MAKERERE UNIVERSITY

COLLEGE OF NATURAL SCIENCES

SCHOOL OF PHYSICAL SCIENCES

DEPARTMENT OF GEOLOGY AND PETROLEUM STUDIES

GLO3203: GEOLOGICAL MAPPING PROJECT REPORT OF GROUP L AT IGAYAZA ISINGIRO DISTRICT, UGANDA

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SUBMISSION DATE: AUGUST 2023

DECLARATION

By submitting this report to this institute for the Bachelor of Science Petroleum Geoscience and Production degree, I GINAMARA ESTHER OTONGA, hereby declare that the content is original to me, has never been presented to this institution or any other institution/organization for educational purposes and is free of any instances of plagiarism.

……………………………….. 11/08/23……………………………

SIGNATURE DATE

PROJECT COORDINATOR

……………………………… 31/8/2023…………………………

DR. AANYU DATE

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Last but not least, I thank the Almighty God for the strength, protection, and resilience, especially in the harsh conditions in the field.

ABSTRACT

Students studying Geology and Petroleum Geoscience at Makerere University are expected to attend a field mapping exercise after second year in Igayaza Isingiro district to develop skills such as collecting, analyzing, interpreting, and making deductions on geologic data. Mapping was carried out in four square kilometers designated areas and geologic maps produced using software to give an overview of the lithology types and their distribution in the area. The area of this study is area L and the main lithology types were quartzite and shale among others. This report contains six chapters i.e., Chapter One *Introduction*, which gives the objectives of the field study, general information about the study area, its location and accessibility, regional geology and is crowned with the materials and methods used. Chapter Two *Stratigraphy* includes a detailed study of the stratigraphy in the Karagwe-Ankolean system, lithologic units in area L, geometric relationship of rock units in time and space, geologic map and cross section of area L, the rock succession, depositional environment, geochronology and age dating, and finally the geologic history. Chapter Three *Structures*, gives details on the structural data, stereographic analysis as well as the description of the structures found in area L. Chapter Four *Petrography and Metamorphism*, details the macroscopic and microscopic descriptions of the rocks as well as the metamorphism. Generally, the area experiences low grade metamorphism. Chapter Five *Regional Synthesis* relates how the geology in the area L can be compared to the geology of the entire Karagwe-Ankolean system. Chapter Six *Conclusions and Recommendation*. And finally, the references and Appendix. The field trip is very hands on, practical and very educative study trip and I would highly recommend for a geoscientist because skills such as map reading, identification on the base map, mapping, taking of measurements, analysis using the optical microscope are attained among others in this trip. I thereby present this report with the findings and discussions attained.

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ACRONYMS

UTM	Universal Transverse Mercator
GPS	Global Positioning System
GIS	Geographic Information System
K-A	Karagwe-Ankolean
Ma	Million ages
B-T	Buganda-Toro
G1, G2, G3, G4	Granite types
NW-SE	North West-South East
NE-SW	North-East – South West
PPL	Plane Polarized light

CHAPTER 1: INTRODUCTION

1.1 BACKGROUND

This field mapping project took place in Igayaza synclinorium located 30km from Mbarara district, in Igayaza Isingiro district. The synclinorium is located in the south-western Uganda Karagwe-Ankolean (K-A) system of 1400-950Ma. The field trip commenced on January 30th and ended on February 8th, a ten-day study. Four square kilometers was assigned to each group of about nine people. This report is a study on area L, located in Kabingo.

1.2 AIMS

Through data collection, documentation, field geology analysis and interpretation, map production and usage as a repository for geologic data, this study aims to introduce students to the fundamentals of geologic mapping. The goals include the following;

- To learn how to use topographic and geologic maps to estimate distances.
- To visualize landforms, and locate/identify features.
- To perform tests and gather data to analyze geologic materials, features and processes.
- To identify geologic features and interpret geologic history.
- To produce a geologic map of the study area.

1.3 STUDY AREA

1.3.1 Location and accessibility

Igayaza is situated in Kabingo subcounty, Isingiro district which is boarded to the north by Kiruhura District, to the east by Rakai district, to the south by Tanzania, to the west by Ntungamo district, and to the north-west by Mbarara district. The largest metropolis in the Ankole sub-region, Mbarara located about 30km southwest of the town of Isingiro. There is an excellent road network from Kampala to Isingiro district, about 235km apart.

Figure 1: A map of Uganda showing the road accessibility to Isingiro district in south-western Uganda (Bahati G, 1998)

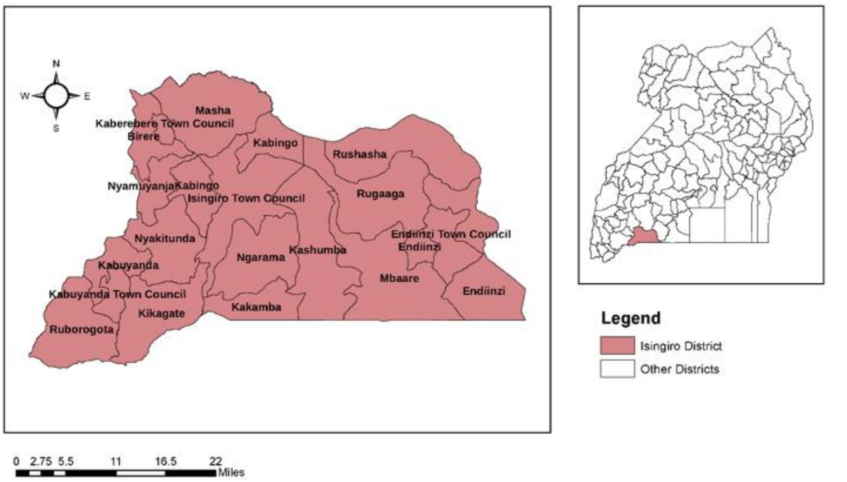


Figure 2: A map of Uganda showing the location of Isingiro district (GIS)

1.3.2 Physiography and Topography

Generally, Igayaza is a steep region with hills that have elongated ridges, V-shaped valleys and gouges. Tectonic phenomena like faulting and folding as well as weathering and erosion processes, have greatly altered its topography leading to formation of the arenas. The circular depressions, i.e., the arenas, with steep in-ward facing walls that resulted from differential weathering. Granite which weathers more significantly than quartzite, formed in the arena. The area was also characterized by an inverted topography, with the anticlines forming the valleys and the synclines forming the hills. This area represented the area originally occupied by the granites, and because of their high feldspar content, the granites were weathered and eroded more rapidly than the more competent quartzite horizon, which now appears as a mound. (Barnes, 1956) A phenomenon known as topographical reversal. Most of the high plateaus were separated from the smaller arenas by valleys. The area had a varied and contrasting topography.

Figure 3: Showing the physiography and topography in the study area L.

1.3.3 Climate

Isingiro is strongly influenced by relief, topography and vegetation (Ucakuwun, 1989). The district experiences two rainy seasons i.e., from April to May and from October to November. The wettest month is April. It also receives a moderate rainfall of 750mm to 1250mm per year (Geochemical Atlas of Uganda, 1973). Isingiro's average annual temperatures are moderate, ranging from 57°F to 81°F and is rarely below 54°F or above 87°F.

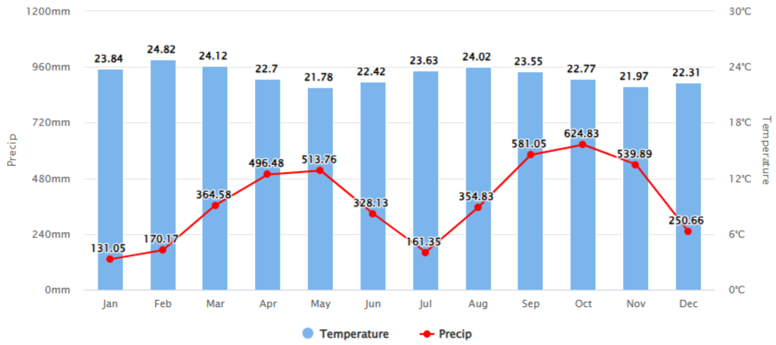


Figure 4: Graphs showing the monthly temperature and rainfall in Isingiro district (levoyageur.net/weather-city)

1.3.4 Vegetation and Drainage

Rifting along the western rift valley resulted in relative upward distortion and a corresponding downward distortion in more distant areas. This led to flow reversals and stagnation along rivers. The vegetation cover is savannah-like in nature, with hilltops covered with several centimeter tall grasses and sparse trees, slopes dominated by grasses of varying heights, and massive thickets with diverse tree species such as eucalyptus and others found in fault zones and valleys. Vegetation density and abundance generally increase downhill into the valleys. Some areas have dense vegetation dominated by shrubs and trees. This is evident in the valleys, faults, along the streams and also in the quartzite-dominated ridgetop. The faults and quartzites on the ridges act as traps for the subterranean water flow, thus supporting the growth of vegetation. Valleys were sites for soil and sediment deposition. The soils in these valleys were fertile and favored the growth of vegetation. In general, Isingiro has a poor drainage pattern due to the presence of seasonal streams, springs and the lack of rivers and lakes.

Three main drainage patterns have been observed, and these include

i. **Angular drainage pattern** resulting from sharply incised, V-shaped, intervening valleys on the sides of the ridges. They are normally traversed by streams during the rainy season, but usually dry up during the dry season. These valleys form tributaries to border valleys, which are mostly swampy.

ii. **Dendritic drainage patterns** and their modifications have been observed in areas underlain by shales, gneisses, granitic gneisses and weathered granite rocks of the Arenas.

iii. **Parallel to sub-parallel drainage patterns** modified areas underlain by phyllites and the less metamorphosed rocks form ridges or rugged topographies with steep slopes. The dendritic drainage pattern is dominant in most areas, which is determined by the geology of the area.

1.3.5 Land use and settlement

Agriculture was the principal economic activity seen. Due to the excellent soils in the valleys and mild slopes, subsistence farming predominated there. Bananas, corn, cassava, sweet potatoes, pineapples, beans, and sorghum are among the many crops farmed. Although there were plantations for some of them, like bananas, the majority are farmed on a local scale. In the region, animal husbandry was also conducted. The animals were allowed to roam freely while grazing on small hills and in vegetated valleys. Raised animals include pigs, cattle, goats, and sheep. On a minor basis, a quarry was also run. In regions where the quartzite outcrop was broken, fractured, or defective, quarries were found. To make smaller stones for construction, quartzites were quarried. Our mapping exercise was impacted by this mining in several regions because of obstruction of geology like folds, joints, etc.

Figure 5: Stone quarrying activities in the area.

According to the Uganda Bureau of Statistics (2010), the region was often sparsely populated, with small, dispersed homesteads making up the majority of the settlements (Uganda Bureau of Statistics, 2010). Since hills are predominately composed of quartzite in-situ and floats that impede settlement, the settlement was seen in low-lying and flat places. Most residents of Area L dwell in the lowlands, whereas only a small number reside there. The Isingiro Kikagati Road and other access roads as well as commercial hubs were the main areas where people were concentrated, resulting in a linear layout of habitation. The low-lying regions are where most of the commercial centers are located, whereas the highlands are remote. These dwellings were discovered to be between 100 and 300 meters apart in the villages and much closer together in the commercial centers. Man-made watersheds were evident in the area, which could serve as a water source during the rainy season.

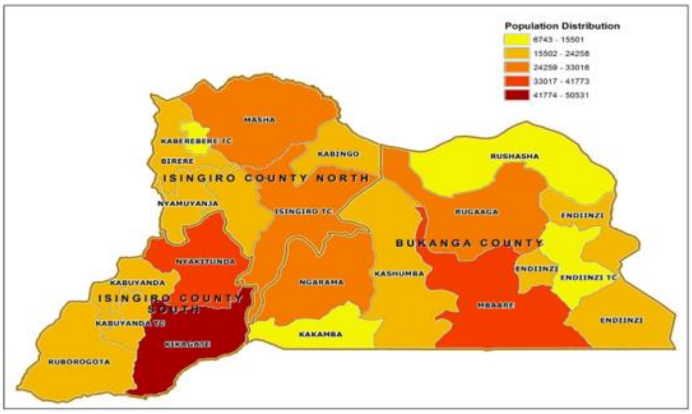


Figure 6: A map showing the population distribution in Isingiro district, 2014 (source: report on findings of National Population and Housing Census (NPHC) 2014 undertaken by the Uganda Bureau of Statistics)

1.4 REGIONAL GEOLOGY

1.4.1 Areal Extent and Early Works

Igayaza area lies within the K-A system of western Uganda which forms part of the northern part of the great Kibaran belt. This Mesoproterozoic Kibaran belt also known as the Kibaran 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).

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 q1 to q4 and he noted q4 as being the thickest underlying the Rugaga plateau and comprising numerous quartzite layers interspersed with thin argillaceous bands. Plumber (1960) described thinning of the quartzite on the north-western limb of the Igayaza syncline east of the

Mbarara-Kikagati road. The study of the aerial photographs showed a striking attenuation of the lower formations from the south-eastern towards the north-western flank of the Igayaza syncline. 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. Sinabantu (1988) noted that the morphological features within the arena floors were similar to the varieties in other granites.

Ex-foliation, horizontal and vertical jointing with subsequent weathering produced pillar-like tors. Spheroid weathering left rounded blocks and in some arena granites, a smooth, gently curved surface was recognizable. Ucakuwum (1989) described the K-A system in south-western Uganda to consist of originally predominantly argillaceous sediments interbedded with numerous quartz veins developed in arenaceous horizons and sporadic conglomerates and siliceous lime at the base of the succession. Biryabarema (1995) suggested an almost synchronous episode in the formation of both regional and cross folds which were modified by dome-like arena structures.

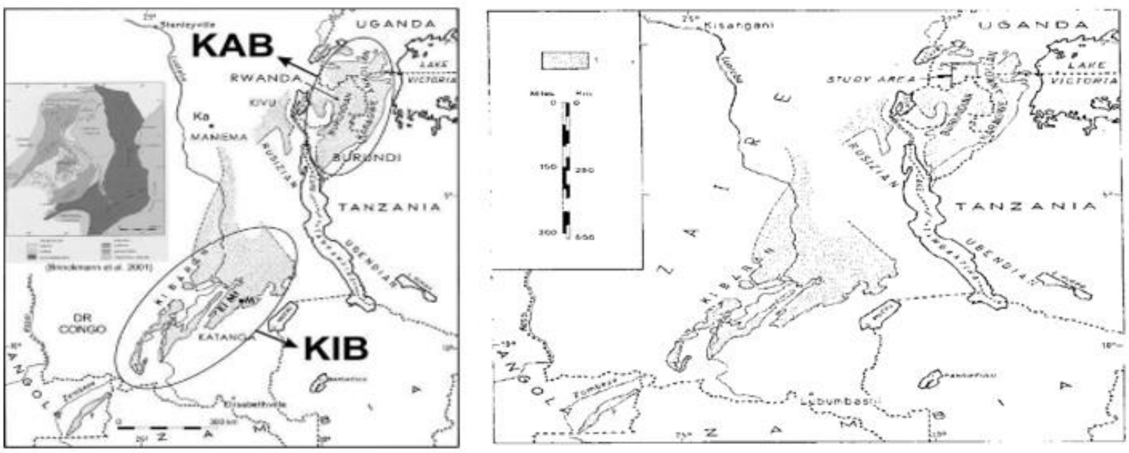


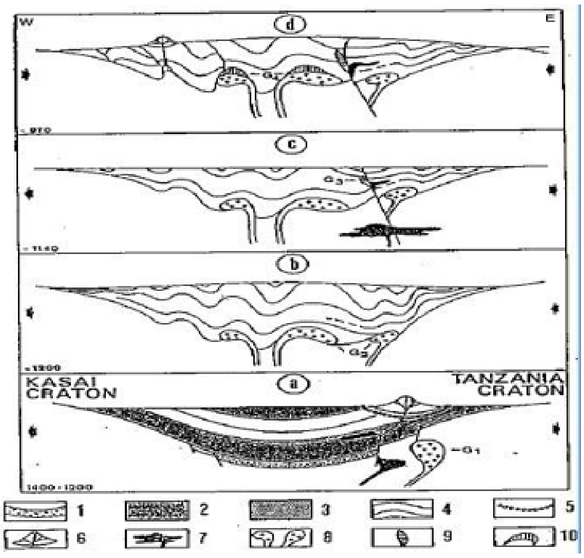
Figure 7:A sketch map (Cahen and Snelling, 1966), showing the Karagwe-Ankole Belt (KAB) and the Kibaran Belt (KIB) as redefined by Tack et al. (2010). Inset after Brinckmann et al., 2001 showing the Kibaran belt as a single and continuous belt. (left) A map showing the areal extent of the Kibaran Belt from Eastern to Central Africa (Modified after Petters, 1991) (right)

1.4.2 Geotectonic Evolution

The K-A system evolved as an intercontinental orogeny between 1400 -900 Ma, according to Pohl and Gunther (1991). Its earlier history comprised of the deposition of a thick pile of clastic sediments with intercalated volcanic rocks. Early orogenic deformation of the belt included thrusting and nappe transport which occurred by 1200 Ma and followed by a major phase of folding that produced a wide anticlinoria and narrow synclinoria. Syn- to late tectonic ademellite granites (G1-G2) were concurrently intruded into the anticlinoria inducing wide halos of thermal metamorphism. This was followed by deformation by regional shear zones and tensional tectonics then followed. At about 1100 Ma, mantle magma was raised along one of these structures accompanied by alkaline biotite granites(G3) and thus formed the Burundian-Tanzanian ultramafic belt.

Between 1000 and 900 Ma, the Kibaran belt was intruded by numerous small bodies of granites, pegmatitic granites and pegmatites (G4). The most evolved members for this suite are the sources of tin and tungsten mineralization. These granites are equigranular or pegmatitic, often clastic and locally sheared biotite-muscovite granites. Their country rocks include older granitoids and sediments. Their roofs are often invaded by suites of hydrothermal pegmatites and quartz veins which host tin, tungsten and niobium-tantalum mineralization. Dome-like structures are common in the Kibaran rock and their morphological feature is the arena granites thus formed in the central parts of which the granites are exposed.

According to Barnes, 1956, it is confirmed that as structural depth increases, the granites tend to increase in size, become less regular in shape and to show greater disturbance effects on surrounding sedimentary structures.



