burundi and Tanzania. Some of the mineralization in this belt includes the following;
o Deposits of tungsten which occurred dominantly in narrow belt in the Kigezi area where they are integrated into a system of sub-parallel, 10 to 20cm thick quartz veins, which strike conformably with the hosting phyllites.
o Soda lime pegmatites containing beryl, tantalite-columbite, cassiterite, amblygonite and iron-manganese phosphates are found for example, in Mutaka and Nyabushenyi.
o Gold deposits are found in limonite veins with bismutite, pyrite, wolframite and cassiterite in south western Kigezi.

o Iron Ore: Iron ore occurs as two types of minerals: hematite and magnetite. Hematite of high quality (90 - 98% Fe_2O_3) occurs in Muko area in Kabale and Kisoro districts with total resources in excess of 50 million tons, which contains negligible sulphur, phosphorus and titanium. Similar hematite iron ore with a resource of 2 million tons
occurs at Mugabuzi in Mbarara district.
o Lithium ores (amblygonite) occur in pegmatite's in Ntungamo, Kabale, Kanungu and Rukungiri districts, but have been exploited only from the Nyabushenyi (Ntungamo)

1.2.3 Stratigraphy and Geochronology

Introduction

This chapter includes the description of the stratigraphy of the mapped area C, as well as for the whole region at a narrow perspective. This involves description of how rocks are arranged in the field, a systematic description of different rock units, description of rocks based on color, size, thickness, nature of contacts, unconformities, structures among others, identification of fossils present, among others.

Stratigraphy is a branch of geology which studies rock layers (strata) and layering (stratification).
Stratigraphy is concerned with the form, arrangement, geographic distribution, chronologic succession, classification, correlation, and mutual relationships of rock strata, especially sedimentary, (McGraw-Hill Dictionary of Scientific & Technical Terms, 2003).

A Stratum is a layer of rock characterized by unifying characters/properties that distinguish it from adjacent layers**.**
Stratigraphy is not only concerned with original succession and the age relations of the rock strata but also with their form, distribution, lithologic composition, fossil content, geophysical and geochemical properties. Stratigraphy is primarily applied to sedimentary rocks and also volcanic rocks.
The different sub divisions of stratigraphy used during the mapping are summarized in the table below;
Many attempts have been made to define the stratigraphic succession and the correlation of the rocks of Kibaran belt. Since the lithologies are similar, a three-fold subdivision was established and generally accepted (*Cahen et al., 1984; Rumvegeri, 1991*). The upper division includes mudstones, siltstones, sandy mudstones, sandstones, grits, and occasional conglomerates which are intercalating with the quarzitic horizons and it's about 3000-5500metres thick. The middle division is composed of sandstones with small pockets of itiritic layers of micaceous hematite predominately, mudstones, shales with grey, cream and pink color, arenaceous mudstones and phyllites, and it is about 2000-3000 meters thick. The lower division consists of schists, quartzites, phyllites, muscovite and calc-arenites, muscovite schists and it's about 4000-6000metres thick.
Stratigraphy hierarchy of the Gayaza study area mainly relies on the "way up" criteria indicated

by depositional structures where available, cross-cutting relationships of lithologies and structures, and geochronology *(Ucakuwun,1989).* The Karagwe-Ankolean system unconformably terminates into the older Buganda-Toro rocks which stratigraphically overlie the Basement rocks (Basement Complex). The K-A system is composed of acid gneisses, migmatites, folded metasedimentary rocks of originally predominantly argillaceous composition intercalated with arenaceous horizons and occasionally conglomeratic basal members, rarely calcareous and volcanic sequences. These rocks have also been intruded by biotitic granites from G1-G4, pegmatites and hydrothermal veins of acid and basic dykes according to *Ucakuwun (1992).* Rocks of the K-A overlie unconformably sheared granitic rocks which seem to be part of an extensive Achaean crust as reported by Straaten (1984). Overlying the Achaean crust and the Karagwe-Ankolean metasediments are almost unmetamorphosed sediments of the Bukoban sys.

Lithostratigraphy	Deals with lithological characteristics that is rock types, their lateral extinction, mineralogical content, color, grain size and other observable features on the outcrop.
Biostratigraphy	It is the branch of stratigraphy which focuses on correlating and assigning relative ages of rock strata based on fossil content in the rock layers.

Chronostratigraphy	This is a branch of stratigraphy that deals with the relative time relations and ages of rock strata. It is based upon deriving geochronological data for rock units both directly and inferring, so that a sequence of time-relative events of rocks within a region can be derived.
Magnetostratigraphy	This is a chronostratigraphic technique used to date sedimentary and volcanic sequences by analyzing and determining the samples detrital remnant magnetism (DRM), that is the polarity of Earth's magnetic field at the time a stratum was deposited
Chemostratigraphy	a technique of sediment characterization and correlation using subtle variations in the elemental composition of the sediments. The technique relies upon the fact that even apparently homogenous sediments show changes in their chemical composition, these changes reflecting minor fluctuations in variables such as sediment source, facies, paleoenvironment, paleoclimate and diagenesis.
Sequence stratigraphy	This is a branch of sedimentary stratigraphy that deals with the order, or sequence, in which depositionally related strata successions (time-rock) units were laid down in the available space or accommodation

Stratigraphy relies mainly on six principles to understand the geologic history and these are described in the table below. These principles were applied in the interpretation of rock sequences in Area C.

Principle of original horizontality**:** "Strata either perpendicular to the horizon or inclined to the horizon were at one time parallel to the horizon." (Steno, 1669). This principle states that layers of sediment are originally deposited at their angle of repose which is always horizontal, under the action of gravity. It is important to the analysis of folded and tilted strata.
Principle of superposition**:** The principle of superposition states that in an undisturbed sequence of rock strata, the younger strata lie on top of older strata. These strata can be aligned in form of sheets, thin and/ or thick sheets of sedimentary rock that, as a group, are visibly distinct from those above or below.
Principle of cross-cutting relations*:* "If a body or discontinuity cuts across a stratum, it must have formed after that stratum" (Steno, 1669). This is a principle of geology that states that a geologic feature which cuts another is the younger of the two features.
Principle of lateral continuity**:** "Material forming any stratum were continuous over the surface of the Earth unless some other solid bodies stood in the way." (Steno, 1669). The principle states that layers of sediment initially extend laterally in all directions i.e., they are laterally continuous.
Principle of inclusions: This states that clasts/fragments in a rock are older than the rock itself. A xenolith, for example, which is a fragment of country rock that fell into passing magma during the formation of a magmatic rock is an indication of this very principle.
Principle of faunal succession: This law was developed by William "Strata" Smith who recognized that fossil groups were succeeded by other fossil groups through time. Also known as the law of faunal succession, it is based on the observation that sedimentary rock strata contain fossilized flora and fauna, and that these fossils succeed each other vertically in a specific, reliable order that can be identified over wide horizontal distances according to their relative ages. This principle has allowed geologists to develop a fossil stratigraphy and provided a means to correlate rocks throughout the world.

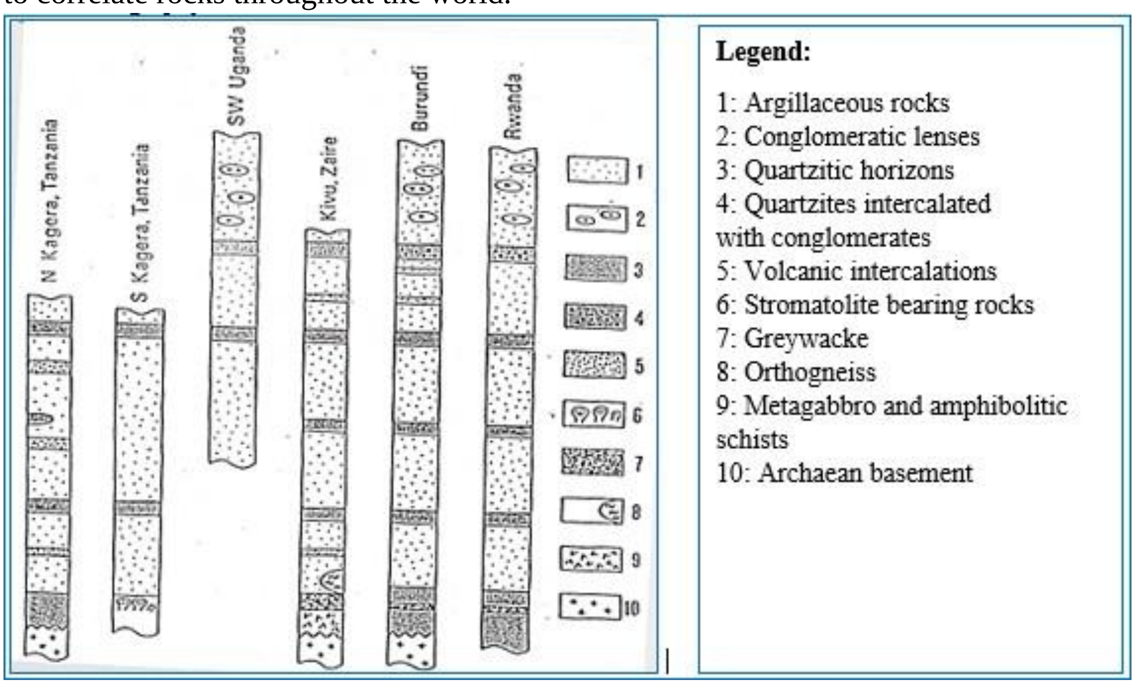


Figure 5: geochronological strata

Geochronologically, several radiometric ages have been determined and reported from Kibaran rocks in north-western Tanzania and south-western Uganda by different scientists including Vernon-Chamberlain, 1967, Lowenstein, 1969, Vernon-Chamberlain and Snelling, 1972, Bugrov et al., 1982, Cahen et al., 1984, Cahen and Snelling, 1988, and Ikingura et al., 1990. The second most recent age determination, being that of Ikingura et al.,1991 after that given by Pohl (1992 and 1994) related to the Pan-African cycle and the post-orogenic g4 granites with their important mineralization as being spatially restricted and therefore belong to the Kibaran belt. However, basing on the analyses from pegmatites and hydrothermal fluids, the following interpretations were generally agreed upon that the synorogenic granites (g1 and g2) yield ages of 1370 ± 25 Ma and 1310 ± 25 Ma respectively. The g3 granites provided a whole rock Rb: Srisochron at 1094 ± 13 Ma, and the g4 granite ages were clustering at about 976 ±13 Ma (Pohl, 1994).

1.2.3.1 Previous Work

A number of geologists have made several attempts to study the stratigraphic succession and correlation of the Karagwe-Ankolean (K-A) system or Kibaran belt, and amongst that, the following personalities and their works are recognized.

Wayland 1919, made a reconnaissance traverse across southern, south western and eastern parts of Ankole, during which he recognized and recorded important points of the lithology and structure of the region.

Combe, 1926, systematically mapped part of Ankole and Kigezi and noted that the Karagwe and Ankole series were the same, and as such proposed the term „Karagwe-Ankolean‟ as the system encompassing the rocks in that region.

Stheeman, 1932, examined a broad area of this system and proposed a threefold classification. The study area was conveniently considered to be the Eastern Rakai, described by the Combe (1932),

since the structures were relatively simple; namely rather regular south-easterly folds, and the lithology is comparable with that over the great part of Karagwe-Ankolean in the region of Tanzania, Rwanda, Burundi as well as of Uganda. Since the lithologies in all areas are similar, the three-fold subdivision has generally been accepted (Cahel et al, 1994, Ruwvegeri 1991).

Due to complex folding and refolding as a result of the granitic intrusions, the stratigraphy is not simple to correlate in many areas according to Biryabarema, 1995.

Basing on the attempts to trace the marker horizons and the recognition of similar succession of quartzites in individual areas, the stratigraphic sequence synthesis of the Karagwe-Ankolean system was done (Combe, 1932). He described two local successions occurring in the eastern parts of Kigezi (Rukiga-Mpalo area) and in western Ankole (Ntugamo-Kafunjo Dwata area). From that work, he used the six quartzite horizons in an attempt to correlate the successions between the two areas and as a basis for the establishment of the lower, middle and upper divisions. These are summarized in the table below.

Division	**Associated rocks**
Upper Division	Mudstones, siltstones, sandy mudstones, sandstones, grits, occasional conglomerates. Intercalations of quarzitic horizons q3, q4, q5, q6
Middle Division	Sandstone with occasional lateritic layers of micaceous hematite. Predominantly mudstones, arenaceous mudstones and phyllites. The more argillaceous rocks are characterized by a color banding in shades of grey, cream and pink.

Lower Division.	Largely muscovite schists, and phyllites with quartzites. Occasional calc-silicate rocks derived from arenaceous limestones.

The three-fold lithologic sub-division of K-A in Uganda according to Cahen et al., 1984 and Rumvegeri, 1991

According to Combe *(Barnes, 1956)*, the lower KA division is characterized by arenaceous conglomeratic horizons with pebbles of quartzite and vein-quartz. They are normally thin and more recrystallized, frequently boudinaged, sheared, or mylonitized and with limited primary structures. Argillaceous lower members are phyllitic shales, phyllites and mica schists. Middle KA consists of predominantly of color banded argillites or mudstones and phyllites. The sandstone which forms the top of the middle group is highly ferruginous at Kasenyi near Muko. It carries Itaberite layers of micaceous specular hematite which is several meters thick *(Bugrov et al., 1980).*

Upper KA division shows great development of shales and mudstones progressively becoming more quartzose towards the top of the succession, through sandy mudstones to siltstones. The limited arenaceous bands in this division are relatively less compact with their original grains often recognizable *(King and De Swardt, 1967).* The KA was deposited on irregular surface *(King and De Swardt; 1967)*.
Phillips (1959) found higher horizons of KA progressively overlapping the basement. Schluter, 1997 explained that the rocks of the Karagwe-Ankolean System in Uganda are characterized by massive argillaceous units intercalated with thinner arenaceous bands of quarzitic sandstones. The succession has been intruded by granites. In the eastern part of Ankole and in Buhwezu plateau, Karagwe-Ankolean rocks lie unconformably with the older schists of BugandaToro system or with the Gneisses-Granulitic complex. The lowest exposed quartzite usually passes in schists which are in contact with the granites of the arenas. Schluter (1997), further explained that in the area SE of Mbarara there occurs one of the greatest concentrations of quartzites in Uganda. The quartzites in such massive concentration appear to have restrained the folding of the covering Karagwe-Ankolean rocks, because only broad synclines are recognizable.
Phillips (1959) identified quartzitic horizons Q1 to Q4 in the N and W respectively of the area underlained by the Igayaza syncline. Biryabarema, 1995 further noted that the rocks of the Karagwe-Ankolean System are largely argillaceous and that the quartzites attenuate fairly abruptly.
Plummer (1960) described that there was thinning of the quartzites on the NW limb of the Igayaza syncline east of the Mbarara-Kikagati road. Up to the stratigraphic level of the Rugaga quartzite (Q4), the rocks are fairly metamorphosed, but sometimes sedimentary structures are still recognizable.
Biryabare.ma (1995), wrote that the rocks to the North and West underlain by the Igayaza syncline are largely argillaceous and the quartzites attenuate fairly abruptly. The first record of sedimentary rocks consisting of shales and sandstones in Karagwe to the West of Lake Victoria was made by Speke in 1863.

