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 FROM 1ST FEBRUARY, 2022 TO 7TH FEBRUARY, 2022

BY

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SUBMITTED TO THE DEPARTMENT OF GEOLOGY AND PETROLEUM STUDIES MAKERERE UNIVERSITY IN PARTIAL FULFILMENT OF THE AWARD OF BACHELOR OF SCIENCE DEGREE IN PETROLEUM GEOSCIENCE AND PRODUCTION.

11th AUGUST, 2023

DECLARATION

DECLARATION

I **NDAGIRE REBECCA,** hereby declare that te content of this report, submitted to Makerere University for the award of Bachelor of Science degree in Petroleum Geoscience and Production, is my own work compiled based on the knowledge and information acquired throughout the field period under the guidance of my supervisors and has never been presented before to this institution or any other organization.

Signature

11th August, 2023

Date

Project Coordinator

Dr. Aanyu Kevin

Signature

31/8/2023

Date

DEDICATION

I dedicate this report to my Father **Mr. Lukanga Joseph** and my mother **Nanyanzi Mary**

ACKNOWLEDGEMENT

I am very grateful and express my sincere thanks to the Almighty God for His protection and the gift of life and the strength to successfully complete this training. To Him is the glory

I would like to express my sincere gratitude to the project coordinator Dr. B. Nagudi and all my supervisors, Dr. M. Kiberu, Dr. J. V. Tiberindwa, Dr. S. Echyegu and Mr. W. Kawule.I also extend my gratitude to all the lecturers in the department of geology and petroleum studies, Makerere University headed by Dr. Batte Anthony for their guidance, intellectual support, advice, encouragement and supervision that enabled me to successfully come up with this report.

I extend my gratitude to the support staff Mr. W. Kasule, Ms. G. Ssekamanya, Mr. M. Kasaka, Mr. E. Emodock, Mr. Tonny.I also thank Mr.R.Ssesanga, geology lab attendant, who made for us our thin sections not forgetting Madam Susan who always provided us with microscopes for our thin section analysis.

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ABSTRACT

This report comprises a detailed compilation of findings, analysis, interpretations, conclusions and recommendations for the Igayaza-Isingiro geological mapping exercise and field excursion to south western Uganda. The Geological mapping exercise was carried out in Igayaza, Isingiro district, western Uganda which lies within the Karagwe-Ankolean system of rocks *(ca. 1400-950 Ma)*, which is the northern most extension of the Kibaran mobile belt with the aim of acquainting students with skills in geological mapping.

This project aiming at practically enhancing students' skills in geologic mapping projects. Materials used included; a geologic hammer, handheld GPS, tape measure, notebook and a compass and the rock samples collected, sorted and taken to the laboratory for further analysis. The data acquired for structures compiled with laboratory data was interpreted and analyzed. The findings were compiled with its interpretation made.

This report looks at the stratigraphic correlation of the mapped area C with that of the entire Karagwe-Ankolean system which suggests that the mapped area has a stratigraphic column similar to that of South-West Uganda. This correlation is aided by the use of the geologic map of area C and its corresponding cross-section and stratigraphic column. The information about the mapping exercise is discussed in six main chapters which are; introduction, stratigraphy, regional synthesis, structures, petrography and metamorphism and conclusion. The introduction defines the objectives of the field trip, location of mapped area, methods and materials used.

The lithology comprised of thin arenaceous formations that were predominated by quartzites while the thick argillaceous formations constituted shales. The quartzites were mainly found at the ridge summits while the shales were found along the flanks of ridges and in valleys between ridges. The

grades of metarmorphism was varying from low grade regional metamorphism which was evidenced by presence of beddings and some index minerals such as chlorite, muscovite. Sandstones and shales were metamorphosed to quartzites and phyllites respectively. Contact metamorphism occurred around granitic intrusions that formed most of the arenas (broad stadium like structures).

The structures in the mapped area include joints, beddings, faults, quartz veins, folds; these were mapped at different scales. 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, forestry, quarrying and brick making.

At the end of the mapping exercise, hotspot presentation were done where students would take lecturers and students to the most interesting areas in their region mapped.

CHAPTER ONE: INTRODUCTION

1.1 Background

The field mapping project was conducted in $4km^2$ Area C, Igayaza, Kabingo sub-county, Isingiro district located in south western Uganda about 30 kilometres from Mbarara town. It was conducted from 1st February,2022 to 7th February, 2022 . The report provides the details of briefing and study of geologic mapping from the area around the camp, the one-day, the five days geological mapping of area C and one-day hotspot presentation.

The area mapped lies in the Karagwe-Ankolean (K-A) rock system. Karagwe-Ankolean is part of long mobile Kibaran belt of Central Africa which extends from Angola through Democratic Republic of Congo, Rwanda, Burundi, Tanzania to Uganda.

bhkThe field work mapping generally encompassed making geological observations, collecting of rock samples, taking measurements of the different structures such as beds, joints and folds. It also encapsulated taking of GPS readings at different stations of interest and at upper and lower boundaries of the quartzite horizons so as to map out the quartzite in the area.

1.2 Aim/objectives of the mapping exercise

1.2.1 Aim of project work

The aim of the study was "To practically learn field geologic mapping and being able to apply it in the future".

1.2.2 Specific objectives

- To enable students, learn how to use different field equipment and tools such as GPS, compass among others in making measurements, estimating distances, visualizing landforms, and locating /identifying features.
- To enable students connect the class learned theory with practical field observations.
- To be able to function as a field geologist in all areas.
- To be able to read a map and locate yourself
- To be able to use available instruments to collect geologic information
- To be able to produce a geological map of the study area.
- To be able to organize relevant data and result and put it in a report and at the end be able to present a complete field mapping report.

1.3 The study area

1.3.1 Location and accessibility

Igayaza is found in Kabingo Sub County,Isingiro district 30 km from Mbarara town in South-western Uganda **(figure 1).**The UTM (Universal Transverse Mercator) coordinates of Igayaza are Eastings (250000-262000) Nothings (9910000-991900).The mapped area C lies between UTM co- ordinates of Eastings (256000-258000) and northings (991700-991900) covering the areas of Katembe, Isingiro and Mpororo hill. It covered a total land area of four square kilometers (4 km^2)**.**

Isingiro district can be accessed from Kampala by the tarmacked Kampala-Masaka-Mbarara highway. From Mbarara town, about 2km off Kabale road is a turn, onto the newly tarmacked

Isingiro-Kikagati highway, along which is Igayaza, about 27km off Ntungamo - Mbarara road, at Maryhill High School.
The base camp for the field project was set up at former Kabingo Sub County Headquarters, presently used as a prison which was accessed through a gravel road of dry weather type which stretched approximately 2km from the main Isingiro-Kikagati highway.

During the mapping exercise most areas were accessed on foot by the individuals, a bus and land cruisers for far mapping areas and a few were not accessed due to gorges and very steep hills.


MOROCCO
ALGERIA
LIBYA
EGYPT
MAURITANIA
MALI
NIGER
CHAD
SUDAN
NIGERIA
CAMEROON
GABON
DEM. REP. OF THE CONGO
KENYA
SOMALIA
TANZANIA
ANGOLA
ZAMBIA
MALAWI
ZIMBABWE
NAMIBIA
BOTSWANA
MOZAMBIQUE
MADAGASCAR
MAURITIUS
SOUTH AFRICA
SUDAN
D. R. CONGO
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Figure 1: Map of Africa showing the location of Isingirodistrict in South western Uganda

1.3.2 Physiology

The area was generally hilly and had intervening areas of lower relief (figure 2). The hills were made up of ferruginous and/or grey and shales and also the quartzites. Ridge summits were covered by erosion-resistant quartzite horizons. Rock outcrop distribution was controlled by the nature of the slopes. Rock exposures were common where the hill sides were steep and along narrow v-shaped valleys. The topography of the area was controlled by mainly two processes i.e. weathering and erosion which led to the formation of the arenas ("stadium like" features). Due to differential weathering, the hard rock's (quartzites) formed the top of the ridges and the weak rocks that were more susceptible to weathering (granites) formed the arenas. Gayaza area was also characterized by reverse topography where the anticlines formed the valleys and synclines formed the hills.

The arena represented the area that was originally occupied by the granites and due to their high feldspathic content, the granites were weathered and eroded faster than the more competent quartzite horizon that are now appearing as hills (Barnes, 1956), a phenomenon known as topographic inversion. Most of the high plateaus were separated by valleys from the minor arenas. The area had a varying and contrasting topography.

Figure 2: showing the general overview of the topography the arena

1.3.3 Climate

Just like other areas lying in the tropics, Isingiro also experiences a tropical climate which is greatly influenced by the relief, topography and vegetation to a small extent due to its rugged relief. Isingiro has two seasons, the wet season during the month of April to May and also from October to November with the wettest month being April. Isingiro receives moderate amount of rainfall ranging from 750mm to 1250mm annually. The mean annual temperatures of Isingiro are moderate ranging from 12.5-15°C to 25-27.5C per year.

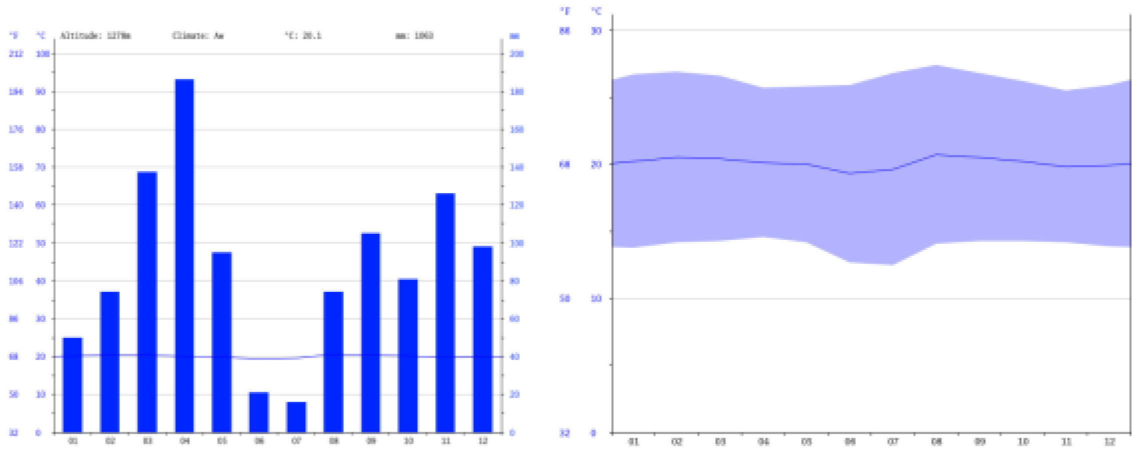


Figure 3:(left) Bar graph showing the annual precipitation in Isingiro with April being thewettest month. (right) Temperature graph showing average temperatures experienced in Isingiro district with the average temperature of 20.70C. Source: climate-data.org

1.3.4 Drainage system and vegetation

Three major drainage patterns were observed and these include:

- ✓ **Angular drainage pattern** which resulted from sharply incised, V-shaped intervening valleys on the sides of the ridges. They usually have streams flowing through them during the rainy season, but usually dry up during the dry season. These valleys constitute tributaries to border valleys, which are mostly swampy.
- ✓ **Dendritic drainage pattern**; looks like the branching pattern of tree roots and its modifications were observed in areas underlain by schists, gneisses, granite gneisses and weathered granite rocks of the arenas
- ✓ **Parallel to sub-parallel drainage patterns** modified areas underlain by phyllites and the less metamorphosed rocks form ridges or rugged topography with steep slopes.

The dendritic pattern is dominant in most areas, and Ucakuwun (1989) suggested that the characteristics pattern of drainage in southwest Uganda is also related to rifting. Rifting along the western rift valley led to relative upwarping, and corresponding downwarping in areas further away. This resulted into river reversal and stagnation along rivers

The vegetation cover is savannah in nature, with the hilltops bearing grasses of several centimeters in height and scanty trees, slopes being dominated by grasses of varying height and massive thickets with different tree species such as eucalyptus and others occuring in faulted zones and valleys. Vegetation thickness and abundance generally increases downslope into the valleys.Some areas have thick vegetation dominated by shrubs and trees. This is evident within the valleys, faults, along the streams and also at the ridge top dominated by quartzite. The faults and the quartzites at the ridges act as traps for the underground flowing water there by supporting the growth of the vegetation. Valleys were sites for soil and sediment deposition. The soils in those valleys were fertile favouring the growth of vegetation.

Generally Isingiro has a poor drainage pattern which is attributed to the presence seasonal streams, springs and lack of rivers and lakes.

1.3.5 Land use and settlement

1.3.5.1 Land use

The main economic activity observed was agriculture. It was basically subsistence farming and predominates in the valleys and gentle slopes as they had fertile soils. There are a number of crops grown and these included bananas, maize, cassava, sweet potatoes pineapples, beans and sorghum. Most of them are grown on small scale, although there were also plantations, especially bananas Cattle rearing was also practiced in the area. Animals were grazed on free range roaming on small hills and within the valleys covered with vegetation. Animals reared include, cattle, goats, sheep and pigs. Stone quarrying was also practiced on a small scale. Quarries were located in areas that had fractured/jointed/faulted outcrops of quartzite. Quartzites were broken in to smaller stones (quarrying) for construction purposes. This quarrying affected our mapping exercise in that in some places you could see folds like today and the next day you find it quarried.

1.3.5.2 Settlement

The area was generally sparsely populated characterised by small scattered homesteads with a population distribution of about 99-115 persons per km2 (Uganda Bureau of Statistics, 2010). However, it was found that these residential houses were about 100-300m apart in the villages and quite closer in the trading centers. Settlement was evident in low lying and flat areas as hills are dominated with quartzite in-stu and floats hindering settlement. Water catchments made by man were evident in the area which could act as water source during the rainy season.