KEY:

1: Conglomerates **2:** Sand and siltstones

3: Turbidities **4:** Pelites **5:** Stromatolic fringing reefs

6: Volcanic Islands **7:** Mafic Intrusions **8:** G1 and G2 granites **9:** G3 granites **10:** G4 granites

Figure 8: Geotectonic evolution of the Kibaran belt (arrows indicate predominantly extensional or compressional regimes). (Modified after Pohl 1992, 1994)

1.4.3 Geology

Rocks of Karagwe-Ankolean system occupy an almost continuous area in SW Uganda being interrupted only in a few places by granitic arenas. The system consists of a succession of originally predominantly argillaceous sediments interbedded with numerous well-defined arenaceous horizons and sporadic conglomerates and siliceous limestone at the base of the succession. Combe (1992) estimated thickness of over 800m for the succession in East Rukiga, and over 4700m eastwards in Ankole and are represented by cleaved mudstones while in other parts they have metamorphosed to varying degrees and are represented by slates, phyllites, and muscovite-sericite schists interbedded with quartzites and sporadic calc-silicate rocks and conglomeratic quartzites at or near the base.

Areas underlain by granites and gneisses generally occupy arenas which are circular depressions rimmed by metasediments of the Karagwe-Ankolean system (K-A) with steep inside-facing walls. The floor of Lugalama arena is characterized by deeply weathered granitic rocks producing undulating topography. The formations in the arena belong to the Kibaran belt which according to Pohl and Gunther (1991), evolved as an intercontinental orogeny between 1400-900Ma.

1.4.4 Stratigraphy and Geochronology

There have been attempts to define the stratigraphic succession and correlation of the rocks of Kibaran belt. A three-fold subdivision was established as many of the rocks are similar. This subdivision is generally accepted by (Cahen et al., 1984; Rumvegeri, 1991).

The upper division includes mudstones, siltstones, sandy mudstones, sandstones, grits, and occasional conglomerates which are intercalating with the quartzitic horizons and it's about 3000- 5500metres thick.

The middle division is composed of sandstones with some small itiritic layers of micaceous hematite, predominantly mudstones, shales (which are grey, pink, and cream in color) as well as arenaceous mudstones and phyllites. It is about 2000-3000 meters thick.

The lower division consists of schists, quartzites, phyllites, muscovite and calc-arenites, muscovite schists. It is about 4000-6000metres thick.

According to (Ucakuwun, 1989) the stratigraphic hierarchy of the Igayaza synclinorium mainly relies on the "way up" criteria indicated by depositional structures where available, cross-cutting 10 relationships of lithologies and structures, and geochronology. The Karagwe-Ankolean system unconformably terminates into the older Buganda-Toro rocks which stratigraphically overlie the Basement rocks (Basement Complex). The K-A system is composed of acid gneisses, migmatites, folded metasedimentary rocks of originally predominantly argillaceous composition intercalated with arenaceous horizons and occasionally conglomeratic basal members, rarely calcareous and volcanic sequences. These rocks have also been intruded by biotitic granites from G1-G4, pegmatites and hydrothermal veins of acid and basic dykes according to Ucakuwun (1992). Rocks of the K-A overlie unconformably sheared granitic rocks which seem to be part of an extensive Achaean crust as reported by Straaten (1984). Overlying the Achaean crust and the Karagwe-Ankolean metasediments are almost 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 magnesium content with pronounced lime deficiency. Greywacke layers with sedimentary structures typical of a turbiditic origin intercalated with pelitic beds. Proximal turbidites also occur in the eastern whereas distal turbidites are found towards the center of the area. Much of the sequence consists of quartzites 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.

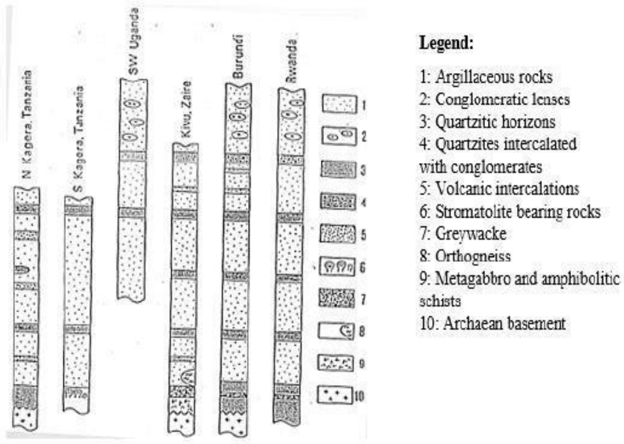


Figure 9: Generalized stratigraphic columns of the Kibaran belt as modified after Rumvegeri et al (1985).

Geochronological radiometric ages have been determined and reported by various scientists, including Vernon Chamberlain, from Kibaran rocks in north-western Tanzania and south-western Uganda; 1967, Löwenstein; 1969, Vernon-Chamberlain and Snelling; 1972, Bugrov et al.; 1982, Cahen et al.; 1984 Cahen and Snelling; 1988 and Ikingura et al.; 1990. The second most recent age determination by Ikingura et al.; 1991 after that of Pohl (1992 and 1994) in connection with the pan-African cycle and the post-orogenic G4 granites with their important mineralization as spatially constrained and therefore belonging to the Kibaran belt. Based on the analyses of pegmatites and hydrothermal fluids, the following interpretations have been generally agreed upon;

- Synorogenic granites (G1 and G2) yielded ages of 1370 ± 25 Ma and 1310 ± 25 Ma respectively.
- G3 granites provided a whole rock Rb-Sr at 1094 ± 13 Ma.
- G4 granite ages were clustering at about 976 ±13 Ma (Pohl, 1994).

1.4.5 Structural Morphology

The general structural trend of Kibaran belt of which the K-A is its northernmost extension is in the NE-SW direction with moderately folded anticlines with syntectonic granites in their cores, which are associated with tightly-folded synclines. (Barnes, 1932). Two major fold trends have been established and described by Barnes et al. (1956). According to Barnes (1956), the predominant Kibaran fold trend is in the NW-SE direction, which was named Ankole fold trend which were later renamed to regional fold trend (King and Swardt (1970). The other folding is called the cross-fold trend that trends in the NE-SW direction, and hence perpendicular to the regional fold.

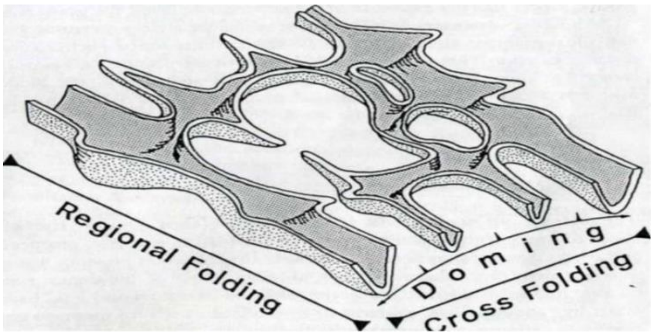


Figure 10: Folding styles of the Karagwe-Ankolean system. (Modified after unpublished sketch by Macdonald, 1972).

Barnes (1956) assumed an almost concurrent episode for the formation of the two-fold trends, but suggested two-fold mechanisms for their development. In one hypothesis he stresses that the cross-folding was due to distortion of the regional axes to release the stress caused in the rocks by regional folding. Alternatively, he considers cross-folding simply as the interference of true geosynclines folding with the regional fold trends. The reason for the change in the trend is not yet known, but it might be compared with a gentle flexuring on an E-W axis, of the Kibaran sequence previously folded on a NE-SW axis. Based on the structural configuration (the attitudes of the folds) of the K-A in SW Uganda, Stheeman (1932) and Ucakuwun (1992) proposed that a stress field oriented in the NE-SW direction was responsible for the major and earlier regional folding phase in the NW-SE direction presumed to have taken place at around 1300-1200Ma. Similarly, a stress field in the NW-SE direction is invoked for the later cross folding along the NE-SW direction. 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). Cleavage and schistocity have been strongly developed in all K-A rocks (Ucakuwun, 1992). The cleavage is axial planar to both the regional and cross folds while schistocity is parallel to bedding. A NW oriented crenulation cleavage is also common within the folds (King and De Swardt, 1970) and arose from crenulations of the NE trending foliation. Axial planar cleavages, schistocity, and crenulations however, might have played an important role as a plane of weakness for the subsequent development of certain faults that are observed to strike parallel to and also replace or even displace the limbs of some folds (King and DeSwardt, 1970). Joints and small-scale folds are also prevalent phenomena within the K-A rocks.

1.4.6 Geo-Tectonic Evolution

According to Pohl and Gunther (1991), the Kibaran belt evolved as an intercontinental orogen between 1400 -900 Ma. Its earlier history comprised the deposition of a thick pile of clastic sediments with intercalated volcanic rocks. Early orogenic deformation of the belt included thrusting and nape transport which occurred by 1200 Ma and was followed by a major phase of folding that produced a wide anticlinorium and narrow synclinorium. Syn- to late tectonic adamellite granites (G1-G2) were concurrently intruded into the anticlinoria inducing wide halos of thermal metamorphism, deformation by regional shear zones and tensional tectonics then followed.

At about 1100 Ma, mantle magma was raised along one of these structures accompanied by alkaline biotite granites (G3) and thus formed the Burundian-Tanzanian ultramafic belt. From 1000- 900 Ma, the Kibaran belt was intruded by numerous small bodies of granites, pegmatitic granites and pegmatites (G4). The most evolved members of this suite are the sources of tin and tungsten mineralization. They are equigranular or, pegmatitic, often cataclastic and locally sheared biotite-muscovite granites. Their country rocks include older granitoid and sediments. Their roofs are often invaded by suites of hydrothermal pegmatites and quartz veins which host tin, tungsten and niobium-tantalum mineralization. Dome-like structures are common in the Kibaran rocks and their morphological feature is the arena granites thus formed in the central parts to which the granites are exposed. As structural depth increases, the granites tend to increase in size, become less regular in shape and show greater disturbing effects on the surrounding sedimentary structures (Barnes, 1956).

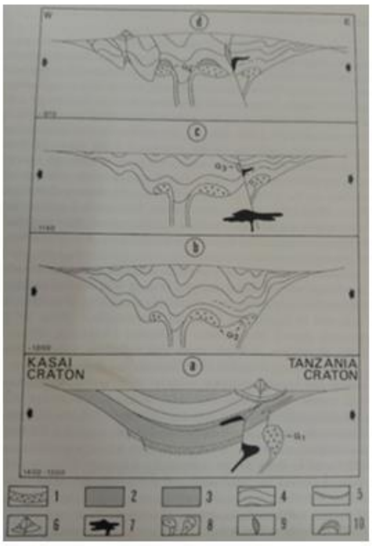
The relative ages and locations of the granites according to Pohl, 1994 are summarized below;

• G1 Granites: Rwantobo (1318 ± 84 Ma), Ntungamo (1170 ± 66 Ma), Kamwezi (1201±134 Ma) and Lugalama (unknown age)

• G2 Granites: Chitwe (1107 ±39 Ma), Chabakonzo (939 ± 39), Masha, Akabeeba

• G3 Granites: Ultramafic rocks of Kabanga.

• G4 Granites: Ibanda, Dwata, Rwabaramira, Karenge.



Legend

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 11: The geo-tectonic evolution of the Karagwe-Ankolean. (Pohl and Gunther, 1991)

1.4.7 Economic Potential

J.S. and D.S Kargarotos were the first to document the economic potential of K-A after discovering cassiterite (tin ore, SnO4) in NW Tanzania system at Kyerwa 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 mineralization in metasomatic zones around granites. He noted four sub-groups of G4 granite-associated mineralization.

- ✓ Pegmatites with Sn and Nb/Ta, Li, Be, U/Th, muscovite, feldspar and kaolinite.
- ✓ Quartz veins with Sn and W, pyrite, siderite, bismuth, gold and uranium.
- ✓ Talc deposits developed by hydrothermal alteration of dolomites and magmatic mafic rocks.
- ✓ Auriferous silicification zones with gold, pyrite, arsenopyrite, magnetite and specularite mineralization.
- ✓ Cassiterite is mainly obtained by small scale artisanal mining from quartz veins near Kikagati. Modern geochemical and geophysical methods resulted in more mineral discoveries in parts of Burundi and Tanzania. Some of the mineralization in this belt includes the following;
- ✓ Deposits of tungsten which occurred dominantly in narrow belt in the Kigezi area where they are integrated into a system of sub-parallel, 10 to 20cm thick quartz veins, which strike conformably with the hosting phyllites.
- ✓ Soda lime pegmatites containing beryl, tantalite-columbite, cassiterite, amblygonite and iron-manganese phosphates are found for example, in Mutaka and Nyabushenyi.
- ✓ Gold deposits are found in limonite veins with bismutite, pyrite, wolframite and cassiterite in south western Kigezi.

1.5 MATERIALS AND METHODS

1.5.1 Materials

The table below shows the geologic materials that were used during the field geologic mapping project and the corresponding use(s) for each of them.

Table 1 The materials used during the field study and their uses

Material	Use (s)
Geologic compass	Determining directions. Structural measurements such as strike, dip, trend and plunge.
Global positioning system (GPS)	To determine location and elevation.
Base Map	Used to mark established stations. For plotting geologic features such as faults, Contacts, geologic boundaries.
Field notebooks, Pencils, Erasers, Rulers and pens	Pens and pencils for plotting points on base map and drawing sketches of structures in the notebooks. Notebooks for annotating the observations and sketches, recording GPS readings, structural measurements and lectures.
Geologic Hammer	For breaking rocks to obtain fresh samples of in-situ rocks at established stations.
Hand lens	For accurate magnification of fine details of rock units
Tape measure	Used to standardize pace lengths and measure the extent of lithologic boundaries and structures in the field.
Binoculars	Magnifying far objects and features.
Camera	For taking the pictures of desired structures
Field bag and field sample bag	Used to carry field equipment and obtained samples
Lunch box and water bottle	To carry food and water respectively for re energizing while in the field.
Rain coat	Protection from rain
Laptop	For seismic analysis and writing the report.

1.5.2 Methods

The major methods used in the study trip include the following; field-work (hands-field geological mapping), laboratory and data analysis and interpretation using microscopes and stereonet respectively and report writing. The first method, fieldwork was all to be done on ground in the study area in Isingiro by making field observations and collecting raw data, while the other involved statistical data processing and interpretation, written and oral geological reporting.

i). **Fieldwork**

After arriving at our camp, the fieldwork began the very next day with the on-camp briefing session by all the lecturers with whom we had travelled in order to give us the guidelines and methods to follow while in the field. In this session nine-member groups were made and each assigned a particular $4km^2$ area in which that group would carry out all their mapping activities during the entire duration of the project.

The fieldwork involved traversing the assigned study area (Area L) along the dip and strike to plan the best way of carrying out the mapping exercise. During the fieldwork, the greatest part of the work involved making observations and taking measurements. In particular, the following steps were followed at each outcrop;

- A station was established at the outcrop and the GPS location of that station taken and recorded in the notebook. Multiple stations were established on one outcrop if it was large enough.
- The outcrop was described. This included stating its size, weathering, degree of metamorphism and identifying all structures that were visible on the outcrop such as joints, faults, lineation, cleavages, folds, schistosity, fractures, bedding planes and many others.
- The field name of the outcrop was then inferred from the observations and noted down.
- Measurements were then taken for the clearly visible structures. The measurements were taken in a ratio of 3:2:1 (from most dominant to least dominant) in case of multiple sets of that particular structure.

- A photo or sketch of some structures would be taken, especially if they were unique. If something could not be included in the sketch, it was included in the notes.
- A fresh hand size sample was then picked at the station and clearly labeled to indicate where it was picked before placing it in the sample bag. Samples picked by my group were labeled with the initials "L" and the station would be added as a subscript, for example a sample from station one had the label "L1".

Finally, GPS readings outlining the outcrop boundary were taken, recorded in a table in the notebook and plotted on the base map. The outcrop lithological boundaries were determined using methods such as;

- ❖ Floats: Rocks not in-situ usually come from upslope, therefore if the outcrop was not present, we could infer that it was buried.
- ❖ Break in slope: Steepness or gentleness states the underlying geology. Steep gradient usually corresponds to hard to weather rocks while gentleness corresponds to easy to weather rocks.
- ❖ Change in vegetation: Some fractured rocks are wet and hence have a lot or good vegetation. Some much drier rocks such as shales have scanty or no vegetation.
- ❖ Change in soil color and also the soil in anthills was also used especially in the arena to determine the extent of the granite.

During the fieldwork, it was mandatory to identify hotspots, which were areas with peculiar features that were not present in other parts of the mapped the area. Particularly the hotspot we picked in area L was a quartzite quarry with relict bedding, an exposure at a road cut.

ii). **Laboratory and data analysis and interpretation**

The laboratory technician created thin slices from the field sample collection, and these sections were examined under a polarizing microscope to describe and identify the minerals present and better understand the lithology of the region. Rosenet, Stereonet, and ArcGIS were utilized to analyse the structural data and depict the overall trend and direction of these structures in the studied region.

iii). **Report writing**

This is the final part of the project, which involves writing a report on the activities, observations and conclusions from the field trip. The report is made up of the following chapters;

- **Chapter 1: Introduction**: This chapter gives general information on the study area, the objectives of the field trip and also states the materials and methods used.
- **Chapter 2: Stratigraphy**: This chapter will give a stratigraphic description of area L and also the general stratigraphy of Igayaza area.
- **Chapter 3: Structures**: this chapters looks into the structures mapped in area L and Igayaza. This chapter thus includes all the structural data, stereograms and the description of the structures.
- **Chapter 4: Petrography and Metamorphism:** This chapter gives a macroscopic description of field outcrops and the given field names, microscopic descriptions of hand specimens, thin sections as well as index minerals and grade and evidence of metamorphism.
- **Chapter 5: Regional Synthesis**: In this chapter, results of all mapped areas (by all other groups) are compared and tied in the geology of the surrounding areas:
- **Chapter 6: Conclusion and Recommendations**: This chapter summarizes the outcome of the mapping exercise, and states the limitations as well as the recommendations on the way forward for the coming mapping exercises.

CHAPTER 2: STRATIGRAPHY

2.1 INTRODUCTION

Stratigraphy is the study of layered rocks. MacLeod (2005), defines stratigraphy as that branch of geology that deals with formation, composition, sequence, and correlation of stratified rocks. In most cases however, stratigraphy focuses on the evaluation of sedimentary rock strata.

Read and Watson (1970), defined stratigraphy as a branch of historical geology that is concerned with the study of the succession of the rock strata and their interpretation as historical records.

Barnes et al. (1980) defined stratigraphy as the arrangement of the strata, especially as the geographic position and the chronological sequence. Combe (1932) and Wayland (1919) modified the definition of stratigraphy as a branch of historical geology that is concerned with the study of the succession of the rock strata and their interpretation as historical records.

Stratigraphy enables the geologist to develop the idea of various phases in long history of deposition. 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.

In geology the present is the key to the past and the conditions under which ancient sedimentary rocks were formed can be inferred from understanding how the modern counterparts are being formed. For this reason, stratigraphy is clearly and broadly understood by dividing it into 3 main phases that is description of the strata, correlation and interpretation of the stratigraphic records.