1.2.4 Description of Lithologic units (Rock types)

Area C lies within the lower division of Karagwe-Ankolean basing on the Lithostratigraphy sub divisions of the Karagwe-Ankolean System in Uganda (modified after Combe 1982). It is made up of mainly of three rock types i.e., grey to white shales, ferruginous shales and quartzites. The Lithologic units in area C were identified basing on their mineralogy and physical properties such as texture, color and fabric. These rocks observed are generally characteristic of the lower division as indicated below.

1.2.5 A map of AREA C

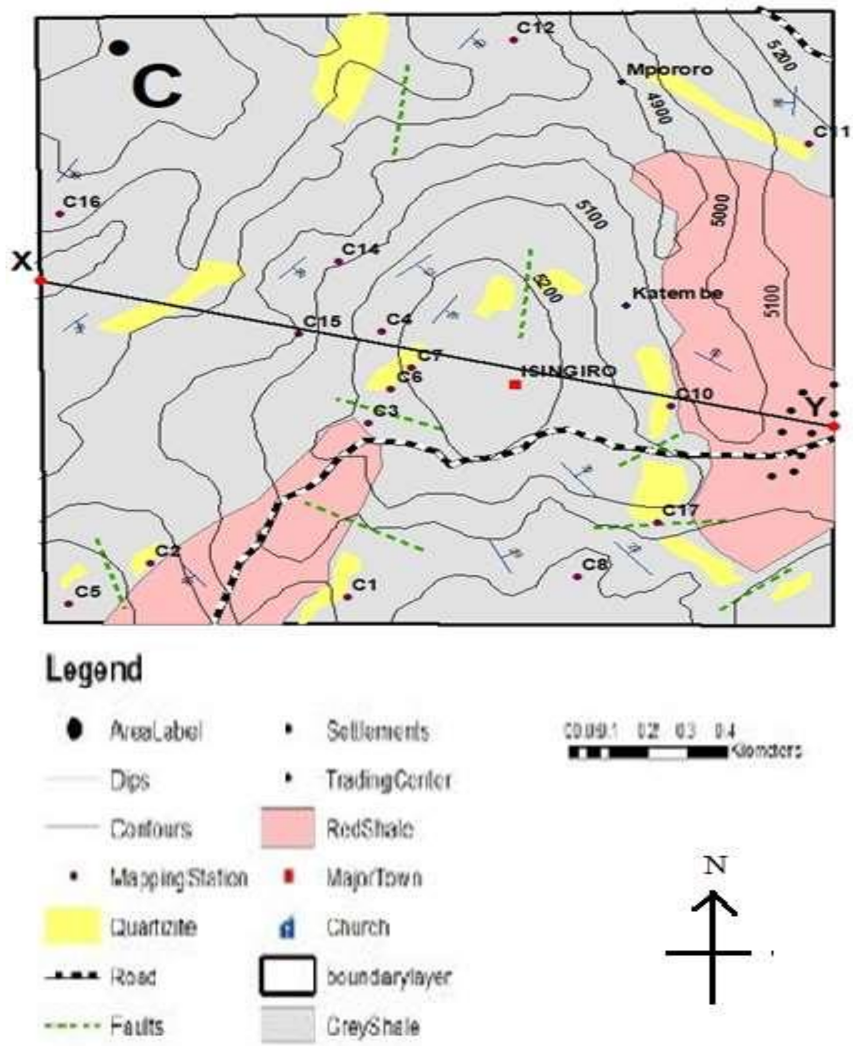


Figure 6: A map of AREA C

1.2.6 CROSS SECTION

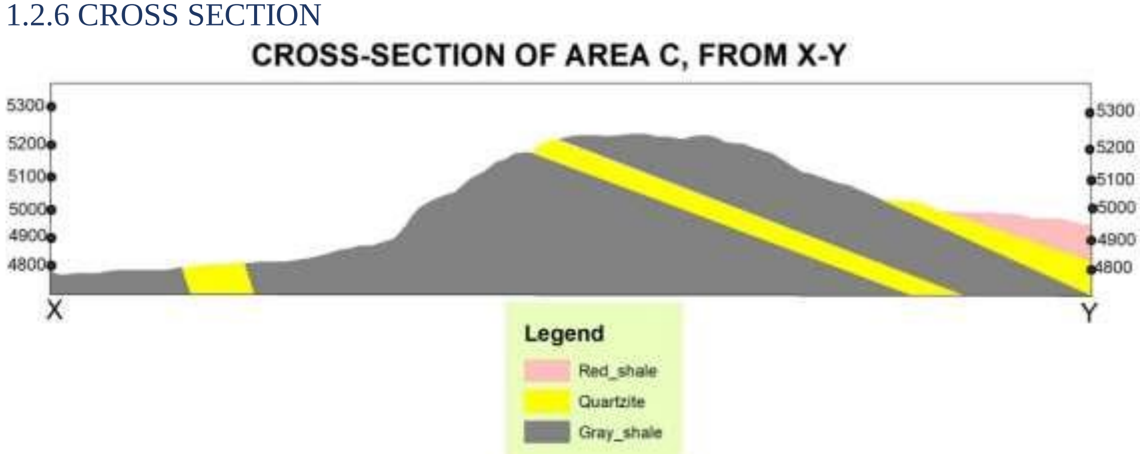


Figure 7: cross section of area C

1.2.7 Stratigraphic column

A stratigraphic column is a representation used in geology and its subfield of stratigraphy to describe the vertical location of rock units in a particular area. (Christopher et al ,2016)

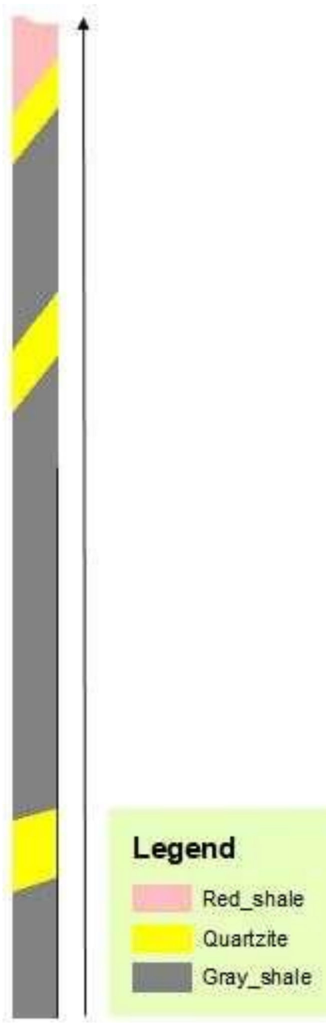


Figure 8: stratigraphic column showing the younging direction

1.2.7.1 Quartzite

Quartzites are metamorphic equivalents of sandstones, distinguished by their granoblastic texture.

This implies that sandstones are the protoliths from which quartzites are formed. These(quartzites), usually assume the composition of their parent rocks except for a few additions which could be as a result of the metamorphic processes or tectonic activity. A quartzite is formed when a quartz-rich sandstone becomes altered by pressure, heat and chemical activity. The said conditions recrystallize the sand grains and as well as the silica cement that binds the grains together resulting in an interlocking network of quartz grains of great strength.

This interlocking crystalline structure makes the quartzite hard, tough, and with great durability such that when stricken with a hammer, it breaks through the quartz grains rather than the boundaries between them, a characteristic that used to distinguish between a quartzite and a sandstone. From thin section analysis of the quartzite samples collected from some outcrops in area C, the major composition about 95 to 99% is quartz with a small percentage of iron oxides. No evident primary structures are preserved in the quartzites except for a few of them that retain some relicts of the beds of their parent rocks. The lack of primary structures in the quartzites is due to the secondary metamorphic processes that usually tend to destroy the primary structures in the parental sandstones. However, the quartzites show more of the secondary structures especially fractures associated with tectonism due to their brittle nature.

The quartzites of area C are grey/ brown (brown color due to iron oxides) and some had stains of purple color due to impurities, forming the tops of the ridges due to their resistance to weathering and erosion. The quartzites were medium to coarse grained and in some cases crystallized quartz veins cut across them for example at station CM8. These rocks are of a low metamorphic grade. This was shown by some relict sedimentary structures of bedding that was recognized in some localities. These rocks had been influenced by regional metamorphism that took place in the area.

They are sandstones which were metamorphosed to form quartzites. The quartzites are highly affected by faulting resulting into intensive fracturing since they are brittle in nature. All quartzite outcrops showed heavy jointing with majorly two sets of joints trending NE-SW and NW-SE directions.

Figure 9: showing a highly jointed Quartzite outcrop encountered in area C (257252,9917580)

1.2.7.2 Shales

Shales are generally defined as fined grained, siliciclastic sedimentary rocks. They are usually composed of primarily clay minerals and fine size quartz and feldspars. Other minerals commonly associated with shales include; carbonate minerals, sulfides (pyrite, marcasite), iron oxides (e.g., goethite) and heavy minerals as well as small amounts of organic carbon. Shales encountered in area C were found to be composed of majorly clay minerals (55-75% range) with a small percentage of fine size quartz and feldspars.

Area C had abundant shales which are of different colors/types. The notable shales are grey shales and ferruginous shales. The reddish color of the ferruginous shale is as a result of oxidation of the iron in them from iron (ii) to iron (iii). These shales in some areas are intercalated with quartzites while in most areas they underlie quartzite ridges. Structures present within the shales are bedding, lamination as well as ripple marks at station CM10.

Grey shales

These ones are grey in color, and often are softer than ferruginous shales. They also contain very little or no iron solutions recrystallized within the lines of weakness present in them.

These shales contain clay minerals. Grey shales however covered a larger area than the ferruginous shale. Due to increasing grey color and muscovite content in the grey shales, they tend towards slates as such they have been referred to as slaty shales.

Figure 10: showing a layered grey shale outcrop encountered in area C (257274,9917496)

Ferruginous shales: These are reddish brown in color owing to the presence of iron in the form of iron (iii) oxide (Fe_2O_3) which is an indication that oxidation affected some parts of the rock when they were exposed to oxidizing conditions.

Figure 11: showing a layered grey shale outcrop encountered in area C (257882,9917378)

It was also observed that in the mapped area C, there were manmade waterholes in which the locals collected water for both home consumption and agricultural purposes. These waterholes were encountered mainly in the shale formation possibly due to their impermeable nature. Also, the fact that the shales were located on the slopes and lowlands could probably have allowed for the collection of running water from the ridges.

Figure 13: A man made water hole from shale in area C (257974,9917400)

1.2.7.4 Conglomerates

Conglomerate is a sedimentary rock made of rounded pebbles and sand that usually held together by silica, calcite or iron oxide. This clastic sedimentary rock is composed of a substantial fraction of rounded to sub angular gravel- size clasts (Fried, 2003). The conglomerates at station 15 are coarse-grained rock made of pebbles, sands and cemented by iron oxide as shown in *figure (2.7)* below. The conglomerate in area C is less than 10 meters and therefore not mappable.

Figure 14: showing angular pebbles of the conglomerates cemented with iron oxides. (257568, 9917311)

1.2GEOLOGIC HISTORY

This section of the chapter tries to give the depositional history and environment based on the field evidence. Both positive (presence of given characteristics and features) and negative (absence of given characteristics and features) criteria are used in trying to reconstruct the ancient depositional history and environment of the area.

Study area C, is covered by low grade metamorphic rocks whose precursor rocks were arenaceous and argillaceous sedimentary rocks. Therefore, sediments were deposited initially after which they underwent diagenesis and eventually were compacted, cemented and stratified to form hard sedimentary rocks. With an increase in pressure and temperature due to burial, these rocks slightly under went regional metamorphism in which shales were metamorphosed to slates, and phyllites whereas sand stones were metamorphosed to quartzites. Compressional forces then caused folding in the area and resulted into the formation of regional and cross folds with a general NW-SE and NE-SW trend directions respectively. Folding was accompanied by formation of an axial planar cleavage at shallow levels (Schlueter, 1997). Tensional tectonism is also observed in form of faulting around this area which was accompanied by intense jointing in the rocks. When sedimentation still continued, granites intruded the deposited sediments during the time span between 1330 and 1250 Ma (Schluter, 1997). Further compression deformation occurred when the granites such as Chitwe intruded syntectonically the upright folds that already existed in the area. The granites intruded preferentially in anticlinoria positions. Since granites are composed unstable minerals under surface conditions, severe erosion on the granites took place in relation to the surrounding rocks when they were exposed resulting into topographic inversion. As a result, the original anticline is now a low-lying area (Masha arena) and the

syncline is now a raised ground.
The metamorphism that occurred initially occurred in the area due to the increase in temperature
and pressure due to burial of sediments was further enhanced by intrusion of the granites. The
metamorphic grade therefore increases towards the arena that is from the quartzite ridges to shales through slates and then phyllites bordering the arena. All consolidated rocks of SW Uganda are non-fossiliferous and they are of Precambrian age. The stratigraphical hierarchy in the formation of SW Uganda greatly relies on the way up criteria indicated by depositional structures that are available such as bedding structures and cross cutting relationships of lithology and geochronology.

1.3.1 Depositional history

Presence of quartzites and shales implies that there was deposition of both arenaceous material (sand sediments) and argillaceous material (clay rich sediments). The sand sediments were lithified to sandstones and clay rich sediments to possibly mud rocks or clay stones (Shale). Due to low grade metamorphic processes in the area, there is a possibility that the sandstones were metamorphosed to quartzites and the water rich clay sediments lost most of their water to form harder, more compacted shales. Intercalations between shales and quartzites would imply that the conditions under which their parental sediments were deposited kept on changing from those of low energy to those of high energy respectively.
Relative thickness of the beds: Thickness of beds can be controlled by any of the following or
combination of the following processes;

➢ Energy of transporting media and the environment in which the sediment is deposited.

➢ Length or duration of deposition.

➢ Amount of sediment available. The presence of relatively thicker beds of fine sediment (shales) as compared to the arenaceous related sediments (quartzites) would therefore, imply that;

- The periods of deposition of fine sediment were always longer implying that the conditions of low energy and slow rates of deposition predominated, possibly being accompanied by availability of large quantity or supply of fine sediment.
- Periods of high energy and rapid deposition were relatively short lived, supplying coarse arenaceous material for short periods of time. Shift from low to high energy conditions of deposition cannot easily be deduced. This can be associated with changes in gradient (topographical changes) due to tectonics resulting into increase in the speed of the transporting medium. Sometimes increase in the volume of transporting media such as water in periods of flooding can bring in a large supply of coarse material as compared to fine material. However, such changes are always short lived after which the system goes back to normal. Short periods of turbulence or high energy currents in relatively calm environments of deposition can also result into a change in the type of sediment deposited at that point in time.

Lateral extent of the rock strata: In spite of the discontinuities of the beds or rock strata by later periods of deformation (folding and faulting), the rock strata (beds) in the area extend laterally for several kilometers. This would imply that in both periods of (low and higher energy) deposition, there was great and uniform dispersion of sediment in the basin of deposition such that the sediments covered wide areas in the basin.