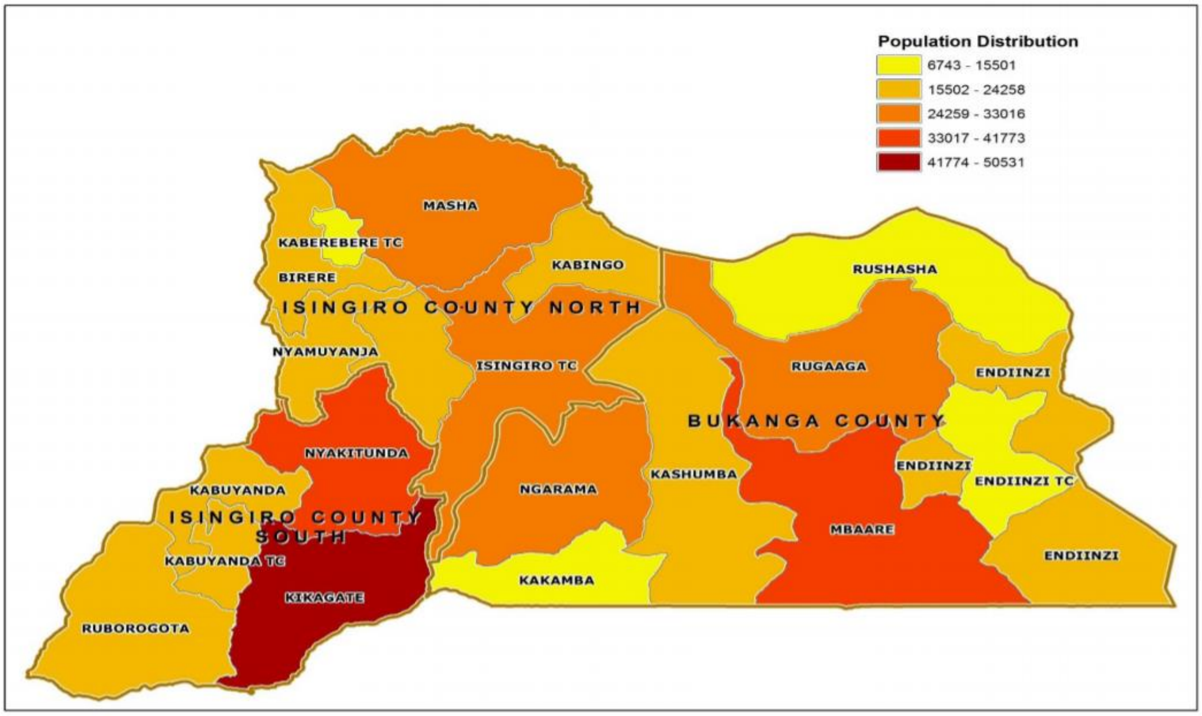


Figure 4:map showing Distribution of Population by Sub-county; Isingiro District, 2014(Source: report on the findings of National Population and Housing Census (NPHC)2014undertaken by Uganda Bureau of Staistics (UBOS)).

1.4 Regional geology

1.4.1 Areal extent and Early works

Igayaza area lies within the Karagwe-Ankolean system of western Uganda which forms part of the northern part of the great Kibaran belt, see figure 5. This Mesoproterozoic Kibaran belt also known as the Kibara belt of Central Africa is often portrayed as a continuous orogenic belt, trending NE to NNE from Katanga, Democratic Republic of Congo in the south up to into SW Uganda in the north (Brinckmann et al., 2001)

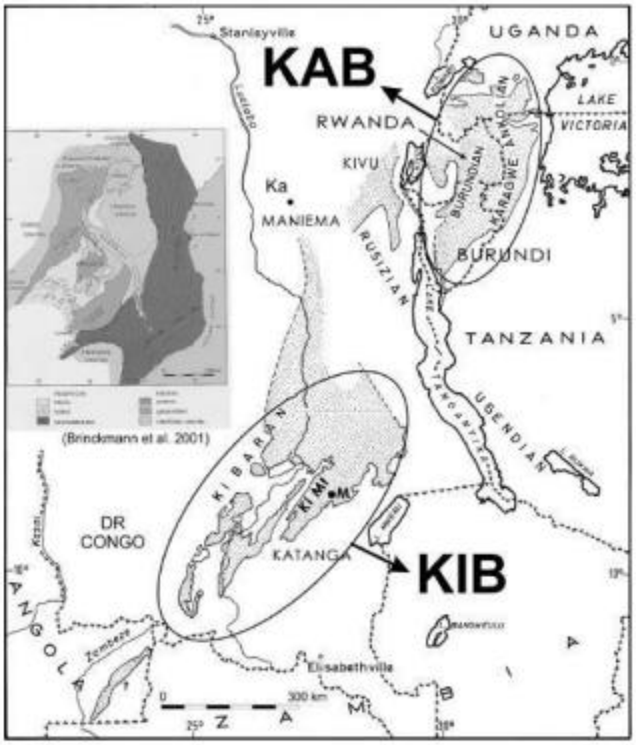


Figure 5: A sketch map (Cahen and Snelling, 1966), showing the Karagwe-Ankole Belt (KAB) and the Kibara Belt (KIB) as redefined by Tack et al. (2010). Inset after Brinckmann et al., 2001 showing the Kibaran belt as a single and continuous belt

A number of scientists have studied the karagwe Ankolean system and have made many observation and conclusions as outlined below.

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 quartzitic horizons q_1 to q_4 and he noted the q_4 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.

1.4.2 Stratigraphy and Geochronology

The Karagwe-Ankolean unconformably terminates into the older Buganda-Toro (B-T) rocks (1700-1800 Ma) which stratigraphically overlie the Basement rocks. Patches of Pleistocene rift sediments and potassic volcanics occur in the western margin of this area. The generalized lithostratigraphy of K-A system is divided into lower K-A, middle K-A and Upper K-A as modified after Combe (1932) and Bugrov et al. (1982).

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 quartzitic horizons.

*Table 1*1: summarising the stratigraphy of the Karagwe Ankolean system*

The rocks of Isingiro are non-fossiliferous and are of Precambrian age. Therefore, stratigraphy hierarchy of the Igayaza 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 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 (Ucakuwun, 1992). 12 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 un-metamorphosed sediments of the Bukoban system. The rocks of the K-A system are made up of thick and monotonous pile of politic and psammitic sediments as have been described by Combe (1932) et.al.

The thicknesses of these sediments were estimated by Stockley and Williams (1938) to be between 9400-14300m. Geochemical studies in the Tanzanian sediments indicate mainly siliceous, ferruginous and aluminiferous low magnesia content with pronounced lime deficiency.

Greywacke layers with sedimentary structures typical for a turbiditic origin intercalated with pelitic beds. Proximal turbidities also occur in the eastern whereas distal turbidities are found towards the centre of the area. Much of the sequence consists of quartzite and phyllites. The rocks of this system are characterized by massive argillaceous units intercalated with thinner arenaceous bands of quartzite and quartzitic sandstones and occasionally by conglomeritic basal members, rarely calcareous and volcanic sequences

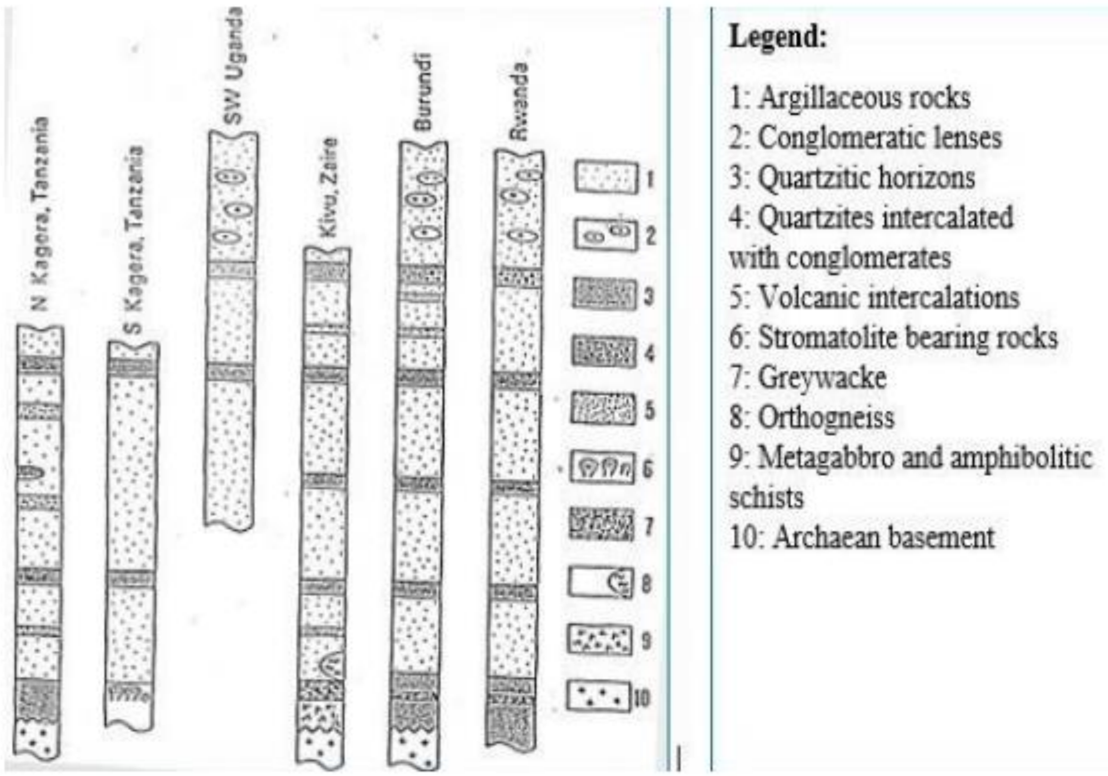


Figure 6: General stratigraphy of Karagwe-Ankolean

Geo-chronoligically, 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; Bugrow et al., 1982; Cahen et al.; 1984; Cahen and Snelling, 1988; 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.

Basing on pegmatite and hydrothermal fluids analysis, the following interpretations were generally agreed;

- The synorogenic granites (G_1 and G_2) yield ages of 1370 ± 25 Ma and 1310 ± 25 Ma respectively.
- The G_3 granites provided a whole rock Rb: Sr isochron at 1094 ± 13 Ma
- The G_4 granite ages were clustering at about 976 ±13 Ma (Pohl, 1994).

1.4.3 Structural and morphology

The general structural trend of the Kibaran belt is in the NE-SW direction where by moderately folded anticlines, with syntectonic granites in their cores are associated with tightly folded synclines (MacDonald, ca.1972).

The formations of the belt have been affected by thrusting and by folding with a north-north-east trend, swinging to the northwest towards Uganda and Tanzania borders (Pohl, 1987). 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 4 below

It has been observed that the folds have axial planar cleavage, schistocity, 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 co-current 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).

The biotitic granites of Rwentobo, Kamwezi, Ntungamo and possibly Lugalama in SW Uganda are presumed to have been intruded syntectonically by the first folding phase, while Chitwe and Chabakonzo are thought to have been intruded with the second folding phase (cross folding). Regional scale thrusts have not been known in the K-A of SW Uganda.

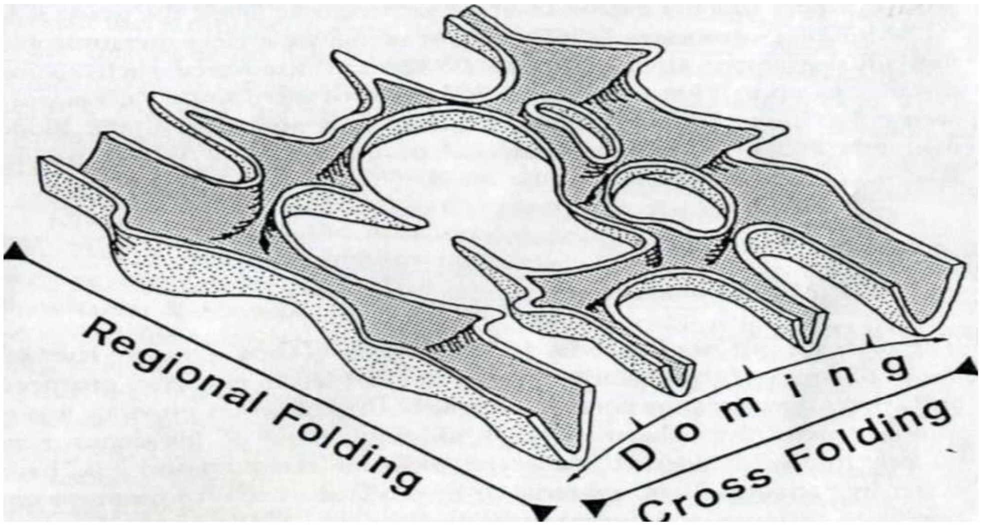


Figure 4: Style of folding of the Karagwe-Ankolean rocks in the arena belt in SW Uganda (modified after unpublished sketch by Macdonald ca., 1972)

1.4.4 Metamorphism

The Metamorphism is generally of a regional nature and is largely of low grade (Pohl, 1987). From rocks of very low grade in the synclinoria, a steep gradient is obvious towards large batholithic granites and basement highs where the amphibolite facies is attained and migmatites may occur. The metamorphism therefore increases with stratigraphic depth and with proximity to the granite intrusions. Accordingly, the sediments noted adjacent to the arena floors are commonly the most metamorphosed.

Rocks in Igayaza area are mudstones, shales, slates, phyllites and schists with relatively minor quartzite. The Rugaga syncline is a broad basin of predominantly argillaceous formations. Metamorphism in this syncline is absent or slight but increases southwestwards. The generalised section across the Karagwe- Ankolean of the Rugaga syncline contains slates and mudstones, phyllites and schists at the bottom. The Lwanda unconformity near Rakai is another feature of special interest in the Karagwe-Ankolean system. Below this unconformity, Simmons (1932) identified the presence of 16 schists and have now been more fully studied in the course of systematic mapping by Phillips (1959).

The rocks vary from pale grey mica and quartz mica schists to micaceous quartzite, the original rocks having been predominantly of mixed arenaceous-argillaceous types. Unconformities are major primary structures and they play an important role in the investigation of deformed rocks. As rocks become micaceous, all such sedimentary structures are obliterated by increasing deformation.