Stratigraphy is divided into several other sub-disciplines that include;

Lithostratigraphy. This deals with rock types and their physical characteristics such grain size, colour and sorting. This helped us infer the mineralogical composition of rocks and metamorphic grade, trace the lithological boundaries and determine the extent of different lithologies. Lithostratigraphy helped us distinguish the topographic highs and lows from stratigraphic highs and lows which result due to topographic inversion caused by differential weathering.

Chronostratigraphy. This deals with ages of different rock strata, both absolute and relative ages. Emphasis was on relative ages which deal with geometric relationships between rock bodies to determine the sequence of geologic events in an area as well as the direction of younging/ succession of different lithologies. It is based on the key principles of stratigraphy.

Biostratigraphy which is concerned with fossil evidence in rock layers.

Magnetostratigraphy dealing with detrital remanent magnetization.

Sequence stratigraphy basically on succession of genetically related strata.

Chemostratigraphy which is concerned with isotopic signature of sediments.

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

- **Principle of original horizontality**:

This principle states that layers of sediment are originally deposited horizontally, under the action of gravity.

- **Principle of superposition**

The principle of superposition states that in an undisturbed sequence of rock strata, the younger strata lie on top of older strata. These strata can be aligned in form of sheets, thin and/ or thick sheets of sedimentary rock that, as a group, are visibly distinct from those above or below.

- **Principle of cross-cutting relations**:

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.

- **Principle of lateral continuity**:

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.

❖ **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 L since the other aspects such as biostratigraphy, magnetostratigraphy, chemo-stratigraphy were not evident in area L. 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 L, reconstruction of ancient depositional environments of Area L and the generalized description of the stratigraphy of Area L in relation to that of the Karagwe-Ankolean system.

2.2 STRATIGRAPHY OF KARAGWE-ANKOLEAN

Wayland (1919) made a reconnaissance traverse across southern, south western and eastern Ankole, during which, he recognised and recorded silent points of the lithology and structure of the region. Thick massive argillaceous rocks, which show an increase in metamorphism towards the base, intercalated with thinner arenaceous rocks of quartzitic sandstone characterize the rocks of the Karagwe-Ankolean system (Ucakuwun, 1989). This succession has been intruded by granite. The system consists of shales and phyllites as well.

Combe in 1932 (p. 22 et seq.), described the Karagwe –Ankolean system as being a hilly area (ridges) with intervening area of lower relief normally occupied by metamorphosed rocks on the fringes with granites occupying the lowlands. Along the ridges, there are quartzites with argillaceous rocks occupying the slopes of ridges and also the valleys within and between ridges. Quartzites range in thickness from a few tens to hundreds of feet, and some six to eight horizons were recorded by Combe (1932). In the higher quartzites, original grains are often recognizable but bedding including current bedding is often difficult to detect, especially in the lowest quartzites. The lower quartzites show increasing recrystallisation and the lowest horizon is strong brecciated. Conglomerate pebbles of quartzite or quartz veins are not uncommon in the lower quartzite horizons.

Barnes (1956) characterized the lower Karagwe-Ankole division by arenaceous conglomeratic horizons with pebbles of quartzite and quartz veins. They are normally thin and more recrystallised, boudinaged, sheared or mylonitised and with limited primary structures. The middle Karagwe-Ankole division consists predominantly of grey colored banded argillites of mudstones and phyllites. The sandstone which forms the top of the middle group is highly ferruginous and carries slayers of micaceous, specular hematite which is in several meters thick. (King and De Swardt, 1967). The upper division shows great development of mudstones and shales. The argillaceous formations are often more quartzose than their appearance would suggest. Barnes (1956) applies the term "siltstones" to many of them and infers that considering bulk composition in the Karagwe-Ankole area as whole, the sediments become more arenaceous upwards. The limited arenaceous bands are relatively less compact with their original grains often recognizable (King and De Swardt, 1967).

Phillips (1959) identified quartzite horizons q_1 to q_4, of them q_4 being thickest which is underlying the Rugaga plateau and comprising of numerous quartzite layers interspersed with thin argillaceous bands.

Plummer (1960) described thinning of the quartzites on the NW limb of the Gayaza syncline east of the Mbarara-Kikagati road, up to the Stratigraphic level of the Rugaga quartzite (q_4), the rocks are fairly metamorphosed, but sometimes sedimentary structures are still recognizable.

Biryabarema (1995) stated that to the N and W in the area underlain by the Gayaza syncline the rocks of the Karagwe-Ankolean system are largely argillaceous with quartzites attenuating fairly abruptly

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 uncomfortably with the older schists of Buganda-Toro system or with the Gneisses-Granulitic complex in the eastern part of Ankole and in Buhweju plateau. (Schluter, 1997). The lowest exposed quartzite usually passes in schists which are in contact with the granites of the arenas. He further explains that in the 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.

Table 2; The three-fold lithostratigraphy of the K-A system in Uganda according to Cahen et al., 1984 and Rumyegeri, 1991

DIVISION	LITHOSTRATIGRAPHY
Upper K-A	Mudstones, siltstones, sandy mudstones, sandstones, grits and occasional conglomerates. Intercalations of quartzitic horizons q3, q4, q5 and q6
Middle K-A	Sandstones with occasional lateritic layers of micaceous haematite. Predominantly mudstones, arenaceous mudstones and phyllites. The more argillaceous rocks are characterized by colour banding in shades of grey, cream and pink.
Lower K-A	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.

2.3 LITHOLOGIC UNITS OF AREA L

Area L consists of quartzites which formed mainly the ridges at the hill tops, grey shale and ferruginous shale. Grey shales made up about 60% of the total area, ferruginous shales made up about 30% and quartzites composed of about 10%. Many quartzite floats were observed overlying the ferruginous shale. There were also some outcrops of conglomerates at some locations however they were quite small to be represented on the scale of the map.

2.3.1 Quartzite

A quartzite is a hard non foliated metamorphic rock composed entirely of quartz mineral. It is formed when a quartz-rich sandstone becomes altered by pressure, heat and chemical activity of metamorphosis. 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.

In area L, quartzite occurs on top of ridges and hilltops due to their resistance to weathering and erosion. Quartzites encountered in area L were mostly white to grey in color. There were some quartzites that had some red bands which is due to the presence of iron oxide ($Fe2O3$). This alteration in the color of the outcrop is due to impurities like water that make their way into the rock causing variations in color.

The quartzites were generally jointed also fractured and in some places intruded by hydrothermal fluids to form quartz veins. This is due to the past tectonic events that have occurred in the area like faulting. From this we are able to deduce that the granitic intrusions are younger that the quartzite in accordance to the principle of crosscutting cross section.

The quartzites were medium to coarse grained and in some cases crystallized quartz veins cut across them. The quartzite encountered are generally of low-grade metamorphism which is supported by the presence of relict bedding such as at location (251427, 991472)

Some of the Quartzite, due to prolonged periods of exposure and intensive reworking of the rock due to faulting, are laterised. Some of the laterite moved down where it mixed with clays in the valleys forming the laterite-clayey soils that supported agriculture in the area.

Figure 12: Quartzite which with relict bedding

2.3.2 Shale

Shales are defined as laminated, fine grained clastic sedimentary rocks, containing mainly silt and clay, with particles less than or two microns in diameter (Huang ,1962).

Shale forms from compaction of silt and clay-size mineral particles also called mud and hence shale sometimes is categorized as a mudstone. It is however different from other mudstones in that it is fissile (readily splits into thin pieces) and laminated.

They are formed under quiet environment such as a lacustrine condition whereby fine-grained sediments are deposited in the basin in a cyclic manner with the heavier sandy material that later formed sandstones and quartzite, a reason for intercalation with quartzite in some locations in area L.

It has a fissile structure due to orientation of clay mineral flakes therefore can split along laminations/bedding planes into thin layers and usually comprises of clay minerals, quartz and calcite.

Generally, shale is known to be grey though most encountered shales had shades of red, brown and yellow colors. The red shale owes its reddish-brown color to iron mineralization mostly containing minerals of hematite, goethite and limonite. The outcrops of this rock were few and mostly found in areas of vegetation cover.

A brief description of the different shale types encountered in area L is illustrated below;

- ✓ **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. The grey colour is as a result of the composition of the shale to consist mainly of clay minerals such as kaolinite, illite and other minerals. and the shade of grey depends on amount the clay and organic matter content.

Figure 13: Beds with grey shales in Area L

- ✓ **Ferruginous shales;** These are reddish brown in colour, owing their colour to the presence of iron in the form of iron (iii) oxide (Fe2O3). This reddish colour is an indication that oxidation affected certain parts of the rock containing iron minerals when exposed to atmospheric oxygen. They are slightly harder than the grey shales.

Figure 14: Ferruginous shale.

2.3.3 Conglomerate

Conglomerate a sedimentary rock formed from rounded gravel and boulder sized clasts cemented together in a matrix (Kulbe et al., 2001). These are poorly sorted coarse-grained sedimentary rocks composed of rounded fragments of diameter >2mm within a matrix of finer grained material. The cement that binds the clasts is generally one of either calcite, silica or iron oxide. The conglomerates encountered in area L had cement composed of iron oxide.

Conglomerates encountered in area L are believed to be younger than the quartzites around because they contain clasts of quartzites. Most of them are polymictic and matrix supported. The small outcrops of the rock were distributed as lens, scattered at far from each other. The outcrop was too small to be placed on the geologic map since the scale of the map is too big.

Figure 15: Conglomerate

2.4 GEOMETRIC RELATIONSHIP OF ROCK UNITS OF AREA L IN TIME AND SPACE

2.4.1 Unconformities/Time gaps

There were no time gaps encountered in area L 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 L, the shales occur at the base followed by quartzites that occur at the ridges. The contacts between the shales and the quartzites in area L are not well defined which implies that the sediments were deposited gradually.

The absence of unconformities in area L 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 L lies.

2.4.2. Horizontality

The beds in area L do not conform to the principle of original horizontality (see cross-Section below). Most of the beds in area L strike in the NE-SW with a SE dip ranging from 31°-40°. The dipping of these beds can be attributed to tectonic activity i.e., folding and faulting that took place in the area after deposition and lithification.

2.4.3. Successions and Age relations

During the mapping of area L, 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 L which would have been used in age relations made the correlation cumbersome.

2.4.4. Lateral continuity of the rock units

The different rock units in area L extend laterally for several square kilometres, cut into several discontinuous masses by the different episodes of tectonism forming ridges and valleys from what was originally a flat extensive formation. This is associated to later episodes of faulting related to the tectonic events that occurred in the region.

2.5 GEOLOGIC MAP AND CROSS-SECTION OF AREA L

The geologic map of area L was constructed using the GPS data obtained by traversing the quartizitic horizons at both the upper and lower boundaries.

From the geologic map, the lithologies encountered in area L can be identified as shown by their geologic colours that is the yellow for quartzite, grey for the grey shales and red for the ferruginous shales. Other lithologies such as conglomerates were also found in area L but occurred in lesser quantities thus 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.

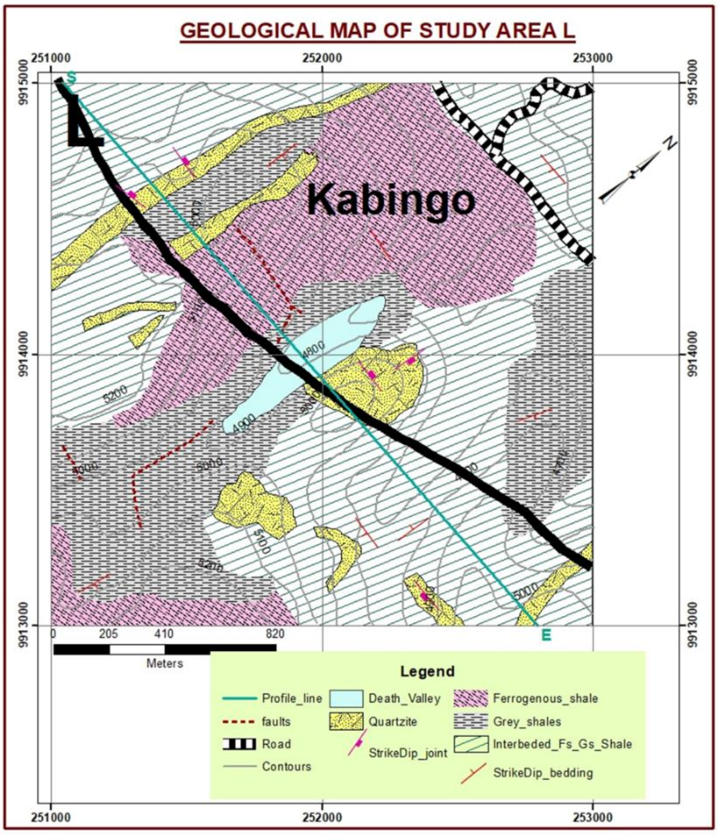


Figure 16: A Geological map of Area L showing the different lithologic units.

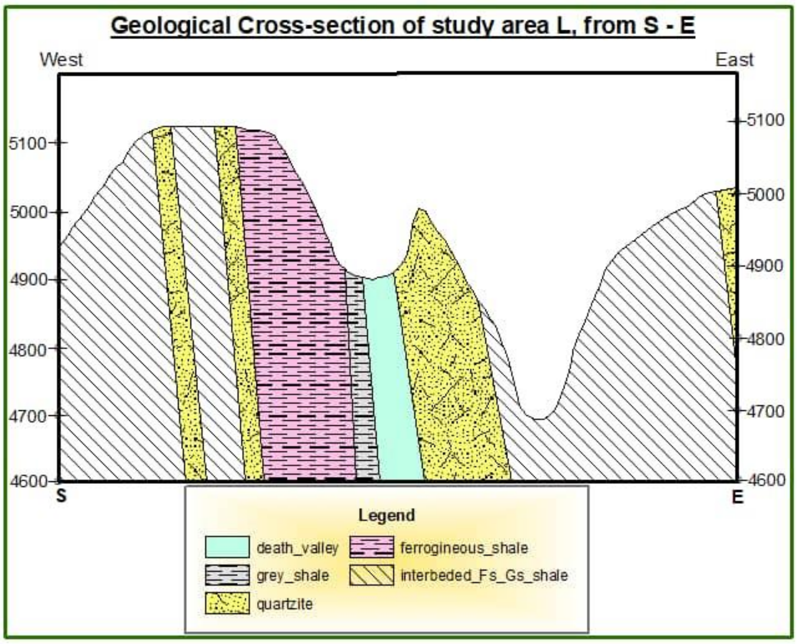


Figure 17: Geological cross section of area L from S-E

2.6 ROCK SUCCESSION

The rocks in area L are arranged in such a way that fine-grained sediments that constitute the shales were laid into the basin first followed by sandstones which as a result of burial and increasing temperature and pressure, were metamorphosed to quartzites. Conglomerates occasionally occur and are younger than the quartzites.

There is observable intercalation between shales and quartzite in some areas which is indicative of cyclic deposition of coarse grained and fine-grained sediments in the basin according to seasons.

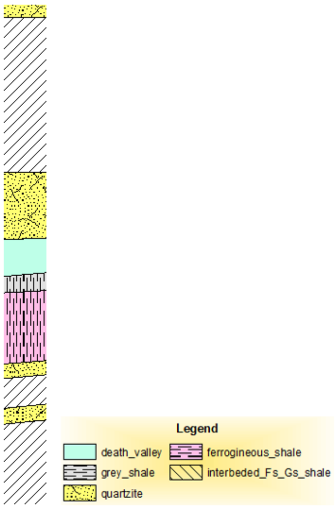


Figure 18: A Stratigraphic column showing rock succession in Area L

2.6.1 Comparison of The Stratigraphic Column of Area L And the Stratigraphic Columns of Karagwe-Ankolean System.

The stratigraphy of the Karagwe-Ankolean as modified after Combe, (1932); and Bugrov et al., (1982) has three divisions which include the upper division, the middle division and the lower division as earlier stated from the early works in table 1 above.

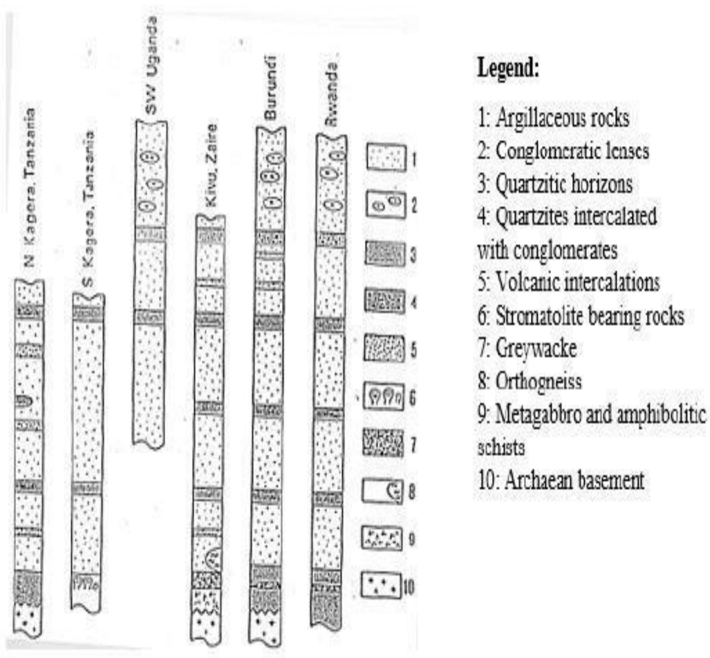
Area L lies within the lower division of Karagwe-Ankolean since it is made up of mainly grey to white shales, ferruginous shales and quartzite.

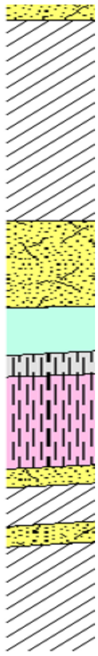
The quartzite horizons are intercalated with various argillaceous rocks and occurred on hilltops. The shales encountered in area L are dominantly of two categories that is Grey Shales and Ferruginous Shales.

The lithostratigraphic column of Area L consists of argillaceous rocks at the bottom that include clay-stones and shales synonymous to the middle division of the Karagwe-Ankolean. These are the most abundant rocks varying according to different estimates of the total sedimentary column. These are overlain by sandstones which metamorphosed to form quartzitic horizons which occur at ridges. These horizons consist of intensely fractured quartzites in some areas and low-grade quartzites in other areas with occurrence of relict bedding as the evidence. In some areas, the quartzites are intercalated with shales and in other areas they are intercalated with conglomerates.

The succession is then topped by argillaceous rocks that include grey shales and ferruginous shales which occur in lesser percentages compared to the grey shales.

In comparison with the stratigraphic columns of the Kibaran rocks, the lithostratigraphic column of Area L can be related to that of South-West Uganda which consists of argillaceous rocks, quartzitic horizons and conglomeratic lenses.





