MAKERERE UNIVERSITY

COLLEGE OF NATURAL SCIENCES

SCHOOL OF PHYSICAL SCIENCES

DEPARTMENT OF GEOLOGY AND PETROLEUM STUDIES

GEOLOGIC MAPPING PROJECT REPORT OF AREA A, IGAYAZA ISINGIRO DISTRICT, SOUTHWESTERN UGANDA

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DECLARATION

I Nabukalu Daisy Mukisa declare to the best of my knowledge that the information in this report wasobtained by me under the guidance of my field supervisors, lecturers, internet research, fellow students and use of written documents. The content in this report has not been by any means submitted to any institution or organization for any award.

APPROVAL

I hereby state that this project and report were done under the supervision of Dr. Nagudi our project co-coordinator.

Signature: .... Date: 18th/06/2024

Nabukalu Daisy Mukisa.

Signature: .... Date: 20/06/2024

Dr. Betty Nagudi

DEDICATION

I dedicate this work to my parents who have been with me throughout my entire academic journey right from the beginning to this level that I currently stand. A Special dedication to my fellow students especially my group members (group A) with whom we shared the mapping activity and compiledthe findings and results presented in this report.

ACKNOWLEDGMENT

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

I would like to express my sincere gratitude to all my supervisors and the lecturers in the department of geology and petroleum studies, Makerere University headed by Dr. Micheal Owor for their guidance, intellectual support, advice, encouragement and supervision that enabled me to successfully come up with this report.

Lastly, I thank all my fellow colleagues in BPG4 with whom we did the field study with most especially my group members.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF ACRONYMS

i)	NE	North East
ii)	SE	South East
iii)	NW	North West
iv)	SW	South West
v)	KIB	Kibaran Belt
vi)	Ma	Million years
vii)	FY	Financial Year
viii)	XPL	Crossed Polars
ix)	NNE	North-North East
x)	SSE	South-South East
xi)	NNW	North-North West
xii)	SSW	South-South West
xiii)	K-A	Karagwe-Ankolean
xiv)	PPL	Plane polarized light
xv)	KAB	Karagwe-Ankolean Belt
xvi)	GPS	Global Positioning System
xvii)	P-T-X	Pressure-Temperature-Time

ABSTRACT

This geologic mapping exercise was carried out in Igayaza located in Isingiro district in south western part of Uganda. The area mapped is within the Karagwe Ankolean system of rocks which strati- graphically overly the Basement complex rocks. The Karagwe-Ankolean (K-A) system (1400- 950Ma) in Uganda is the northern most extension of the Kibaran mobile belt. The sediments of this system occupy a continuous area in southern and central Kabale, southern Mbarara, Bushenyi, Isin- giro, Rakai and south eastern Masaka districts. The Buhweju plateau and surrounding hills in Bushe-nyi district belong to this system as well.

This field work was aimed at imparting the skill required to carry out a geologic mapping exercise besides other aims such as familiarizing one's self with field conditions and equipment, collectionand interpretation of data among others.

The area to be mapped was gridded, my group members and I exclusively mapped area A. This re- port contains data obtained within this region which includes the rock types, structures present, economic potential, stratigraphy, metamorphism of the area as well as the regional synthesis using the data obtained by other groups as well.

In the mapped area, the major rock types observed include Quartzite, ferruginous shales, Phyllitic shale, Granite, phyllites and conglomerates. Mudstones and slates were also observed in other areas within the region that were out of the area A. All these rocks, being in a region greatly affected by various stress and deformation events such as faulting and folding possessed a number of structures such as quartz veins, boudins, foliation, lamination and mud cracks, joints, beds and folds and folds most of which trended in the NW-SE direction, the major regional trend and a few in the NE-SW di-rection, the cross-fold trend. Some of these structures not only existed in a macro but also in a micro scale as will be shown in the petrographic analysis.

There are a number of economic activities in the mapped area such as quarrying of majorly quartzite and mining of sand for the construction industry. Agriculture through growing of majorly Bananas inthe valleys and the arena and rearing of livestock was also carried out.