Laminated beds: The laminae in the shale beds observed in the area can tell that there existed less severe (low energy) shorter lived fluctuations in sedimentation conditions than those that generated the relatively thick massive shale beds.

Thin section analysis: Some samples of shale collected from the area exhibited micro laminations of quartz or siliceous material between clay rich material which can further tell that even the very short-lived periods of low energy deposition conditions were never uniform but exhibited micro fluctuations.

1.3.2 Depositional environment

To deduce the depositional environment both positive and negative criteria are used. Positive criteria involve deductions made from the characteristics and features of rock strata as observed in the field. On the other hand, the negative criteria involve deductions made due to the absence of certain characteristics and features expected in sedimentary rocks.

Positive criteria;

• Presence of laminae: Laminae have the potential of being preserved in reducing or toxic (unfavorable environments) environments where organic activity is minimal. Therefore, the possible depositional environments as per this evidence are; terrigenous/continental environments such as deep lacustrine environments. Also, deep marine environments are possible. This is because both of these environments are associated with calm, anaerobic conditions with no organic activity.

• Sediments: The presence of thicker beds of argillaceous material as compared to the arenaceous material leads to a suggestion that; the depositional environment was a predominantly calm one with short lived changes in the conditions that led to deposition of arenaceous material. For example, increase in the energy of currents due to wind fluctuations in environments such as those mentioned above could have led to the deposition of arenaceous material. However extensional tectonics could have also played part in the creation of conditions that led to deposition of the arenaceous material implying that a tectonic environment can be suggested too.

Negative criteria;

• Absence of fossils: This suggests reducing or toxic (anoxic) environments into which sediment was deposited.

• Absence of fossils and most of the sedimentary structures that could be indicative of particular

environments could also suggest a tectonic environment where tectonic deformations could have possibly destroyed the originally formed sedimentary structures and the fossils which could probably be in the unstable and unfavorable conditions of the Precambrian times.
The Quartzites that were mapped in area C, were generally medium to coarse grained. This suggested that the original sand/silt sized rocks from which the quartzites were metamorphosed, were transported under a relatively high energy environment, such as an active river which was capable of carrying large pebbles and boulders. This was further supported by the presence of a ripple mark siliceous shale bed encountered at station CM10. The ripple marks in the shales observed at Station CM10 were oxidized which indicated that the shale bed was exposed for a relatively long period of time before the subsequent deposition of other beds. Thus, the area suffered a period of no deposition.
The rocks in area C were of sedimentary origin and low-grade metamorphism. Precursor materials that were deposited were silts, clays and sands. Clays and silts formed clay stones and silty clays (in some areas) while the sands formed sandstones. Due to increased pressure and temperature as well as burial depth, these rocks slightly under went regional metamorphism to form quartzites and shales. These water rich environments favored the formation of iron oxides present in the ferriginised shales and in quartzites (blackish color). The quartzites indicated that, the currents that deposited sand must have been sufficiently strong to move and distribute the sand. Existence of conglomerates with pebbles of all sizes is evidence for high energy currents after the formation of the rocks (presence of quartzite pebbles in conglomerates).

1.3.2.1 Suggestions from early geologists

Wayland (1920) suggested two possible environments of deposition; (1) that the sediments were laid down in a large continental basin without connection with the ocean, and (2) that the sediments were laid down in the sea or depression which had limited connection with the ocean but in which currents were operative as a means of distributing sediments.
The first option seems to be more befitting backed up by the above evidence from observations made in the field. It should also be noted that Pohl and Gunther (1991) in giving the geotectonic evolution and intrusion of the Karagwe-Ankolean suggested that the Kibaran belt (Karagwe-Ankolean) evolved as an intercontinental orogen where deposition of thick pile of elastic sediment with intercalated volcanic rocks and very rare carbonates took place. With this information and the field evidence discussed above, a continental (lacustrine) depositional environment of the Precambrian times can tentatively be suggested.

1.4 Stratigraphic rock succession

The rocks of area, C, are arranged in such a way that the fine-grained sediments that later formed shales were deposited first in the sedimentary basin. They were later followed by sands which formed sandstones. With increasing favorable metamorphic conditions such as burial and increasing temperature, sandstones were later metamorphosed to quartzites while the shales were metamorphosed to higher grades such as phyllites. There was observable intercalation between shales and quartzites in some areas. This is indicative of cyclic deposition of coarse grained and fine-grained sediments in the basin according to seasons.

1.4.1 Tectonic Evolution

The geotectonic evolution occurred during the Kibaran tectogenesis and is thought to have begun around 1400 Ma *(Ucakuwun, 1989).* This is presumed to have been initiated by extensional tectonics that led to the shrinking of the crust with possible rifting. During further extension, there was active deposition of the K-A sediments concurrently with depression of lower crust, hence deepening the basin of deposition *(Ucakuwun, 1989)*. This was followed by a change in the stress field from extensional to compressional. Disharmonic folding of the sialic crust and the sedimentary pile led to the formation of synclinoria and anticlinoria structures. Tensional fractures were accentuated and faults developed in the sialic crust. General thickening of the crust then caused intrusion of the asthenosphere into the lower crust and triggered anatexis of the generation of mantle magma *(Ucakuwun, 1989).*

The absence of the volcanic sequence within metasediments of south-western Uganda suggests that the rifting probably did not take place, although regional faulting may have occurred *(Ucakuwun, 1989).* The sedimentary sequences and the underlying crust were subjected to different metamorphic conditions depending on the depth of burial, with low grade metamorphism being effective near the base of the sedimentary pile in the deepest regions. The major deformational phase which characterizes the K-A began with a change in regional stress situation from extensional to compressional both in the NW-SE direction, although the reason for the change in the stress situation is not known. *(Ucakuwun, 1989)* The upright and overturned geometry of the folds and absence of associated regional thrusts indicate weak compressive stress caused by some distant collision event such as the second phase of deformation. During this stage, the sedimentary pile and the underlying sialic crust of the basin were disharmonically folded on the NW-SE axes. The schistosity formed during stage (b) was folded, while crenulations and crenulation cleavages were formed in some places. Crustal thickening in the basin occurred to accommodate shortening resulting into the coherence of the sialic crust, and folding with greater amplitude. The folds within the sialic crust explain the major anticlinoria and synclinoria structures of the Karagwe-Ankolean system of the study area. The K-A was a tectonically high zone and this was manifested by exposure of gneisses. Thickening of lower crust depressed into hotter parts of the asthenosphere into the lower crust producing granitic melts through anatexis or differentiation of basic magma derived from the upper mantle that accumulates in magma chambers in the lower parts of the sialic crust *(Ucakuwun, 1989).*The anticlinal zones of the folds within the sialic crust were more favorable for intrusion of granitic melts because they were regions of lower pressure than the synclinal regions *(Ucakuwun, 1989).*The resulting granitic melts from the lower parts of the crust therefore migrated preferentially into the anticlinal zones. The vertical fractures that formed during the extensional phase would tend to deepen their roots in the lower crust in anticlinal regions while the fractures in the synclinal regions tended to close up. The open fractures in the anticlinal zones could have facilitated the easy intrusion of parts of the accumulated melt into higher levels of the crust *(Ucakuwun, 1989).* After the intrusion of the granites; the accumulated granitic melt in the lower crust underwent some fractionation. The tectonic activity related to the second folding phase created intrusion of some granites particularly Chitwe and Chabakonzo..

According to *Pohl and Gunter, (1991)* the Karagwe-Ankolean system evolved as an intercontinental orogeny between about 1400 to 900Ma. Arrows indicate predominantly extensional or compressional regimes: Kibaran basin formation from about 1400-1300Ma. Kibaran orogeny at about1300Ma, with the formation of the open folds of granite gneiss dome and haloes of thermal metamorphism.
Rifting affecting the Kibaran belt at about 1275Ma, with mantle magmas inducing crustal melting and rise along tensional faults to form layered mafic intrusions within the Kibaran metasediments. The Lomamian orogeny at about 950Ma, inducing renewed compressive deformation, elevation and glaciations of the Kibaran Mountains, and intrusion of G4 granites.

1.4.2 Geochronology and Age Dating

Absence of evidence of fossils in the entire K-A and the study area in particular made the age determination of the different lithologic formations purely speculative. In spite of this, radiometric dating of granites of southwestern Uganda by different scholars, approximate ages of the K-A system were obtained. Radiometric also known as isotopic dating is an absolute age dating technique.
Shown in table 2.2, below are various ages of southwestern Uganda granites obtained using the Rb/Sr and K/Ar isotropic ratios. The generally accepted age of Karagwe-Ankole rocks system is 1400-950 Ma (Schluter, 1994). Since the study area is in close proximity or rather a big portion of it is covered by the Marsha granite which dated to be 1300 Ma (Pohl 1994), therefore the age of the rocks in the study area C is approximately 1350 Ma.

Granites	**Age (ma)**	**Scholar (s)**
Masha	1300	Pohl., 1994
Chitwe	119.5	Cahen et al.,1984
Chabakonzo	939	Cahen et al.,1984
Kamwezi	1201	Cahen et al., 1984
Rwentobo	1318	Cahen et al., 1984
Ntungamo	117	Cahen et al., 1984

Table 2-2: The relative ages of granites of Southwestern Uganda.

CHAPTER THREE: STRUCTURES

3.1 Introduction

This chapter focuses on the various geologic structures that were found in mapped area, C. It includes a full descriptive account of all the structural geology information obtained from field observations, laboratory structural data analysis, structural (cross section) profiles. Structures are the larger, generally three-dimensional physical features of rocks; they are best seen in outcrop or in large hand specimens rather than through a microscope.
Structures are usually the result of the powerful tectonic forces that occur within the earth. Sedimentary structures develop through physical and chemical processes before, during and through diagenetic processes. Such processes occur during deposition and after deposition
The study of geologic structures has been of prime importance in economic geology, both petroleum geology and mining geology. Folded and faulted rock strata, commonly form traps that accumulate and concentrate fluids such as petroleum and natural gas. Deposits of gold, silver, copper, lead, zinc, and other metals, are commonly located in these structurally complex areas.
This chapter presents a detailed discussion on the geologic structures encountered during the geological mapping activity in area C, Igayaza area in Isingiro district. The chapter presents all the observed characteristics, observations, measurements and analysis made on the different geological structures observed in the project area C. In the project area, both primary and secondary geologic structures were encountered. These structures were further sub-categorized into major and minor structures basing on the relative abundance or dominance as encountered in the entire mapped area C. The table 3-1 below summarizes the geologic structures encountered in area C and the different categories they were placed.
Structures that are produced at the same time as the sedimentary rock in which they occur are called primary sedimentary structures such as bedding or stratification, cross bedding, ripple marks whereas Secondary structures are as a result of deformation and tectonic activity usually referred to as post depositional structures and they include faults, joints, folds and veins.

CATEGORY	*SUB-CATEGORY*	
	Major structures	***Minor structures***
Primary structures	*Bedding planes*	*Lamination*
Secondary structures	*Joints*	*Faults, folds.*

Summary of the types and categories of the structures encountered in area C

The purpose of the detailed study of the geologic structures in this chapter is to try to deduce the geologic history, especially the deformational/tectonic history of the project area C

3.2 Structural data (field measurements)

This section of the chapter presents the measurements of some of the geologic structures encountered in the field. These measurements include mainly the attitudes of the planar structures such as joints/fractures and bedding planes. Also, the orientations of quartz veins encountered in the field were also noted. General trends of some of these structures were also deduced from the measurements taken. Several measurements were made especially for the attitudes (strike and dip) of joints and bedding planes and only a summary consisting of the mean strikes and dips of these measurements are given in the table 3-2. All the strikes and dips of the joints and bedding planes are shown in appendix 1. Distribution of some of these structures and their orientations is indicated in the geologic map of area C in chapter two above.

CATEGORY	SUB-CATEGORY	
	Major structures	**Minor structures**
Primary structures	Bedding planes	Lamination
Secondary structures	Joints	Faults, folds.

Table 3-2 Summary of the measurements of orientation of joints and bedding planes in area C

3.3 Stereographic analysis

Large amounts of geometrical and orientation data collected for planar and linear geologic structures such as bedding planes, joints, faults etc. does not usually make much sense unless some sort of statistical analysis is done. This section of this chapter therefore, presents some of the statistical analysis done on the large orientation data collected for the joints and bedding planes during the mapping exercise. The analysis was done by stereographically projecting the orientations of the joints and bedding planes separately. In this case, contour, density and rose diagrams were the forms of stereographic projections used for the analysis and these were obtained by use of a computer software called Stereo net win 64- a free license computer software downloaded from internet.
Stereographic projection is a form of mathematical (statistical) analysis used to determine the average, systematic nature or a particular pattern in the orientation of a given planar or linear geologic structure without much regard to the spatial location of the structure.

3.3.1 Stereographic analysis of bedding planes

3.3.1.1 Rose diagram analysis for bedding planes

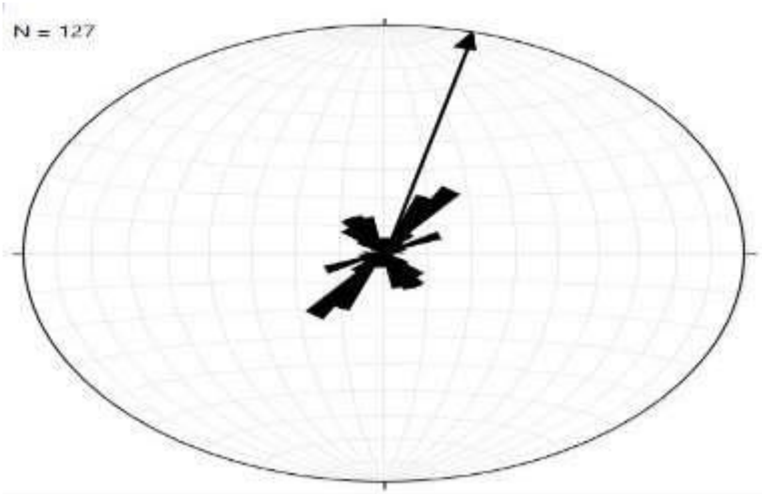


Figure 15: Rose diagram showing different strike directions and trends taken by beds in area C

Interpretation

A total of 113 measurements for strike and dip of bedding planes were obtained during the mapping activity using a geologic compass of the silver type. Figure 3.1 treats the data as axes with directional significance. it can be seen that all the beds of the rock strata encountered in the area c strike in majorly two directions that is to the Northeast and Northeast. However, most of the beds more than half of the number strike to the Northeast direction (see appendix 1) for analysis of bedding planes in the different quadrants. Also, most of the beds in the Northeast direction tend to strike more to the North-northeast direction as indicated by maximum value of beds striking in the range between 31 and 400. it can also be noted that the trend of NW-SE can also be deduced. Existence of two trends of bedding planes in one area could imply that there is small scale folding on the major limb of a large-scale fold. Alternatively, this could mean existence of both limbs of a large-scale fold in the same area.