2.7 DEPOSITIONAL ENVIRONMENT

Both positive and negative criteria are used to infer the deposition environment. The positive benchmark includes deductions made from rock strata properties and characteristics observed in the field. On the other hand, the negative criteria include deductions made for the absence of critical properties and features expected in sedimentary rocks.

Positive criteria:

- Laminae have the potential to be preserved in reducing or toxic environments where organic activity is minimal. Therefore, according to this evidence, the possible depositional environments are terrigenous/continental environments such as deep lake environments. Deep sea environments are also possible. This is because both of these environments involve 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 general intercalation of argillaceous and arenaceous rock units in area L suggests that there were changing depositional environments for the rocks.

The quartzites in the area are medium to coarse-grained implying that the original sands from which the sandstones were subsequently formed had been transported by a relatively high energy transport medium such as an active river which was capable of carrying large pebbles and boulders. These were deposited in the aqueous or sub-aqueous part of a basin environment where at times sub aerial conditions prevailed.

The fine-grained shales were deposited first for a longer time given their large thickness. The depositional environment could have been low kinetic energy in quiet waters. The shales in the study area exhibit laminations which are characteristic of calm deposition by large rivers whose volume varied time to time in response to wet and dry seasonal changes. The fine particles were deposited, compacted and underwent diagenesis to form shales which were then metamorphosed to form slates and phyllites.

Two modes of depositions were proposed by Wayland, 1920.

i. The first of which is that the sediments were laid down in a large continental basin without connection with the ocean,

ii. The second being 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. This basin in which the K-A sediments were laid down approximates 26828 square miles.

The first mode seems the most plausible to support sedimentary deposition in study area L due to the presence of finely bedded shales of varying thicknesses whose deposition could not be favored by the currents mentioned in the second mode, but rather by a calm environment in the first while no connection to the ocean was envisaged, the main quartzite strata of the area were deposited in the sub-aqueous part of the delta. The rocks may have been subjected to intense tectonic forces that destroyed the fossils, hence no fossils have been observed.

2.8 GEOCHRONOLOGY AND AGE DATING

Since no fossils were encountered in the study area, it was difficult to tell the ages of the different lithologic formations. However, using radiometric dating techniques, absolute ages of rocks can be found. These were used by previous workers to approximate ages of the granites of southwestern Uganda.

Radiometric (isotropic) dating is an absolute age dating technique. Radioactive isotopes for instance uranium, thorium and potassium undergo systematic change with time by gaining or losing subatomic particles. All these reactions proceed as an exponential function of time, which can be characterized by the half time abundance of the parent nuclei.

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.

The Karagwe-Ankolean meta-sediments of Rwanda suggested that the age is 128 ± 40 Ma by using isotopic 23 dating according to Ucakuwun. The other workers included Cohen and Snelling (1984) who dated the granites using radiometric age dating techniques of Rubidium-strontium (Rb/Sr) and Potassium-Argon (K/Ar) isotopic ratios resulting into ages of 1201-117 Ma.

According to Vernon Chamberlain, the Masha granite dated 1972 Ma, Chitwe 119.5 Ma, Chabakonzo 939 Ma, Kamwezi 1201 Ma, Rwentobo 1318 Ma and Ntungamo 117 Ma. Macdonald grouped granites into I-type and M- type using Rb/Sr isotopic ratios. The granites were also grouped according to their relative ages into G1, G2, G3 and G4.

1. G1 granites: For example, is the Rwentobo (1318+ 84 Ma), Ntungamo (1170+/-66ma), Kamwezi (1201+134 Ma) and Lugalama (unknown age). These are the oldest granites and were formed syn to the late tectonic event.
2. G2 granites: An example is the Chitwe (1170±39Ma) and Chabakonzo (939±39Ma) granites
3. G3 granites: an example are the ultramafic rocks of Kabanga.
4. G4 granites: For example, at Ibanda, Dwata, Rwabaramira, Karenge (1000-900 Ma).

Table 3; The relative ages of granites of southwestern Uganda

Granites	Age (Ma)	Scholar(s)
Masha	1300	Phol.,1984
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

2.9 GEOLOGICAL HISTORY

Most of the rocks in area L are sedimentary though some are slightly metamorphosed. These rocks slightly underwent regional metamorphism and have also been affected by contact metamorphism that resulted from granitic intrusion. The compressional forces which affected this area led to formation of regional and cross folds. It also resulted into formation of axial planar cleavage in this same place. Tensional tectonics led to faulting and hence intense jointing in the rocks of area L.

Figure 19: Showing folds

The geochemical character of these granites is collisional (Rumvegeri & Katabarwa, 1990). The volcanic interlude followed the swallowing of the basin (Schluter, 1997) led to formation of the major Gayaza synclinorium.

Granites intruded anticlinoria between 1330 and 1250Ma (Schluter, 1997) and because of the composition of the unstable minerals under surface conditions, severe erosion on the granites took place resulting into topographic inversion. As a result, the original anticline is now a low-lying area known as the Masha arena and the syncline is now a raised ground.

CHAPTER 3: STRUCTURES

3.1 INTRODUCTION

Geological structures are fundamentally defined as geometric features in rocks whose shape, form and distribution can be described (Ben et al., 2004). Geologic structures are usually the result of the powerful tectonic forces that occur within the earth.

This chapter describes various geologic structures found in mapped area L. It includes a detailed descriptive account of all the structural geology information obtained from field observations, laboratory structural data analysis, and structural (cross-section) profiles.

Structures are the larger, generally three-dimensional physical features of rocks; they are best seen in outcrops or in large hand specimens rather than through a microscope.

These structures encountered in the area, have been categorised into primary and secondary structures. Primary structures are those that were formed at the same time the rock was being formed. These generally include beddings, lamination and ripple marks whereas secondary structures are structures reflecting subsequent deformation or metamorphism i.e., were formed after deposition of sediments. Such structures include; joints, faults, folds, cleavage, and foliation (Bruce et al, 1976).

These structures can be further categorised into minor and major structures. Major structures are those that are extensively distributed for example folds, faults and beds whilst minor structures are those that are not common and are sparsely distributed rock units for example, cleavage, laminations, crenulations and quartz vein.

Application of geologic structures include the following:

- ❖ They aid in determining the relative ages of the structures e.g., folding can predate faulting in juxtaposed fold lithologies and obtaining relative ages of rocks in which they occur.
- ❖ Determine the way up or stratigraphic succession of the area.
- ❖ Obtain on paleocurrent flow directions as well as the energy of the transporting medium.

Economically, structures are exact points for mineralisation for example deposits of gold, silver, copper, lead, zinc, and other metals. They also aid in petroleum exploration. 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 L.

Table 4; Summary of structures in Area L

TYPE	CATEGORY	
	Major Structures	Minor Structures
Primary Structures	Bedding planes	Laminations
Secondary Structures	Joints	Faults, boudins, folds.

3.2 STRUCTURAL DATA (FIELD MEASUREMENTS)

This section of the chapter presents the measurements of some geological structures encountered in the field. These measurements mainly include the positions of the planar structures such as joints/faults and bedding planes. The orientations of quartz veins encountered in the field were also noted. General trends of some of these structures were also derived from the measurements performed. All the strikes and dips of the joints and bedding planes are also shown in appendix 1 and 2 respectively. Distribution of some of these structures are their orientations is indicated in the geologic map of area L in chapter two above.

Different measurements such as strikes, dips and plunges of structures, thickness of the beds, width and length of veins were made for structures like beds, joints, faults and folds.

a) **Joint measurements**:

Measurements of strike and dip of joints were made with the aid of a geologic compass and the results were summarized in the table shown in Appendix 1.

b) **Bedding plane measurements**:

The strikes and dips of bedding planes were measured using a geologic compass and the results were summarized as indicated in a table shown in Appendix 2.

3.3 STEOREOGRAPHIC 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. Therefore, below is 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 are the forms of stereographic projections used for the analysis and these were obtained by use of a computer software called Stereonet and Georose a free license computer software downloaded from internet.

3.3.1. Stereographic Analysis of Joints

- **Rose Diagram**

In a rose diagram, the petals are parallel to the strike/trend of the planar structure-joints in this case. The width of the petals is a constant interval of 100 and the length of the petals gives the total number of the planar structures encountered in the project area within a given range of strike readings in the 100 intervals.

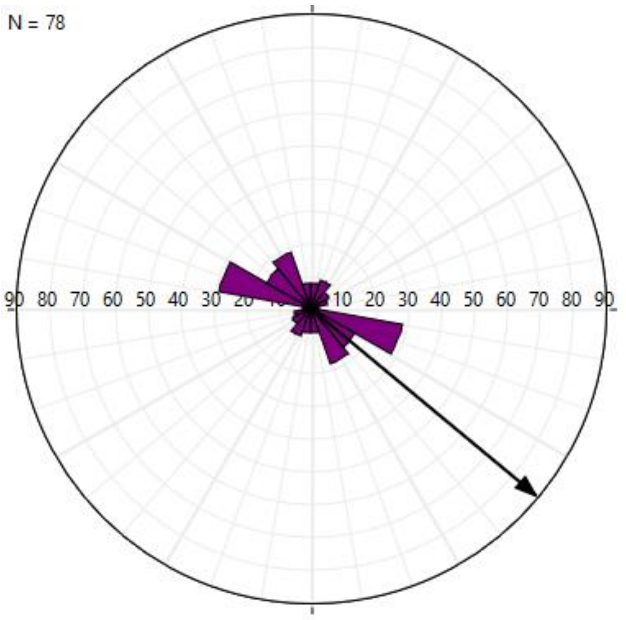


Figure 20: Rose diagrams showing strike directions of the joints encountered in area L

The joints showed two major trends, the dominant one being the NW-SE trend evidenced by the mean vector arrow, corresponding to the regional fold trend and also implying that the stress field was striking in the SE direction based on the structural configuration of the Karagwe-Ankolean in southwest Uganda, Stheeman (1932) and Ucakuwun (1992) and the minor trend being the NE-SW, corresponding to the cross-fold trend.

- **Contour and Density Diagram**

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.

The density and hence the contour diagram were both obtained from poles calculated from planar joint measurements by the stereo net win 64 software as shown in figure below;

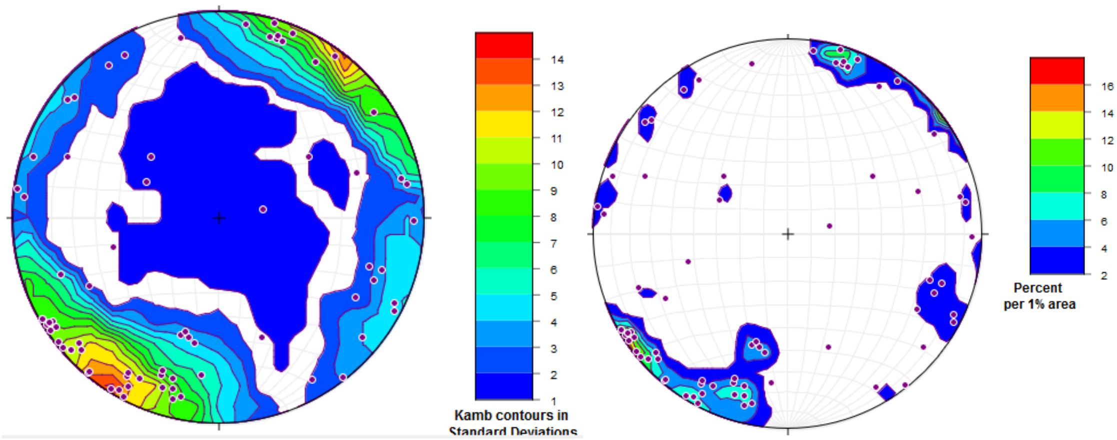


Figure 21: Density and contour diagram showing preferred orientations of joints encountered in area L

From the contour diagram, we can see that the main joint set is dipping towards the SW and the minor joint set in the NE evidenced by two bulls eyes. The poles are more concentrated in the NE and SW hence confirmation of the general NW-SE trend which is suggestive of the regional folds.

3.3.2 Stereographic Analysis of Bedding Planes

- **Rose Diagram**

As stated earlier, bedding was evident and more pronounced in shale lithology although in rare cases some (relict bedding) occurred in the quartzite.

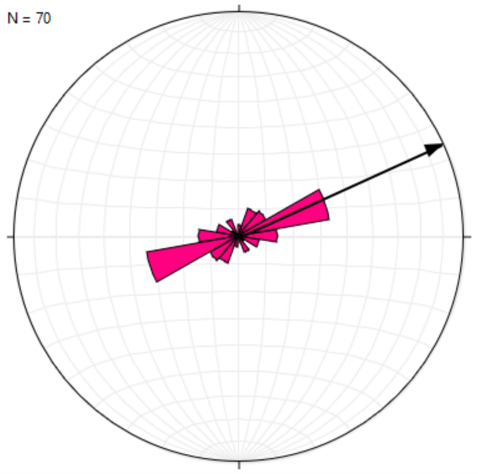


Figure 22; Rose diagram showing the different strike directions and trends taken by beds in area L

From the stereographic projection above it can be seen that, the beds have a general strike (orientation) of NE-SW, at an average angle of 70^0 and a general dip in the NW-SE direction. A few beds are seen to deviate from this trend, and this could be a result of disturbances due to fault movements.

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

- **Contour and Density Diagram**

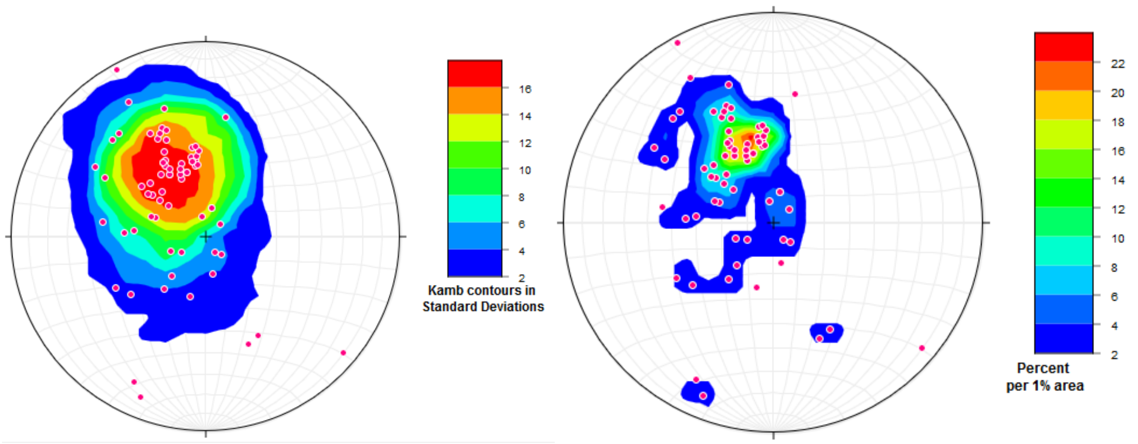


Figure 23: Density and contour diagram showing preferred orientations of beds encountered in area L

The contour diagram illustrates the concentration of the beds measured within the study area on the stereogram, most of the beds plot close to the centre of the sphere implying they are gently dipping. This could imply that the measurements of the orientations of the bedding planes were taken close to the axis of a fold.

3.4 DESCRIPTION OF STRUCTURES

This section of the chapter deals with a detailed description of each of the structures given in the first section of the chapter. Different structures were encountered in area L. Orientations (strike and dip) were taken for joints and bedding and subjected to stereographic analysis as already seen in the preceding section. Other measurements were taken in the field for the joints and bedding and other structures as well. As will be seen later, the structures will be employed in attempt to explain the geologic history of the mapped area. The structures encountered in area L were both primary and secondary which were further subdivided into major and minor structures based on the criteria already given in the first section of this chapter. Below then is a detailed description of the structures which include; Bedding, joints, fault, folds, fissures and boudins and laminations.

Structural data was obtained by the following procedure;

- ✓ A station was established on an outcrop of interest
- ✓ At the established station, observations, field description of the structures and features of interest were carried out. Description involved noting the dominant structures seen at the outcrop.
- ✓ Measurements of the structural trends (strikes, dips and plunges of the structures, thickness of beds, width and length of veins) were done at the outcrop and observations made.
- ✓ These measurements were achieved by the use of a compass (for strike, dip and plunge) and a ruler (for thickness).
- ✓ We then used these measurements in constructing the rose diagrams, contour diagrams and great circle diagrams on a stereonet for the structures of the area mapped in the field.

3.4.1 Major Structures

- ✓ **Bedding**

A bed is the smallest lithostratigraphic unit, usually ranging in thickness from a fraction of a centimetre to several meters and distinguishable from beds above and below it. Bedding therefore can be described as the layering in sedimentary rocks of varying thicknesses and character thus from massive layering to delicate and thin laminations and follow the principle of original horizontally.

In Area L beddings were well established in the shales, while we had some relict bedding occurring in quartzites. The thickness of the beds ranged from 1cm to several metres thick with differing texture depending on the regime of deposition.

Intercalations of the arenaceous and argillaceous rock layers which was evidence of the varying velocities in the current of deposition (i.e., during the episodes when the current velocity was high, sediments with coarse grains like sands were deposited and on reduction in the current velocity in another episode, much finer sediments like the clays and silts were deposited).

Generally, the beds strike in NE-SW and dip in SE. The dip angles of the beds change along the length of the bed but the direction remains consistent. The angles of dip vary from the axis of the syncline towards the arena. Around the axis of the synclinorium, the beds are almost horizontal with very low dip angles, the angles of dip increase towards the apex of the limb as the arena is approached.

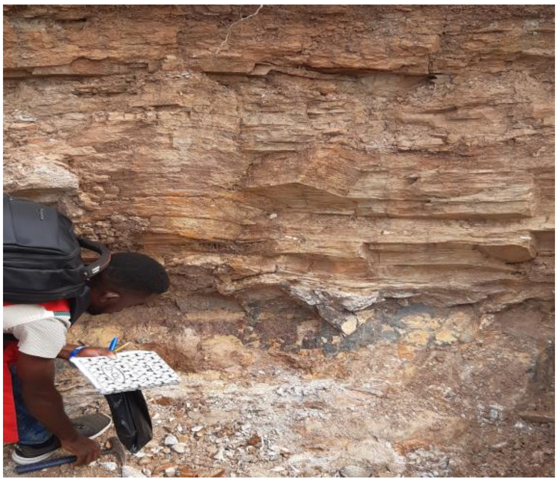


Figure 24; Bedding

- ✓ **Joints**

A joint is a break or fracture of natural origin in the continuity of either a layer or body of rock that lacks any visible or measurable movement parallel to the surface (plane) of the fracture. Although they can occur singly, they most frequently occur as joint sets and systems. A joint set is a family of parallel, evenly spaced joints that can be identified through mapping and analysis of the orientations, spacing, and physical properties. A joint system consists of two or more intersecting joint sets.