CHAPTER ONE: INTRODUCTION

1.1 BACKGROUND

Geologic mapping is a very important skill required for everyone in the geology field therefore to introduce this, Makerere University through the department of Geology and Petroleum studies sets up mandatory field mapping exercises for academic years(1-3) where students while in groups are required to map an area of about four-square kilometers to attain the necessary and vital skills in this area.

A one week mapping exercise was organized from ***31st May 2022 to 5th June 2022*** in Igayaza Isingiro district which lies within the Karagwe-Ankolean (K-A) system of Uganda and the northern most extension of the Kibaran mobile belt. The sediments of this system occupy a continuous area in southern and central Kabale, southern Mbarara, Bushenyi, Isingiro, Rakai, SE Masaka districts, the Buhweju plateau and surrounding hills in Bushenyi district. The system is dated to between 1400 and 950 Ma.

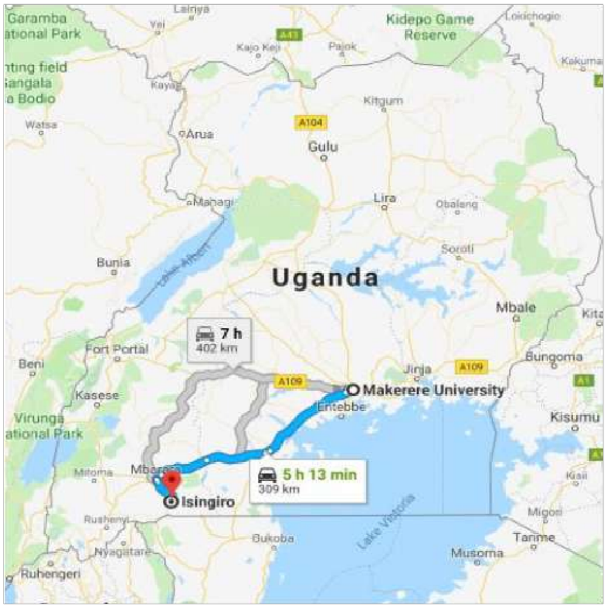
The system gives rise to mountainous or hilly country with intervening areas of lower relief normally occupied by metamorphosed rocks on the fringes with granites occupying the entire lowland. Quartzites run along the summits of the ridges with the rest of the argillaceous rocks occupying the slopes of the ridges and the valleys within and between the ridges. In the area SE of Mbarara in Isingiro, occurs one of the greatest concentrations of quartzites in Uganda. The quartzites in massive concentrations appear to have restrained the folding of the covering Karagwe-Ankolean rocks because only broad synclines are recognizable. Phillips (1959) identified quartzitic horizons q1 to q4 of them q4 being the thickest which is underlying the Rugaga plateau and comprising numerous quartzite layers interspersed with thin argillaceous bands. To the N and W in the area underlain by the Igayaza syncline (Biryabarema, 1995), the rocks of the Karagwe-Ankolean system are largely argillaceous and the quartzites attenuate fairly abruptly. Plummer (1960) described thinning of the quartzites on the NW limb of the Igayaza syncline E of the Mbarara-Kikagati road. Up to the stratigraphic level of the Rugaga quartzite, the rocks are fairly metamorphosed, but sometimes sedimentary structures are still recognizable especially in a microscopic scale as observed during the laboratory petrographic analyses.

Because of this regions' very diverse geologic environment, it creates an ideal condition for both educational and research purposes hence endeavoring a broad coverage by students during mapping exercise of the field.

1.2 OBJECTIVES OF STUDY

- To enhance and develop the students' approach to research, data collection (lithologic and structural), presentation of their findings to an audience and compilation into a detailed report.
- To formulate consistent approximate models, basing on the data collected leading to reasonably simple inverse problems and direct deductions from them
- To obtain and gain expertise in the use of various geologic equipment e.g. compass and GPS.
- To understand the background and potential of the rocks in this field further proving the theoretical views learned off the field.