3.3.1.2 Density/ Contour diagram analysis for bedding planes.

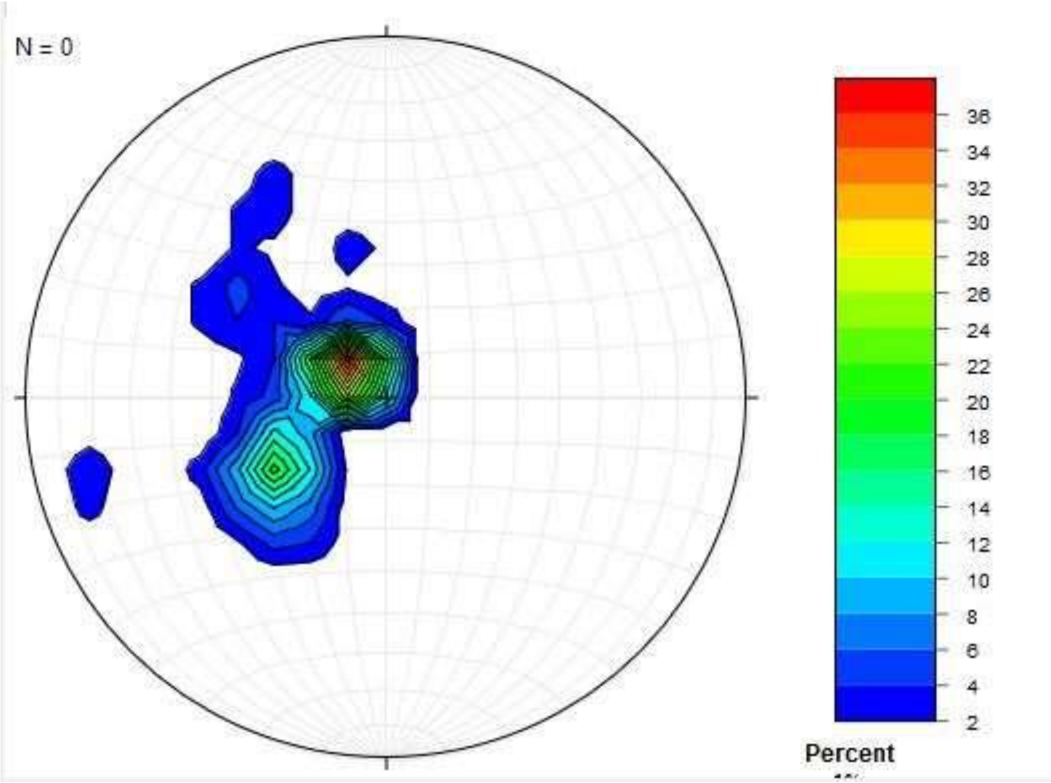


Figure 16: contour diagrams showing preferred and strength of preferred orientation taken by the beds encountered in area C

Interpretation

In the figure 3.2, above, it can be seen that the poles of the bedding planes form two maxima/clusters of points which is indicative of two preferred orientations of bedding planes in area C. However, there is a greater concentration of points in the NW quadrant than in the SW quadrant. This implies that the NE-SW (SE dip) is strongly preferred as compared to the NW-SE (NE dip). This could explain the occurrence of a small-scale fold on one limb of a large-scale fold or the area of investigation covers more of one limb of a large-scale fold than the other. From the contour diagram, it can be deduced that the beds are generally gently dipping as most of the poles to the bedding planes plot close to the center of the stereogram. This could imply that the measurements of the orientations of the bedding planes were taken close to the axis of a fold.

3.3.2 Stereographic analysis of joints

3.3.2.1 Rose diagram analysis for joints

The rose diagram is a form of stereographic projection/statistics that is usually preferred for analysis of strike or trends of planar geologic structures such as joints, faults, bedding planes etc. In a rose diagram as will be seen below, the petals are parallel to the strike/trend of the planar structure-joints in this case. The width of the petals is a constant interval of 100 and the length of the petals gives the total number of the planar structures encountered in the project area within a given range of strike readings- in the 10^0 interval.

A total of 145 measurements for strike and dip of joints were obtained during the mapping activity using a geologic compass of the silver type. These were then plotted on a stereo net using a software called stereo net win 64 to obtain the rose diagrams shown in figure 3.3 below from which the following interpretations on trends of the joints were made as elaborated below

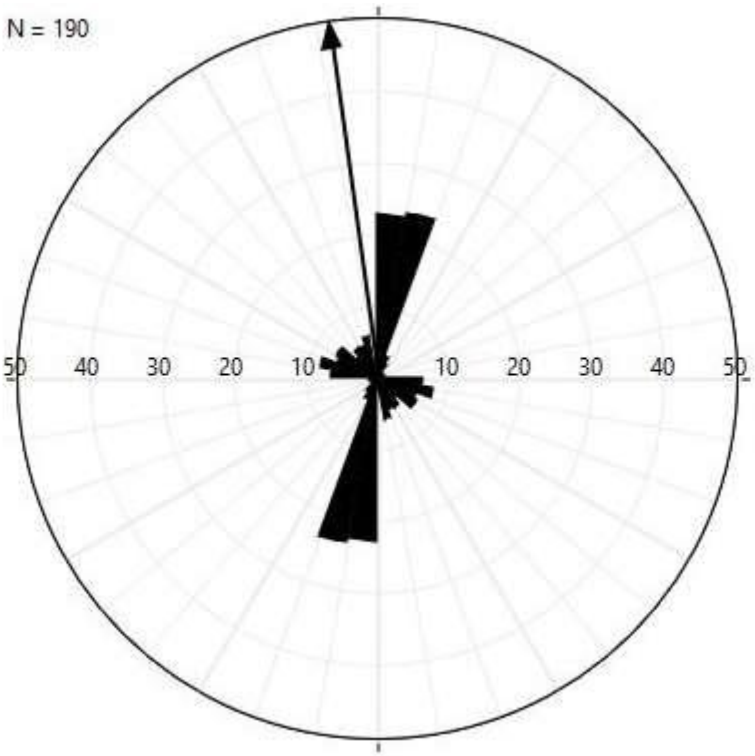


Figure 17: Rose diagram showing strike directions of the joints encountered in area C

Interpretation

The following interpretations were made on the trends of joints encountered in the project area C;

The joints tend to strike in all the four directions i.e., in the Northeast, Southeast, Southwest and Northwest. However, most of the joint strike, tend to lie in the Southwest quadrant. This implies that the preferred strike is southwest. However, it can also be noted that most of the joints in this quadrant have strikes between 181 and 1900 which further implies that a more specific preferred strike direction of South-southwest (SSW) can be deduced.

Quadrant four contains the second largest number of joints as depicted in rose diagram above. Despite the fact that most of the joints strike in the SW direction, this number of joints that strike in the NW direction is also significant.

3.3.2.2 Density/Contour diagram analysis for joints.

Density diagrams display poles calculated from planar structures which are represented as points on the stereogram. From density diagrams, contouring is done at a given interval to obtain a distribution density pattern of planar structures. In this case, the contour diagram was obtained through 1% area contouring at an interval of 2% with the darkest contour representing zones of the highest density of points outward to lighter contours of low-density zones. The density and hence the contour diagram were both obtained from 145poles (lines) calculated from planar joint measurements by the stereo net win 64 software as shown in the figure 3.4 below.

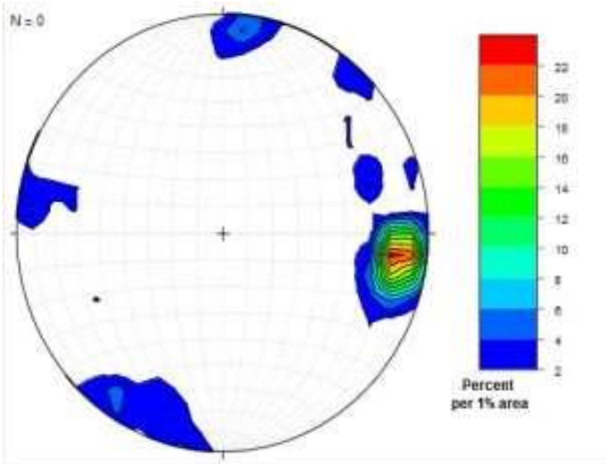


Figure 18: Contour diagrams showing preferred orientations of joints encountered in area C.

Interpretation

From the density and contour diagrams in the figure 3.4 above, the joints tend to form one maximum/cluster/concentration of points in the SE or second quadrant (Azimuth) indicating one preferred orientation of joints in area C. Points in other quadrants do not show a marked reproducible concentration of the poles except in the SW or third quadrant (Azimuth) where the points tend towards local concentrations of the points hence a tendency to form the second preferred orientation of the joints. In the contour diagram, the contours take form of half circles and are diametrically opposite i.e., half circles in SE quadrant correspond to those in NW and those in SW to those in NE quadrant. This could imply a complementary origin in the formation of the joints in the opposite quadrants. This could further imply preferred trends in the NW-SE and NE-SW directions however, the NW-SE trend is more pronounced.

In the contour diagram, it is observed that contours are at the periphery of the stereogram implying that the joints are generally steeply dipping. Overall stereographic analysis of joints indicates steeply dipping joints with a preferred strike in Southwest direction; preferred trend in the NE-SW direction. However, most of the joints tend to strike in the South-southwest direction; trending NNE-SSW.

3.3.3 Other stereographic analyses.

This section of stereographic analysis presents a summary of other stereographic analyses made on joints and bedding planes.

Joints/planes involved	Angle (acute angle) in degrees	
Mean orientation of joints in NE quadrant	Mean orientation of joints in SE quadrant	72
Mean orientation of joints in SW quadrant	40	
Mean orientation of joints in the NW quadrant	76	
Mean orientation of joints in SE quadrant	Mean orientation of joints in SW quadrant	48
Mean orientations of joints in NW quadrant	40	
Mean orientation of joint in SW quadrant	Mean orientation of joints in WN quadrant	78
Mean orientation of beds and joints in different quadrants.		
Mean of orientation of beds (NE-SW trend)	Mean orientation of joints in NE quadrant	52.5
Mean orientation of joints in SE quadrant	76.5	
Mean orientation of joints in SW quadrant	87.6	
Mean orientation of joints in the NW quadrant	75.9	
Mean of orientation of beds (NW-SE trend)	Mean orientation of joints in NE quadrant	53.7
Mean orientation of joints in SE quadrant	73.6	
Mean orientation of joints in SW quadrant	82.8	
Mean orientation of joints in the NW quadrant	43.1	

Mean orientation of beds trending NE-SW and those in NW-SE		
Mean of orientation of beds (NE-SW trend); 044,18	Mean of orientation of beds (NW SE trend);329,33	Line of intersection(fold axis) is 121,17 and the orientation of the axial plane is;111,61
Mean orientations of the poles to the joints and the fold axis		

Fold axis (121,17)	Mean orientation of joints in NE quadrant (294,21)	39
Mean orientation of joints in SE quadrant (52,17)	66	
Mean orientation of joints in SW quadrant (102,18)	17	
Mean orientation of joints in the NW quadrant (212,19)	86	

Table 3-3 Structural information obtained from other stereographic analyses of joints and bedding planes.

Interpretation

From this analysis it can be seen that joints that trend in the same direction i.e., NE-SW (But with dips in SE and NW) and NW-SE (But with dips in the NE and SW) intersect at relatively acute angles which could imply that they are conjugate joints. However, the different trending joints generally intersect at higher angles. The intersection of the mean of the bedding planes is a line, S590E, 170SE which can be taken as a fold axis with NW-SE trend which is characteristic of regional folding in the Karagwe-Ankolean system in southwestern Uganda. The NW-SE trending joints cut the fold axis at relatively high angles as compared to the NE-SW trending joints.

3.4 Description of structures.

The rocks of area C had a number of primary and secondary structures. Among the notable structures that were observed were faults, joints, bedding planes as well as ripple marks. These structures were identified in the field on outcrops that were exposed, and where possible structural measurements were taken and their general descriptions recorded. Structures have been distinguished as major and minor. The major structures are those that were dominant in many areas whereas the minor ones are those that were appearing less dominant.

The results in the field were obtained using different techniques. Stations were established at various outcrops of interest. The location of each station was also obtained from the Global positioning System (GPS) and noted. Precise observations and descriptions of the interesting features and structures present on the outcrops at the stations were then made and noted. The structural data were collected in the field by measurements of orientations of faults, joints, faults among others. For linear structures, measurements were made for plunge and trend whereas for planar structures, the strike and dip were measured using a geologic compass.

3.4.1 Major Structures

3.4.1.1 Beds

Bedding refers to a stack of different layers of rock of varying properties such as color, texture, thickness and composition separated by surfaces called bedding planes. Each layer of rock may represent a different depositional episode or change in depositional conditions. It is a common primary structure in sedimentary rocks that usually forms when sediments settle out from water during deposition of sediments in a definite pattern to form layers of rock. Thickness of beds varies from a few millimeters to several meters.

In the mapped area C, Beds were more pronounced in shales both ferrigenous and grey shale. The beds in this area had varying thickness and the individual beds had different colors and texture.

They indicate deposition under several different episodes. Most of the beds ranged from about 5mm thickness to about 10 cm. The beds are not horizontally lying but are tilted generally trending in two directions. Most of the beds trend in the NE-SW direction and dip to the SE whereas their counter parts trend in the NW-SE direction, dipping to the NE as deduced from stereographic analysis. This gives a fold with NW-SE trend which is characteristic of the regional folding in the region. For the NE-SW trend, the strike angle ranged from as low as 050 to 880 and the dip angle was ranging from about 10^0 to 70^0.There were some cases however where bedding planes were trending in the NW-SE direction although this was a minor trend. The contacts or the bedding plane surfaces between quartzites and shale are sharp. On the other hand, the bedding plane surfaces between the shale beds especially the laminae usually tend to be gradational. However, sharp contacts are dominant in both cases.

Figure 19: showing thin bedding in shale (256125,9917700)

3.4.1.2 Joints

A **joint** is a fracture in a rock in which there has been little or no displacement. A joint does not involve shear displacement and forms when tensile stress breaches its threshold. In other kinds of fracturing, like in a fault, the rock is parted by a visible crack that forms a gap in the rock. They can be differentiated from faults as there is very little or no displacement as is in faults. Majority of the joints occurred in the arenaceous horizons as compared to the argillaceous horizons. In area C, the joints were mainly observed in quartzites and shales but are more pronounced and common in quartzites. This is because the quartzites are more brittle than the softer shales. Joints are a result of brittle deformation which arises due to tectonic forces. Some of the joints encountered were very penetrative and extend deep into the under lying lithologies. This could be attributed to the folding and faulting that occurred in the area such that the fractures that originally existed in the area prior to the folding were made even deeper and wider, after the folding and fracturing episodes. Two major joints sets were observed in area C i.e.,
the major and minor joints with the NW-SE and NE-SW trends respectively.

Major joints

These showed a general strike direction in the NW-SE direction and is in line with regional folding of the Karagwe-Ankolean System.

Minor joints

These showed a general strike trend direction in the NE-SW which is in line with the Cross folding of the Karagwe-Ankolean system and is perpendicular to the regional fold.