Joints are formed by tectonic processes such as folding and faulting acting upon brittle rocks forcing them to undergo brittle deformation i.e., in quartzites and ferruginous shales than in ductile pure shales. These structures are therefore present in all the rock types but since they are mainly a result of brittle failure as some deformational forces act on rocks in a given location, they are more pronounced in the hardened formations for instance the quartzites, slates, phyllites and even the shales (the would-be soft formations) that have been intruded by hydrothermal solutions like iron oxide that percolated from beneath in the subsurface forming ferruginized shales. These formations are hard enough as to attain a certain degree of brittleness and thus the joints can be located among these.

In area L, there are two joint sets, the major striking in the NW-SE corresponding to the regional fold trend of the Karagwe-Ankolean rocks. and dipping in the NE. The minor set striking in the SE and dipping in the SW.

Figure 25; A jointed Quartzite Outcrop and a jointed shale outcrop

The Joints had narrow apertures ranging from a few millimetres to about 20 centimetres, and these were filled with soils, weathered rock fragments, and at times quartz and hematite intrusions especially in the shales. Some of these joints extended deeper into the underlying lithologies while others were less penetrative. This is attributed to the folding and faulting that occurred in the area whereby the fractures that originally existed in the area prior to the folding were made even deeper and wider, after the folding and fracturing episodes.

- ✓ **Faults**

A fault is a planar fracture between two blocks of rock which shows relative displacement of one or both the blocks, parallel to the fracture plane due tectonic stress. Faults occur when stresses (tensional or compressional forces) overcome the internal strength of the rock.

Area L is dominated by fault zones and gouges due to the tectonic episodes in the area. But the major being a strike-slip fault which is a fault where the blocks move left or right relative to each other. This is evidenced by the fault raptures and the relative displacement of the quartzite ridge leftward and rightward relative to each other.

Some of the clues we look for identifying faults included:

- ✧ The presence of fault breccia which is associated with the intense process of shearing that is caused by the fault as it traverses an area. Fault breccias are angular or subangular quartzite fragments grinded due to friction and cemented together by iron oxides between two rock blocks during faulting.
- ✧ Linear pattern of vegetation especially in valleys due to presumed abundance of ground water in fault lines.
- ✧ Nearly straight scarps that trend some-what uphill or downhill.
- ✧ The presence of spring lines along the valley because the fault exposed the ground water level and hence water seeps to the surface. All this point to the presence of a fault trending in the NW-SE.

Figure 26; A Fault where the vegetation is abundant

3.4.2 Minor Structures

✓ **Quartz veins**

Veins are distinct narrow bands of crystallized minerals within a rock. Veins form when mineral constituents carried by an aqueous solution within the rock mass are deposited through precipitation where they solidify along lines of weakness in the shales and quartzites. The major veins in the area are those of hydrothermal iron-rich solutions and also of quartz rich material that fill the spaces between the formations for instance through the joints and fractures. These veins are usually younger than the host rocks in which they are emplaced.

Veins are widely spread in the joints of most of the jointed and fractured rocks, particular the brittle quartzites. Their trends are closely related to the trends of the joints (NW-SE)

Figure 27; Quartz vein within a Quartzite rock.

- ✓ **Folds**

Folds are secondary geologic structures that form when planar surfaces of rocks deform by bending instead of breaking under compressional stresses. Folds form as a result of the ductile deformation of originally planar surfaces to form non-planar surfaces. Minor folds as the one encountered in area L are usually described as drag or parasitic folds-smaller scale folds, which develop on the limbs or hinges of larger scale folds. In the Karagwe-Ankole system, minor folding has been postulated to form due to incompetence during regional folding or by differential movement between quartzites, which are closely spaced.

Figure 28; Micro folds in area along fault scarps

3.5 DISCUSSION

The tectonic events that were associated with the formation of the East Africa Rift System led to the thinning of the crust and most likely must have initiated or created vertical and sub-vertical fractures in the attenuated crust without triggering rifting known as extensional tectonics

This later formed an elongated basin in which sedimentation took place. The deposited sediments led to the formation of the beds which were laid down horizontally obeying the law of horizontality in the initial stages but were turned to different angles of dips after some time relative to the tectonic episodes that came in thereafter.

Depending on the burial depth sediments and the underlying crust were subjected to different metamorphic conditions of low-grade regional type. Compressional tectonics later occurred in the northwest-southeast direction. There was no significant regional thrust indicating a relatively low compressive stress. These 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 which trend is similar to that of the faults.

Most of the structures such as the faults, folds, joints, beds and the associated mineralization such as the quartz in the joints are all expected to have been triggered by the tensional and the compression tectonic events that affected the area.

CHAPTER 4: PETROGRAPHY AND METAMORPHISM

4.1 PETROGRAPHY

4.1.1 Introduction

Petrography is a branch of petrology that focuses on the detailed descriptions and study of rocks. It is an in-depth investigation of the chemical and physical features of a particular rock sample and microscopic description of their respective thin sections based on the optical properties of the constituent mineral grains. The mineral content and the textural relationships within the rock are described in detail.

The classification of rocks is based on the information acquired during the petrographic analysis. Petrographic descriptions start with the field notes at the outcrop and include macroscopic description of hand specimens. However, the most important tool for the petrographer is the petrographic microscope. The detailed analysis of minerals by optical mineralogy in thin section and the micro-texture and structure are critical to understanding the nature and origin of a rock.

Representative samples of the rocks from these outcrops were then obtained, described using an unaided eye and hand lens at some instances and appropriate field names assigned to the rocks (macroscopy). These samples were further described microscopically by analysing their thin sections obtained from the geologic laboratory.

This chapter therefore summarizes the petrographic study of selected representative samples highlighting the outcrop descriptions, the macroscopic description, microscopic description and metamorphism of the rocks from area L. The detailed microscopic descriptions of the samples have been provided in the appendix.

Petrogenesis and petrography are the two branches of petrology.

Petrogenesis: This deals with the origin of rocks that is how they form and their history. It also covers the processes that the rocks have undergone since their formation.

Petrography: It is the descriptive part of petrology that handles the composition of rocks, their textures, mineralogy and chemistry. The identification of minerals constituting a rock can be done in the field by eye or using a hand lens. Very fine-grained rocks or those that contain glass can be studied using the petrographic microscope.

Uses of petrographic analysis

- Petrographic analysis can give a great deal of geological information, from which we can infer the conditions of rock deposition for the case of sedimentary rocks, and conditions under which metamorphism occurred, for the case of metamorphic rocks.
- Petrographic analysis on rocks with structures such as ripple marks and beds can give clues on the depositional history of sedimentary rocks.

4.1.2 Descriptions of Rock Outcrops in The Field

During the field study, samples were collected and 5 were selected and analysed in the laboratory. A total of 17 outcrops were visited and studied during the mapping exercise in area L. These were identified and named consecutively from L1 to L17.

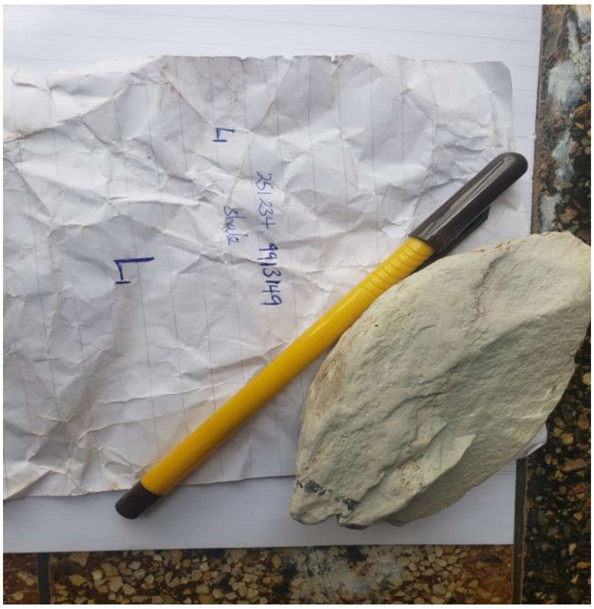
The descriptions of 5 outcrops from which the rock samples were collected are given below;

OUTCROP	LOCATION	DESCRIPTION
L1	251234E,9913149N Hill	Large natural highly weathered outcrop. It undergoes low grade metamorphism which increases downslope due to presence of hydrothermal iron-rich fluids. Chemical weathering of the grey shale resulted in a reddish-brown shale on top of the slope.
L8	252297E,9914334N From the slope of the hill downhill to the valley then to the other side of the hill.	Large grey shale located along a slope of the hill. Presence of clay minerals which are highly physically weathered.
L13	252484E,9913092N	Large naturally exposed highly weathered outcrop. With both physical and chemical weathering processes due to reddish-brown shale suggesting that the chemical weathering was to a small extent. No cementing material was observed.
L14	252307E,9913355N	Very large natural weathered outcrop
L15	252167E,9913314N	Large shale outcrop, which is highly physically and chemically weathered.

4.1.3 Macroscopic and Microscopic Analysis of Samples

4.1.3.1 Sample L1

Sample field name: Grey Shale



MACRSOCOPY

Colour- pale grey, white

Texture-Aphanitic

Sorting-well sorted

Grain size- fine grained

Mineral composition-clay minerals, quartz

Figure 29: A hand sized sample of L1

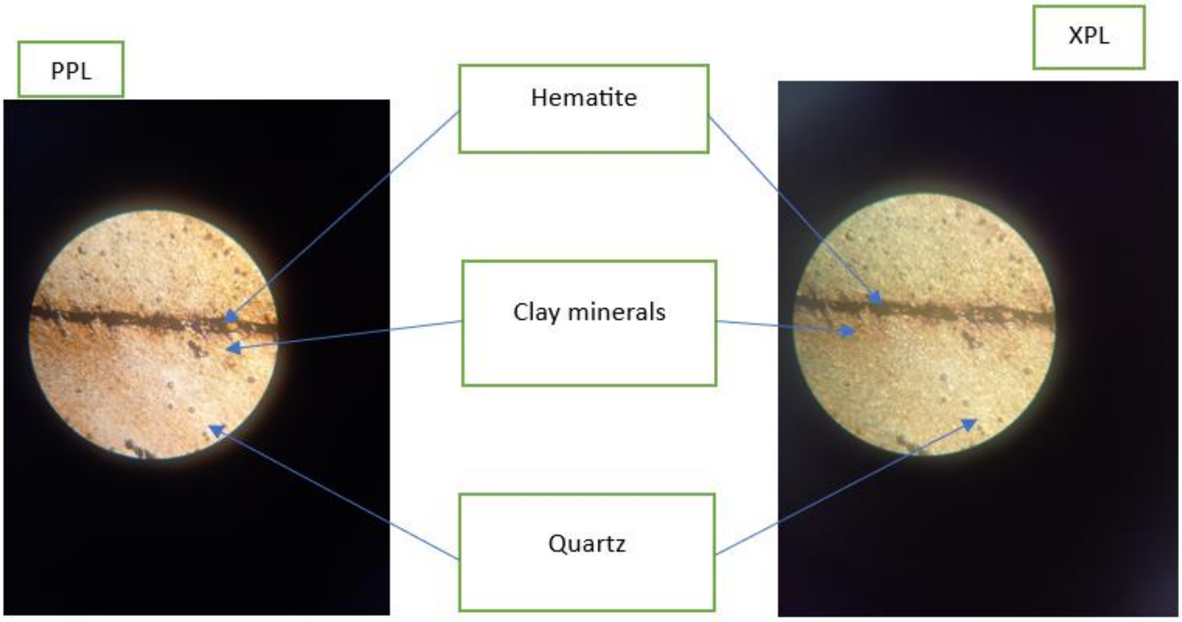
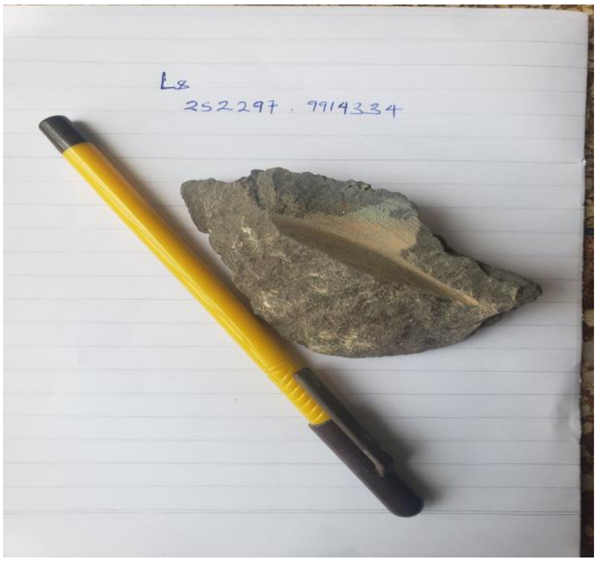


Figure 30; Photomicrographs of sample L1 XPL (left) and PPL (right)

Minerals	Model mineralogy by volume percentage	Rock name
Clay minerals	~60%	Siliceous grey Shale
Quartz	~25%	
Hematite	~15%	

4.1.3.2 Sample L8

Sample Field Name: Grey Shale.



MACRSOCOPY

Colour- Dark grey

Texture- Aphanitic

Sorting-well sorted

Grain size-Fine to medium grained

Mineral composition-clay minerals

++

Minerals	Model mineralogy by volume percentage	Rock name
Magnetite	~5%	Siliceous grey shale
Quartz	~25%	
Kaolin	~60%	
Hematite	~10%	

Macroscopic description of L8

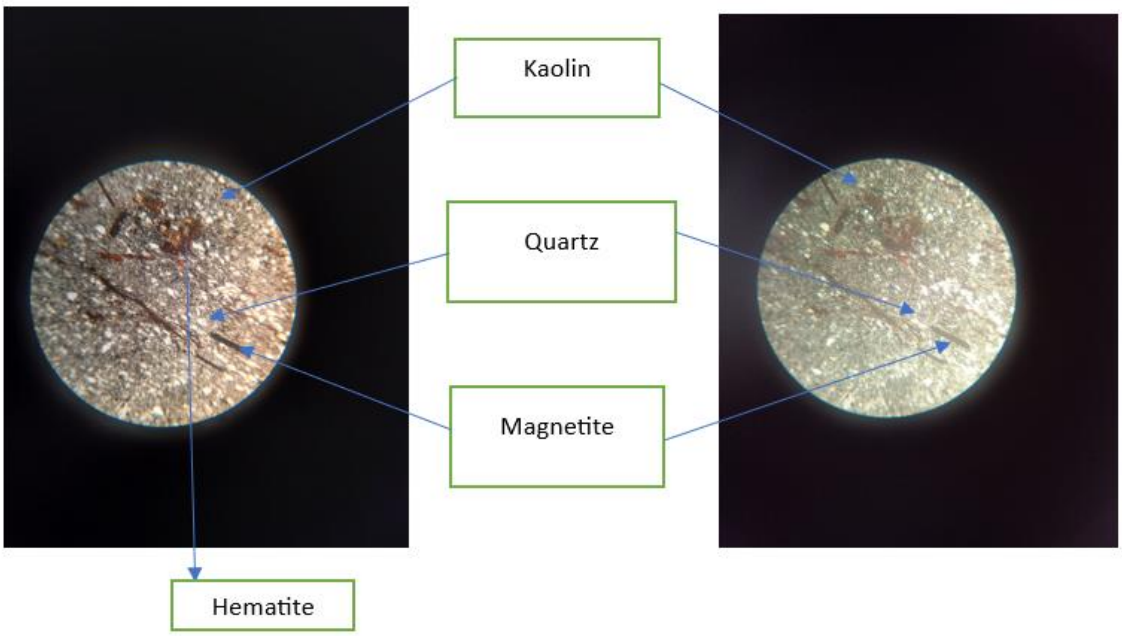
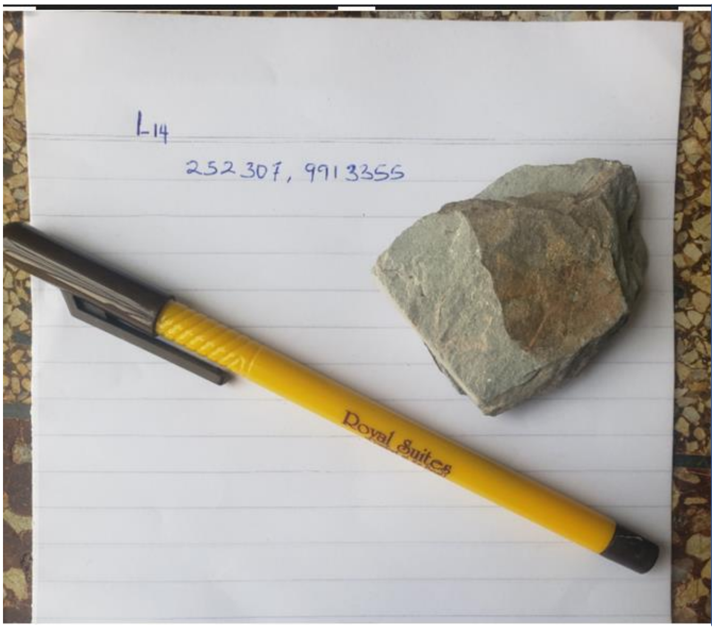


Figure 31; Photomicrographs of sample L8 PPL (left) and XPL (right)