1.3 LOCATION AND ACCESSIBILITY



Igayaza is located in Isingiro district in SW Uganda about 30km south of Mbarara. Isingiro District. It lies between Latitude 1 - 30 degrees south and 0-30 degrees north Longitude 30-20 degrees east and 31-20 degrees east.

It is 1800 meters above sea level. It shares borders with Tanzania in the south, Rakai district in the east, Ntungamo district in the west, Mbarara district in the NW and Kiruhura district in the north.

The area is easily accessed through major tracks e.g the Mbarara-Kikagati highway that is an extension of the Kampala-Mbarara Highway which is joined by multiple motorable roads and footpaths at major towns and trading centers.

***Figure 1**: Shows the location and accessibility of Isingiro*

Due to the rural and hilly nature of the region, some of the areas cannot easily or even be accessed through the use of machinery like vehicles, motorcycles and bicycles, but can be accessed by hiking and climbing.

1.4 PHYSIOGRAPHY

The study area gives rise to mountainous or hilly landscape with the lower lying areas containing metamorphosed rocks possibly as a result of granitic intrusion and the valleys containing the weathered granites themselves. Quartzites run along the summits of the ridges with the rest of the argilla- ceous rocks like shales and granites occupying the slopes of the ridges and the valleys within and be-tween the ridges.

Conglomerates were also found to have been deposited on top of the quartzites thus were considered to be younger than the Quartzites, a type of discontinuity known as non-conformity. The conglomerates trend from NW to SE. The matrix support in the conglomerates was found to be grains hence called a para-conglomerate.

The conglomerates were also found to be having clasts that seemed to have been derived from outside the basin of deposition and of different sizes hence considered to be extra-formational and polymictic respectively.

1.5 CLIMATE AND VEGETATION

Isingiro has a tropical climate. It basically has two rainy seasons per year, each followed by a dry spell. The climate here is classified as Aw by the Köppen-Geiger system.

The District enjoys equatorial climate and it receives an average rainfall of 1200mm, temperatures normally range from 17 to 30 degrees Centigrade averaging.. It has two main rainy seasons during the months of March to April and September to November in each calendar year. Some areas however have recently been faced with dry spells especially in Masha sub-county and Kikagati. Some parts of Bukanga are also sometimes unfortunate as they get hit by hail storms especially at the beginning of the September to November wet rainy season. The warmest month of the year is often July and August and the lowest average temperatures in the year occur in June.

Wetlands in Isingiro District occupy 2.08% of the total land area. Seasonal wetlands occupy at least 60%, permanent wetland covers 40%. The District's ecological system is prone to chronic drought and the terrain is characterized by bare hills and rangelands. Thorny bushes and trees, grassland savannah, scattered swamps and valleys, and bare hills with stone deposits characterize the District vegetation. The soils are mainly of clay, late rite loam, and sandy nature.

The District natural resources include fertile soils in almost all sub-counties. The district has two forest reserves under NFA and 1 natural forest which is privately owned. The district is embarking on an afforestation plan. In the financial year (FY) 2007/08, 119,965 trees were planted and in FY 2009/10, the District covered 120Ha of land with trees.

1.6 LAND USE AND SETTLEMENT

The 2002 census classified land tenure as free hold mailo land, leasehold and others. The table below shows Land Tenure of Occupancy by sex of Household Head in the District. Information in the table indicates that 76.23 percent of the land is held under customary land tenure system while 1.49 percent is under Mailo land.

Land Tenure	*Male Head*	*Female Head*	*Total*	*Percentage Total*
Customary	***40,828***	***10,566***	***51,394***	***76.23***
Free hold	***3,253***	***781***	***4,034***	***5.98***
Mailo land	***788***	***219***	***1,007***	***1.49***
Lease hold	***2,607***	***533***	***3,140***	***4.66***
Other	***6,129***	***1,718***	***7,847***	***11.64***
Total	***53,605***	***13,817***	***67,422***	***100.00***

Source: Direct census analytical report 2002

The major activity carried out in this area is crop growing and livestock rearing or herding. The sector provides employment for 72% of the labour force in the entire national economy. However, most the agriculture is of a subsistence nature which is usually associated with risk, uncertainty (basing on seasonal rains) and low productivity. The main crops grown are bananas, maize and beans usually in the valleys although some growing is done along some gentle slopes due to the abundance of potassium rich soils obtained from the weathering of shales. Animal rearing of cattle, goats plus sheep is also carried out majorly on the rocky hill tops that would not support easy cultivation.