1.4.5 Geotectonic 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).*

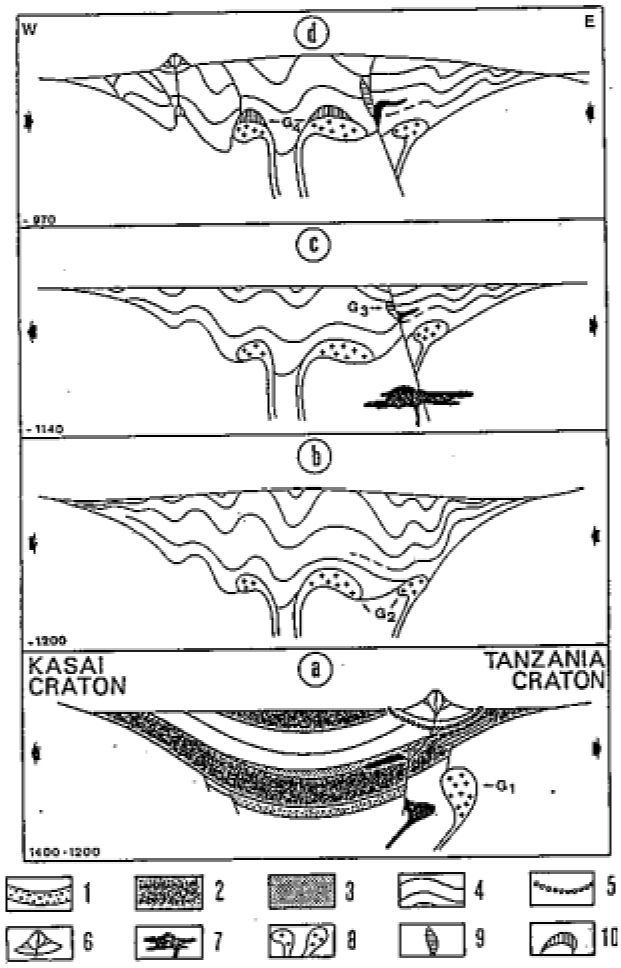
The absence of the volcanic sequence within metasediments of south-western Uganda suggests that the rifting probably did not take place, although regional faulting may have occurred *(Ucakuwun, 1989).*

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 gjfkgsituation 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 (Figure 7). Arrows indicate predominantly extensional or compressional regimes



Key

1: Conglomerates

2: Sand and Siltstones 3: Turbidites

4: Pelites

5: Stromatolic fringing reefs 6: Volcanic islands

7: Mafic intrusions

8: G1 and G2 granites 9: G3 granites

10: G4 granites

Figure 7: The geotectonic evolution of the Kibaran belt

The description of the stages of evolution as shown in fig 7 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 granitegneiss 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.

Timing relative to tectonism	Type	Example
Syn-tectonic	G1 granites	Rwantobo, Ntungamo, Kamwezi and Lugalama
	G2 granites	Chitwe, Chabakonzo, Masha, Akabeba
Post-tectonic	G3 granites	Ultramafi rocks of Kabanga
	G4 granites	Ibanda, Dwata, Rwabaramira, Karenge.

Table 2: Categories of the different granites, with examples

Economic Potential

The economic potential in K-A system was first documented by J.S. and D.S Kargarotos at Kyerwa in NW Tanzania where cassiterite which is a tin ore (SiO4) 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 solutions 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 mineralisation 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 mineralisation.

The Cassiterite which is an ore for tin is obtained mainly on small scale by artisanal mining from quartz veins near Kikagati. There are gold deposits found in limonite veins with Bismutite, pyrite, wolframite and cassiterite in south western Kigezi.

Also worth noting is that the area is an agricultural hub for a number of crops because of the fertile soils in the area. The crops grown include bananas which are in large plantations, cereals such as millet, sorghum etc. Also a number of animals are kept such as cattle, sheep, poultry on a small scale.

Fishing & Fish farming: 8 landing sites with fish species such as Tilapia, Miller caps, lung fish and Claris. Commercial Fish farming is also practiced using fishponds which are mainly mixed.

1.5 Materials and methods

1.5.1 Materials

Some of the tools that were used both in the field and during the compilation of this report are summarized in the table

PURPOSE	TOOL	APPLICATION
Sample collection	Geological Hammer	For breaking off pieces of rocks from in situ rocks
	Chisel	Used in conjunction with the hammer for sample collection
	Sample bags	Sample collection and storage
Field measurements.	Global Positioning System (GPS)	For determining location and elevation
	Binoculars	For viewing far off objects and features
	Tape Measure	For measuring lengths of rock units and standardizing the pace for traversing

	Geological Compass	Taking geological bearings such as strike, dip, trend and plunge.
Field records	Field Note books	Taking field records
	Camera	For taking photographic records from the field
	Base maps	For plotting geologic features and GPS readings to mark out the boundaries.
	Writing tools	For drawing and recording data and information
	Hand lens	For magnification of details of rock units
	Clip board	For proper storage of base maps and important reference documents issued
Laboratory data analysis	Microscope	For analyzing thin sections
	Thin sections	For microscopic analysis of rock samples
Personal tools used in the field	Lunch box	For carrying lunch to the field.
	Water bottle	For storage of drinking water
	Ruck sack	For carrying field tools, personal tools and rock samples from the field to the camp
	Mobile Phones	For communication with group mates and taking pictures of structures for future reference.

Table 3: Materials/tools used in their field and their purpose.

1.5.2 Methods

1.5.2.1 Fieldwork

On the first day, Lecturers briefed us on what we were expected to do while in the field, how to use the Global Position System (GPS), take the readings like the dip, strike and plunge. On this same day, groups of five students were formed and different groups given different areas of study.

Technique	Description
Traversing	This was done by climbing the hills and moving on the lowlands. This technique was utilized in mapping rock contacts for example the quartzite horizon, by traversing both the upper and lower boundaries.
Pacing	Pacing involves standardizing one's pace. A certain distance was measured, we moved to and from while counting the paces. To calculate the pace length, divide the measured distance by the number of paces. This was done on flat ground, downslope and upslope and my pace length was 0.74m, 0.62m and 0.60m respectively.
Station establishment	Stations were established at outcrop with interesting geology. While at the station, we described the outcrop, structures, took structural readings such as strike, dip, trend and plunge, described the rock and took a fresh sample for laboratory analysis.
Rock description	Rock description was done by observation and it was based on colour, grain size, shape, structures among others. We gave field rock names and field rock types
Consultations	Consultations from the lecturers and the local people was done and the information provided was recorded and guided me in report writing.

Table 4: Data collection methods used in the field

1.5.2.2 Laboratory and data analysis

The collected hand size samples were selectively sorted with the guidance of one of our supervisors.The thin sections were prepared from the selected samples which were later examined under a petrography microscope to give descriptions of the sample such as grain texture, sorting etc.

The structural measurements of the dips and strikes of the various structures while in the field, as well as measurement of plunge and trend were then plotted on digital stereoscopic nets to obtain density diagrams. Rose-net and Stereonet were the two distinct software used to obtain these structural plots and therefore describing of the attitudes and the trends of the different structures encountered.

1.5.2.3 Field report write up

This was the last stage of the project, after data compilation, laboratory work and interpretation.

The main chapters for the project report include;

1) **Introduction**; This gives a generalized overview of the study area and the study aims for carrying out the mapping exercise.
2) **Stratigraphy**; This discusses the rock successiovns of area B and the entire Igayaza area.

3) **Structures**; This chapter organizes a full descriptive account of all the structural geology information obtained from field observations, laboratory structural data analysis, thin-section microscopy, structural (cross-sectional) profiles among others.
4) **Petrography and Metamorphism**; It discusses the mineral properties of the different rock formations in the study area, both macroscopic and microscopic characteristics.
5) **Regional synthesis**; It compares results of all areas mapped, as well as the geological tie-ins of the surrounding areas.
6) **Conclusions and Recommendations**; It's a general summary of the geological mapping exercise, limitations, challenges encountered and suggestion to improve the mapping exercise.

CHAPTER TWO: STRATIGRAPHY

2.1 Introduction

Stratigraphy is the study of stratified (layered) rocks. Understanding the stratigraphy of an area is important because the rock layers preserve a chronological record of Earth history and past life therefore conditions under which ancient sedimentary rocks were formed can be inferred that is, the depositional environment and depositional sequences. Stratigraphy enables the geologist to develop the idea of various phases in long history of deposition (Modified from Combe, 1932 and Wayland, 1919).

It studies rock layers and layering with the general concern of understanding relations of the strata in connection with their compositional, geochemical, fossil content, and lithological properties in sedimentary and layered volcanic rocks. The term stratum refers to the single unit of the rock spread as a sheet over the accumulated surface. Stratigraphy uses the knowledge of sedimentary petrology and the principles of sedimentation.

In stratigraphy, rock successions are described and interpreted in terms of a geological time scale. Stratigraphy is a wide branch of geology but can be broadly divided into mainly three phases which include; description of the strata, correlation and interpretation of the stratigraphic records.

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 colour, size, thickness, nature of contacts, unconformities, structures among others, identification of fossils present, among others.

Stratigraphy is divided into the following branches;

Lithostratigraphy	This is concerned with the description and nomenclature of the rocks of the Earth based on their lithology and their stratigraphic relations. 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. It is based on fossil evidence in the rock layers. For example, strata from widespread locations containing the same fossil of fauna and flora are correlatable in time.
Chrono-stratigraphy	Is the branch of stratigraphy that deals with the relative time relations and ages of rock bodies. A chronostratigraphic unit is a body of rocks that includes all rocks formed during a specific interval of geologic time and only those rocks formed during that time span.

Magneto-stratigraphy	The branch of stratigraphy that deals with the magnetic characteristics of rock bodies. It is used to date sedimentary and volcanic sequences by analyzing and determining the samples detrital remnant magnetism (DRM. Magnetostratigraphic classification is the organization of rock bodies into units based on differences in the magnetic field reversal.
Chemo-stratigraphy	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, palaeoenvironment, palaeoclimate and diagenesis.
Sequence stratigraphy	Deals with the order or sequence in which depositional related strata successions (time-rock) units were laid down in the available space or accommodation.

Table 5: Sub-divisions of stratigraphy

Other branches of stratigraphy include; archeo-stratigraphy which is used to better understand the processes that form and protect archaeological sites and cyclo-stratigraphy which documents the often cyclic changes in the relative proportions of minerals (particularly carbonates), grain size, or thickness of sediment layers and of fossil diversity with time, related to seasonal or longer term changes in paleoclimate.

The stratigraphic description and interpretation of rock strata is aided by mainly six principles however mainly five of these were used to interpret the rock sequences in Area C that is;

1) ***Principle of original horizontality*:** This principle states that layers of sediment are originally deposited at their angle of repose which is always horizontal, under the action of gravity. "Strata either perpendicular to the horizon or inclined to the horizon were at one time parallel to the horizon." (Steno, 1669). It is important to the analysis of folded and tilted strata.
2) ***Principle of superposition*:** Niels Steno (1669) stated that at the time when any given stratum was being formed, all the matter resting upon it was fluid, and, therefore, at the time when the lower stratum was being formed, none of the upper strata existed. 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.

3) ***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. A dike intrusion that cuts across a sandstone rock layer is always younger than that rock. This principle is important in relative age dating.
4) ***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. The sediment layers however do not extend indefinitely. They are limited by the amount and type of sediment available together with the size and shape of the sedimentary basin.
5) ***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.
6) ***Principle of uniformitarianism***: This principle states that processes which operate on the Earth's surface today are similar to those that operated in the past. This is a fundamental principle in sedimentary geology.

It is important to note that mostly one aspect of the rock bodies that is lithostratigraphy will be emphasized in study area C since the other aspects such as biostratigraphy, magnetostratigraphy, chemo-stratigraphy were not evident in area C. This chapter therefore emphasizes the aspect of lithostratigraphy which considers rock units in terms of lithologic characteristics of rocks and their relative stratigraphic positions.

The relative stratigraphic positions of the rock units is determined by considering geometric and physical relationships that indicate which beds are older and the ones which are younger. This chapter also shows how this aspect has been applied in the construction of geologic map of Area C, reconstruction of ancient depositional environments of Area C and the generalized description of the stratigraphy of Area C in relation to that of the Karagwe-Ankolean system

2.2 Stratigraphy of K-A system

2.2.1 application of stratigraphy

Rock deposition on earth can be understood simply by use of Stratigraphy. The processes leading to formation of rocks are the same throughout, this therefore helps in the reconstruction of the paleoclimatic conditions, patterns of formation of different basins in geologic history, permits an understanding of ore genesis and mineralization where metalliferous deposits occur in the intrusive igneous rocks or their contacts in metamorphic aureoles.

2.2.2 Previous Work

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

Wayland 1919, recognized and recorded salient features of the lithology and structure of SW Uganda through making a reconnaissance traverse across southern, south western and eastern parts of Ankole.

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).

According to Biryabarema 1995, there is complex folding and refolding due to the granitic intrusions which led to the overturning of the sequence in most places, thus making stratigraphic correlation difficult. Lack of evidence of fossils made the age determination purely speculative.

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, six quartzite horizons were used in correlating the successions between the two areas and as a basis for the establishment of the lower, middle and upper divisions which are summarized below;

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 colour 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, q2a and q2

Table 6: Subdivisions of K-A Systemfdd

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 colour 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 sand 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 progrestmsively 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 quartzitic 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 Buganda-Toro 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 underlined 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.

Biryabarema (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.

2.1 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 thus 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.

2.1.1 Quartzite

A quartzite is a hard non foliated metamorphic rock composed entirely of quartz. It is formed when a quartz-rich sandstone becomes altered by pressure, heat and chemical activity of metamorphosed. These 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 due the quatzite's granoblastic texture. This implies that sandstones are the protoliths from which quartzites are derived.

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 and feldspars. 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 colour due to impurities, found on the summit 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 CS2.

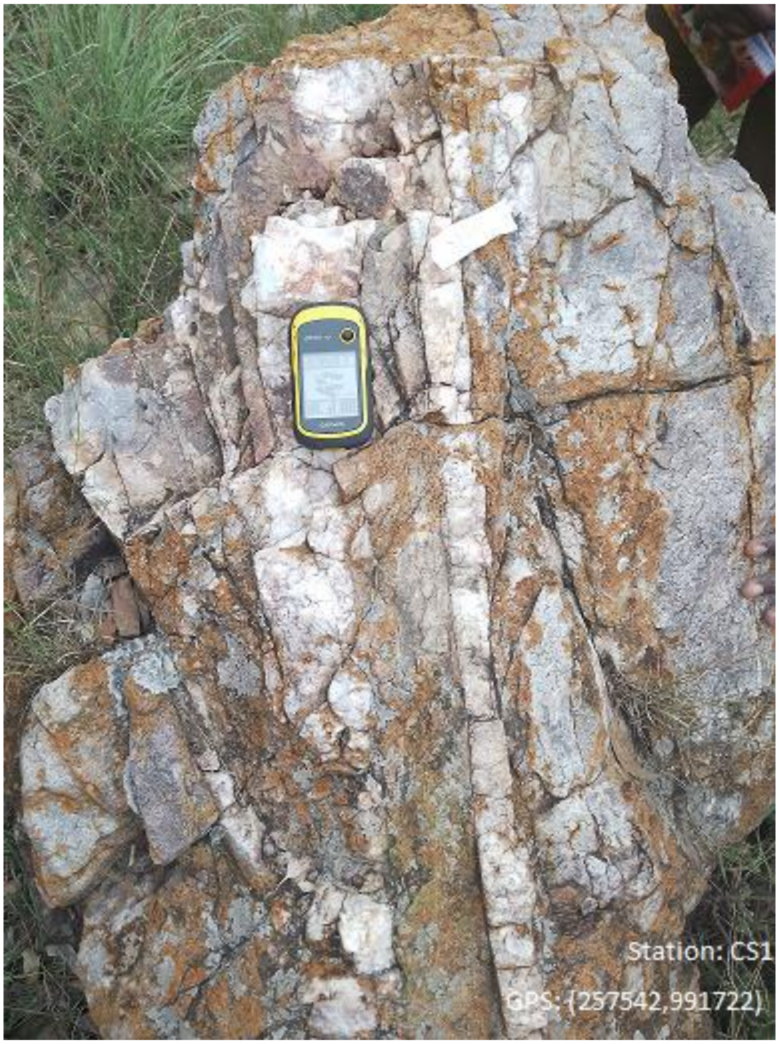


Figure 8: Showing the Quartizite outcrop with a Quatz vein captured from area C

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.