Figure 20: showing a joint *(256135,9917741)*

Figure 21: systematic joints in quartzite (257498,9918639)

3.4.1.3 Faults

A fault is a planar fracture or discontinuity in a mass of rock along which displacement of blocks has occurred. Presence of faults in area C can be given by various evidences both on maps and in the field. The most common evidence of faulting in area C is the offset seen in the ridges as observed in the field.

Also in the geologic map of the area, several offsets can be seen in some of the geologic units especially the quartzites which occupy the tops of the ridges which is also evidence of faulting. In most cases narrow and sometimes wide deep to shallow valleys exist between the offset ridges in the area which could imply that zones of shear (fault plane) created weak rock material which might have been eroded and washed away. However, not all the valleys observed in the area document evidence of faulting.

Other evidences for the presence of faults in area C were the presence of fault breccias which are associated with the intense process of shearing, linear pattern of vegetation especially in valleys, nearly straight scarps that trend some-what uphill or downhill, nearly straight valleys that cross structures obliquely or appear to offset other valleys and water seeking plants that prefer fault zones due to presence of water that percolates into the zone and also by identifying the relatively

Joint displaced mass of earth (rock), one of which forms the hanging wall and the other, the foot wall as is with orientation.
Estimation of the fault trends indicate that most of the major faults in the area trend in the northwest-south east direction. However, most of the minor faults that tend to intersect the major ones at smaller acute angles tend to trend Northeast-southwest. From keen observations in the field, most of the faults are strike slip (dextral and sinistral) faults in which the displacement is parallel to the strike of the fault. Basing on the relationship of the attitude of the faults and that of the country rocks of the area, they can be generally regarded as tear faults since they tend to generally strike transverse to the strike of the country rock.

Mechanism of faulting

Because of friction and the rigidity of the constituent rocks, the two sides of a fault cannot always glide or flow past each other easily, and so occasionally all movement stops. The regions of higher friction along a fault plane, where it becomes locked, are called *asperities*. When a fault is locked stress builds up, and when it reaches a level that exceeds the strength threshold, the fault ruptures and the accumulated strain energy is released in part as seismic waves, forming an earthquake.
Strain occurs accumulatively or instantaneously, depending on the liquid state of the rock; the ductile lower crust and mantle accumulate deformation gradually via shearing, whereas the brittle upper crust reacts by fracture resulting in motion along the fault. A fault in ductile rocks can also release instantaneously when the strain rate is too great.

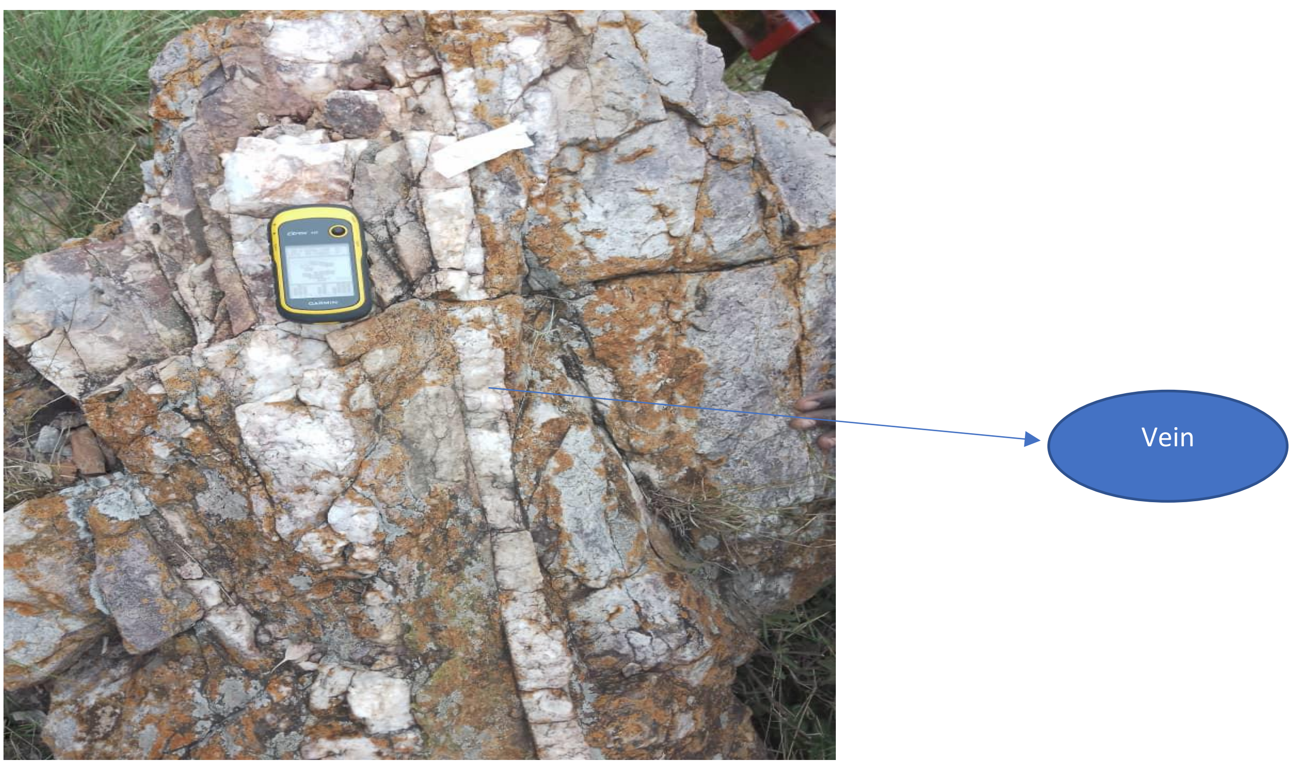
Figure 22: A fault zone with NE-SW trend evidenced by a linear pattern of vegetation especially in valleys and nearly straight scarps that trend some-what downhill

3.4.2 Minor Structures

This category is made up of those structures that do not appear on a regional scale. They are mapped in few rock units. Examples include; quartz veins and ripple marks.

3.4.2.1 Quartz veins

Quartz veins are defined as distinct sheet like bodies of crystallized minerals within rocks composed chiefly of sutured quartz crystals of pegmatitic or hydrothermal origin. They form when mineral constituents carried by aqueous solutions within the rock mass are deposited through precipitation along lines of weakness such as joints. The veins observed were majorly of quartz rich material which filled the fissures and joints in the rock masses. They were probably as a result of high fluid phase associated with magmatic intrusions such that silica-rich fluids moved through the fractures, cooled and got emplaced there. They had varying thicknesses ranging from l cm to about 5 or more cm. Cross cutting quartz veins are observed in places that have undergone intense fracturing. Hydrothermal quartz veins allow establishment of chronologic order of events for the rock in which they are found. They are formed after the formation of joints in the rock and thus younger than the veins. Veins are of prime importance to mineral deposits, because they are the source of mineralization either in or proximal to the veins. Hydro fracture breccias are classic targets for ore exploration as there is plenty of fluid flow and open space to deposit ore minerals. Fault Ores related to hydrothermal mineralization, which are associated with vein material, may be composed of vein material and/or the rock in which the vein is hosted



3.4.2.2 Ripple marks

Ripple marks are primary structures formed within a rock due to deposition of finer sediments in a calm aqueous environment. Ripple marks usually form in conditions with flowing water, in the lower part of the Lower Flow Regime. There are two types of ripple marks i.e., symmetric ripple marks and asymmetric ripple marks.

Symmetrical ripple marks: Often found on beaches, they are created by a two-way current, for example the waves on a beach (swash and backwash). This creates ripple marks with pointed crests and rounded troughs, which aren't inclined more to a certain direction.

Asymmetrical ripple marks: These are created by a one way current, for example in a river, or the wind in a desert. This creates ripple marks with still pointed crests and rounded troughs, but which are inclined more strongly in the direction of the current. For this reason, they can be used as paleocurrent indicators.

The ripple marks observed in area C were asymmetric ripple marks. This indicated that finer sediments were deposited in a particular direction. The current direction was observed basing on the direction of the steeper shorter face in relation to the longer gentler face. Current direction is from the steeper shorter face towards the gentler longer face. It was observed to be NE-SW direction. Besides the paleo current indicator, the ripple marks are also indicators of depositional environment and this shows that it was a shallow water environment where the flow is weak and sluggish. The **wave length** of the ripple was measured to be about **8.5cm**.

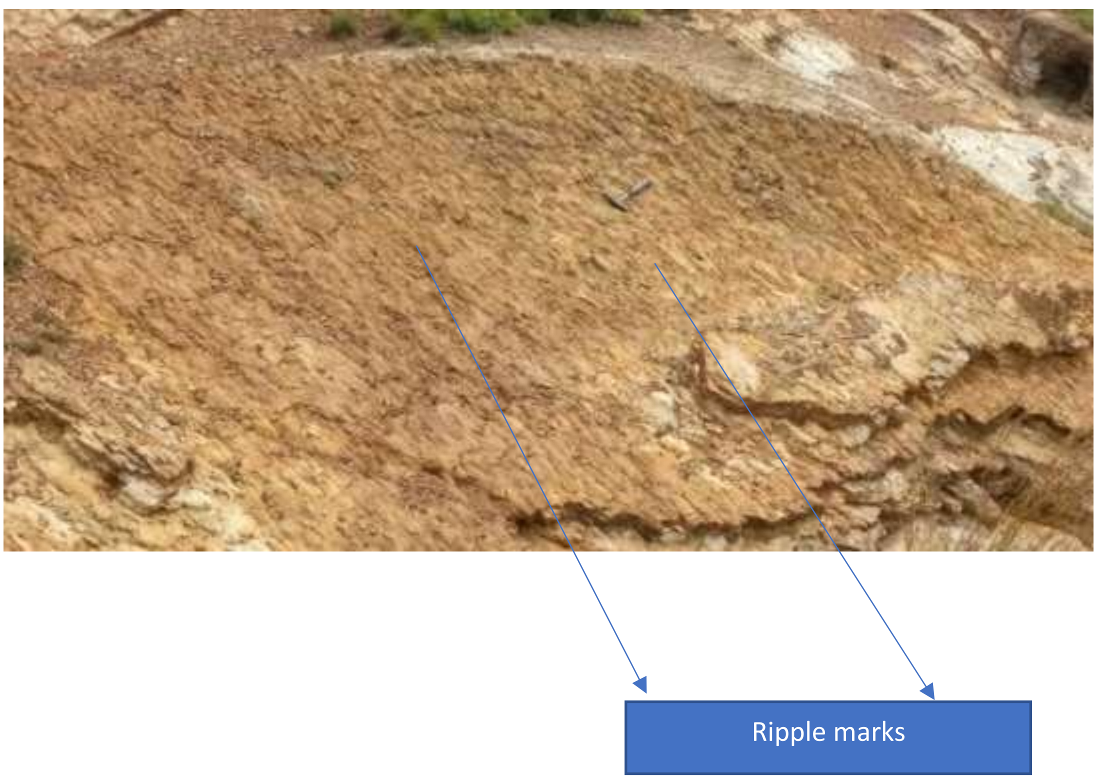


Figure 23: Asymmetrical ripple marks on shale outcrop

3.4.2.3 Folds

A fold is a secondary structure produced in rocks when planar surfaces have been deformed to produce non-planar or curved surfaces. Folds usually form under a compressive field stress by different mechanisms such as buckling, flexural slip and shear or slip folding with several other factors controlling the process in each of these mechanisms. Barnes (1956); Cahen and Snelling (1966) and Cahen et al, have described two major fold trends in the Karagwe-Ankolean system. These include the regional set, trending Northwest-southeast and the cross folds trending Northeast-southwest. The folds have been characterized as generally open with wave lengths ranging from 8-16km.

In area c, the major, open folds are not easily observed in the field but their presence can be deduced by the large-scale tilting/dip of the beds of the rocks especially the shales and quartzites Ripple marks of the area. In places where the two trends of the beds exist for example in some parts of area c, the trend of the fold is given by the line of intersection of the beds of the two trends. As such a fold trending NW-SE is deduced from stereographic analysis of the bedding in area C. This is characteristic of regional folding which is quiet more evident in the Kibaran belt in the extreme south west of Uganda.

Also in this area, several minor/small scale folds were encountered which is characteristic of small scale folding in the Karagwe Ankolean system. These seem to form on the limbs of the large-scale folds in the area hence the term synclinoria and anticlinoria commonly used as regards to the folding in the Karagwe-Ankolean system in south west Uganda. These have a general North west southeast trend conforming to the regional fold trend. The minor folds are mainly associated with thin layers of quartzites and shales-argillaceous rocks of the area. Their formation is associated with incompetence of the argillaceous rocks during regional folding or by differential movement between the quartzites which are closely spaced in cases where the small-scale folds are found within quartzites

Figure 24: A fold in a quartzite trending in the NE (257040,9918414)

3.5 Discussion

3.5.1 Relationship between different structures.

There was no much evidence obtained from the field about relationship of the different structures. However, the relationship between the different structures can be backed up by some of few evidences from the field and laboratory work (stereographic plots)

According, to Pohl and Gunther (1991), folding which produced NW-SE and NE-SW trending wide anticlinoria and narrow synclinoria is considered to be one of the first phases of deformational or tectonic activity that affected the Kibaran belt (Karagwe-Ankolean). Folding in the area is manifested by small scale folds such as that described in the preceding section of this chapter. The relatively large anticlinoria and synclinoria are not easily noticeable in the area but can be inferred from the large-scale dipping patterns of the beds of rock in the area.

Faulting can be considered to have followed the folding phase and therefore faults could be later in history than the folds. This is observed in the displacements of the quartzite ridges from each other which were affected by earlier folding.

From stereographic analysis of joints, jointing can be related to folding in the area since joints trend in the same directions as the folds i.e., NW-SE trending joints take the same trend as the regional fold (also NW-SE) trend whereas the NE-SW trending joints take the same trend as cross folds-NE-SW trending. The relationship between joints and folds according to Ben. A. et al, 2004, is that several sets of joints may develop in response to folding. Conjugate shear joints oblique to the fold axis develops by compression whereas tension joints may develop due to bending particularly in the vicinity of the fold hinge. Joints parallel to strike of the fold axis are called strike joints whereas those parallel to the dip of the limbs are known as dip joints. From stereographic analysis, it can be noted that the NE-SW trending joints trend in the same direction as the beds and can be referred to as dip joints and more some parts of this area are close to the axis of the Gayazasyncline. The formation of boudins (boudinage) can be considered as a later episode after folding

since the asymmetrical boudinage seemed to take place on already folded strata.

3.5.1.2 Types of stress field

Compressive/ shear field stress.

Most of the secondary structures which include folds, boudins, faults and joints observed in the area of investigation indicate a compressive/shear field of stress as the major player in the deformation of the rocks observed. However, the changes in the orientation of the principal stresses that is the maximum, intermediate and minimum principal stress fields during the different episodes of deformation could be one of the causes of the changes in the orientation of the structures. The brittle behavior exhibited in the deformation of the rocks can be tagged more to factors such as confining pressure, temperature such that the deformation can be regarded to have taken place close to the crustal surface and at low temperatures.