Other land use activities include stone quarrying so as to obtain aggregate and stones for the construction industry, mining of mineral ores such as cassiterite is also carried out at Mwerasandu and Kikagati.

The district has a total land area of about 3010 square kilometers and a current population density of 124 person per square kilometer (2002 national census). It is also important to note that as much as the population density of Isingiro is below the national (127 persons per square kilometer), the district has a lot of inhabitable high lands, wet lands and lakes. A vast land area of about 135km is also preserved as a refugee and settlement camp. Settlement is seen along main roads and feeder roads and clustered around the trading centers and Isingiro town.

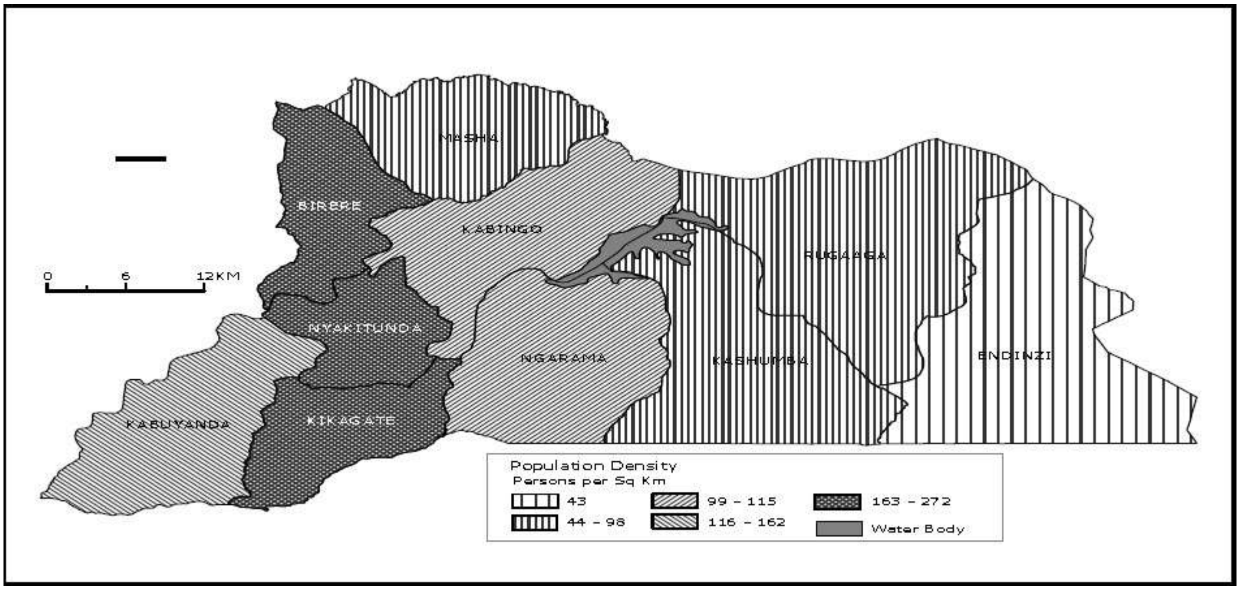


Figure 2: Shows the population density in Isingiro District as of 2002.

1.7 DRAINAGE

Isingiro district has a variable nature in its drainage pattern largely dependent on the nature of the underlying rocks, in addition to the tectonism of the area that created the complexities of the folding, jointing and faulting. The area has many water holes widely spread throughout the region with most of them in the valleys.

There are 2 permanent rivers and 1 stream, which are Kagera and Rwizi, Kagera flows through the sub counties of Kikagate, Ngarama and Kabuyanda and Rwizi flows through the sub-counties of Ma- sha and Kabingo. The stream flows through Kabibi Town Council.