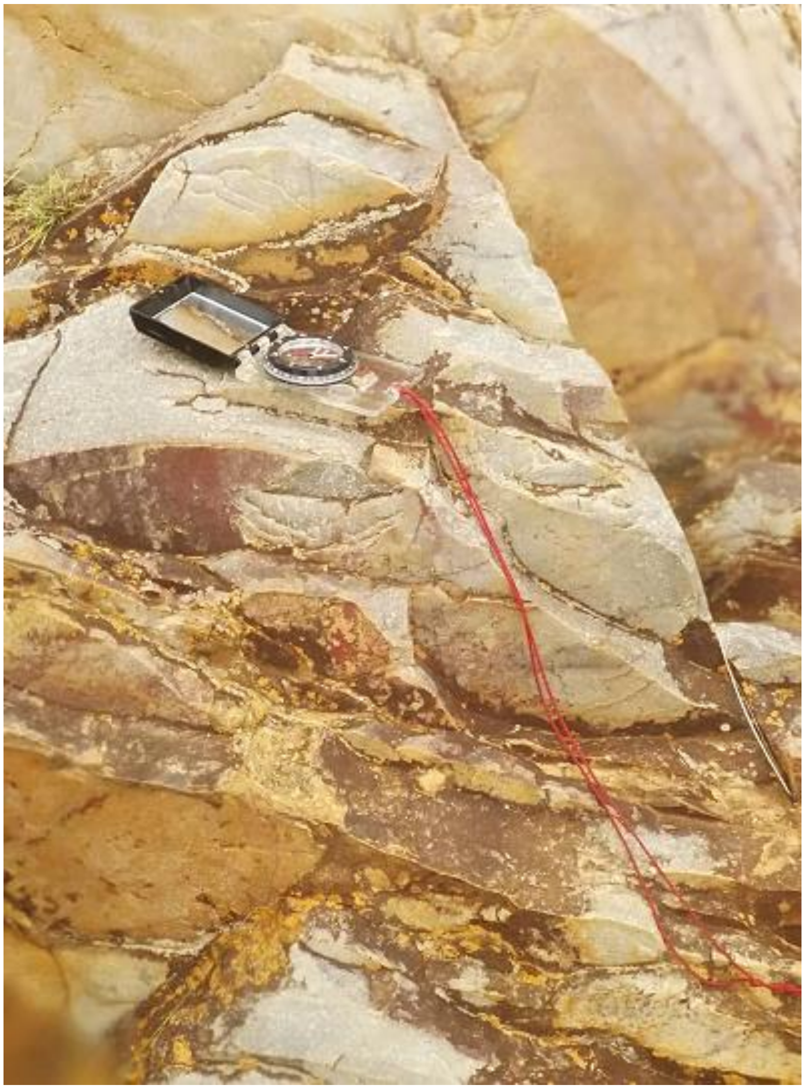


Figure 9: Showing a quartzite with relict beds and many joint faces capture from area C

2.1.2 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 colours/types. The notable shales are grey shales and ferruginous shales. The reddish colour of the ferruginous shale is due to the perforation of iron rich fluids along the shale beds thus oxidation of the iron 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. The different types of shale in area C are briefly discussed below;

Ferruginous shales: These are reddish brown in colour which is due to the perforation of iron rich fluids along the shale bed planes and the iron transformed 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. They are generally less competent compared to the grey shale because most of them were found to be shuttered seen at station CS7.

Figure 10: Image showing a ferruginous shale captured from area C

Grey shales: These ones are grey in colour, 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 11: image showing the bedded gray shale capture from area C

There was also an exposure of a ripple marked shale bed and there existed a non-conformity between the ripple marked shale and the grey shale. 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.

2.1.3 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, for the rounded indicating that they had traveled a long distance to destination. And the subangular which were course grained indicating that they had travelled a short distance. The conglomerates at station CS3 are coarse-grained rock made of pebbles, sands and cemented by iron oxide as shown in *figure 12* below. The conglomerate in area C is less than 10 meters and therefore not mappable.

Figure 12: Showing conglomerate with pebbles cemented with iron oxide

2.1.4 Geometric Relationship of Rock Units of Area C in Time and Space

2.1.4.1 Unconformities/Time gaps

There were no time gaps encountered in area C during mapping which implies that there are no long periods of erosion or non-deposition in this study area. However, during the mapping, it was observed that the rock units were conformable to one another and separated gradational contacts.

This is because as you move upwards the stratigraphic column of area C, the shales occur at the base followed by quartzites that occur at the ridges. The contacts between the shales and the quartzites in area C were moderately defined and sharp which implies that the sediments were deposited gradually.

These contacts were observed due to;

- change in vegetation between shale and quartzite areas.
- change in slope whereby, shale was more steeper than quartzite slope.
- presence of anti-hills of the same color (brown/pinkish) on shale side and those found in the quartzite outcrops were dark colored.
- The floats of quartzite falling into the shale outcrop.

The absence of unconformities in area C is synonymous to the Karagwe-Ankolean system since according to Stheeman, 1932 there are no unconformities encountered in the Karagwe-Ankolean system in which area C lies.

2.1.4.2. Horizontality

The beds in area C do not conform to the principle of original horizontality (see cross-section, figure 2.6). Most of the beds in area C strike in the NE-SW with a SE dip ranging from 310-400. The dipping of these beds can be attributed to folding and faulting that took place in the area.

2.1.4.3. Lateral continuity of the rock units

The different rock units in area C extend laterally for long distances although this extension is cut into several discontinuous masses by the different episodes of tectonism forming ridges and valleys from what was originally a flat extensive formation.

2.1.4.4. Successions and Age relations

During the mapping of area C, it was observed that most of the quartzites occurred on top of the ridges while the shales occurred in the valleys and on the slopes of different hills. Taking this perspective, it can be concluded that the quartzites are younger than the shales.

However, this conclusion may not be right because the occurrence of quartzites on top of the shales can be explained by differential weathering. The concept of differential weathering explains that the shales could have been on top of the quartzites at some point in time but because the shales are more prone to weathering, they were weathered and transported to the lower parts that is the valleys and slopes. Since the quartzites are resistant to weathering, they were left at the top giving rise to this arrangement. The absence of fossils in area C which would have been used in age relations made the correlation difficult.

2.1.5 Geologic Map and Cross-Secbtion of Area C

The geologic map of area C was constructed using the GPS locations obtained by traversing the quartzitic horizons at both the upper and lower boundaries. From the geologic map, the lithologies encountered in area C can be identified as shown by their geologic colors that is the yellow for quartzite, grey for the grey shales and red for the ferruginous shales. Other lithologies such as phyllites were also found in area C but occurred in lesser quantities hence were not mappable. The geologic map also shows the stations established during the mapping project. These stations were established at outcrops with peculiar structures and where different structural measurements were made

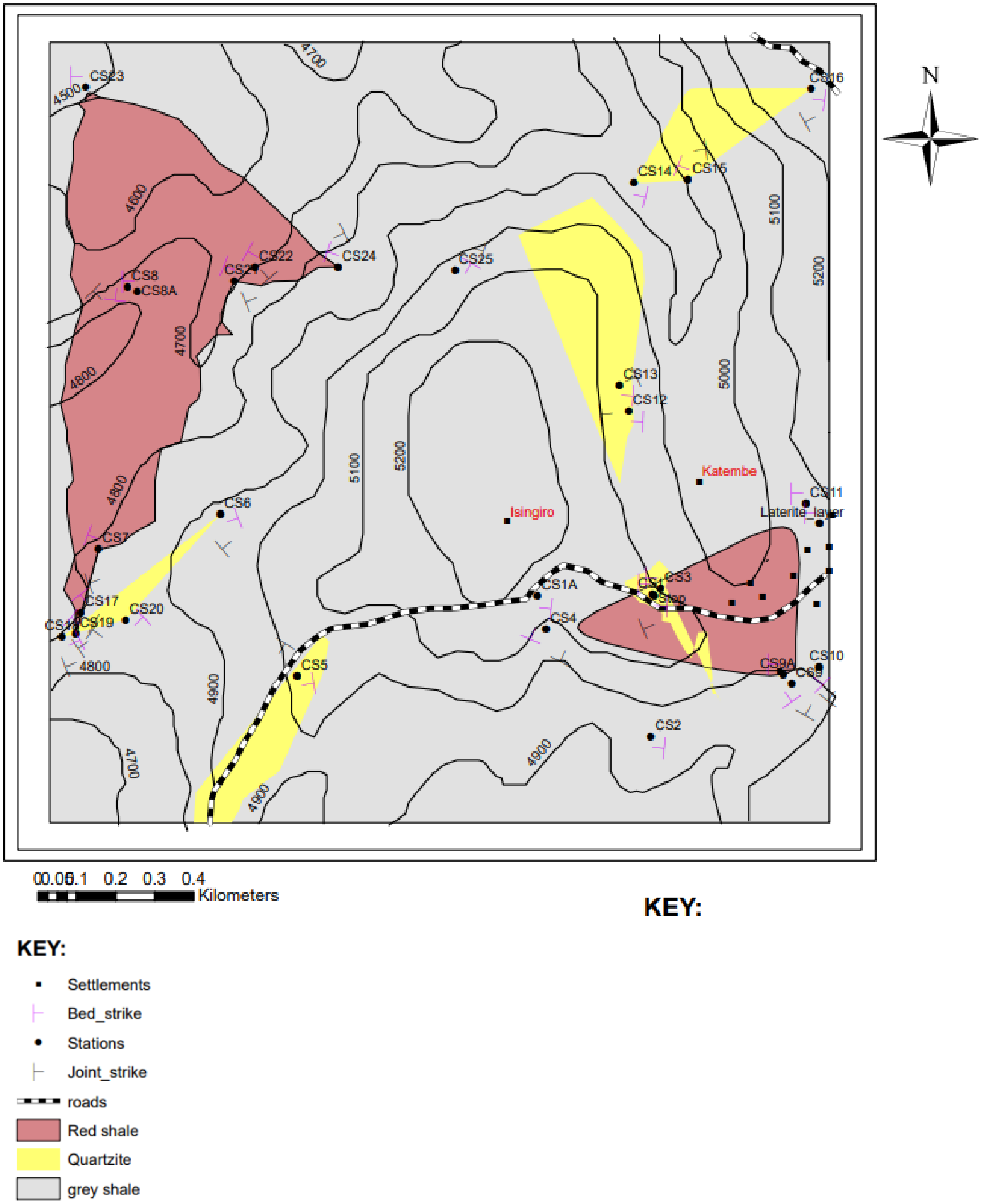


Figure 13: Geologic map of area C and Cross section showing different features

GEOLOGIC CROSS SECTION OF AREA C ALONG X-X

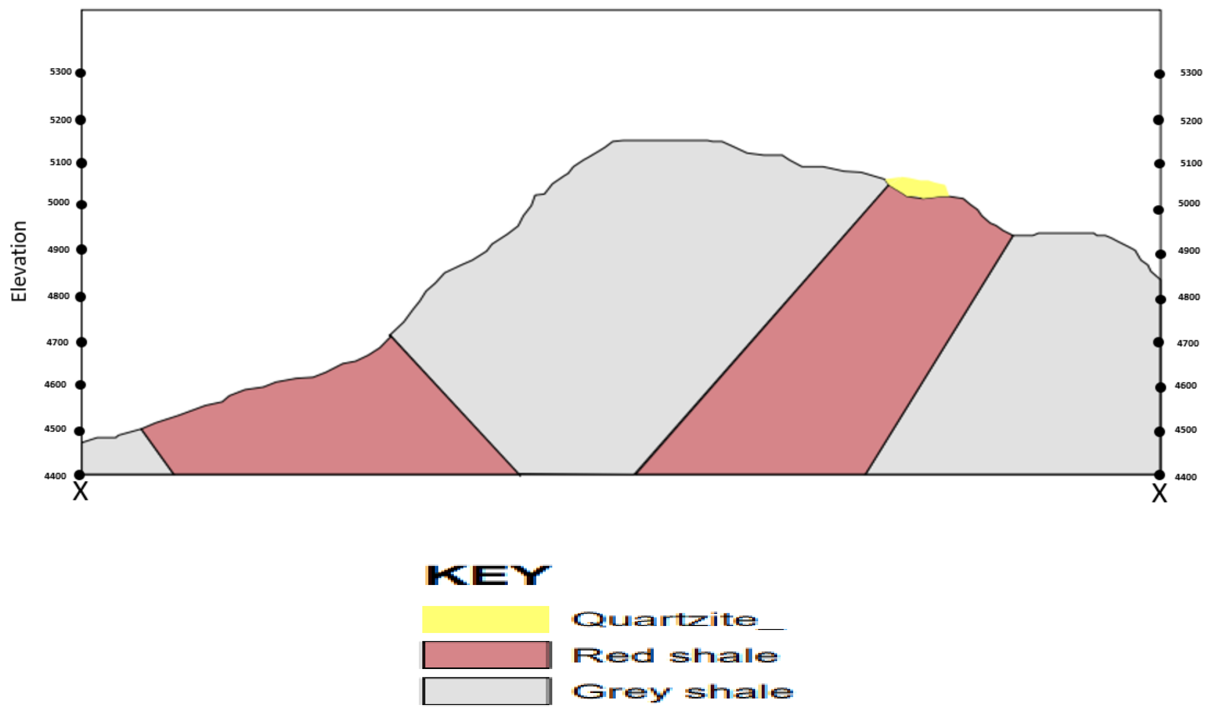


Figure 14: Showing a cross section eveloped from the geologic map of area C

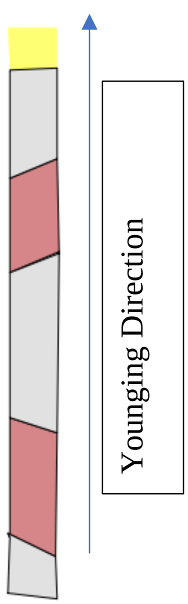


Figure 15: A stratigraphic column with arrows showing the younging direction

2.2 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)