In area C where the major fold trend is Northwest-southeast, a compressive field stress oriented in the Northeast-southwest is proposed to be responsible for the folding (Stheeman, 1932 and Ucakuwun, 1992). Existence of boudins where thin layers of quartzites are embedded in thin layers of shale implies an extension field induced during folding or intrusion of granites into the anticlinal folds. Presence of conjugate faults and joints in the area is another good evidence of shear stress which could have played part in the deformation of the rocks in the area.

3.5.2 Tectonic history/deformation history of the area

According, to Pohl and Gunther (1991), folding which produced NW-SE and NE-SW trending wide anticlinoria and narrow synclinoria is considered to be one of the first phases of deformational or tectonic activity that affected the Kibaran belt (Karagwe-Ankolean). Folding in the area is manifested by small scale folds as described in the preceding section of this chapter. The relatively large anticlinoria and synclinoria are not easily noticeable in the area but can be inferred from the large-scale dipping patterns of the beds of rock in the area. Faulting can be considered to have followed the folding phase and therefore faults could be later in history than the folds. This is observed in the displacements of the quartzite ridges from each other which were affected by earlier folding. The presence of tear faults further concretizes the fact that faulting is later than folding.

From stereographic analysis of joints, jointing can be related to folding in the area since joints trend in the same directions as the folds i.e., NW-SE trending joints take the same trend as the regional fold (also NW-SE) trend whereas the NE-SW trending joints take the same trend as cross folds-NE-SW trending. The relationship between joints and folds according to Ben. A. et al, 2004, is that several sets of joints may develop in response to folding. However, formation of joints can also be related to faulting in the area and since joints can be formed by different processes, it becomes difficult to tag the formation of the joints to a particular episode of a tectonic event in this area.

CHAPTER FOUR: PETROGRAPHY AND METAMORPHISM

4.1 Petrography

4.1.1 Introduction

Petrography refers to a branch of petrology that focuses on detailed description and study of rocks. Petrographic studies involve both macroscopic-study of rocks at out crops (*in situ* rocks) and at hand specimen scales; and also, the study of rocks at microscopic scale, where descriptions are done by aid of a petrographic microscope. Macroscopic description of rock samples was done followed by analysis of thin sections of the samples. This was performed using a polarizing microscope, and microscopic rock descriptions were then performed.

While in field, stations were established on outcrops that had interesting geology based on changes in lithology, color and distance from previous station. Outcrop descriptions were made which included the description of size and location of the out crops, tectonic activity and extent of weathering among others. Samples were collected from fresh rock (rock that has not been weathered) and labeled CM1, CM2 and so on. From the samples that were collected from the field, representative samples were selected at the end of the mapping exercise depending on the rock type and distribution in the mapping area.

Petrography, in this case, was important in defining the metamorphism of the study area C as will be seen in the next section of this chapter. It was also important in other studies such as revealing the geologic and tectonic history as seen in the preceding chapters.

4.1.2 Description of field out crops.

During the field study, 6 representative samples were selected and analyzed from a total of 17 samples collected in the field. A total of 20 out crops were visited and studied during the mapping exercise in area C. These were identified and named consecutively from C1 to C19. The descriptions of 6 outcrops from which the rock samples were collected are given below.

Station 1

Rock name: Quartzite

Location: (0257547 ,9917584)

The outcrop is a large natural exposure of highly weathered and fractured quartzite intruded by quartz vein 5.5-16.5 cm long located on a hill. The outcrop lies in a faulted zone. The faulting was evidenced by the presence of fault breccia with angular rock fragments of quartz, siliceous shale cemented by iron minerals. As you traverse the outcrop south Eastwards, the relative abundance of floats decreases downwards accompanied by a change in the slope and vegetation type from thorny trees to grasses. The bottom parts were characterized by the presence of laterites which could have been as a result of weathering of the shale.

The sample obtained at this station was **CS1**

4.1.3 Macroscopic description.

This section deals with the description of the collected rock samples from the stations described above. The rock samples were described both in the field and in the laboratory. The description was done with an unaided eye except in some instances where a hand lens was used. GPS coordinates for the location of sample collection are the same as those of the stations of sample collection. Several samples were collected but only 6 of them were selected for analysis and these are the ones described in this section. These include samples identified as CS 1, CS 1A, CS 2, CS 5, CS 6 and CS 12. The description entails features such as color, texture, structures, major minerals and field name of a given sample.

Sample CS 1

The rock is black to reddish brown in color, medium to coarse grained and massive composed of mainly iron oxides and micas. The rock has a phaneritic texture.

Macroscopic description of the sample CS 1

The rock is black to reddish brown in color, medium to coarse grained and massive. The major mineral composition is iron oxides and micas. The rock has a phaneritic texture.

Field name: Ferrignized quartzite

Figure 24: sample CS1

Hand-size sample CS 1showing the dominant reddish-brown oxides with micas

The rock is composed of mainly quartz and some hematite attributed to reddish brown color. The quartz is cemented with hematite. The largely quartz containing rock, collected from a fault zone,
has quartz grains that have been recrystallized (interlocking quartz grains in micrograph under XPL). The thin section of the sample was analyzed under both plane polarized light (PPL) and cross polarized light (XPL)

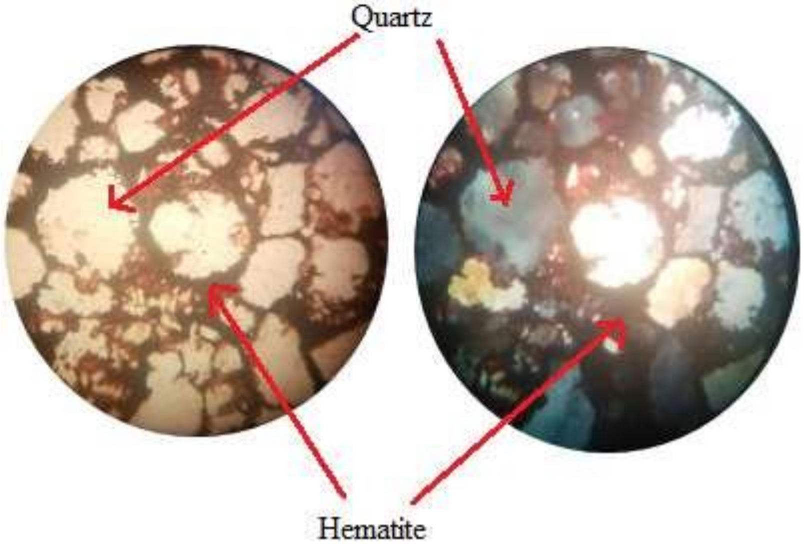


Figure 25: (left) A photomicrograph of the thin section of sample CS 1 under PPL (X100). (right) the photomicrograph of the same thin section under XPL indicating the minerals in the sample (X100).

Mineral composition by percentage

Table 4-1: Mineral composition by percentage volume for sample CS 1

Mineral	Modal mineralogy by volume percent
Quartz	75
Hematite	25

Station 10
Rock name: Ferriginized shale.
Location: (257974, 9917400)
The outcrop is a large artificial exposure of slightly weathered grey shale with a high percentage of clay minerals mainly kaolin. The outcrop is highly weathered due human activity i.e., quarrying and the type of minerals which are highly susceptible to weathering. The bed thickness range from 0.5cm to 5 cm. The outcrop lies in a faulted zone with a dendritic drainage pattern in the area i.e., many small channels flow into a major channel. The samples obtained from this station was **CS 55**

Figure 26: sample CS 55

Macroscopic description of the sample

Mineralogy: Clay minerals, iron oxides

A grey fine grained laminated rock composed of mainly clay minerals with iron oxides. The sample has a perfect cleavage and an aphanitic texture.

Field name: grey shale

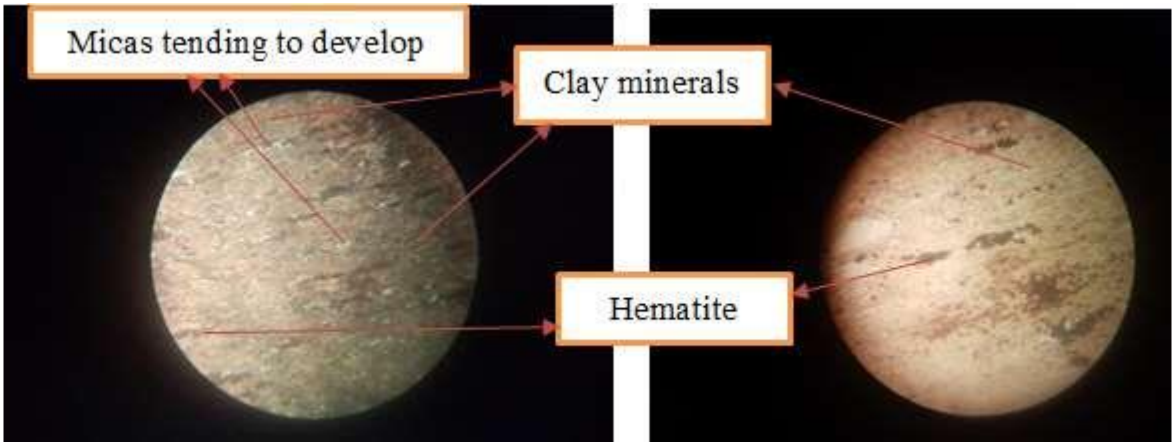


Figure 27: (left) A photomicrograph of the thin section of sample CS 55 under XPL (X100). (right) the photomicrograph of the same thin section under PPL indicating the minerals in the sample (X100)

Mineral composition by percentage

Table 4-2: Mineral composition by percentage volume for sample CM4A

Mineral	**Modal mineralogy by volume percent**
Clay minerals	95
Hematite	03
Micas	02

Station 4
Location: (0257274, 9917496)
The outcrop is a large natural outcrop of grey shale located at the top of the hill with some layering and laminations. Sampl**e CS 17** was obtained from this station.

Macroscopic description of the sample
A grey laminated fine-grained rock composed of mainly clay minerals, micas and iron oxides. The rock has an aphanitic texture and a perfect cleavage.
Field name: grey shale

Figure 28: sample CS 17

Microscopic description
The rock is composed of mainly clay minerals and some hematite attributed to reddish brown color. The thin section of the sample was analyzed under both plane polarized light (PPL) and cross polarized light (XPL).

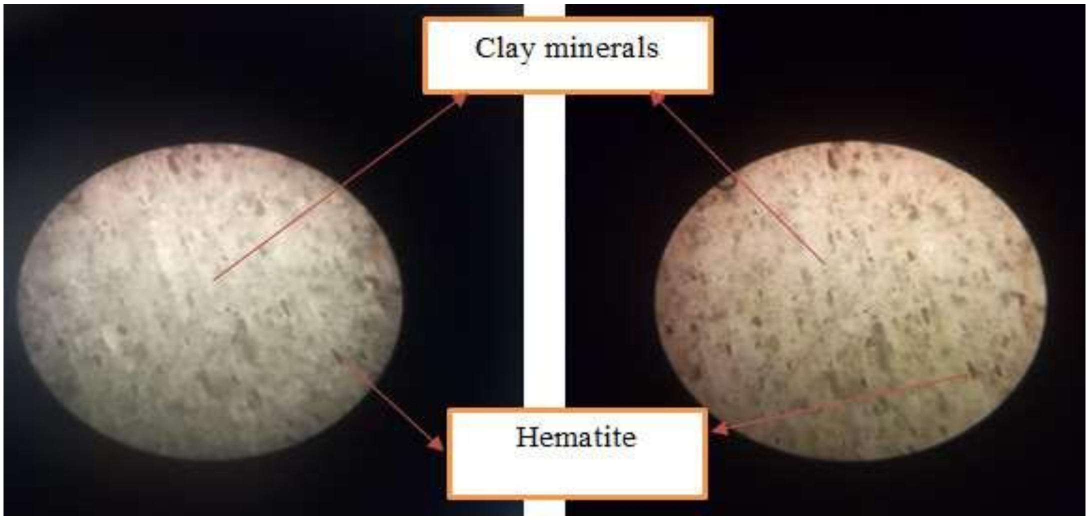


FIGURE 29: (left) A photomicrograph of the thin section of sample CM10 under XPL (X100). (right) the photomicrograph of the same thin section under PPL indicating the minerals in the sample (X100)

Mineral composition by percentage

Table 4-5: Mineral composition by percentage volume for sample CM10

Mineral	Modal mineralogy by volume percent
Clay minerals	70
Hematite	30

Station 21

Rock name: quartzite

Location: (257486 ,9918055)

A large outcrop of highly weathered quartzite naturally exposed along the slope in a faulted zone. The quartzite is highly jointed with two major joint sets. **Sample CS 12** was obtained.

Macroscopic description of the sample

A grey to whitish, coarse grained and massive (i.e., no structures) rock composed mainly of quartz and iron oxides. The sample has a phaneritic texture with poor cleavage. Field name: Quartzite.

Figure 30: photograph of Hand-size sample CS 12.

Microscopic description

The rock is composed of mainly clay minerals and some hematite attributed to reddish brown color. The thin section of the sample was analyzed under both plane polarized light (PPL) and cross polarized light (XPL).

(left) A photomicrograph of the thin section of sample CM12 under PPL (X100).
(right) the photomicrograph of the same thin section under XPL indicating the minerals and the wavy extinction in the sample (X100).

Mineral composition by percentage

Table 4-6: Mineral composition by percentage volume for sample CM12

Mineral	**Modal mineralogy by volume percent**
Quartz	100

4.2 METAMORPHISM

Metamorphism refers to the solid-state mineralogical and structural changes that usually occur in rocks due to the changes in the conditions usually of temperature and pressure in the environments in which the rocks exist; zones of diagenesis and weathering are usually excluded from such environments. The grade of metamorphism is given by the extent to which the metamorphic process has proceeded usually being controlled by the temperature and in some cases by pressure of metamorphism. This section tries to outline the details of the metamorphism of the mapped area C basing on the evidence from the field study of the geology and laboratory study of the rock samples obtained from the field.

4.2.1 Types of Metamorphism

There are various types of metamorphism known, but area C has mainly experienced regional metamorphism. The various types of metamorphism which occur in rocks are discussed below;

Regional Metamorphism: This is most evident at deeper levels of the earth's crust and occurs over wide areas of tens to hundreds of kilometers in width powered by a broad thermal gradient of a broad region. The heat and consequently the temperature are due to deeper and deeper burial of the rock body. The ultimate sources of heat may be radioactivity in the earth's interior, hot juvenile fluids, magmas rising above an active subduction zone or the combination of the three factors above. Regionally metamorphosed rocks tend to outcrop in Precambrian shields and in the eroded roots of great fold mountains. Regional metamorphism may be subdivided into;

Burial metamorphism: This is as a result of pressure and temperature imposed regionally at depth without apparent deformation or localized heat source. It is commonly of low temperatures less than 250 0C typically for blue schists. Because of lack of penetrative deformation in this type of regional metamorphism, equilibrium mineral assemblages are rarely attained. Hence relict features are common in these rocks.

Dynamic/Cataclastic metamorphism: This involves moderate to high pressure, high strain, high fluid partial pressure and variable temperatures. In this type, heat is a regional extent but may involve localized addition such as rising magma. It takes place in response to intense shear strain especially in shear zones and along the fault planes. Dynamic metamorphism is the most common type of regional metamorphism and mylonites are the typical products of this metamorphism.