The area also has 4 permanent lakes with L. Nakivale and L.Mburo as the biggest ones. L. Mburo is shared with Kiruhura District, it boarders Masha and Rugaga. Misyera. Lake Nakivale is inside the district also boardering Isingiro town council, Ngarama, Kashumba and Rugaaga subcounties. Other lakes include Oruchinga and Misyera.

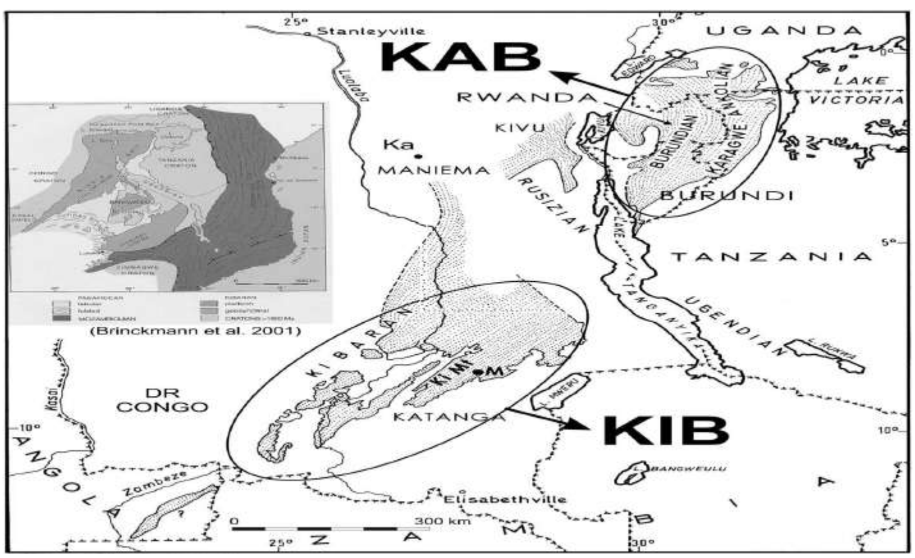
The water bodies create a complex drainage pattern which can possibly be classified as a dendritic pattern for the areas underlain by more competent rocks of higher grade metamorphism such as schists, gneisses and the weathered granitic rocks of the arena, whereas for areas where ridges were formed due to the alternating competent(quartzites) and less competent rock(shales) patterns follow a parallel to sub-parallel drainage pattern which is the most evident nature of drainage pattern in area A which on a regional scale falls back to dendritic drainage pattern.

1.8 REGIONAL GEOLOGY

1.8.1 Literature review

The earliest classification of formations in Uganda after the inception of the Geological Survey was necessarily on a lithological basis. Although the term Karagwe Series had already been applied by Scott Elliot and Gregory (1895) to certain predominantly argillaceous formations occurring in and around north-western Tanganyika, Wayland preferred initially to employ the non-committal term Argillite Series (1921a, 9-10). This was applied to all typically low- grade and non-metamorphic sedimentary assemblages, which, however, included extensive developments of arenaceous as well as argillaceous formations, and was in contrast to the micaschists, metamorphic quartzites and gneisses which were placed in the Archaean or Basement Complex.

Meanwhile Combe had established the individuality of the Argillites of the south-west, which then became known as the Ankolean Series (Wayland, 1923; Combe, 1925). Thereafter further investigation showed their identity with the formations of the adjacent parts of Tanganyika, and the name Karagwe -Ankolean applied to the whole group (Combe, 1926, 15). Thus it was that term " Argillite Series " was abandoned (Wayland, 1925, 9), and its place there appeared a number of systems or series of widely differing ages: Karroo, Bunyoro Series (Wayland, 1931, 13), Mityana and Butologo Sandstones (later to be included (King, 1943, 35)), and the KaragweAnkolean be noted, however, that the Karagwe-Ankolean, to the structurally continuous formations Masaka districts, also included non-metamorphic morphosed sediments of Singo county and parts the Jinja area, parts of Bunyoro (and later of the Sese Islands (Simmons, 1927, 19-21), Kenya border in south-eastern Uganda. This on the virtual or complete lithological identity these more or less widely separated areas localities to the south-west. Although in many places, notably Karagwe and Kigezi, the stratigraphy and structures of the Karagwe-Ankolean rocks are comparatively simple and could be effectively elucidated, a very general problem that presented itself was the nature of the base of the system and its relations with the Archean Complex which originally on quite general grounds had been inferred to underlie it



(Wayland, 1921a, 9).