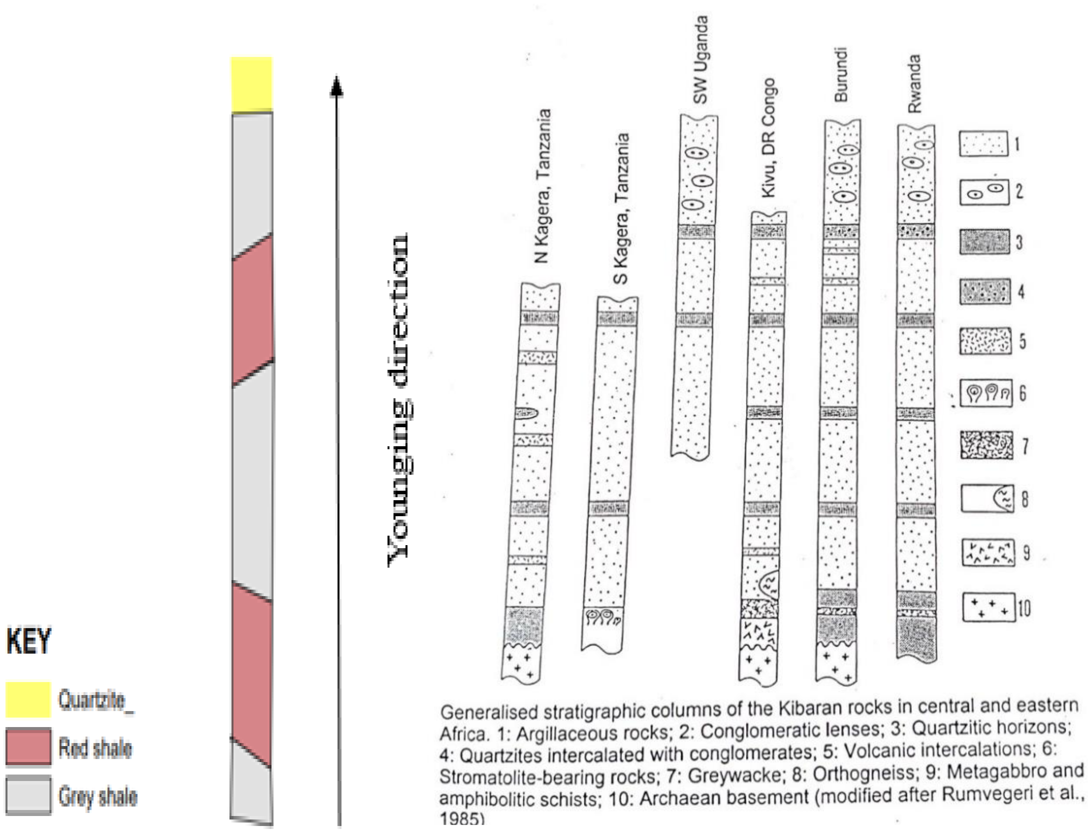


Figure 16: Stratigraphic column with arrow showing the younging direction

2.3 Geologic history

This section of the chapter is based on the field evidence to give the depositional history and environment. 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.

2.3.1 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.

2.3.2 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 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 claystones 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 favoured the formation of iron oxides present in the ferriginised shales and in quartzites (blackish colour).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).

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.

2.4 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.

2.5 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. Isotopes such as uranium, thorium and potassium undergo systematic change with time by gaining or losing subatomic particles. The reactions proceed as an exponential function of time, which can be characterized by the half time abundance of the parent nuclei. Since we know the determined ages of the associated igneous rocks (granites), we can estimate the ages of the other rocks in the mapped area.

According to Schlueter, 1994, the accepted age of the Karagwe-Ankolean System is about 1140-1100 Ma and was obtained from isotopic dating using the Potassium-Argon (K/Ar), and Rubidium-Strontium (Rb/St) isotopic ratios. Potassium-Argon (K/Ar) ratios from muscovite yielded ages of 32 between 467-670 Ma suggesting later thermal disturbances.

Shown in table 8, 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 7: The relative ages of granites of Southwestern Uganda

CHAPTER THREE: STRUCTURES

3.1 Introduction

Geological structures are structures in the Earth's crust that have geological causes. These structures are usually the result of deposition of sediments and effect of powerful tectonic forces that occur within the earth and most of these forces are related to plate tectonism. They are formed when sediments were deposited and forces folded and broke rocks.

The study of the processes that result in the formation of geologic structures and how these structures affect rocks is referred to as **structural geology**. Geological structures are useful to a structural geologists in the following ways;

i. To obtain paleo-current flow directions as well as the energy of the transporting medium
ii. They aid in determining the relative ages of the structures and obtaining relative ages of rocks in which they occur.
iii. Determine the way up or stratigraphic succession of the area.
iv. They are useful in petroleum exploration.
v. Structures are exact points for mineralization for example deposits of gold, copper, zinc, lead, silver, and other metals.

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.

They are categorized into two types that is;

Primary structures: These are features of rocks that are present before the onset of deformation of a rock. These generally include beddings, lamination and ripple marks.

Secondary structures: These are structures reflecting subsequent deformation or metamorphism. Such structures include; joints, faults, folds, cleavage, and foliation (Bruce et al, 1976).

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

Table 8: Summary of structures in Area C.

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 8 above 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.

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.

Geologic structure	**Mean Strike (Azimuth in degrees)**	**Mean Dip (Degrees)**	**General trend(s)**
Joints	026; 194	65; 75 respectively	Northeast-southwest
	140; 306	71; 72 respectively	Northwest-southeast
Bedding planes	040; 332	15; 34 respectively	Northeast-southwest and Northwest-southeast.

Table 9: 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 plan*

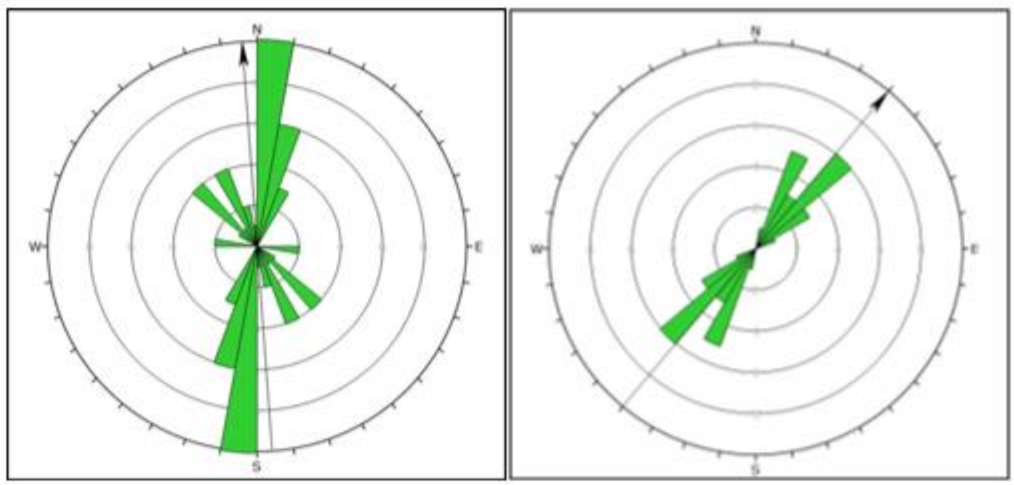


Figure 17: Rose diagrams showing different strike directions and trends taken by quartzite beds on the left and shale beds on the right in area C

Interpretation

A total number of measurements for strike and dip of bedding planes for both shales and quartzite were obtained during the mapping activity using a geologic compass of the silver type. Figure 17 treats the data as axes with directional significance.

From figure 17 it can be seen that the quartzite beds of the rock strata encountered in the area c strike in majorly two directions that is to the NorthEast and Southeast. However, most of the major beds strike to the NorthEast direction more to the North-northeast direction as indicated by maximum value of beds striking in the range between 31 and 40^0 and a few in the Southeast (see appendix 1) for analysis of bedding planes in the different quadrants. Likewise all the shale beds strike in majorly Northeast direction in a range of 20^0 to 50^0.

The 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.*

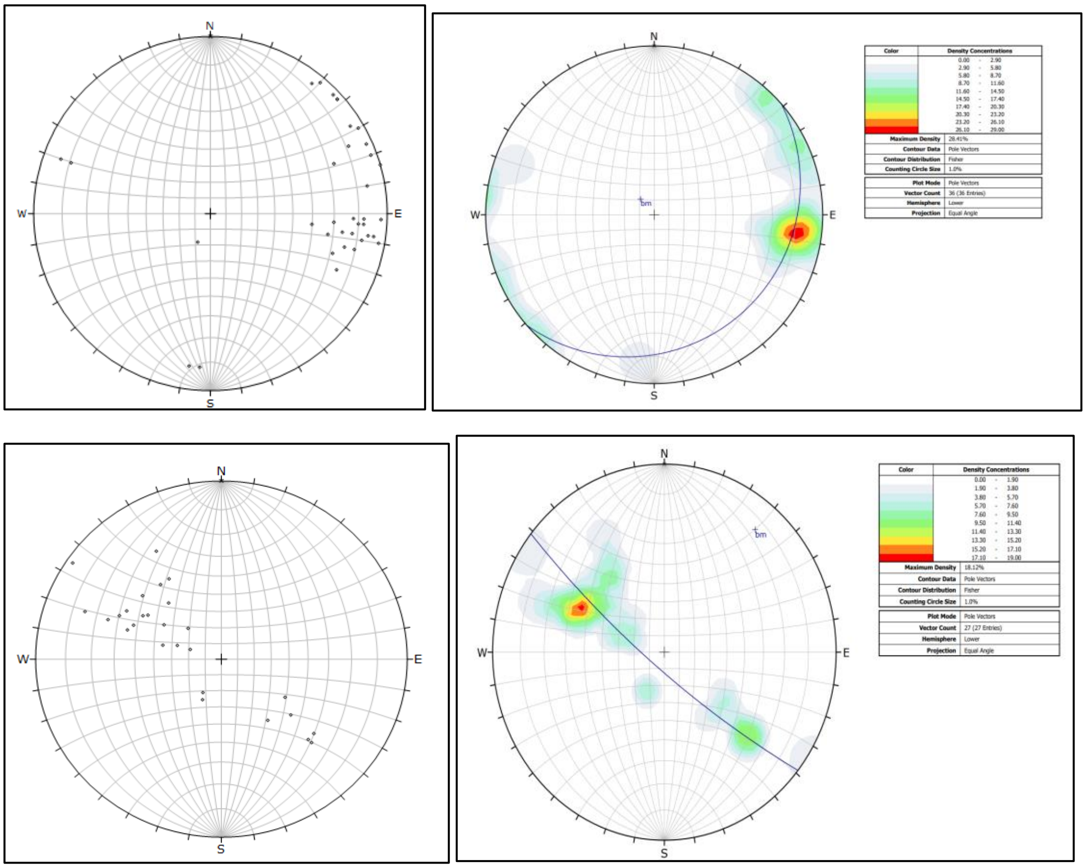


Figure17: contour diagrams showing preferred and strength of preferred orientation taken by the quartzite beds up and shale beds down encountered in area C

Interpretation

In the figure 18 above, it can be seen that the poles of the bedding planes form two maxima/clusters of points which is indicative of two preferred orientaions of bedding planes in area C. However, for quartzite beds, there is a greater concentration of points in the SE quadrant than in the NE quadrant. This implies that the NE-SW is strongly preferred as compared to the NW-SE (NE dip). For shale beds, 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 orientaions 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 10^0 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.

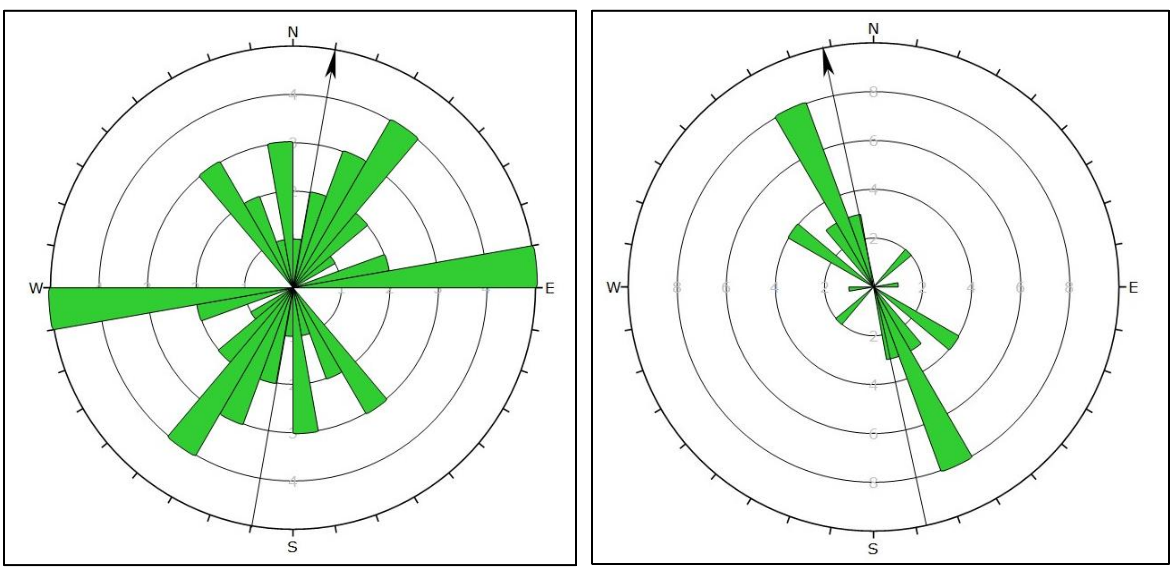


Figure 18: Rose diagram showing strike directions of the quartzite joints on left and shale beds on right encountered in area C

Interpretation

All the joints together of both quartzite and shale 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 190^0 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 stereonet win 64 software as shown in the figure 19 belo