4.1.3.3 SAMPLE L14

Sample field name: Grey shale



MACROSCOPY

Color - grey, white

Texture - Aphanitic

Sorting-well sorted

Grain size-fine grained

Structures- bedding

Mineral composition-clay minerals quartz,

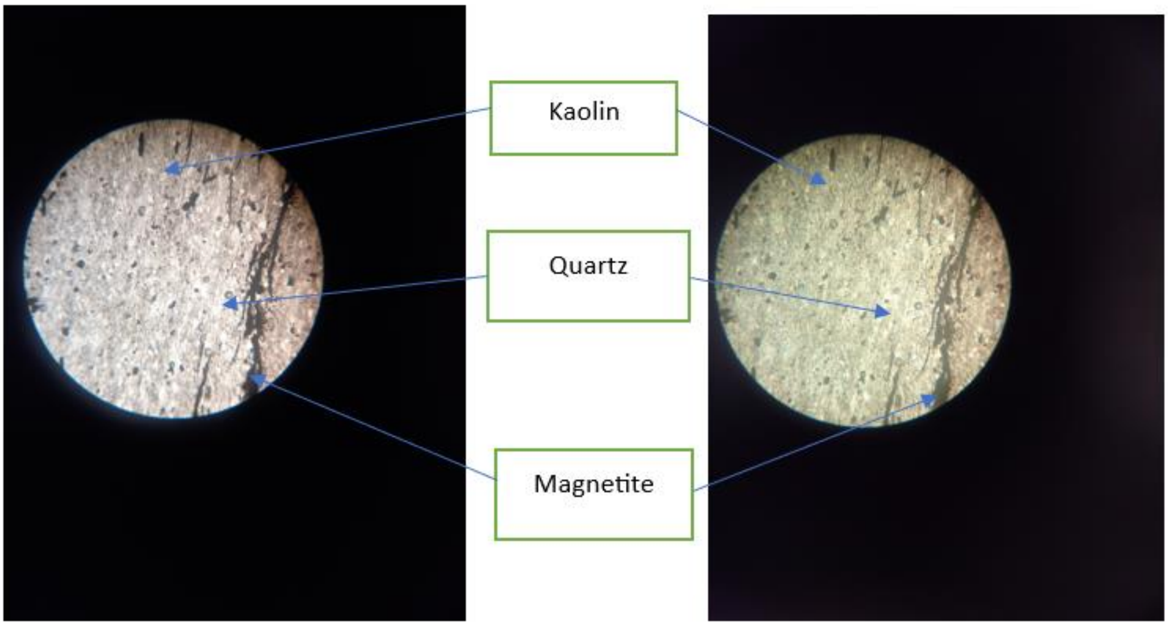
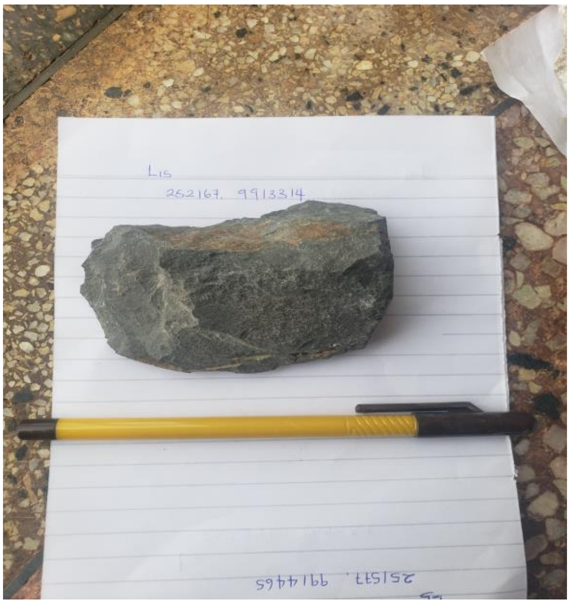


Figure 32; Photomicrographs of sample L14 PPL (left) and XPL (right)

Minerals	Model mineralogy by volume percentage	Rock name
Kaolin	~50%	Siliceous grey shale
Quartz	~40%	
Magnetite	~10%	

4.1.3.4 SAMPLE L15

Sample field name: Grey shale



MACROSCOPY

Colour – grey, white

Texture - Phaneritic

Sorting- moderately sorted

Grain size- fine to medium grained

Mineral composition- clay minerals, quartz, biotite

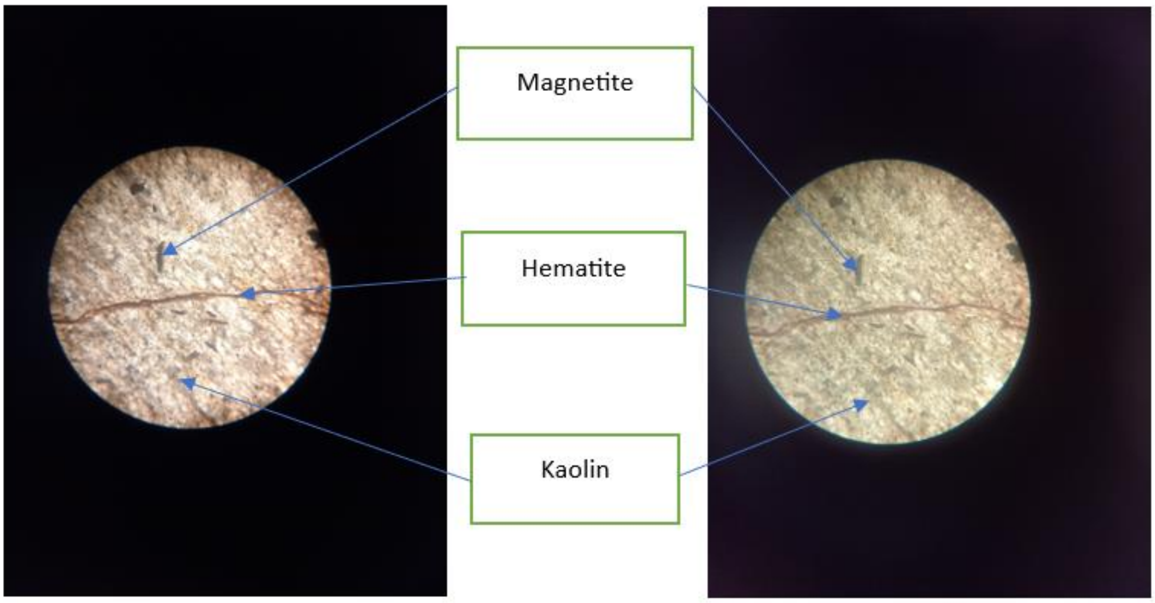
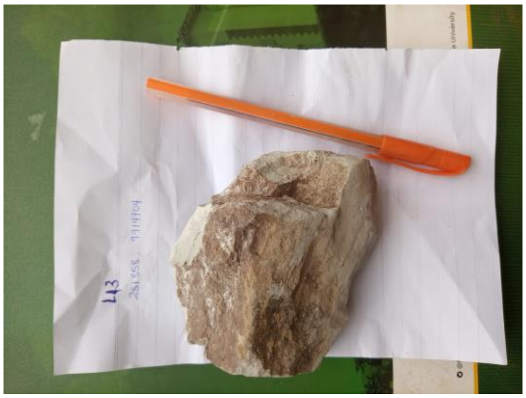


Figure 33; Photomicrographs of sample L15 PPL (left) and XPL (right)

Minerals	Model mineralogy by volume percentage	Rock name
Magnetite	~5%	Siliceous Grey shale
Hematite	~15%	
Kaolin	~60%	
Quartz	~20%	

4.1.3.5 SAMPLE L13

Sample field name: Grey Shale



MACROSCOPY

Colour - grey

Texture - Aphanitic

Sorting-good sorting

Grain size-fine grained

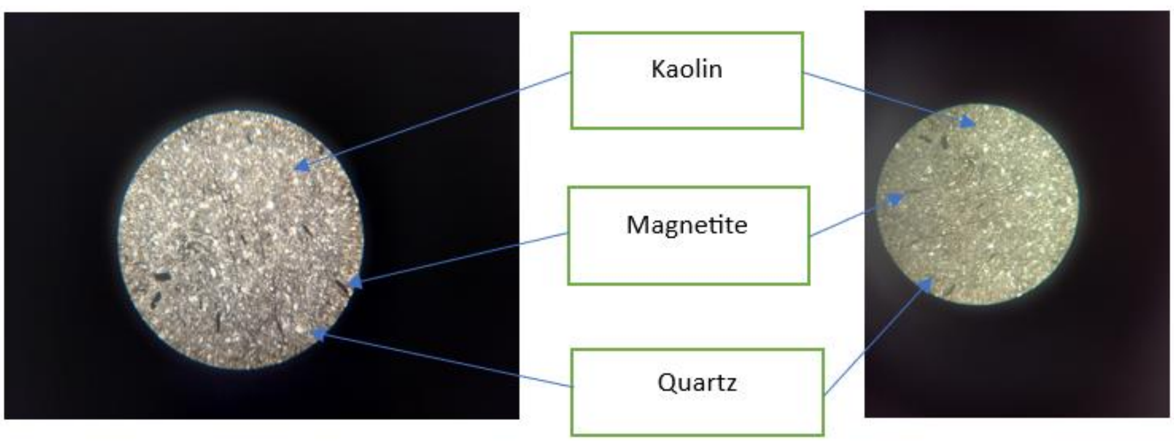


Figure 34; Photomicrographs of sample L13 PPL (left) and XPL (right)

Minerals	Model mineralogy by volume percentage	Rock name
Kaolin	~50%	Siliceous grey shale
Quartz	~30%	
Magnetite	~20%	

4.2 METAMORPHSIM

4.2.1 Introduction

Metamorphism is a process by which pre-existing rocks either sedimentary, igneous or even already metamorphosed rocks change form, mineralogy and/or chemical composition when subjected to conditions of temperature, pressure and fluids activity different from those under which the rocks originally were. (Myron G.B, 1982). The process of metamorphism is driven by changing physical and/or chemical conditions in response to large-scale geological dynamics.

Metamorphism does not include by definition, similar processes that occur near the earth's surface such as weathering, cementation and diagenesis. Two limits of metamorphism exist namely; low temperature limit and high-temperature limit. At low-temperature limit the process grades into diagenesis and at high-temperature limit it merges with partial melting as anataxis. Different rock types may have different limits, that are the more hydrous, porous, permeable, polymineralic rocks are most susceptible (shales, volcanic tuffs) and fine-grained size and immature material is highly susceptible to alteration even at low grades, hence the onset of metamorphism may differ from rock type to rock type. The factors which cause metamorphism includes increase in temperature, increase in pressure, deviatoric stress which causes strain and influx of fluids. There are various types of metamorphism which occur in rocks.

4.2.2 Types of metamorphism

Regional metamorphism

This mainly occurs at deeper levels of the earth's crust and affects wide areas of tens to hundreds of kilometres in width due to a steep thermal gradient of an extensive region. The thermal gradient is a result of the increasing heat and temperatures with increasing depth of burial, the heat itself being derived from: (i) Radioactivity within the earth's interior, (ii) Hot juvenile fluids, (iii)Magma rising above an active subduction zone (iv) A combination of the above. Rocks affected by regional metamorphism tend to outcrop in Precambrian shields and in the eroded roots of great fold mountains. There are two categories of regional metamorphism:

- *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 250ºC typically for blue schists. Rocks of this type of metamorphism occur in thick piles of hydrous sediments or fragmental volcanic material such as tuffs. 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 at 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.

This is due to impact of large, high velocity meteorite bodies 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.

Contact metamorphism (thermal metamorphism)

It occurs in the vicinity of plutonic or extrusive igneous bodies. Hence it is a localized phenomenon as opposed to regional metamorphism. Little or no deformation takes place and therefore new minerals form at random. The characteristic products are termed as hornfels. The zone around an intrusive body with in which the effects of contact metamorphism can be noted is called a contact aureole. Contact metamorphism is mostly pronounced in relative hydrous rocks such as politic sediments (shales) and limestones.

4.2.3 Metamorphism of Karagwe-Ankolean System

The Karagwe-Ankolean rocks have undergone various degrees of metamorphism including regional, contact and dynamic metamorphism (Barnes 1956)

The sandstones have been metamorphosed to quartzites, and conglomerates have been metamorphosed and pebbles flattened while shales have been metamorphosed to slates, phyllites and schists in some areas especially in the west. (Combe 1932)

The metamorphic grade generally increased significantly towards the base of the Karagwe-Ankolean System, in most places a progression from mudstone and shales through slates, phyllites (with sericite and chlorite) to schists (with muscovite and biotite) to the base of the succession is noted. The increase in grade also corresponds to increasing proximity to granites of the Arena. Contact metamorphic minerals are also present due to proximity to the granitic rocks. Low grade metamorphic assemblages represented by actinolite, tremolite, chlorite-mica schists and biotite-epidote schists characterise the Konse Series of

Central Tanzania. The chlorite (green mineral in the thin sections) is thus representative of low-grade metamorphism in some parts of the area. Similarities in lithology have suggested a correlation with the Karagwe Ankolean. Recognition of true metamorphic grade is hindered by intense weathering.

4.2.4 Metamorphism of study area L

The metamorphic grade of the rocks in area L was studied basing on the mineralogy, texture and structures of the rocks. Some rock samples and rock outcrops especially quartzites, showed relict bedding which suggested that they were of low-grade metamorphism. The facies and the assemblages of rock forming minerals analysed both macroscopically and microscopically, rule out the possibility of occurrence of retrogressive metamorphism, and emphasizes low grade metamorphism. The low regional metamorphic grade of the rocks in area L was also revealed by;

Type of Metamorphism	**Grade of metamorphism.**	**Petrographic evidence**
Regional metamorphism (Due to burial)	Very low to high grade	Initial development of platy minerals (micas) Wavy extinction in quartz in sample L13, L8 and L14 thin section.
Dynamic metamorphism	Medium grade	Wavy extinction in quartz in thin section of sample L8, L13 and L14
Contact metamorphism	Medium-High grade	Granite within the arena

4.2.5 Progression of metamorphism

Metamorphic grade progressively increases with increase in stratigraphic depth and proximity to granitic intrusion in the arena. The rocks encountered in contact with the arena are more foliated compared to those far away from the arena.

4.3 Discussion and Conclusion.

The petrographic analysis of the samples indicates the most dominant minerals are quartz and clay minerals while minor minerals include hematite and magnetite. And most rocks are fine-grained except for quartzites.

This analysis also gives evidence of low-grade metamorphism (presence of chlorite index mineral and wavy extinction in quartz grains) which is consistent with the works of many previous geologists. For example, Pohl (1987) asserted that that the metamorphism is generally of a regional nature and is largely of low grade. From rocks of very low grade in the synclinorium, a steep gradient is obvious towards large batholithic granites in the arena hence the metamorphism increases with stratigraphic depth and with proximity to the granite intrusions. Consequently, the sediments noted adjacent to the arena floors are commonly the most metamorphosed and the metamorphic grade is medium.

The reason why the grade of metamorphism increases with depth and proximity to granitic intrusion is because with these factors, the temperature and pressure conditions increase and hence accelerating the rate of metamorphism.

CHAPTER 5: REGIONAL SYNTHESIS

5.1 Introduction

This chapter compares all of the outcomes from all of the map regions. With regard to lithologies, stratigraphy, structures, topography, drainage, and economic potential, we specifically compare our mapped area L to the other mapped regions (A, B, C, E, G, I, J, and H) in the Igayaza region and the broader Karagwe-Ankolean, as well as to earlier research. These characteristics are explained, the formation processes are examined, and a conclusion is reached based on a comparison of in-field observations and prior research.

With UTM coordinates of Eastings (0252000-0254000) and Northings (9915000-91700), the Igayaza area is located in the Isingiro district in the southwest of Uganda. It is made of mid-Proterozoic group of rocks, which date back to about 1400-950Ma and include quartzites, shales (including grey and ferrigenous shales), granites, conglomerates, laterites, and phyllites in some areas. One of the most notable geological features in Central and Eastern Africa is the Proterozoic Kibaran orogenic belt, which includes the Igayaza region. Between 1400 and 900 Ma, the belt is believed to have developed as an intra-continental orogen. Field research in the area reveals that the underlying lithology's resilience to weathering and fold structure have a significant impact on the topography. Two significant fold trends and thrusting have both had an impact on the formations (Barnes, 1956).

Table 5: Showing a summary of information obtained from different groups.

Group	Location	Description	Rock Type	Structures	Metamorphism
A	(252077, 9915938) 1385m	Large artificial outcrop	Quartzites Conglomerates Ferruginous phyllitic and grey shale	Bedding, Joints Faults (both major and minor). Veins Fractures	Low grade metamorphism.

B	(255610, 9918246)	Natural, highly weathered outcrop	Quartzites Conglomerates Ferruginous phyllitic and grey shale Mica schists and granites.	Boudins folds (both regional and cross folds). Axial planar cleavage. Joints	grade of metamorphism in rocks increased downwards towards the arena
C	(257259, 9917455) 5140m	Large weathered outcrop	Quartzite, red shale, grey shale	Microfolds Micro faults Bedding planes joints	
E	(256123, 9916554) 1474m		ferruginous and grey shale on the slopes and phyllitic shale. Quartzite	boudins, bedding, faults and joints.	
G	(254964, 9916428) 1498m		Quartzites conglomerates and shales.	bedding folding lamination faulting.	
I	(251851, 9915792) 1373m	Close to the road on the slope of a hill. Large, jointed and weathered outcrop	quartzites, shales of three types i.e., the ferruginous phyllitic grey shale (intruded by pegmatites)	joints, faults, bedding planes.	Low grade and metamorphism increased towards the arena contact metamorphism
J	(255772, 9914224) 1306m	Large, artificially exposed	Quartzite, shale i.e., grey shale, phyllitic shale and ferruginous shale. conglomerate	faults with general trend in the NE direction, cyclic beds, joints in the shale	
H	(253223, 9914100)		shales (grey and ferruginous)	faults, sinistral faults.	

	1374m		and quartzites (brecciated).	joints which trend to the NE-SW parasitic folds with synclinorium structures and load casts, quartz veins	
L	(251424, 9913256) 1555m	Large artificial outcrop	quartzites, grey and ferruginous shale breccias	faults, minor folds, beds striking in the SW-NE direction joints that majorly strike in the SE.	Regional metamorphism

5.2 Topography

The Karagwe-Ankolean system topography comprises hills and ridges with intervening low relief areas. Quartzites occupy the ridges and hills whereas the shales occupy the slopes and the valleys. The low-lying arenas are occupied by granites and granite gneisses. The area has a general altitude ranging from 1200 to 1600 giving it generally a higher relief. The topography of Igayaza is influenced greatly by weathering and erosion as well as tectonism such as faulting, folding which modify the already existing topography. For instance, from our observation faulting has caused formation of ridges and V-shaped valleys/gorges which have greatly influenced the topography. Folding has caused anticlines and synclines leading to a rounded hill tops and valleys between the different hills. The arena has developed as a result of erosion of the granite intrusion. This region has an inverted topography because initially the granite intruded the anticlines and this granite intrusion was later differentially eroded to form the arenas which is currently at the lower at altitude(anticlines) and the synclines are now the high points. The quartzites occupy the hilltops because they are more resistant to weathering than shales and granites. This is because quartzite is composed of majorly quartz grains which are hard and resistant to weathering while the feldspars in granite are easily weathered and the entire intrusion can be easily weathered to form arenas (Figure 5.1). Arena topography is one of the most famous features of Karagwe-Ankole system found throughout Igayaza area represented by Masha arena which covers Area I, B, and A of the mapped region. Generally, arenas developed by differential weathering whereby granites, more susceptible to chemical weathering than the adjoining shales in the synclines were eroded causing topographical inversion.