Figure 3: Shows the Karagwe-Ankole Belt (KAB) and the Kibara Belt (KIB) as redefined by Tack et al.(2010). Presenting the Kibara Belt as a single and continuous belt.

The K-A system rocks in Uganda were first described by Speke in 1863, consisting of shales and sandstones west of Lake Victoria. Elliot (1893) passed through southwest Uganda and Karagwe from where he collected samples of rock specimens which were subsequently described in his joint paper with Gregory (Elliot and Gregory, 1895) bringing up the name the 'Karagwe series' before after an extensive mapping of the Ankole Kigezi region plus Karagwe in Tanzania, Combe in 1926 came up with a term Karagwe Ankolean. His work was published later in 1932. Wayland (1919) carried out some reconnaissance across southern, south-western and western Ankole and from it the most important lithologies, features and structures were recorded.

Combe (1932) also described two local successions occurring in the eastern part of Kigezi (Rukiga-Mpalo area) and in the western Ankole (Ntungamo-Kafunzo-Dwata area). He used six quartzite horizons in an attempt to correlate the successions between the two areas and as a basis for assigning lower, middle and upper divisions.

Stheeman (1932) wrote about the geology of the wider region of southwest Uganda which was majorly directed towards economic geologic aspects.

Phillips (1959) reported that south of Mbarara were the greatest quartzite concentration which appeared to have restrained the folding of covering K-A rocks. This was attributed to only broad synclines being recognizable. He further identified quartzite horizons q1 to q4 with q4 being the thickest of all, underlie the Rugaga plateau and comprises numerous quartzite layers interspersed within argillaceous horizons.

Biryabarema (1995) noted that to the north and west of the area underlain by the Igayaza syncline, the rocks of the K-A system are largely argillaceous with quartzites attenuating fairly abruptly. These argillaceous rocks of the K-A system showed a progressive increase in metamorphism towards the base from shales and slates through phyllites to muscovite or sericite schist. This progressive trend in metamorphism also corresponds with their proximity to granites in anticlinal cores. These massive argillaceous rocks were intercalated with thinner arenaceous bands of quartzites and quartzitic-sandstones and the succession had been intruded by the granites.

1.8.2 General geology

The K-A system rocks are characterised by an eastward decrease in both deformation and metamorphism (Tack et al., 1994). A basal conglomerate in this system unconformably overlies either gneissic basement, which is part of the Archaean Tanzania Craton, or the Paleoproterozoic Ruwenzori Fold Belt. In contrast to the Kibaran belt, the K-A belt is devoid of S-type granitoids and economic mineralisation.

The Karagwe-Ankolean is also characterized by argillaceous units intercalated with thinner bands of quartzites and quartzitic sandstones. It is composed of acid gneisses, migmatites and folded metasedimentary rocks. This area generally contains rocks such as shales, slates, phyllites, quartzites, and some conglomerates that often occur as lenses. The system is also composed occasionally of con- glomeritic basal members and minor volcanic and calcareous sequence, pegmatites, quartz veins and basic dykes (Ucakuwun, 1989)