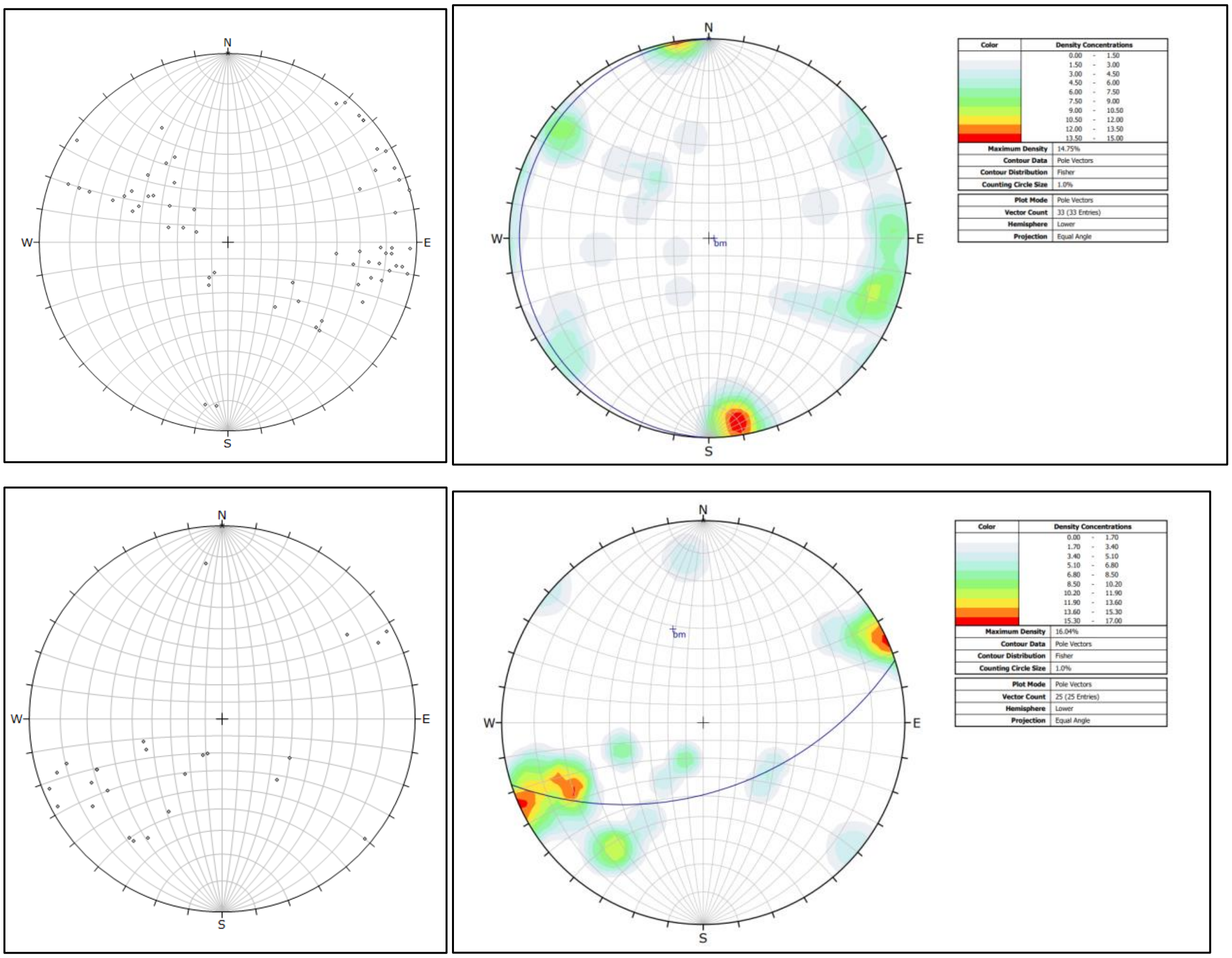


Figure 19: Contour diagrams showing preferred orientations of quartzite joints up and shale joints down encountered in area C.

Interpretation

From the density and contour diagrams in the figure 19 above, the quartzite joints tend to form a maximum/cluster/concentration of points in the SE or second quadrant (Azimuth) indicating one preferred orientation of Quartzite 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.

However, for the shale joints form a maximum/concentration of points in the SW or the third quadrant indicating the one orientation of shale 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 10: 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, S59^{0}E, 17^{0}SE 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

A bed can be defined practically, genetically and geologically. Genetically, a bed represents a depositional episode during which conditions were relatively uniform. Practically, a bed is a layer of rock which is thick enough that is can be measured and described. Geologically, it is the smallest lithostratigraphic unit, usually ranging in thickness from a fraction of a centimetre to several metres and distinguishable from others above and below it. 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 observed in shales both ferrigenous and grey shale and relict beds in quartizite. 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 05^0 to 88^0 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 tends to be gradational. However,

Figure 20: showing relict bedding in quartzite (left) and thin beds of shale on the (right).

Figure 21: laminations in shale (left)and intercalations of thin shale and quartzite beds turned into boudins (right)

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 ie 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 22: systematic joints in quartzite(left), joint in shale(right)

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 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.

Figure 23: Showing a growth fault in area C

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 24: 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. Hydrofracture breccias are classic targets for ore exploration as there is plenty of fluid flow and open space to deposit ore minerals. Ores related to hydrothermal mineralisation, which are associated with vein material, may be composed of vein material and/or the rock in which the vein is hosted.

Figure 25: A quartz vein of about 2cm thick intruding a shale on the left and another intruding a quartzite on the right.

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 palaeocurrent 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 26 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 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 Northwest-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 27: A fold in a quartzite trending in the NE (left) and Small scale fold with a Northwest-southeast trend encountered in area C(right)

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. (Seegeologic map of area C in chapter 2).

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 develop 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 Gayaza syncline. 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.

3.5.2 Types of stress field

Compressive/ shear field stress.

Most of the secondary structures which include folds, 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.

3.5.3 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.

In the field, stations were established on outcrops that had interesting geology based on changes in lithology, color and distance from previous station. Descriptions were made on the outcrops through observation and analysis and these included the description of structures, size and location of the out crops, tectonic activity, extent of weathering and metarmophism. Samples were collected from fresh rock (with the use of a hummer) and labeled CS1, CS2, CS3 and so on, basing on the station number. From the samples 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.

This chapter also defines the metamorphism of the study area C as will be observed in the lower section of the chapter. It was also important in other studies such as revealing the geologic and tectonic history as seen in the preceding chapters.

The detailed microscopic description has been provided in the appendix.

4.1.2 Description of field out crops.

During the field study, 5 representative samples were selected and analyzed from a total of 1 samples collected in the field. A total of 25 out crops were visited and studied during the mapping exercise in area C. These were identified and named consecutively from CS1 to CS25 including those from almost the same area but with different description thus named under the same station but with an added letter to indicate a different description For example CS9A . The descriptions of 6 outcrops from which the rock samples were collected are given below.

Station 1

Location: (0257550 ,9917583)

The outcrop is a large natural exposure of highly weathered due to the presence of anthills and floats, highly jointed with two major sets identified from the joint faces and relict bedding. The Quartzite intruded by quartz vein 8.1-10.5 cm long cutting across the beds thus evidencing to be younger that the beds and the outcrop located along the slopes of the hill alongside the road. The outcrop lies in a faulted zone, the faulting was evidenced by 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 5, CS 9A, CS 10, CS 17 and CS 22. 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 quartz and feldspars. The rock has a phaneritic texture.

Macroscopic description of the sample CS 1

The rock is gray to reddish brown in color, medium to coarse grained and massive. The major mineral composition is quartz and feldspars. The rock has a phaneritic texture.

Field name: Quartzite

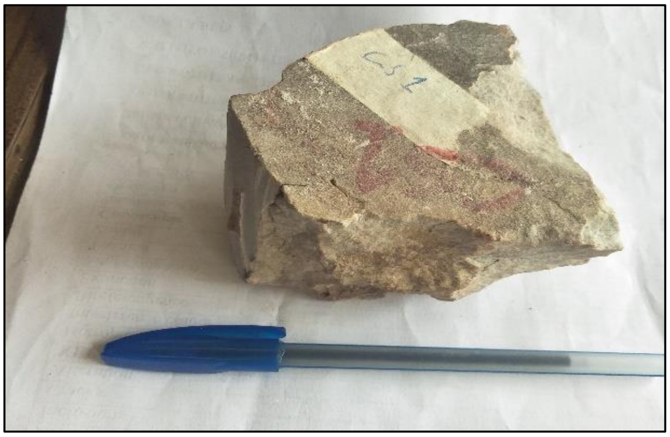


Figure 28: Photograph of Hand-size sample CS 1 showing the dominant reddish brown oxides with micas

4.1.4 Microscopic description

This section deals with the analysis of the thin sections cut from the samples already described in the preceding section. The thin sections obtained were viewed under a petrographic (Polarizing) microscope under Plane polarized, crossed polarized arrangement of the microscope. Different optical properties of the minerals in the thin sections under the two arrangements were observed and described. The corresponding minerals-with the observed properties, were identified and their relative proportions (modal mineralogy by volume percent) estimated throughout the thin section. The rock name was then deduced from the modal mineralogy.

A summary of the identified minerals from each section, modal mineralogy (approximate) and rock name with the micrograph of each thin section is given below.

Sample CS 1

Microscopic description

The rock consists of **Quartz** (90%, **under PPL**; white, subhedral with low relief, **under XPL**; anisotropic, 10 grey, black and undullose extinction), **Biotite** (6%, **under PPL**; black, anhedral, medium to high relief with pleochroism, cleavage and inclusions present, **under XPL**; anisotropic, 3^0 brown, strong birefringence and parallel extinction), **Feld spars**(4%) and thus the rock name is a **quartzite**.

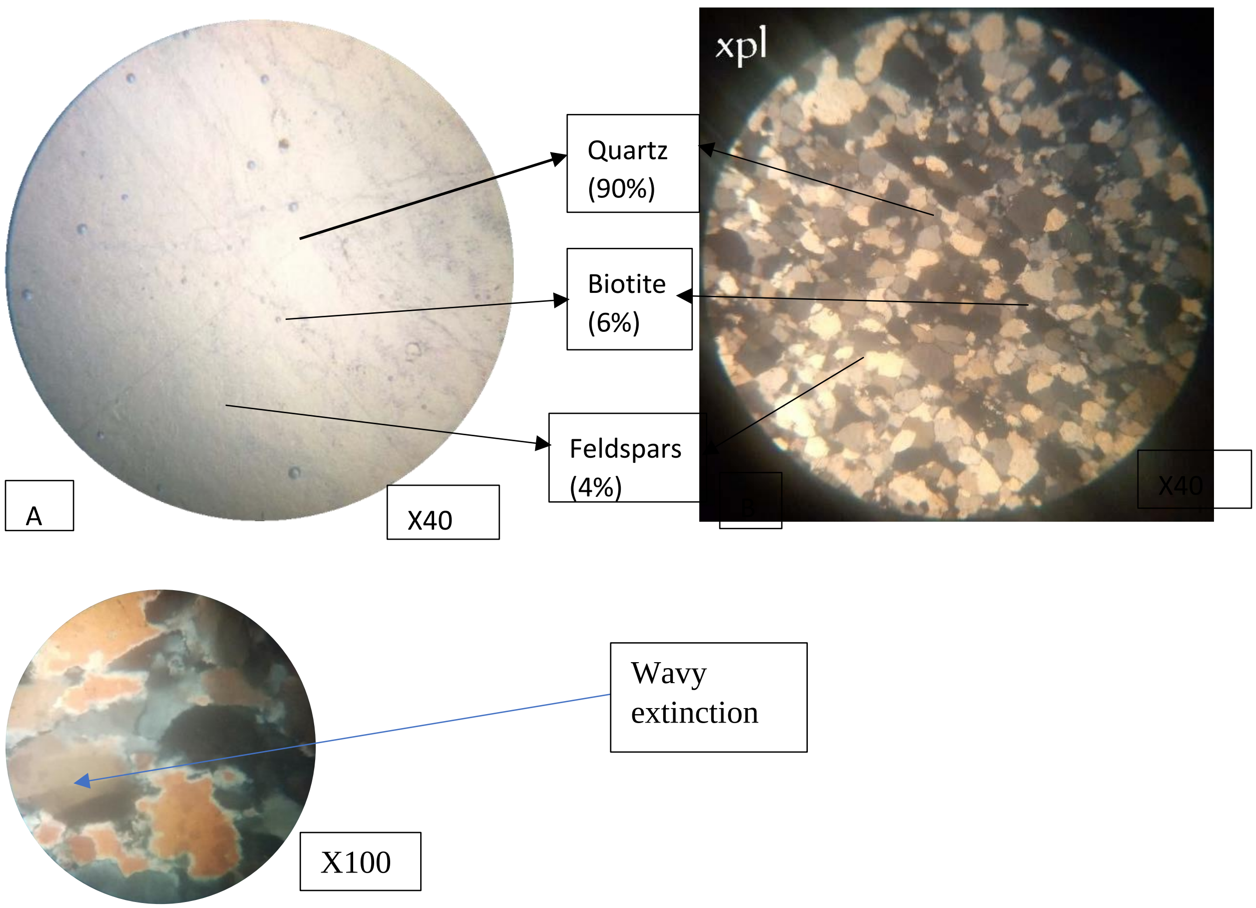


Figure 29: A photomicrograph of the thin section of sample CS1 under PPL (X100). (right) the photomicrograph of the same thin section under XPL indicating the minerals in the sample (X100).

Interpretation of properties of sample CS1

The rock name of sample CS1 is quartzite and hence a metamorphic rock. It could have formed from weathering of a sandstone. The sands were then transported by fluvial events and deposited in marine environment. These were compacted into a sandstone which was later metamorphosed into a quartzite.

Sample CS9A

Station 9A

Location: (0257882E, 9917378N)

The outcrop is large and artificially exposed since it is a manmade quarry. It is mechanically weathered, on a slope and mainly composed of grey shale. It contains clay minerals majorly. It's made up of minor folds which are inaccessible. The joints within the outcrop are longitudinal and cross thus are parallel to bedding planes.

The structures present within the outcrop include; Joints, quartz veins, bedding planes and faults

Macroscopic description of the sample (CS9A)

Mineralogy: Clay minerals e.g. Kaolinite

CS9A rock sample is a fine grained grey shale consisting of mainly clay minerals with lamination.

Field name: Grey shale

Figure 30: Photograph of Hand-size sample of CS9A

Microscopic description

The rock is composed of mainly clay minerals and it is laminated. The thin section of the sample was analyzed under both plane polarized light (PPL) and cross polarized light (XPL).