Hydrothermal Metamorphism: It is due to localized circulation of hot fluids. It is common around igneous intrusions, sheared and faulted regions. Mostly, however it results from the interaction of heated sea-water with newly formed oceanic crust at mid oceanic ridges. It is accompanied by a change in composition and therefore a form of metasomatism. This metamorphism is usually a low grade and rarely goes to medium grade in these basalts and some gabbros plus peridotites of the ocean floors.

Impact Metamorphism: This is due to impact of large, high velocity meteorite body on a planetary surface. On some bodies on the solar system e.g. moon, impact metamorphism is perhaps the major geologic process. The extreme shock may cause the formation of high-pressure polymorphs of quartz such as stishovite and coestite.

4.2.2 Types of Metamorphism in the mapped area C

The rocks of area C are basically sedimentary (shales) and low-grade metasedimentary rocks (quartzites). The metamorphism of area C was deduced based on both field and laboratory evidence. Among the field evidence used to deduce the existence of metamorphism is the

presence
of quartzites, a metamorphic rock as seen in samples CS 1and CS 12 and also the increased grey color of the grey shale which meant that the shale was becoming more phyllitic with increasing grey color as observed from rock samples CS 17.

In the laboratory, thin sections of most quartzites shows that the quartz grains have suffered some
form of straining which resulted into elongation and wavy extinction in the quart grains evidenced
from the photomicrograph of sample CS 12. This provided a clear indication of metamorphism in
these rocks.
The metamorphism in the mapped area C is generally of regional nature (Regional metamorphism)
especially due to burial. Initial development of platy minerals (micas) as observed in thin sections
of sample CS 4 under XPL and Wavy extinction in quartz in sample CS 12 are evidence of regional metamorphism due to burial. Rock samples obtained at different locations especially at lower relief areas such as exposures at valleys exhibited metamorphic changes in their structure and in the properties of their constituent minerals. These changes were observed in most of the rock samples especially those collected from low-relief areas for example samples CS 4 and CS 12. In sample CS 4 (Grey shale) mica minerals were observed in their initial growth stage which is not typical of shales but rather an onset of a metamorphic process. In sample CS 12 (a quartzite), wavy extinction was observed in the constituent quartz minerals of the rock sample; under normal conditions, quartz exhibits uniform non-directional extinction but the wavy extinction usually develops as a result of strain in the quartz which would have been exerted by the overlying rock strata.
Dynamic metamorphism is deduced from rock samples collected from fault zones. Compared to rock sample CS 12 (of similar composition) obtained from a non-fault zone, sample CS 1, obtained from a fault zone is more reworked. This implies that there is an additional strain which resulted into the deformation and changes in the rock fabric observed in sample CS 1. This deformation is attributed to the stress in the rocks during the formation of the fault and is usually referred to as cataclasis associated with fracturing, rotation and frictional sliding which occurs in rock producing a fault/crush breccia. In terms of grade of metamorphism, the grade is generally of low due to the existence of shales as observed in the field study since these are literally still sedimentary rocks. From laboratory analysis, no typical mineral assemblage is observed except of some micas which are starting to develop in some shales but which are still difficult to distinguish in terms of their types.

CHAPTER 5: REGIONAL SYNTHESIS

5.1 Introduction

This chapter contains a summary of the whole mapping exercise in the entire area (from all the groups). The creation of the groups (of 5 students each) was to increase the effectiveness of the of the mapping exercise i.e., to engage all the students. The mapping exercise was concentrated

in
area C northwest of Kabingo sub-county, Isingiro district in southwestern Uganda. This chapter details the geology as was observed in mapped area C and other mapped areas and how this information confirms to the already known geology of the K-A system of rocks. The chapter also involves comparison of the results (fieldwork, structure, stratigraphy, petrography and metamorphism) of all areas mapped with those from our own area C. Other areas that were mapped included A, B, E, G, I, J and L and these areas were visited during hotspot presentations exercise and the results from these groups are summarized in the table 5-1 below. A field excursion was also conducted through selected areas in SW Uganda and geologic information that is used during discussions in this chapter was obtained.

5.2 HOT SPOT PRESENTATIONS

Group	Location	Rock types	Structures	Metamorphism
A	(0253919E, 9915287N) 1546m above sea level.	quartzites on the upper parts of the hills, ferrigenous shale, grey shale and phyllitic shale near the arena, granites, conglomerates.	Bedding, Joints Faults (both major and minor).	
B	**(**0255691E, 9917945N) 1458m above sea level	quartzites at the top of the ridges, shales (both ferrigenous and grey) which occupied the lowlands, mica shists and granites.	included boudins i.e., pull apart and pinch and neck boudinage, folds (both regional and cross folds). Axial planar cleavage	grade of metamorphism in rocks increased downwards towards the arena
E	(0256974E, 9916303N) 1433m above sea level.	ferrigenous and grey shale on the slopes and phyllitic shale.	boudins, bedding, faults and joints.	
G	(0254956E, 9916633N) 1463m above sea level	quartzites and shales.	bedding generally striking in the SW-NE in the shale. small scale folding was as well as faulting.	
H	(0253595, 9913599) 1550m above sea level	shales (grey and ferruginous) and quartzites (brecciated).	faults, joints which trend to the NE-SW and load casts, quartz veins sinistral faults.	Low grade and metamorphis m

I	(0251935E, 99154N)	quartzites, shales of three types i.e., the ferruginous shale, phyletic shale and grey shale (intruded by pegmatites)	joints, faults, bedding.	increased downwards the arena
J	(0255511E, 9914904N)	Quartzite, shale i.e., grey shale, phylitic shale and reddish brown shale.	faults with general trend in the NE direction, beds, joints in the shale	
L	(0251364E, 9914142N); 1574m above sea level.	quartzites, grey shale, ferruginous shale and breccias	faults, minor folds, beds striking in the SW-NE direction and joints that majorly strike in the SE.	

Summary of information obtained from different groups.

5.2.1 Discussion and interpretation of all the information gained.

On a regional scale, the rocks as observed from different groups are predominantly argillaceous (shales, phyllitic shales, ferruginous shale) with other rocks such as quartzites, laterites, granites and conglomerates. These rocks have contributed to structural control and the topography of the entire system depending on where they occur. For example, boudinage structures observed in areas B, and E form where the silica rich rocks are sandwiched between shale during deformation.

Also, more resistant quartzites form ridges while less resistant shales form the entire lowland and slopes, as was observed in all the mapped areas.

At first, Combe (1932) divided these rocks into three different classes i.e., pre-Karagwe-Ankolean basement gneiss and two types of post-Karagwe-Ankolean intrusive granite. *Grooves (1932)*, however, on the basis of thin section examination and heavy mineral separation alone, decided that Combe's G1 and G2 were indistinguishable and hence co-magmatic. *Combe (1932)* eventually accepted Groove's conclusion, partly because of lack of outcrops that prevented him from determining the field relationship between G1 and G2, and partly because he considered "the structural relationship of G1 to the Karagwe-Ankolean would be difficult to explain unless the gneisses are intrusive". So, he stated categorically that, "All of the granites within the area mapped are intrusive into the rocks of the K-A System".

Stratigraphically, the Igayaza area is found in the lower division of the Karagwe-Ankolean rocks system composed mainly of muscovite schists, and phyllites with quartzites (Schluter 1997).

It can be deduced that the stratigraphy of the area followed the sequence described below:
1. Deposition of sediments was initiated by formation of an elongated basin which resulted into very coarse-grained even conglomeratic sedimentation at the base. Conglomerates are observed in areas A and C
2. The sediments deposited in intercontinental basin were buried and worked upon by digenetic processes of compaction, lithification and recrystallization which was followed by three phases of deformation which have been recognized within the K-A metasediments in which the first phase is represented by schistosity parallel to bedding, the second by the NW regional folding and the third by the NE cross fold.
3. This was eventually followed by controls of uplift and erosion that depend on the major rock types, metamorphic grades, mineralization and present-day joints.
4. Granitic intrusions which are pronounced in the K-A have been an aspect of uplift and erosion, and occurred preferentially in anticlinoria.
5. Due to unstable mineral composition under surface conditions of granitic intrusion, severe erosion took place.

None of the areas mapped any rocks with fossils thus these rocks can be thought of as of Precambrian age.

The lithologies in all the mapped areas were similar, therefore a three-fold subdivision was established and is generally accepted.

Upper division
Mudstones, siltstones, sandy mudstones, sandstones, grits and occasional conglomerates Intercalations of quartzitic horizons q3, q4, q5 and q6
Middle division
Sandstone with occasional itabiritic layers of micaceous hematite Predominantly mudstones, arenaceous mudstones and phyllites. The more argillaceous rocks are characterized by a color banding in shades of grey, cream and pink.
Lower division
Largely muscovite schists and phyllites with quartzites. Occasional calc-silicate rocks derived from arenaceous limestones.

Thin quartzitic bands, semi persistent and frequently boudinaged, sheared or mylonitized. Intercalations of quartzitic horizons q1a, q1, q2q, and q2

Generalized lithostratigraphy of the Karagwe Ankolean system in Uganda (modified after Combe, 1932 and Bugrov et al., 1982)

Topographically, the area is generally a hilly or mountainous country with intervening areas of lower relief normally occupied by metamorphosed rocks on the fringes with granites occupying the entire lowland. In all the mapped areas, Quartzites occupy the top of the ridges with the rest of the argillaceous rocks occupying the slopes of the ridges and the valleys within and between the ridges, However, according to Lowenstein (1969), who noticed that Gayaza, like most other areas in the K-A system lies at elevations between 4,500 and 6,000 ft. above sea level with the topography being influenced strongly by the geology, I suggest that it is erosion and weathering that has contributed highly to the present topography for example by causing the present day arenas. Rounded hills such as the breast hills of area B are covered at the peak by either ferruginous shales, conglomerates or laterite which are resistant to weathering. These hills are rounded in shape because that is their most stable form.

The drainage pattern of SW Uganda in general is barely related to rifting although it appears to be largely controlled by major joints or fracture partners of the granitic rocks of the arenas. The drainage pattern in Gayaza is generally the same throughout though not geology restricted except for areas adjacent to the arena where evidence of some structural control is noted for example the stream from Kabingo hills to Kamuli along the main road. Dendritic drainage pattern and its modifications are more pronounced in Gayaza as was observed in our mapped area C. In some areas, however, the intervening valleys between ridges aligned parallel to sub-parallel to each other give an impression of an angular with a superimposed parallel to sub-parallel drainage pattern *(Ucakuwun, 1989).* These have running streams during the rainy season but run dry during the dry season.

The Structures found in the entire mapped area (Gayaza area) occur in two categories, the major structures which include joints, faults, beddings and folds. The other category is the minor structures such as laminations, quartz veins, minor folds and faults, foliation and boudinage. Folding (both major and minor) is more pronounced in plastic shales than in brittle quartzites which show mainly fracturing and joints. Most of the beds trend in the NE-SW direction and dip to the SE whereas their counter parts trend in the NW-SE direction, dipping to the NE as deduced from stereographic analysis. This gives a fold with NW-SE trend which is characteristic of the regional folding in the region. Large scale and small-scale faulting, cleavage and beddings are also common structures in the region. The granites form arenas. Major joints showed a general strike direction in the NW-SE direction and is in line with regional folding of the Karagwe-Ankolean System whereas minor joints showed a general strike trend direction in the NE-SW which is in line with the Cross folding of the Karagwe-Ankolean system and is perpendicular to the regional fold.

Different types of boudins such chocolate, tablets, pinch and swell boudins were found in areas B, and E. Boudinage structures form as a result of deposition of sediments i.e. shales and

sandstones.
Folding of the shales took place creating spaces, followed by intrusion of the granitic melt sending hydrothermal fluids into country rock which were flowing along the bedding planes. Another folding phase took place which folded the already folded shale and the siliceous materials causing the siliceous material to be folded. Whereas the shales react by flow and folding, the brittle material react by brittle deformation forming boudinage structures.
From the information obtained from various groups that mapped different areas, the Karagwe-Ankolean rocks are metamorphosed to various degrees and there is a progressive increase in metamorphism towards the base, from shales or slates, through phyllites (sericite-chlorite) to mica schists (muscovite and finally biotite-bearing). At the same time this progression corresponds to increasing proximity to the granitic rocks of the arena. Pohl (1987) argues that the metamorphism of K-A is generally of regional nature and is largely of low grade. The regional and low-grade metamorphism of the rocks of Karagwe-Ankolean System is evidenced by the presence of relict bedding structures observed in some quartzites. Petrographic analysis of the rocks both in laboratory and in the field is evidence due to the presence of minerals such as chlorite, and elongated quartz, micas tending to develop (as seen from the photo micrograph of sample CS 4, wavy extinction in sample CS 12).
From the information gained from different areas, depositional history and environment can be deduced. Presence of quartzites and shales implies that there was deposition of both arenaceous material (sand sediments) and argillaceous material (clay rich sediments). The sand sediments were lithified to sandstones and clay rich sediments to possibly mud rocks or clay stones (Shale). Intercalations between shales and quartzites would imply that the conditions under which their parental sediments were deposited kept on changing from those of low energy to those of high energy respectively.
The presence of relatively thicker beds of fine sediment (shales) as compared to the arenaceous related sediments (quartzites) would therefore, imply that the periods of deposition of fine sediment were always longer implying that the conditions of low energy and slow rates of deposition predominated, possibly being accompanied by availability of large quantity or supply of fine sediment. Shift from low to high energy conditions of deposition cannot easily be deduced.

This can be associated with changes in gradient (topographical changes) due to tectonics resulting into increase in the speed of the transporting medium. Sometimes increase in the volume of transporting media such as water in periods of flooding can bring in a large supply of coarse material as compared to fine material. However, such changes are always short lived after which the system goes back to normal.
To deduce the depositional environment both positive and negative criteria are used. Positive criteria involve deductions made from the characteristics and features of rock strata as observed in the field. On the other hand, the negative criteria involve deductions made due to the absence of certain characteristics and features expected in certain sedimentary rocks. The presence of

laminae, which have the potential of being preserved in reducing or toxic (unfavorable environments) environments where organic activity is minimal. Therefore, the possible depositional environments as per this evidence are; terrigenous/continental environments such as deep lacustrine environments. Also, deep marine environments are possible. This is because both of these environments are associated with calm, anaerobic conditions with no organic activity. The presence of thicker beds of argillaceous material as compared to the arenaceous material leads to a suggestion that; the depositional environment was a predominantly calm one with short lived changes in the conditions that led to deposition of arenaceous material.

The absence of fossils suggests a reducing or toxic (anoxic) environments into which sediment was deposited. Absence of fossils and most of the sedimentary structures that could be indicative of particular environments could also suggest a tectonic environment where tectonic deformations could have possibly destroyed the originally formed sedimentary structures and the fossils which could probably be in the unstable and unfavorable conditions of the Precambrian times. The Quartzites that were mapped in area C, were generally medium to coarse grained. This suggested that the original sand/silt sized rocks from which the quartzites were metamorphosed, were transported under a relatively high energy environment, such as an active river which was capable of carrying large pebbles and boulders. This was further supported by the presence of a ripple mark siliceous shale bed encountered at station CM10 in area C. The ripple marks in the shales observed at Station CM10 were oxidized which indicated that the shale bed was exposed for a relatively long period of time before the subsequent deposition of other beds. Thus, the area suffered a period of no deposition. Existence of conglomerates with pebbles of all sizes is evidence for high energy currents after the formation of the rocks (presence of quartzite pebbles in conglomerates).