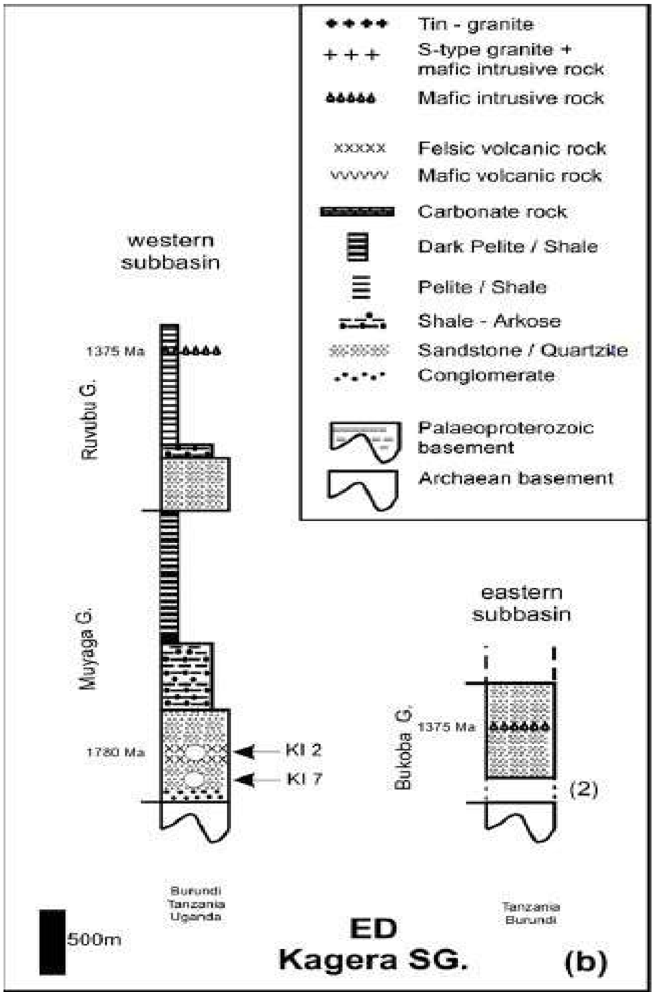


Figure 4: Shows synthetic litho-chronostratigraphic logs of the KAB for the WD (a) and ED (b) withposition of 4 dated samples (KI 2, KI 7, KI 8 and KI 25).

1.8.3 Structures of the K-A system

The major folds of the K-A are comparatively simple but the associated structures on a smaller scale are often very much more complex. The major structures depend mainly on their recognition of the understanding of the stratigraphy. Thus in SW Ankole and Kigezi, owing to the uncertainty in placesof correlating the critical quartzite horizons, Combe (op. cit., 79) showed that there were corresponding ambiguities in interpreting the major folds.

In Koki and Buhweju, the K-A occurs in broad synclinal basins, the form of which is clear not only from the deposition of the sedimentary formations themselves but also from the behavior of the un- conformable base, the position of which can be more or less readily mapped. In Kigezi the major structures consist of a series of rather open anticlines and synclines, the axial planes of which are nearly vertical and the axes trending around NNW-SSE (Combe, op. cit., 78). In Ruampara and the adjacent part of Isingiro, Ankole, the dominant structures have a similar style, while in the interven- ing terrain of Kazara, in the extreme SW of Ankole, the basement is extensively brought up in a prev- alently anticlinal area, the Ankole Anticlinorium of Barnes (1956, 42).

Refolding of the primary cleavage has occurred in many localities, notably towards the base of the succession where deformation has often evidently been more intense, especially in the arenas' vicini ty. A second planar structure often having character of a strain-slip cleavage, developed in relation torefolding. An important observation by Phillips (op. cit., 62-78) is that as metamorphism increases there develops a pervasive phyllitic schistocity which lies near to the original bedding, combined with mild regional metamorphism, since it's folded together with the bedding, by the smaller NNW- SSE folds which produced the axial plane flow cleavage and strain slips.

The connection between cleavage and folding is emphasized by the fact that at certain localities, gen- erally high in succession and where folding is slight, the shales or mudstones are devoid of cleavage. Examples are to be found near Nsika, Buhweju, North of Igayaza in Isingiro.. The argillaceous for- mations display almost everywhere a true flow or slaty cleavage, commonly described as agreeing with the bedding and indeed, close/ precise agreement can frequently be demonstrated. However fold closures are visible in a structure that is in an axial plane cleavage. The arenaceous formations which predominate in the northern part of the Buhweju plateau are broadly flat-lying. Reece, in order to rec- oncile these observations, suggested that the dips generally represent current bedding, implying depo- sition under deltaic conditions a conclusion that he regards as supported by the prevalently southerly dips in parts of the area.