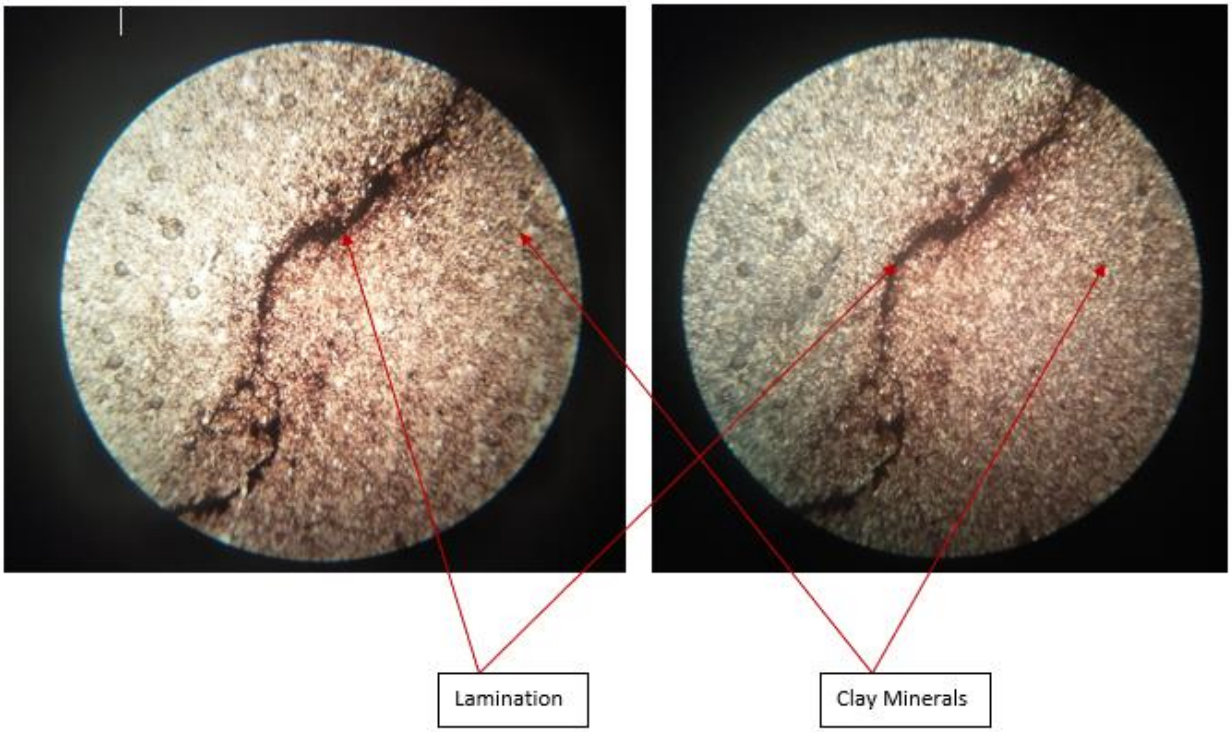


Figure 31: (left) A photomicrograph of the thin section of sample CS9A under PPL (X40). (right) the photomicrograph of the same thin section under XPL indicating the minerals in the sample (X40).

<u>Mineral composition by percentage</u>

Table 11: Mineral composition by percentage volume for sample CS9A

Mineral	**Modal mineralogy by volume percent**
Clay minerals	100

Field Name: Grey Shale

Station 10

Location: (0257974E, 9917400 N)

The outcrop is a large natural exposure of slightly weathered shale (ferruginous). It's on a steep slope and bedded. It mainly contains clay minerals and fine grained in size. The structures present were bedding planes and joints. The sample CS10 was obtained from this outcrop.

Macroscopic description of the sample (CS10)

Mineralogy: Clay minerals, iron oxides

It's a medium to fine grained ferruginous shale composed of mainly clay minerals and iron oxide as the cementing material and laminated.

Field name: Ferroginous shale

Figure 32:Photograph of Hand-size sample of CS10

Microscopic description

The rock is composed of mainly clay minerals which are so fine that when crossed they are isotropic and iron oxide attributed to the reddish gray color. The sample under XPL shows some blue shinning which is a characteristic of mica like Muscovite thus the sample becoming phylitic. The thin section of the sample was analyzed under both plane polarized light (PPL) and cross polarized light (XPL).

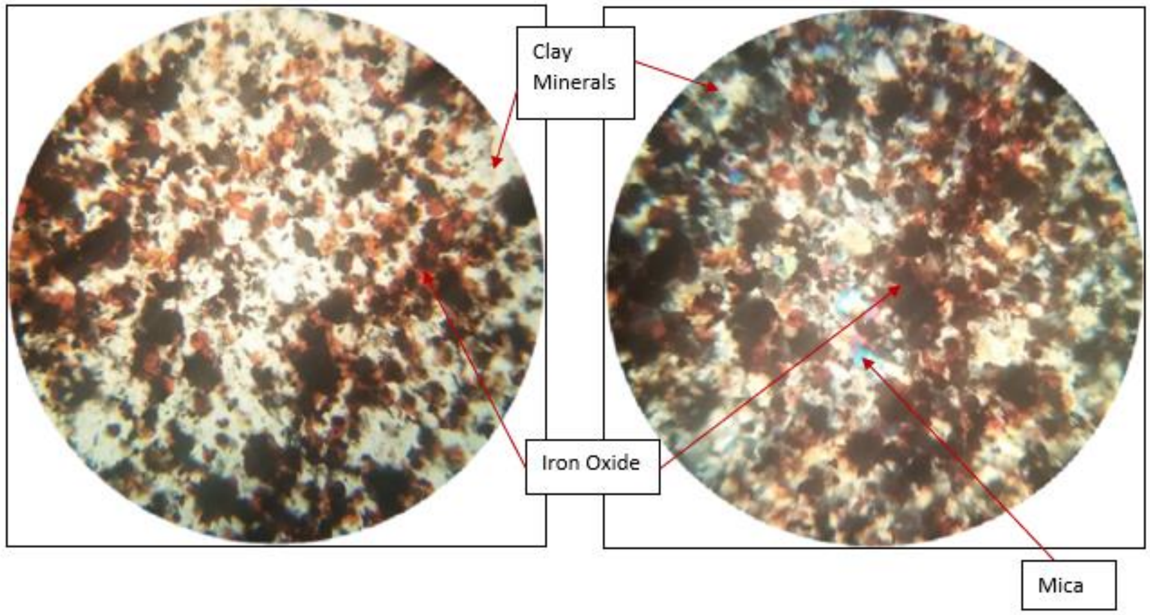


Figure 33: (left) a photomicrograph of the thin section of sample CS10 under PPL (X100). (right) the photomicrograph of the same thin section under XPL indicating the minerals in the sample (X100)

Mineral composition by percentage

Table 12:Mineral composition by percentage volume for sample CS10

Mineral	Modal mineralogy by volume percent
Clay minerals	70
Iron oxide	20
Micas	10

Rock name: Ferriginized-micaceous- shale.

Station 17

Location: (0256080E, 9917537N)

The outcrop is a large natural outcrop of grey shale located on a gentle slope. It's highly weathered and the beds are dipping inwards. Sample CS17 was obtained from this station. The sample is mainly clay minerals.

Sample CS17

Macroscopic description of the sample

A grey laminated fine grained rock composed of mainly clay minerals. The rock has an aphanitic texture and a poor cleavage. The lamination is trending in the North-East direction. The structures present include; beddings and laminations.

Field name: Grey shale

Figure 34: photograph of Hand-size sample of CS17

Microscopic description

The rock is composed of mainly clay minerals. The thin section of the sample was analyzed under both plane polarized light (PPL) and cross polarized light (XPL).

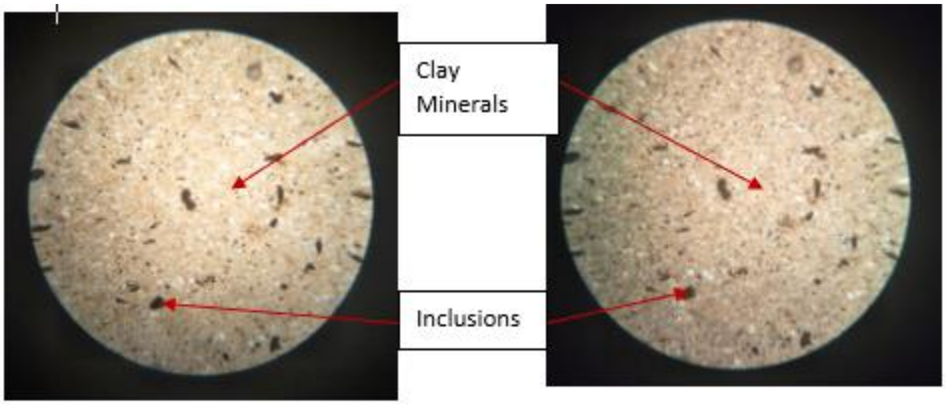


Figure 35: (left) A photomicrograph of the thin section of sample CS17 under PPL (X40). (right) the photomicrograph of the same thin section under XPL indicating the minerals in the sample (X40)

Mineral composition by percentage

Table 13: Mineral composition by percentage volume for sample CS17

Mineral	Modal mineralogy by volume percent
Clay minerals	90%
Inclusions	10%

Rock name: Gray shale

Station 22

Location: (0256527E, 9918422N)

The outcrop is large and naturally exposed. It's highly weathered and located at the summit of the ridge. It's made up of beds dipping inwards and the grain size is fine. The sample is made up of clay minerals and iron oxide evidenced by the brownish colour. The structures present include; relict beds, joints and lamination trending in the NE direction. CS22 rock sample was obtained from this outcrop.

Sample CS 22

Macroscopic description of the sample

A grey brownish, fine grained rock composed mainly of clay minerals and iron oxides.

Field name: grey shale.

Figure 36: photograph of Hand-size sample CS22

Microscopic description

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

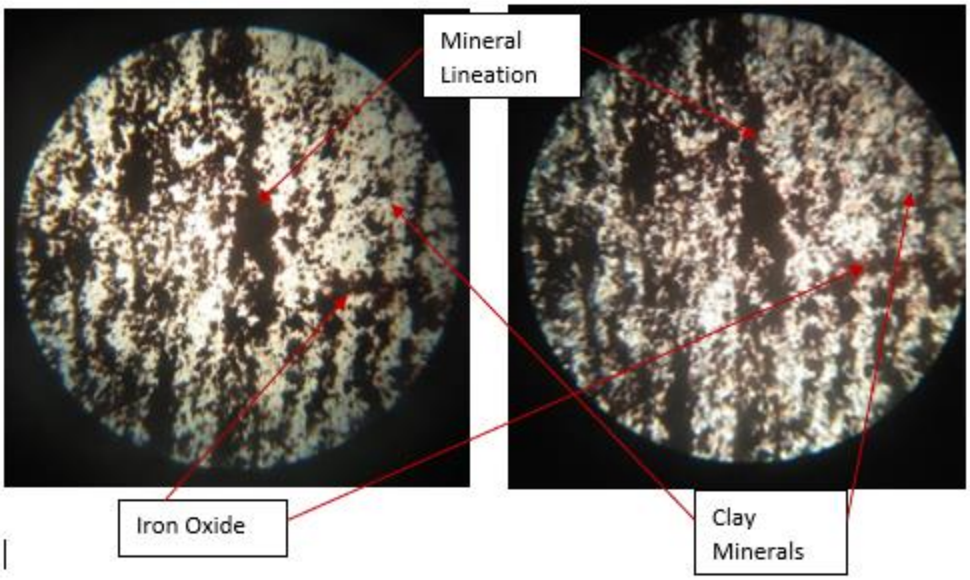


Figure 37: (left) A photomicrograph of the thin section of sample CS22 under PPL (X40). (right) the photomicrograph of the same thin section under XPL indicating the minerals and the wavy extinction in the sample (X40).

<u>**Mineral composition by percentage**</u>

Table 14: Mineral composition by percentage volume for sample CS22

Mineral	**Modal mineralogy by volume percent**
Clay minerals	90%
Iron oxide	10%

Rock name: Gray shale

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 ^{0}C 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 (allochemical metamorphism). 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

Metamorphism grade of area C increases down the slope as observed Quartzites being at the top of the slope with low metamorphism and the shales at the low part of the slope with high grade of metamorphism and nearly in the valley the shales with micas are highly metamorphosed tending to phyllites.

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 metarmorphic rock as observed in sample CS1 and also the increased grey color of the grey shale which meant that the shale was becoming more phyllitic as seen from rock samples CS9A, CS17 AND CS22.

In the laboratory, thin sections of most quartzite shows that the quartz grains has suffered some form of straining which resulted into elongation and wavy extinction in the quart grains evidenced from the photomicrograph of sample CS1. 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 CS10 under XPL and Wavy extinction in quartz in sample CS1 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 CS17. In sample CS9A (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 CS1 (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. (See the microscopic descriptions of these samples in the preceding section of the chapter for these details)

Dynamic metamorphism is deduced from rock samples collected from fault zones. Compared to rock sample CS9A (of similar composition) obtained from a non-fault zone, sample CS10, 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 CS10. 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.

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 maximumly 10 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, H, I, J and L and these areas were visited during hotspot presentations exercise and the results from these groups are summarized in the table 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.

Group	Location	Rock types	Structures	Metarmorphism
A	(0252077E, 9915938N) 1385m above sea level.	quartzites on the upper parts of the hills, ferruginous shale, grey shale and phyllitic shale near the arena, granites, conglomerates, Breccia.	Bedding, Joints Faults (both major and minor).	
B	**(**0255616E, 9918248N)	quartzites at the top of the ridges, shales (both ferruginous and grey) which occupied the lowlands, mica schists and granites.	Boudins, folds (both regional and cross folds), Axial planar cleavage (70^0SE), Bedding planes and Joints.	grade of metamorphism increased downwards towards the arena
E	(0256123E, 9916554N)	Ferruginous and grey shale on the slopes, phyllitic shale.	bedding, faults and joints.	

	1474m above sea level.			
G	(0254964E, 9916428N) 1589m above sea level	Quartzites, shales and conglomerates	Beddings, Joints, Folds and Lamination	
H	(0253223E, 9914100N) 1374m above sea level	shales (grey and ferruginous), brecciated quartzite.	Joints, beddings, foldsefff	
I	(0251851E, 9915792N) 1373m above sea level	quartzites, shale	Joints(both major and minor), and beddings.	Low grade metamorphism which increased downwards in the arena
J	(0255772E, 9914224N)	Quartzite, shale (both grey and ferruginous)	Beddings, Joints	
L	(0251424E, 9914256N); 1555m above sea level.	quartzites, shale (both grey and ferruginous) and breccias	Joints, quartz veins and beddings	

Table 15: Summary of information obtained from different groups.

5.2 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, C, 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, arenaceeaous mudstones and phyllites. The more argillaceous rocks are characterised by a colour 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

Table 16: Generalised 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.

Boudinage structures in B form as a result of deposition of sediments ie 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 andthere 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 an 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 CS9A, wavy extinction in sample CS1).