CHAPTER SIX: CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

In conclusion, it is important to note that all the objectives of the field mapping project were successfully achieved. We were able to make observations on outcrops, take measurements on structures and also record all this in our filed notebooks. Description of lithology, metamorphism, structures as well as taking measurements on these structures were done successfully and the data recorded in note books. This data was later analyzed using different techniques such as laboratory petrographic tests as well as interpreting the structural data using stereo-nets and rose-nets not forgetting the use of ArcGIS to digitize the map. In doing so we were able to integrate knowledge from different fields of geology such as stratigraphy, structural geology, metamorphic petrology, etc. Therefore, practical application of the knowledge learnt from classroom was to the full satisfaction of our expectations achieved.

In addition, it is now clear that that the geology of the Karagwe-Ankolean system which needless to say is one of the major rock systems in Uganda is now very much familiar. With the geotraverse and field excursions done, knowledge pertaining the granitization of the Karagwe-Ankolean system is now more appealing as we were able to visit the different granites that intruded the system.

It has been evident that the area is generally characterized by a hilly topography except for intervening low lying areas. This topography makes it hard to access most of the remote areas in the area. Drainage in the area is topography controlled; being dominated by parallel and dendritic drainage patterns. The settlement in the area is predominantly linear. Topographic inversion is also noted in the area.

Lithologically, the Karagwe-Ankolean system consists of mainly shales, phyllites, schists, grits and quartzites. The succession was intruded by granites of various ages. The Lower -K-A consists of schists, quartzites, phyllites, muscovite and calc arenites. The Middle K-A consists primarily of phyllites, mudstones and arenaceous mudstone whereas the Upper K- rests upon sandstone horizon with mudstones, siltstones and phyllites.

Also, it was found out that the rocks of the Karagwe-Ankolean system had been metamorphosed to various degrees, the degree of metamorphism said to be increasing towards the arena. There is however a missing gap in the geological information pertaining this fact because no contact aureole has been observed to have occurred due to expected contact metamorphism as the granitic bodies intruded the system.

The region (Karagwe-Ankolean) suffered different episodes of granitic intrusions during its evolution right from its initial development to the late stages of its development. The later granitic intrusions host the most important tin-tungsten mineralization in the region.

From the information obtained from various groups that mapped different areas, the Karagwe-Ankolean rocks are metamorphosed to various degrees and there is a progressive increase in metamorphism towards the base, from shales or slates, through phyllites (sericite-chlorite) to mica schists (muscovite and finally biotite-bearing).

Structures mapped in the area which include; bedding, folds, faults, joints, and boudins suggest changes in the stress regimes in the area and the whole region. It cannot go unmentioned that there was notable destruction of geological features especially by the locals in their bid to do mining, agriculture, grazing etc. without their knowledge that this information is of great geological importance. This actually made some observations difficult in some areas.

6.2 OBSERVATIONS

6.2.1 MICROSCOPIC OBSERVATION FOR SECTION

SAMPLE CS 1 and CS 55

These two rocks had similar mineralogical compositions (quartz and hematite) but different quantitative mineral composition CS 1(Quartz 10%, Hematite 60%, clay minerals 30%),
CS 12(Quartz 10%, Hematite 8%, clay minerals 82%).

SAMPLE CS 15 and CS 17

These rocks had similar mineralogical compositions (quartz and hematite) but different quantitative mineral composition CS 15(Quartz 97%, Hematite 3%),
CS 17(Quartz 98%, Hematite)

CS 1 - QUARTZITE

MINERALS	**H**	**Q**
PPL		
Color	Brown	Colorless
Form/ habit	anhedral	Euhedral

Relief	strong	Low
Pleochroism	absent	Absent
Cleavage	imperfect	absent
Inclusions	present	Present
Alteration	present	Absent
Parting	absent	Present
XPL		
Isotropic/ anisotropic	anisotropic	anisotropic
Twinning	absent	Absent
Interference color	2nd order red	1st order gray
Birefringence	Strong	Weak
Extinction	absent	Present(wavy)
Zoning	present	Absent
MINERAL	Hematite	Quartz

SAMPLE CS 1 – GREY SHALE

MINERALS	**C**	**H**
Color	Colorless	Colorless
Form/ habit	anhedral	euhedral
Relief	Weak	Strong
Pleochroism	absent	Absent
Cleavage	imperfect	imperfect
Inclusions	present	Absent
Alteration	absent	Absent
Parting	absent	present
XPL		
Isotropic/ anisotropic	Anisotropic	anisotropic
Twinning	Absent	Absent
Interference color	1st order grey	2nd order blue
Birefringence	Weak	Strong
Extinction	Absent	Absent
Zoning	Absent	Absent
MINERAL	Clay mineral	Chlorite

SAMPLE CS 55- FERRUGENOUS SHALE

MINERALS	**M**	C	**S**
PPL			
Color	Brown	Colorless	Colorless
Form/ habit	anhedral	anhedral	euhedral
Relief	strong	Weak	Strong
Pleochroism	absent	absent	Absent
Cleavage	imperfect	imperfect	imperfect
Inclusions	present	present	Absent
Alteration	present	absent	Absent

Parting	absent	absent	present
XPL			
Isotropic/ anisotropic	anisotropic	Anisotropic	anisotropic
Twinning	absent	Absent	Absent
Interference color	2nd order red	1st order grey	2nd order blue
Birefringence	Strong	Weak	Strong
Extinction	absent	Absent	Absent
Zoning	present	Absent	Absent
MINERAL	Hematite	Clay mineral	Chlorite

JOINTS AND BEDS

Major joints

Strikes	**Dips**	**Strikes**	**Dips**	**Strikes**	**Dips**	**Strikes**	**Dips**
N22°W	84°NE	S40°E	88°SW	N40°W	78°NE	N10°W	62°NE
N08°W	88°NE	S66°E	88°SW	N50°W	88°NE	N45°W	86°NE
N45°W	84°NE	N62°W	89°NE	N62°W	76°NE	N04°W	88°NE
N30°W	56°NE	S48°E	88°SW	N52°W	80°NE	N18°E	88°SE
N52°E	44°SE	S60°E	84°SW	N40°W	88°NE	N14°E	80°SE
N70°E	69°SE	N30°E	89°SE	N54°E	86°SE	N05°W	86°NE
N28°W	82°NE	N25°E	80°SE	N12°W	82°NE	N10°E	88°SE
N14°W	82°NE	N70°E	86°SE	N20°W	80°NE	N26°W	64°NE
N10°W	80°NE	N10°W	36°NE	N20°W	72°NE	N20°W	88°NE
N14°W	66°NE	N20°W	88°NE	N12°W	88°NE	N62°W	72°NE
N18°W	60°NE	N48°W	40°NE	N10°W	89°NE	N74°W	82°NE
N10°W	80°NE	N46°W	70°NE	N22°W	80°NE	N20°W	74°NE
S42°E	82°SW	N22°W	70°NE	N70°W	82°NE	N48°W	80°NE
N16°W	67°NE	N08°W	50°NE	N30°W	88°NE	N10°W	68°NE
N16°W	70°NE	S82°W	60°NW	N10°W	62°NE	N10°W	78°NE
S50°E	88°SW	N18°W	86°NE	N24°E	86°SE	N70°W	84°NE
N10°W	80°NE	N42°W	82°NE	N60°W	72°NE	N30°W	86°NE
N18°W	89°NE	N40°W	72°NE	N06°W	76°NE	N26°W	68°NE
N60°W	80°NE	S11°W	82°NW	S64°E	88°SW	N34°E	70°SE
S08°W	82°NW	N30°W	82°NE	N18°W	80°NE	N70W	80°NE
N12°W	86°NE	N68°W	80°NE	N26°W	78°NE	S10°W	78°NW
N40°W	72°NE	S30°E	80°SW	S70°E	82°SW	N05°W	68°NE
S32°E	88°SW	S60°E	80°SW				

Minor joints

Strike	**Dip**	**Strike**	**Dip**	**Strike**	**Dip**	**Strike**	**Dip**
N54°E	62°SE	N30°E	70°SE	N36°E	64°SE	N70°E	88°SE
N60°E	86°SE	N52°E	84°SE	40°SE	N70°E	N70°E	50°SE
N62°E	88°SE	S16°W	86°NW	S08°W	74°NW	N26°E	68°SE
N48°E	88°SE	N22°E	88°SE	N08°E	76°SE	S70°W	56°NW
S70°W	28°NW	S88°E	68°SW	N58°E	70°SE	N70°E	60°SE
N08°E	74°SE	N60°E	54°SE	S20°W	70°NW	N62°E	18°SE

N68°E	87°SE	N46°E	88°SE	S68°W	72°NW	S70°W	76°NW
N70°E	86°SE	N72°E	84°SE	N50°E	10°SE	N72°E	72°SE
N68°E	60°SE	S60°W	82°NW				

Shale beddings

Strike	**Dip**	**Strike**	**Dip**	**Strike**	**Dip**	**Strike**	**Dip**
N300E	S300E	N220E	S700E	N880E	S500E	N740E	S400E
N400E	S420E	N880E	S540E	N800E	S380E	N300E	S400E
N40E	S220E	N520E	S320E	N650E	S400E	N300E	S200E
N380E	S420E	N300E	S440E	N300E	S680E	N300E	S400E
N300E	S580E	N520E	S400E	N200E	S600E	N560E	S660E
N380W	N300E	N680W	N420E	N400E	S380E	N880W	N400E
N880E	S300E						

6.2.3 Materials used

The equipment and materials used in the field during the mapping exercise include;

1. Hand lens	It's an optical instrument which was used to magnify mineralogy and texture of fine-grained rock samples.
2. Compass	This was used for making structural measurements such as dip and strike of structures like joints, bedding planes etc. and also plunge of folds.
3. Camera	This was used to take field photographs which would be used in the report write up.
4. Global Positioning System (a handheld GPS):	Was used for locating stations and to map boundaries of geologic units using the UTM coordinate system.
5. Geological hammer:	This was used for obtaining representative, fresh, rock samples.
6. Sample bag:	used for carrying collected rock samples.
7. Tape measure	For measuring lengths of rock units, standardizing the pace for traversing, etc.
8. Pencil and notebook	Scholastic materials used for noting and recording of field data collected.
9. Markers	These were used for labelling the samples collected from the field.
10. Binoculars	For viewing far off features such as gorges, faults and other structures of interest.
11. Base maps	For plotting geologic features such as contacts, valleys, faults and boundaries, data in the group mapping exercise and also plotting stations and rock types.
12. Clip board	For proper storage of base maps and important reference documents.
13. Mobile Phones	For communication with fellow group members and lecturers in case of emergencies.
14. Personal tools used in the field	these included Lunch box (for food storage), Water bottle (for storage of drinking water).

6.3 Recommendations

It is worth noting that, the entire mapping exercise was successful right from the field to laboratory work up to the reporting process which I give credit to the efforts of the coordinator of the exercise, Dr. Naguddi and the entire Department of Geology and Petroleum studies, Makerere University. However, some of the areas as listed below need improvement/attention and may be future considerations. These areas include;

We were unable to visit all the stops planned for the geo-traverse and excursions due to limited time. With this said therefore, I recommend that more time and resources be allocated for this particular part of the field mapping project.

Some of the mapping instruments were faulty and could give misleading readings, for example the GPS which we were given could show you that you are standing in a valley yet in actual sense you are standing in a ridge. Thus, these instruments need to be checked for accuracy before being used

For the purpose of complete engagement and beneficial study purposes, students should be encouraged to take part in preparation of their rock samples (cutting and making thin sections) obtained from the field. This may also ensure that the students acquire some skills in preparation of areas such as research which are very involving.

Also worth noting is that there was so much to learn. It would not be infallible to suggest that the time allocated for this exercise is not enough to exhaust all the geology in the area. Therefore, I would recommend that some more days be added on the two weeks usually spent in the area.

The software used to analyze the data was unfamiliar and it was troublesome learning it on our own. I would therefore recommend that students be taught this software as part of the computing course unit.

Knowledge of optical mineralogy was very necessary especially in discerning the metamorphic grade of the rock samples and yet it is an elective. I therefore recommend that this course unit should cease being an elective.

REFERENCES

1. Bahati G., 1998, Geothermal Energy Exploration and Its Potential in Uganda.

2. Barifaijo. E, (2002), Regional Geology of Uganda.

3. Ben. A. Van Der Pluijm, Stephen Marshak (2004). Earth Structure; An Introduction to StructuralGeology and Tectonics. Second Edition.W.W. Norton and Company, New York-London.138-162pp.
4. Barnes, J.W. (1956). Precambrian structures and the origin of granitoid rocks in South-West Uganda. PhD thesis, University of London, UK.

5. Cahen, L. Snelling, N.J, Vail, J.R (1984). The Geo-chronology and Evolution of Africa. Clarendon Press, Oxford, 512p.

6. Combe.A.(1984): The Geology of Southwest AnkoleAnd Adjacent Territories with Special Reference to The Tin Deposits, Geological Survey, Entebbe.

7. Davis, G.H. (1984). Structural Geology of Rocks and Regions. John Wiley and Sons. Pp 492-495.

8. Gary Nichols (2009). Sedimentology and stratigraphy.Second edition.John Wiley and Sons Ltd.299-306pp.

9. Holmes, A., Cahen, L. (1955). African geochronology. Col. Geol. Min. Res., 5, pp

10. King, B.C., de Swardt, A.M. (1967). Problems of structure and correlation in the Precambrian
    systems of Central and Western Uganda. Geological Survey of Uganda, Entebbe, Uganda. pp127.
    King, B.C. (1947a). The mode of emplacement of the post-Karagwe-Ankolean granite of SouthWest Uganda. Geol. Mag., 84, pp 140-150.

11. Makerere University. Department of Geology and Petroleum Studies Field Excursion Guide:
Western Uganda.
12. Pohl, W. (1994). Metallogeny of the NorthEastern Kibaran belt, Central Africa- Recent Perspectives. Ore geology review, 9, pp100-130.

13. Sam, B. Jr. (2006). Principles of sedimentology and stratigraphy.Fourth edition. Pearson PrenticeHall, Upper Saddle river, New Jersey. 76-432PP. Sherbon Hills.E (1972).

14. Elements of Structural Geology.Second Edition.Chapman and Hall Ltd
and Science Paperbacks.143-261pp.

15. Rumvegeri et al (1985). Lithostratigraphieet evolution structural de la chaineKibarienne a l'Ouestdu Lac Kivu (Zaire).

16. UNESCO Geology for Development Newsletter-Bulletin 4.83-90, ParisNairobi.
Wayland, E. J., 1925. Petroleum in Uganda. *Geological Survey of Uganda*, Memoir