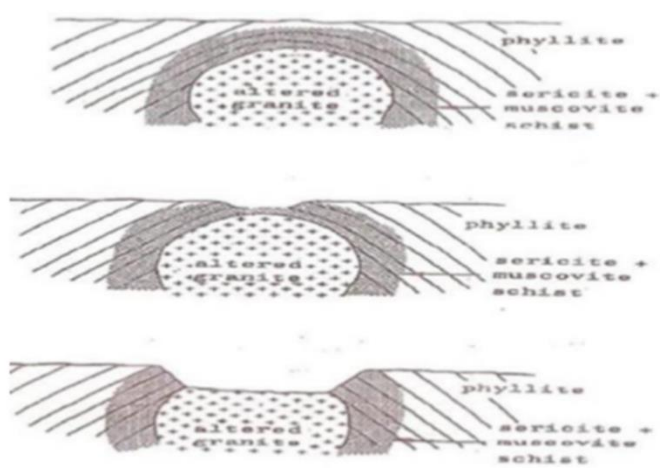


Figure 35: Schematic illustration of the sequence in the development of an arena topography. (Source: Pohl et al, 1994) a) Even Erosion b) Differential erosion c) fully developed arena topography

The arena formation transformed hills to valleys and the valleys to hills. Rounded hills for example the breast hills in study area B (Figure 42) are either covered at the peak by ferruginous shales, conglomerates or laterite which are resistant to weathering. These hills form a rounded shape because that is the most stable form attainable in nature. Faulting and emergence of streams have led to the cutting of some sections of the elongated ridges on the sides hence further modifying the topography

In conclusion, our findings very much agree with the past work done in the area in the area of topography.

5.3 Land use and settlement

The land use in K-A system is mainly influenced by relief and drainage patterns, in the arena and other lowlands. Mainly agriculture activities such as growing of crops such as maize, bananas, beans, potatoes among others and rearing of livestock takes place in most parts of the mapped area. On top of hills and ridges, where there are quartzites, stone quarrying is the major activity, small-scale mining also takes place, for example, tin mining is done in Kikagati. Brick laying also takes place on a small scale for construction materials. All these activities earn some income for the locals.

Settlement in this area is mainly along the road and sparse on flat ridges and trading centers, homes are found in valleys and arenas.

5.4 Lithostratigraphy of K-A in the mapped areas

This sub-topic describes the succession, arrangement and deposition of the rocks. The stratigraphic successions and correlation for the rocks of the Kibaran Belt is very complicated, because of the complex folding and refolding due to granitic intrusions in most of KA area, which in most places overturned the sequence hence the stratigraphy is not simple to correlate in many areas (Biryabarema, 1995). The generalized Litho-Stratigraphy division of the Karagwe-Ankolean rock System is found in chapter two table 2.

From field observations and comparison with other groups, most part of the mapped areas is occupied by phyllites, shales and quartzites and granite are only found in areas A, B and I. This suggests that the lithostratigraphy of the mapped area falls under the lower division of K-A

The sediments deposited in intercontinental basin were buried and worked upon by diagenetic processes of compaction, lithification and recrystallisation. This 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. This was eventually followed by controls of uplift and erosion that depend on the major rock types, metamorphic grades, mineralization and present-day joints. Granitic intrusions which are pronounced in the K-A have been an aspect of uplift and erosion, and occurred preferentially in anticlinoria positions but due to unstable mineral composition under surface conditions of granitic intrusion, severe erosion took place. Our findings are in line with this literature. Intrusion of granites or hot magmatic bodies was responsible for formation of phyllites from metamorphism of shales adjacent to the intrusion.

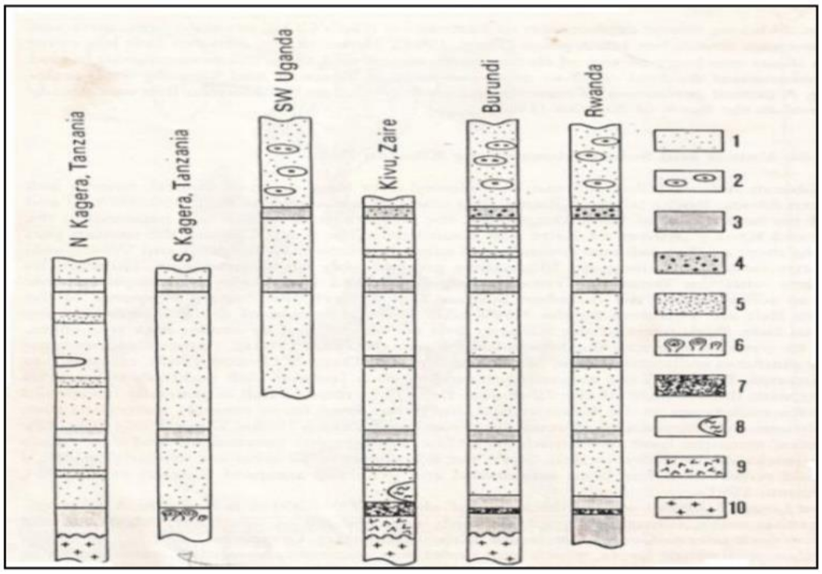


Figure 36: Generalized stratigraphic columns of the Kibaran rocks in eastern and central Africa. 1: Argillaceous rocks; 2: Conglomeritic lenses; 3: Quartzitic horizons 4: Quartzites intercalated with conglomerates 5: volcanic intercalations 6: Stromatolite-bearing rocks; 7: Greywackes 8: orthogenesis; 9: metagabbro and amphibolitic schists; 10: Archean Basement (source: modified after Rumvegeri et al., 1985).

Changes in the circumstances in the depositional settings may have caused the intercalations of the various lithologies in south-western Uganda (figure 5.2). The more coarse-grained elements that produced sandstones (later metamorphosed to quartzites) and conglomerates were deposited during times of high energy waves or stream/river conditions, whereas the argillaceous sediments were most likely deposited during low-energy periods or in lacustrine basins. Since the majority of beds strike in the NE-SW direction, it is likely that the paleocurrent likewise moves in this direction. Following the process of sedimentation, the rocks experienced metamorphism as a result of burial, resulting in meta-sedimentary rocks such quartzites.

Table 6: A summary of the rocks in Gayaza area.

Rock type	Description
Shales	These are the dominant rock types in the arena; they have a varying composition, i.e., organic shales, ferruginous shale in area I, phyllitic around the arena.
Quartzites	These occupy mainly the hilly tops forming ridges due to resistance to erosion, most of them are highly fractures and brecciated.
Phyllites	These are found around the arena I, B and A mainly. They are of very low grade, they occupied small areas so were not mappable.
Conglomerate lenses	the conglomerates were found in study area A and on ridge tops, they had matrix mainly made up of well sorted quartz sand, pebbles bounded by siliceous cement and iron oxides.
Laterites	These were mainly of shale and quartzite. Most of the valley bottoms are occupied by lateritic shales.
Mylonite	These rocks were encountered in area B near the arena. They have elongated, and ellipsoidal quartz grains. This means that they probably formed as a result of shearing during the Masha granite intrusion. However, this rock is not mappable.
Weathered acid gneisses	These are coarse grained metamorphic rocks displaying a gneissose structure. These were small outcrops found at Nyabugando hill in area I that exhibited schistosity, egg tray structures and foliation and were weathered which led to alteration of feldspars to clay minerals.

5.5 Drainage and vegetation

The common drainage patterns are the dendritic, sub-parallel to parallel. The major drainage pattern in the Igayaza area is the modified dendritic drainage pattern. Drainage is controlled by the major joints or fracture patterns of the granitic rocks of the arenas. A parallel to sub-parallel drainage pattern is typical in areas underlain by phyllites and less metamorphosed rocks forming the ridges or rugged topography with steep slopes. Rifting and weathering processes form sharp-cuts in valleys through which streams run during the rainy seasons. These valleys drain towards the low-land/arena hence forming a tree-like drainage pattern.

Underlying lithology together with rock structures also control the vegetation cover of the area where short grasses and a few trees dominated quartzite horizons while grassland with scattered thickets dominate the hills which are covered with argillaceous rocks. The fault zones in this area also have very thick vegetation due to the ability of fractures at these points to draw up underground water.

In a nutshell, the most pronounced drainage pattern in the mapped region is the dendritic type. However, some areas with 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. These have running streams during the rainy season but run dry during the dry season.

5.6 Metamorphism

The rocks in the mapped area were affected by regional metamorphism of generally low grade (Pohl,1987). The grade of metamorphism appears to increase with stratigraphic depth. This is evidenced by the fact that at the top of the sequence, unaltered or slightly altered shales are encountered while at the bottom, the shales are being metamorphosed to phyllitic shales and phyllites.

The grade of metamorphism increases with burial as temperatures and pressures increase due to increase in overburden, internal heat of the earth (geothermal gradient) and tectonic forces that cause the rocks to deform and hence accelerating the rate of metamorphism. This is because some minerals are only stable under certain conditions of pressure and temperature, when these change, chemical reactions occur to cause the minerals in the rock to change to an assemblage that is stable at the new pressure and temperature conditions.

Another type of metamorphism that exists in the mapped area is contact metamorphism and its grades increases with proximity to the granite intrusion. This is caused due to rocks being heated by an intrusion of hot magma and being in contact with hydrothermal fluids. It is a high temperature, low pressure metamorphism. In the Igayaza area mapped, the evidence of this is the presence of foliated phyllites in contact with the granite towards the Masha arena. Only a small area of surrounding the intrusion is heated by magma and the grade of metamorphism increases in all directions towards the intrusion.

Generally, the older granitic rocks are overlain by less metamorphosed cover rocks and though not necessarily of equivalent stratigraphical age these rocks were probably originally deposited during the same episode and later metamorphosed and intruded by granites to different degrees and at different tectonic levels.

In some areas, regional metamorphic effects cannot be distinguished from those due to granitic emplacement. Metamorphism is more intense in the anticlinoria than in the synclinoria partly due to the former's intrusion by granitic rocks (Barnes, 1956). This is evidenced by presence of mylonites in the anticlinal area around Nyabugando hills.

The contact metamorphism seems to postdate the regional type since the intrusion event came in much later, however, they appear to have a combined effect in some areas (occur at the same time). Contact metamorphism in K-A and the entire kibaran belt is more pronounced in areas with arenas where hot magmatic bodies intruded the sequence.

Cataclastic metamorphism appears to have affected rocks in the fault zones as they are crushed or sheared when rocks slide past each other during tectonic movement making them resemble very soft clay to fine-grained material or schist as evidenced by mylonites in area L.

Petrography

Petrographic analysis identifies the origin, whether igneous, sedimentary, or metamorphic, and the mineral content for the classification of a rock. The petrographic analysis of the samples indicates the most dominant minerals are quartz and clay minerals while minor minerals include iron oxides, magnetite, biotites. And most rocks are fine-grained except for quartzites.

This analysis also gives evidence of low-grade metamorphism (presence of chlorite index mineral and wavy extinction in quartz grains) which is consistent with the works of many previous geologists. For example, Pohl (1987) asserted that that the metamorphism is generally of a regional nature and is largely of low grade.

5.7 Structure of the mapped area

According to Pohl, 1987, the Kibaran belt has been affected by thrusting and folding with a predominantly north-north-east trend which swings to the northwest towards Uganda and Tanzania borders. These thrusting and folding events led to formation of various range of structures in the rocks of K-A, both major and minor structures.

5.7.1 Major structures

Folds:

Folding occurs when a stack of originally planar surfaces is curved or bent during permanent deformation (figure 5.3). Folding in the Kibaran belt is characterized by two major fold trends each dominating in separate regions. The predominant trend fold in the mapped area, the regional fold trend. The other is a cross fold trend which is perpendicular to the regional fold trend (with north-north-northwesterly trend). However, in other regions of Kibaran like in Rwanda, Angola and Burundi, the Northeasterly trending cross fold dominates (Cahen, et al. 1984). Barnes (1956) suggested two possible mechanisms for the formation of these two kinds of folds. One is that the cross folding was due to the distortion of the regional axis to release the stress caused in the rocks by regional folding. In the other hypothesis, he considers cross folding simply as the interference of true geosyncline folding with the regional trends. Our findings agree more with the first hypothesis as evidenced by the superimposition of cross folds on regional folds especially around Nyabugando hills.

The folding of the K-A led to the formation of arching which are broad open anticlinal folds on is regional scale.

The different types of folds observed in the mapped area include tight and open folds, symmetrical and asymmetrical folds. Small scale folds were observed showing a NE -SW trend relative to the cross folds. Parasitic folds were also observed on the flanks of the major folds.

In the mapped region, the most dominant trend is the regional trend and, in some places (around Nyabugando hills), the cross fold appear to be superimposed on the regional type. The regional folding phase appears to have reworked structures of NE-SW trend folding. This is consistent with the observations of Biryabarema, 1995. This implies that the two folding phases could have occurred concurrently and the regional fold direction continued to develop after the cross fold had stopped.

Figure 37: Folding and Faulting

Faulting

Faulting is widespread in the rocks of the Karagwe-Ankolean system. There are two sets of faults that is a ubiquitous and dominant set striking in NW-SE direction, and another transverse to it.

The faulting consequently lies in the similar trend to folding. Some of the faulting appears to have taken place together with the folding or in the closing stages of the folding episode, whereas some of the faulting is clearly much later (King and De Swartd 1970). Some major faults were recognized in the field by presence of breccias, steep slopes of the valleys and displacement of lithology and slicken sides. The common types of faults observed were the normal faults and strike slip faults. The strike slip fault was the major fault observed in the mapped area on a larger scale.

There are numerous faults and these are easily recognized where quartzites are involved. These are post-folding, and since they often produce significant displacements of vertical or steeply dipping formation, are correspondingly tear faults. In some cases, younger faults are infilled and older ones are not because possibly by the time the infilling material was intruding, the older faults were no longer active. Other faults, which occur, also bear a more intimate relation to the folding and usually replace limbs of sharp folds.

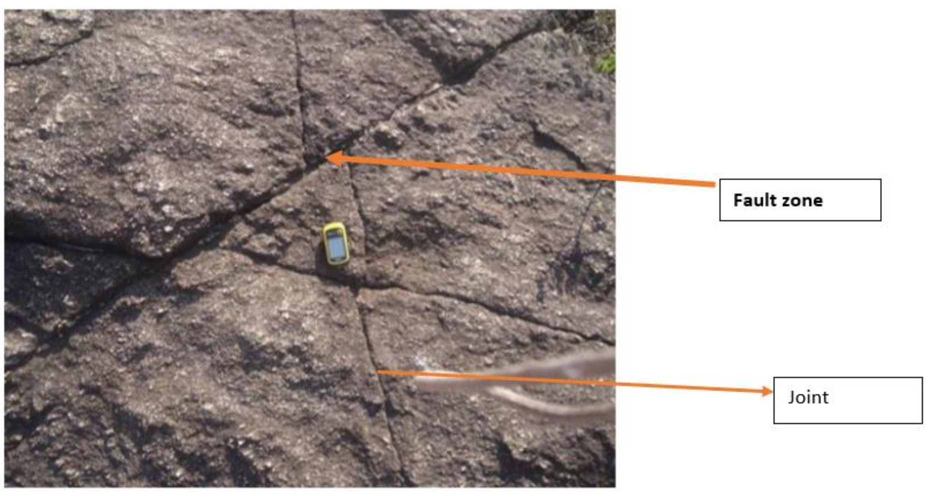


Figure 38: Strike-slip fault and joints on the Akabeeba granite

Joints

These are fractures in which there is no observable relative displacement. They were scattered throughout the study area and their intensity varied from one place to another. In some places such as Kyabirukwa hill, these cut across beds. Several joints were seen in quartzite horizons and they were more open compared to those in the shales. This could be due to the brittle nature of quartzite. These joints have two trends that is NW-SE which are more predominant and corresponds to the regional folds and the NE-SW trends that cross cut the NW-SE and corresponds to the cross-fold trends. In addition to tectonism, magmatic intrusion may have caused further fracturing. The two above major trends (NW-SE and NE-SW) are approximately in ratio of 3:1 hence the NW-SE dominates and resulted from similar forces that caused regional folding.

Generally, most joints form when the overall stress regime is tensional rather than compression. The tension can be from a rock contracting such as during cooling of volcanic rock, this explains the presence of joints in granite (figure 5.4), exfoliation joints occur when a rock expands in response to pressure reduction such as when overlying rock is eroded and appears to be flaking off in sheets. It is also possible for joints to develop under compression like where rocks are being folded because the hinge zone of the fold is under tension as it stretches to accommodate the bend. Jointing can also be as a way to accommodate the change in shape for a rock under compression.

Bedding

These are structures mainly found in shales and phyllites rocks of the Karagwe-Ankolean System. The predominant trend for these beds is NW-SE although trends on NE-SW also exist in the area.

The beds have been formed as a result of sediment deposition in varying energy environments. At the axis of the syncline, the beds dip at very low angles and some are nearly horizontal, away from the axis the beds tend to dip at very high angles and some are nearly vertical. Distortions in the beds are seen where faulting occurs.

Layering in rocks ranges from very thin laminations (usually measured in millimeters) to beds (measured in centimeters to about a few meters) forming massive layering of beds. The layers are distinguished from one another by their varying colors, thicknesses, grain sizes, textures, compositions, mineral types and particle sizes. They were commonly seen in mainly shales and phyllites; though there were some relicts observed in quartzites in some areas for example at the quarry in area L. This is clearly evidence of low-grade metamorphism in the study area. Concentric-like laminations resulting from weathering were also observed in shales on Kyabirukwa hill. They are dark grey in color and composed of iron minerals. The concretions could have been caused by precipitation of hydrothermal solutions to form iron hydroxides followed by a phase with solutions rich in silica or could also have resulted from weathering of pyrite (normally found in muds) releasing Fe which oxidizes to form Fe oxides.

5.7.2 Minor structures

Veins (Quartz veins)

During the study of Igayaza area, observations of both quartz and iron rich veins are observed in fractures or joints of the quartzitic and granitic horizons. Veins occur mostly within the widely spaced joints in quartzitic horizons, the material for vein formation is derived from mostly hydrothermal solutions that enter and fill the open spaces within the rocks. The veins are very common in quartzites throughout K-A rock system and this was observed throughout quartzites of Igayaza during the field mapping. Hence, it is evidence for intrusion of magmatic/hydrothermal fluids.

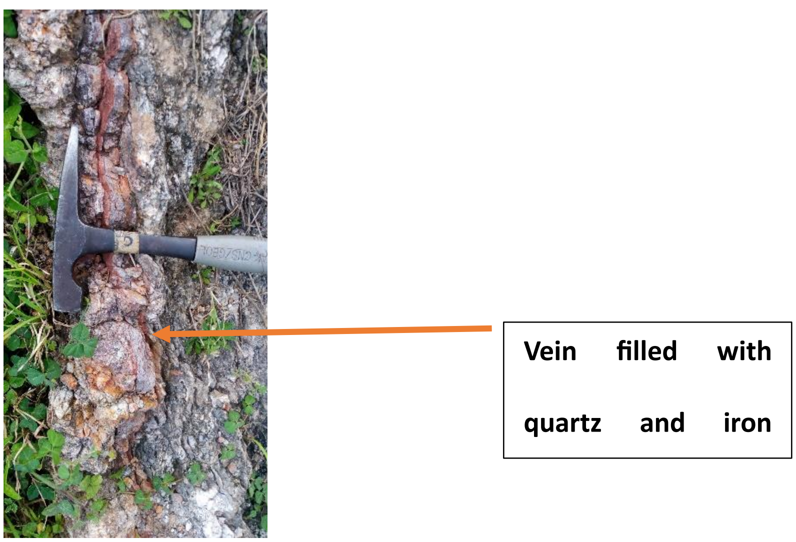


Figure 39: Vein filled with quartz and iron minerals.