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 fossilssuggests 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 CS10 in area C. The ripple marks in the shales observed at Station CS10 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).

Information from the field visit to Kitagata Hot Springs indicates a high geothermal gradient favourable for the maturation of Organic matter in the source rock if organic matter is to present in the region. The water at the hotspring is believed to be meteoric and warms up to 80 °C and can be thought to contribute to the geothermal gradients that can accelerate the thermal maturation of source rocks. However, a suitable oil window is defined by the temperature range of 60-120°C but since the hot springs temperatures lies with in the oil window, then there are greater chances of no “overcooking” or cracking the oil to form thermogenic gases like methane.

From all these information (in sections 5.1 and 5.2), the geology of the entire Karagwe-Ankolean system seems to be harmonized in the evolution and intrusion history as suggested by Pohl and Gunther (1991).According to the duo, the Kibaran belt (Karagwe-Ankolean) evolved as an intercontinental orogen between 1400 to 900 Ma. Its earlier history comprises the deposition of a thick pile of elastic sediments with intercalated volcanic rocks and very rare carbonates. Early orogenic deformation of the belt included possibly thrusting which was followed at about 1200Ma by a major phase of folding producing wide anticlinoria and narrow synclinoria. Syn-to late tectonic adamellite granites (G1 and G2) were concurrently intruded into the anticlinoria inducing wide halos of thermal metamorphism which was followed by deformation by regional shear zones (evidenced in some of the pinching out quartz veins in

Chitwe granite) and tensional tectonics. Mantle magma was able to rise along one of these structures accompanied by alkaline-biotite granites (G3) and forming the Burundian-Tanzanian ultramafic belt.

Between about 1000 and 900 Ma, the Kibaran belt was intruded by numerous small bodies of granites, pegmatitic granites and pegmatites-G4 granites. Dome-like structures in the central parts of which the granites are exposed, are in the Kibaran rocks and famous for the morphological features which are usually termed as arenas.

CHAPTER SIX: CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

In conclusion, the mapping project was perfect and I acquired a lot of experience such as geologic mapping skills, using geological equipment that is compass and GPS.

Geologically Uganda is divided into a number of tectono-thermal domains, often closely related to continental scale "building blocks", each characterized by a specific geodynamic evolution. The lithostratigraphic units of the building blocks are described focusing on the hierarchy of the constituting units and field relationships, which jointly make up the local geology. A large number of outcrop photographs and chemical whole rock analyses are presented with GPS coordinates to give a more detailed description of the lithologies.

Stratigraphically, five dominant lithologic units were discovered and observed In the mapped area C. These included quartzites, shales, slates, phyllites and Granites with the granites occuppying the arena (Bottom of succession) and quartzites on top. The granite intruded the already laid shales and quartzites therefore are younger. The Stratigraphy of the area is found to be greatly influenced by tectonic activity, particularly folding and minor faulting. A number of rock units have been distinguished from others using age relationships and other peculiar characteristics such as colour, texture, thickness and shape of the rock units.

The structures encountered include joints, beds, folds, faults, quartz veins, laminations, crenulations, boudins, cleavage, and foliations and these were grouped into primary, secondary, minor or major. The major compressional forces that affected the area brought about the formation of regional folds trending in the NW-SE direction and cross folds trending in the NE-SW direction. Folding was accompanied by formation of an axial planar cleavage at shallow levels (Schluter, 1997). Tensional tectonics also affected the area especially through the faulting and jointing. The fault development was accompanied by intense jointing. The joints could have also formed due to contraction in the rocks after desiccations.

Five (5) fresh rock samples were collected during mapping, analyzed and the macroscopic and microscopic properties described under Plane Polarised Light, **PPL** and Crossed Polarised Light, **XPL** and thus the field and rock names given to the samples. The metamorphism that occurred in the area increased towards the base into schists therefore some structures are not visible, enhanced by the increase in temperature and pressure due to burial of sediments. Sedimentary structures and textures like fine lamination in argillaceous rocks, original grains, across bedding surfaces in arenaceous rock members can still be discerned in the horizons. All consolidated rocks of SW Uganda are nonfossiliferous and they are of Precambrian age.

The Karagwe-Ankolean system (~1.55−0.95 Ga), comprises abundant G-type, peraluminous granitoids that can be divided into the syn-tectonic G1 and G2 granites, as well as the posttectonic G2 and G4 granites. These igneous rocks are more or less coeval with a thick pile of metasediments of the Karagwe-Ankolean with a total thickness estimated to range from 9 to 14.5 km in the centre of the North Kibaran trough (e.g., in central Rwanda) to a few kilometres in the east. The Karagwe- Ankolean metasediments have been invaded by minor G3-type granites (1.25 Ga) and largely sub- outcropping the G4 'tin granites' (1.10−1.00 Ga) and related pegmatite bodies (0.97 Ga) and quartz veins (0.95 Ga). Metamorphism is generally low grade, and common structures include folds, minor faults, and beddings.

Generally, the mapping exercise was a great success and we were acquainted with the necessary geologic mapping skills. Attainment of field data in terms of structural trends measurements, the analysis of the obtained data and the interpretation of the mechanisms by which rock deformations occur are no longer a challenge to us as it used to be previously before the mapping.

6.2 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. Kevin Aanyu 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 considersations. 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 not in gis that there was so much to learn. It would not be in fallible 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 these softwares 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.

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APPENDIX

Appendix 1: Optical properties for minerals in CS1. Magnificatio: X40

Properties	**Sample CS1**

	Minerals
	A
PPL	
Color	Colorless
Pleochroism	Absent
Form/Habit	Anhedral
Cleavage	poor
Parting	Absent
Relief	low
Inclusions	present
Alterations	Absent
XPL	
Anisotropic/Anisotropic	Anisotropic
Interference colour	First order grey to white
Birefringence	weak
Extinction	Wavy extinction
Twinning	Absent
Zoning	Absent
Minerals present	**Quartz**
Model mineralogy	**100%**
Field name	**Quartzite**
Rock Name	**Quartzite**

Appendix 2: Optical properties of minerals in sample CS10. Magnification X100

Properties	**Sample CS10**		
	Minerals		
	A	**B**	**C**
PPL			
Color	Colourless	Colourless	Brown
Pleochroism	Absent	Absent	Absent
Form/Habit	Anhedral	Anhedral	Anhedral

Cleavage	poor	poor	poor
Parting	Absent	Absent	Absent
Relief	low	low	high
Inclusions	Absent	Absent	Absent
Alterations	Absent	Absent	Absent
XPL			
Anisotropic/Isotropic	Isotropic	Anisotropic	Isotropic
Interference colour	Not Determined	1st order grey	Not Determined
Birefringence	Not Determined	weak	Not Determined
Extinction	Not Determined	Wavy	Not Determined
Twinning	Not Determined	Absent	Not Determined
Zoning	Not Determined	Absent	Not Determined
Minerals present	Clay	Quartz	Hematite
Model mineralogy	60%	10%	30%
Field name	Ferrogenous shale		
Rock Name	Siliceous Ferrogenous shale		

Appendix 3: Optical properties of CS9A. Magnification X40

Properties	Sample CS9A
	Minerals
	A
PPL	
Color	Colourless
Pleochroism	Absent
Form/Habit	Anhedral
Cleavage	Absent

Parting	Absent
Relief	Low
Inclusions	Absent
Alterations	Absent
XPL	
Anisotropic/Anisotropic	Isotropic
Interference colour	ND
Birefringence	ND
Extinction	ND
Twinning	ND
Zoning	ND
Minerals present	Clay minerals
Model mineralogy	100%
Field name	Grey shale
Rock Name	Grey shale

Appendix 3: Optical properties of minerals in sample CS17. Magnification X40

Properties	Sample CS1	
	Minerals	
	A	B
PPL		
Color	Grey	Black
Pleochroism	Absent	Absent
Form/Habit	Anhedral	Anhedral
Cleavage	Absent	Poor
Parting	Absent	Absent
Relief	Low	High
Inclusions	Absent	Absent
Alterations	Absent	Absent
XPL		
Anisotropic/Anisotropic	Anisotropic	Isotropic
Interference colour	ND	

Birefringence	ND	
Extinction	ND	
Twinning	ND	
Zoning	ND	
Minerals present	Clay minerals	Iron oxide
Model mineralogy	80%	20%
Field name	Shale	
Rock Name	Ferrogenous Shale	

Appendix 5: Optical properties of minerals in sample CS22. Magnification X40

Properties	Sample CS1	
	Minerals	
	A	B
PPL		
Color	Colourless	Brown
Pleochroism	Absent	Absent
Form/Habit	Anhedral	Anhedral
Cleavage	Poor	Poor
Parting	Absent	Absent
Relief	Low	High
Inclusions	Absent	Absent
Alterations	Absent	Absent
XPL		
Anisotropic/Anisotropic	Anisotropic	Isotropic
Interference colour	1st order grey to white	ND
Birefringence	Low	ND
Extinction	Parallel	ND
Twinning	Absent	ND
Zoning	Absent	ND
Minerals present	Quartz	Iron oxide
Model mineralogy	60%	40%
Field name	Quartzite	

Rock Name	Ferrogenous quartzite

Appendix 6: GPS readings for contact of quartzites at Isingiro.

(256699, 9917482)	(257462, 9917869)
(256717, 9917464)	(257481, 9917986)
(256699, 9917378)	(257499, 9918024)
(256636, 9917238)	(257493, 9918139)
(256590, 9917134)	(257510, 9918261)
(256495, 9917060)	(257525, 9918388)
(256488, 9917035)	(257521, 9918458)
(256465, 9917000)	(257482,9918603)
(256369, 9917000)	(257392, 9918603)
(256375, 9917078)	(257202, 9918506)

Appendix 7: Attitudes of bedding planes in Area C.

Strike	**dip**	**Strike**	**dip**	**Strike**	**dip**
S2^{0}W	88^{0}NW	N24^{0}W	28^{0}NE	S80^{0}E	84^{0}SW
S4^{0}W	82^{0}NW	N28^{0}W	24^{0}NE	S74^{0}E	89^{0}SW
S8^{0}W	78^{0}NW	N8^{0}W	82^{0}NE	S70^{0}E	88^{0}SW
S10^{0}W	82^{0}NW	N4^{0}W	82^{0}NE	S68^{0}E	74^{0}SW
S6^{0}W	60^{0}NW	N24^{0}W	20^{0}NE	S66^{0}E	88^{0}SW
S10^{0}W	68^{0}NW	N20^{0}E	84^{0}SE	S64^{0}E	82^{0}SW
S54^{0}W	46^{0}NW	N20^{0}E	80^{0}SE	S58^{0}E	86^{0}SW
S40^{0}W	52^{0}NW	N20^{0}E	76^{0}SE	S60^{0}E	88^{0}SW
S32^{0}W	44^{0}NW	N20^{0}E	66^{0}SE	S46^{0}E	88^{0}SW
S44^{0}W	68^{0}NW	N34^{0}E	88^{0}SE	S48^{0}E	88^{0}SW
S2^{0}W	78^{0}NW	N44^{0}E	28^{0}SE	N28^{0}E	60^{0}SE
S4^{0}W	70^{0}NW	N60^{0}E	70^{0}SE	N18^{0}E	28^{0}SE
S8^{0}W	74^{0}NW	N52^{0}E	56^{0}SE	N48^{0}E	46^{0}SE
S14^{0}W	80^{0}NW	N40^{0}E	58^{0}SE	N14^{0}E	36^{0}SE
S2^{0}W	82^{0}NW	N58^{0}E	56^{0}SE	S38^{0}E	86^{0}SW

S4^{0}W	80^{0}NW	N32^{0}E	40^{0}SE	S48^{0}E	88^{0}SW
S18^{0}W	72^{0}NW	N22^{0}E	54^{0}SE	S40^{0}E	88^{0}SW
S24^{0}W	76^{0}NW	N18^{0}E	20^{0}SE		
S14^{0}W	76^{0}NW	N18^{0}E	56^{0}SE		
S8^{0}W	84^{0}NW	N30^{0}E	52^{0}SE		
S10^{0}W	88^{0}NW	N24^{0}E	62^{0}SE		
S8^{0}W	86^{0}NW	N32^{0}E	50^{0}SE		

Appendix 8: Attitudes of major joints in Area C.

Strike	**dip**	**Strike**	**dip**	**Strike**	**dip**
N68^{0}W	20^{0}NE	S40^{0}W	88^{0}NW	S74^{0}E	60^{0}SW
N26^{0}W	34^{0}NE	S32^{0}W	64^{0}NW	S64^{0}E	84^{0}SW
N28^{0}W	24^{0}NE	S24^{0}W	80^{0}NW	S58^{0}E	80^{0}SW
N23^{0}W	22^{0}NE	S10^{0}W	82^{0}NW	S86^{0}E	84^{0}SW
N50^{0}W	88^{0}NE	S30^{0}W	44^{0}NW	S82^{0}E	84^{0}SW
N50^{0}W	84^{0}NE	S84^{0}W	88^{0}NW	S62^{0}E	88^{0}SW
N30^{0}W	58^{0}NE	S84^{0}W	88^{0}NW	S64^{0}E	84^{0}SW
N34^{0}W	38^{0}NE	S82^{0}W	78^{0}NW	S56^{0}E	76^{0}SW
N32^{0}W	72^{0}NE	S84^{0}W	84^{0}NW	N58^{0}W	70^{0}NE
N38^{0}W	76^{0}NE	S76^{0}W	86^{0}NW	N68^{0}W	46^{0}NE
N84^{0}W	58^{0}NE	S20^{0}W	84^{0}NW	N74^{0}W	46^{0}NE
N62^{0}W	78^{0}NE	S28^{0}W	74^{0}NW	N72^{0}W	84^{0}NE
N68^{0}W	70^{0}NE	S48^{0}W	46^{0}NW	N74^{0}W	80^{0}NE
N68^{0}W	80^{0}NE	S4^{0}W	88^{0}NW	N62^{0}W	88^{0}NE
N56^{0}W	78^{0}NE	S38^{0}W	52^{0}NW	N68^{0}W	88^{0}NE
N64^{0}W	74^{0}NE	S148^{0}W			
N36^{0}W	76^{0}NE	86^{0}NW			

Appendix 9: Attitudes of the minor joints in Area C.

Strike	dip	Strike	dip
$N22^0E$	42^0SE	$N84^0E$	78^0SE
$N78^0E$	88^0SE	$N40^0E$	60^0SE
$N45^0E$	40^0SE	$N40^0E$	88^0SE
$N52^0E$	48^0SE	$N34^0E$	82^0SE
$N80^0E$	54^0SE		