Cleavage

These are planes of weakness along which a rock can easily break. This occurs in most rocks except the most arenaceous. It is strongly puckered in the lower parts of the system and further complicated by distortion of structure caused by emplacement of granite. The primary cleavage has a similar relationship to both regional and cross folding; and it swings from one direction to the other in a general conformity with the change in strike of the bedding. In Buhweju, Masaka and S.W. Ankole, the cleavage is axial planar to folds. Crenulation and fracture cleavages are also present. Cleavage develops as a result of deformation and metamorphism. In the mapped area, the cleavage is axial planar to both regional and cross fold trends and it could be attributed to crenulation of the NE trending foliation and as a result orienting in the NW direction. This is consistent with the works of King and De Swardt, 1970.

Boudinage

A boudinage is a structure formed as a result of extension forces in which a rigid tabular body is stretched and deformed in the middle of a less competent surrounding layer. The competent layer in response to stress begins to breakup, forming boudinage. These structures are common in K-A system found in strongly deformed sedimentary rocks, in which the originally continuous competent layer between less competent layers have been stretched, thinned, and broken at regular intervals.

These structures were mainly found in areas around the arenas probably due to the great intensity of folding in those areas. The main trend of the boudins is NE-SW similar to that of the cross folds. The boudins are commonly found in silica rich rocks in between the more ductile, silica poor layers of shale or phyllites. This is because silica is brittle and can easily break compared to clay layers. In the mapping area, boudins were observed in area B and J where deformation by folding is more pronounced.

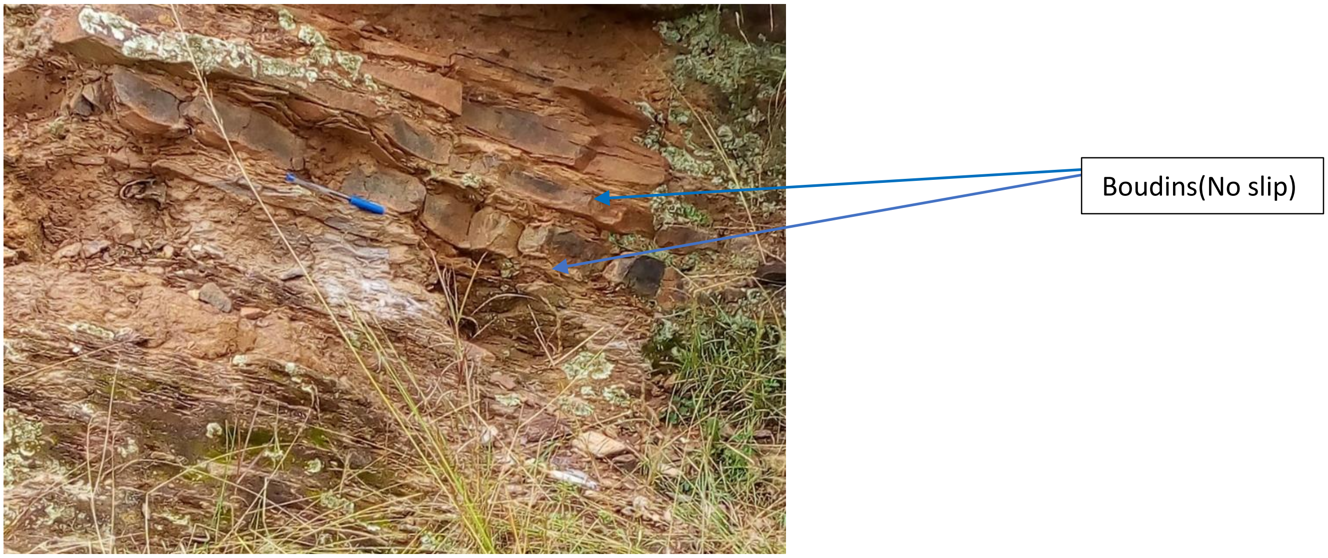


Figure 40: ***An image showing boudins in folded area found in Area B****:*

5.8 Economic Potential the mapped Area and the entire K-A system

Mineralization

The Karagwe-Ankolean System is of special interest owing to the commercial quantities of mineral deposits in its rocks. Pohl (1994) described the Kibaran (Karagwe-Ankolean) as the extensive tungsten metallogenic province of East to Central Africa with Sn-W-Nb-Ta-Be-Li the zone of metasomatic alteration around granites. Tin and tungsten ores are the major hydrothermal metallic mineral deposits. They are related post-orogenic granites and occur in distal veins in the country rocks surrounding the Evidence of structural control of mineralisation as noted by Ucakuwun (1992) in his examination of the mineralised bodies when he found that most of them were intruded along existing planes, schistocity, axial plane cleavages and faults zones in the country rocks the arena granites in South western Uganda. Beryl, together with Niobium tantalum and are found in pegmatites, which also occur in metasediments near granite bodies. occurs in quartz veins and breccias with muscovite, arsenopyrite, pyrite (evident in chalcopyrite, sometimes also with magnetite and specular hematite. Alluvial gold is with thick quartzites or sandstones in the Karagwe-Ankolean system. Most gold has been from streams draining the quartzite. The mineralised veins vary in size from small centimeters in width to massive bodies several meters in width and hundreds of meters in length.

Small scale mining of casserite is done in Kikagati which is located north of kagera river near the Uganda and Tanzania border. Other economic minerals mined from K-A rocks are rock salt in katwe.

K-A system has fertile soils suitable for agriculture from the weathering of shales, fertile loamy soils have been derived that can be effectively applied for agriculture purposes and this was observed in Igayaza area where crops like bananas, coffee, maize, and groundnuts are grown on larger scale. Animal rearing also takes place where animals are fed on natural grasses. Quartzites in K-A are quarried for aggregates, this is because, these rocks have high quartz mineral content which makes them had and very stable/resistant to weathering.

CHAPTER 6: CONCLUSION AND RECOMMENDATIONS

6.1 CONCLUSION

The goals specified for the field mapping project were accomplished, and practical field mapping skills such data collection, structural measurement analysis and interpretation, outcrop description creation, and petrographic analysis and interpretation were learned.

Using a compass, measurements of the joint and bedding plane attitudes on the outcrop were recorded in the field notebooks. We also observed the outcrops, described various properties, and identified structures. Finally, we traced lithological boundaries and plotted them on a map. It was successful to describe the lithology, metamorphism, and structures, and the data was later analyzed using a variety of techniques, including laboratory petrographic analysis, interpretation of thin sections under a microscope, analysis and interpretation of structural data using Stereonet and Georose software, and use of the ArcGIS application to digitize maps and create geological cross-sections. During the fieldwork, travelling to delineate lithological borders and measuring the attitudes of structures were the most popular techniques.

Geology: Generally, the hilly topography of the area is governed by tectonism and weathering that affected the area. It is comprised of ridges, rounded hills, valleys, arena structure and some plateaus. The differential erosion that formed the arenas in the area is attributed to the fact that granites are more susceptible to chemical weathering than the surrounding rocks because they have a greater percentage of feldspar minerals which easily weather and thus led to inverted topography. The sediment deposition that took place in this area is thought to have been under varying conditions of low and high energy environments within an intra-continental large basin leading to formation of intercalations of arenaceous and argillaceous layers. Tectonism led to formation of synclines and anticlines which greatly influenced the topography of the area. To some extent, tectonism is also believed to have contributed to topographical inversion. For instance, folding has led to formation anticlines and synclines which give the area a hilly and valley-like topography. Faulting has caused formation V-shaped valleys bounded by steeply sloping escarpments.

Stratigraphy and lithology: The stratigraphy of the entire mapped area is dominated by grey and ferruginous shales and quartzite lithologies occupying the ridges while the arena is occupied by granites that intruded the sequence. Other lithologies present in the area are conglomerates, breccias and acid gneisses.

Structures such as; Bedding planes, Laminations, Joints, Faults, Folds, Quartz-Veins, Foliation, Axial-planar cleavage and Boudinage were observed in the Igayaza Area. The major structural trends attributed to both Regional and Cross-folding oriented in the NW-SE and NE-SW directions respectively hence this is in harmony with the previous work done in the area by several geologists.

Metamorphism: The Karagwe-Ankolean rock system is affected by both Regional and Contact metamorphisms to various grades (degrees). The metamorphism of the area is generally of low grade as evidenced by relict bedding in quartzites**,** wavy extinction present in quartz grain, presence of chlorite as an index mineral in most thin sections. The grade of contact metamorphism increases with proximity to the arena. This is because the depth of burial increases hence temperature and pressure increase and proximity to the intrusion of magmatic bodies.

Petrography: The petrographic analysis shows that most of the rocks are fine-grained except quartzites and the major minerals present in most samples are quartz and clay minerals. Wavy extinction in quartz grains indicates that the quartz was subjected to low levels of stress or strain hence validating the fact that the metamorphic grade in the area is generally low. The presence of index mineral Chlorite further confirms low grade metamorphism.

Minerals have yet to be discovered in this area in potentially economic volumes. The major economic activities carried out include stone quarrying mainly in quartzite horizons, farming (agriculture and cattle keeping), brick-making from shales and clays, and charcoal burning.

6.2 RECOMMENDATIONS

I recommend that more lecturers accompany the students during the days of field work so that each group should be allocated a lecturer to guide them each day at least; because at the start, most students are unaware of what data to collect and are not well versed with the geology to make quick obvious interpretations like locating lithologic boundaries thus time wastage.

Verification of collected samples should be done daily so that students can make improvements during further collection.

I recommend that all students are taught how to use and execute software such as Stereo-net, Georose and ArcGIS with close guidance from lecturers to point out the most critical features that are essential for geological mapping.

Since the field mapping process is intense, I recommend that the number of days be increased to at least 2 weeks for the entire project.

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APPENDICES

Appendix 1: Structural reading of Joints.

NUMBER	STRIKE (AZIMUTH)	DIP
1	290	82NE
2	300	78NE
3	298	82NE
4	202	70NW
5	318	80NE
6	006	84SE
7	040	80SE
8	320	88NE
9	302	88NE
10	322	88NE
11	286	70NE
12	110	70SW
13	290	70NE
14	026	32SW
15	126	86SW
16	060	80SE
17	181	84SW
18	098	84SW
19	078	78SE
20	042	36NW
21	344	44NE
22	022	68SE
23	318	86NW
24	300	76NE
25	122	78SW
26	106	88SW
27	146	44NW
28	162	60SW
29	146	80SW
30	054	80SE
31	232	88NW
32	038	82NE
33	170	18SW
34	328	84NE
35	018	84SE
36	276	66NE
37	284	50NE
38	281	52NE
39	288	50NE
40	286	48NE
41	250	52NE
42	298	88NE
43	300	86NE
44	318	86NE
45	316	82NE
46	240	80NW
47	220	80NW

48	198	72NW
49	198	66NW
50	340	70NE
51	332	60NE
52	310	88NE
53	310	87NE
54	210	66NW
55	330	88NE
56	328	86NE
57	326	84NE
58	328	88NE
59	328	86NW
60	326	88NE
61	328	86NE
62	330	88NE
63	108	80SW
64	110	80SW
65	106	80SW
66	108	82SW
67	008	88SE
68	296	76NE
69	290	68NE
70	285	75NE
71	112	86SW
72	110	80SW
73	208	86NW
74	206	84NW
75	170	82SW
76	168	80SW
77	282	78NE
78	288	76NE
79	284	80NE

Appendix 2: Measurement of bedding planes.

NUMBER	STRIKE (AZIMUTH)	DIP
1	212	84NW
2	046	58SE
3	060	30SE
4	020	22SE
5	100	52SW
6	060	68SE
7	068	50SE
8	054	32SE
9	050	58SE

10	002	34SE
11	008	44SE
12	004	30SE
13	336	16NE
14	258	16NW
15	296	72NE
16	308	28NE
17	284	26NE
18	310	22NE
19	140	8SW
20	104	12SW
21	032	56SE
22	030	50SE
23	326	12NE
24	330	44NE
25	322	40NE
26	238	8NW
27	228	10NW
28	248	50NW
29	242	48NW
30	062	86SE
31	104	12SE
32	292	78NE
33	220	82NW
34	064	40SE
35	068	44SE
36	064	46SE
37	066	48SE
38	070	48SE
39	062	50SE
40	072	58SE
41	060	36SE
42	060	30SE
43	062	36SE
44	060	34SE
45	062	32SE
46	060	36SE
47	074	28SE
48	068	26SE
49	068	28SE
50	072	32SE
51	070	30SE
52	074	28SE
53	082	30SE
54	080	34SE
55	083	32SE
56	084	30SE
57	080	32SE
58	084	34SE

59	080	32SE
60	082	38SE
61	086	36SE
62	084	38SE
63	040	20SE
64	020	24SE
65	038	24SE
67	038	34SE
68	046	26SE
69	038	28SE
70	036	30SE
71	044	32SE
72	080	08SE

Appendix 3: Breast hills in Area B

Appendix 4: Microscopic description of the samples analyzed.

Table: Showing the optical properties of sample L1

OPTICAL PROPERTIES	MINERALS PRESENT		
	A	B	C
ORTHOSCOPIC (PPL)			
Colour	Brown	Reddish-brown	Colourless
Pleochroism Form/Habit	Absent	Absent	Present
Form/Habit	Anhedral	Anhedral	Anhedral
Cleavage	Poor	Poor	Poor
Parting	Absent	Absent	None
Relief	Low	High	Moderate
Inclusions	Absent	Absent	None
Cracks	Absent	Absent	None
Alteration	Absent	Absent	Absent
XPL			
Isotropic/Anisotropic	Isotropic	Isotropic	Anisotropic
Interference	Absent	Absent	1st Grey
Birefringence	Absent	Absent	Present
Extinction	Absent	Absent	Wavy
Twinning	Absent	Absent	Absent
Zoning	Absent	Absent	Absent
MINERALS	**Clay minerals**	**Hematite**	**Quartz**
Model mineralogy	60%	15%	25%
ROCK NAME	**Siliceous grey shale**		
ROCK TYPE	Sedimentary rock		

Table: Showing the optical properties of sample L8

OPTICAL PROPERTIES	**MINERALS**			
	A	**B**	**C**	**D**
ORTHOSCOPIC (PPL)				
Colour	Black	Reddish-brown	Colourless	Grey
Pleochroism	Absent	Absent	Absent	Absent
Form/Habit	Euhedral	Anhedral	Euhedral	Anhedral
Cleavage	Good	Poor	Good	Poor
Parting	Absent	Absent	Absent	Absent
Relief	High	High	High	Low
Inclusions	Present	Present	Absent	Absent
Cracks	Absent	Absent	Present	Absent
Alteration	Absent	Absent	Present	Present
XPL				
Isotropic/Anisotropic	Isotropic	Isotropic	Anisotropic	Isotropic
Interference	Absent	Absent	1st Grey	Absent
Birefringence	Absent	Absent	Present	Absent
Extinction	Absent	Absent	Wavy	Absent
Twinning	Absent	Absent	Absent	Absent
Zoning	Absent	Absent	Absent	Absent
MINERALS	**Magnetite**	**Hematite**	**Quartz**	**Kaolin**
Model mineralogy	5%	10%	25%	60%
ROCK NAME	**Siliceous grey shale.**			
ROCK TYPE	Sedimentary rock			

Table: Showing the optical properties of sample L14

OPTICAL PROPERTIES	**MINERALS PRESENT**		
	A	**B**	**C**
ORTHOSCOPIC (PPL)			
Colour	Colourless	Black	Grey
Pleochroism	Absent	Absent	Absent
Form/Habit	Euhedral	Subhedral	Anhedral
Cleavage	Good	Poor	Poor
Parting	Present	Absent	Absent
Relief	Low	High	Low
Inclusions	Absent	Absent	Absent
Cracks	Present	Present	Absent
Alteration	Absent	Absent	Absent
XPL			
Isotropic/Anisotropic	Anisotropic	Isotropic	Isotropic
Interference	1st Grey	Absent	Absent
Birefringence	Present	Absent	Absent
Extinction	Wavy	Absent	Absent
Twinning	Absent	Absent	Absent
Zoning	Absent	Absent	Absent
MINERALS	**Quartz**	**Magnetite**	**Kaolin**
Model mineralogy	40%	10%	50%
ROCK NAME	**Siliceous Grey shale**		
ROCK TYPE	Sedimentary rock		

Table: Showing the optical properties of L13

OPTICAL PROPERTIES	**MINERALS PRESENT**		
	A	**B**	**C**
ORTHOSCOPIC (PPL)			
Colour	Colourless	Grey	Black
Pleochroism Form/Habit	Absent	Absent	Absent
Form/Habit	Euhedral	Anhedral	Anhedral
Cleavage	Good	poor	Poor
Parting	Absent	Absent	None
Relief	High	Low	High
Inclusions	Absent	None	None
Cracks	Present	None	None
Alteration	Absent	Absent	Absent
XPL			
Isotropic/Anisotropic	Anisotropic	Isotropic	Isotropic
Interference	1^{st} Grey	Absent	Absent
Birefringence	Present	Absent	Absent
Extinction	Wavy	Absent	Absent
Twinning	Absent	Absent	Absent
Zoning	Absent	Absent	Absent
MINERALS	**Quartz**	**Kaolin**	**Magnetite**
Model mineralogy	30%	50%	20%
ROCK NAME	**Siliceous grey shale**		
ROCK TYPE	Sedimentary rock		

Table: Showing the optical properties of sample L15

OPTICAL PROPERTIES	MINERALS PRESENT			
	A	**B**	**C**	D
ORTHOSCOPIC (PPL)				
Colour	Colourless	Reddish brown	Black	Grey
Pleochroism Form/Habit	Absent	Absent	Absent	Absent
Form/Habit	Euhedral	Anhedral	Euhedral	Anhedral
Cleavage	Good	Poor	Poor	Poor
Parting	Absent	Absent	Absent	Absent
Relief	High	High	High	Low
Inclusions	Absent	Absent	Absent	Present
Cracks	Present	Absent	Absent	Present
Alteration	Absent	Absent	Absent	Present
XPL				
Isotropic/Anisotropic	Anisotropic	Isotropic	Isotropic	Isotropic
Interference	1st Grey	Absent	Absent	Absent
Birefringence	Present	Absent	Absent	Absent
Extinction	Wavy	Absent	Absent	Absent
Twinning	Absent	Absent	Absent	Absent
Zoning	Absent	Absent	Absent	Absent
MINERALS	**Quartz**	**Hematite**	**Magnetite**	**Kaolin**
Model mineralogy	20%	15%	5%	60%
ROCK NAME	**Siliceous grey shale**			
ROCK TYPE	Sedimentary rock			