The most important feature of the K-A fold pattern is that it conforms to two directions approximately at right angles to each other. Indeed the notion of "main" and "cross" folds was employed by both Combe and Steeman in 1932 long before it was a familiar in the geologic literatures. Whereas in the Caledonites of NW Europe or the Alps, the direction of the main folding is quite clear, for it is that ofthe great recumbent structures, in the K-A the choice is less obvious since the folds on both direc- tions possess a similar style.

Considering SW Uganda as a whole, the prevailing fold direction is around NNW-SSE, sometimes more nearly NW-SE as in Buhweju. This main trend is even more dominant southwards into Tanga- nyika, although here the directions swings towards N-S. the direction of cross folding varies from about NE-SW to NNE-SSW, a major fold of this type being the broad syncline of Isingiro. Others ap- parent to the north and south of the Marsha arena and traversing the Ankole anticlinorium.

Reece concluded that in Buhweju cross-folding on NE-SW axes preceded the main folding on NW- SE axes. Phillips similarly finds that the structures which regionally are to be regarded as cross-folds antedate the NNW-SSE (main) folding. Here the major cross-fold is a complex syncline in thick quartzites which dominates the Isingiro area. This formed a massive block that resisted the main fold- ing which is thus developed principally in the largely argillaceous formations farther east in Koki.
The later folding has had the effect of deflecting earlier fold axes and on a small scale the sequence of movements can be seen in the presence of refolded folds and superimposed cleavages.

1.8.4 Stratigraphy and geochronology of the K-A.

The type area of the K-A is conveniently regarded as south western Ankole and Eastern Kigezi since it was concerning this region that Combe (1932) presented the first detailed account. He described the system as consisting of "dominantly alternating strata of thinly bedded and unbedded mudstones, thinly bedded and laminated phyllitic shales and phyllites, with sandstones and quartzites''(op. cit., 22). The sandstones and quartzites often show current bedding and ripple marks, contains lenses of conglomerate. They are regularly spaced throughout the succession and are remarkably persistent over considerable distances.

Farther east of Isingiro, Phillips (1959, 53) estimated a quartzite thickness of no less than 8000ft. around the middle of a succession totaling over 22000ft. Farther east of Masaka district, the quartzites thin rapidly and the only quartzites in the entire sequence become discontinuous lenses. In this area, Philips infers that successively higher members of K-A overlap on to the basement formations.

The disconnected area of K-A forming the Buhweju plateau in NW Ankole shows a great develop- ment of arenaceous formations which thicken rapidly northwards, however, the main development of these sediments lies at or near the base of the succession and contains grits and conglomerates as the lowest members. Reece (1959, 78) estimated the maximum thickness of these arenaceous formations at 5000 ft. and infers a deltaic mode of formation, the material originating from the north. South- wards and SW, they are overlain and in part replaced by up to 3000ft. of shales and a higher group of quartzites which attain a maximum of 1200ft.

UPPER K-A
Mudstones, siltstones, sandy mudstones, sandstones, grits & occasional conglomerates Intercalations of quartzitic horizons, q3, q4, q5 and q6
MIDDLE K-A
Sandstone with occasional itabiritic layers of micaceous hematite Predominantly mudstones, arenaceous mudstones and phyllites. The more argillaceous rocks are characterized by a colour banding in shades of grey, cream and pink
LOWER 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

The above is a summary of the 3 sub-divisions of the K-A system (modified after Combe, 1932; and Bugrov et al., 1982)

In Uganda, only formations in the central and western have been correlated with the K-A which occurson the great northern spur of Rwenzori and at Kabuga in south Toro. The Rwenzori occurrence con- sists of sediments resting uncomfortably on inferred basement gneisses whereas Kabuga is composed of distinctly cleaved quartzitic sandstone, closely comparable with the dominant formation of northern Buhweju.

If it appears that the Buganda series is not correlated with the K-A, this is because the shales and phyllites are poorly exposed farther to the NE around L. Kyoga, generally referred to as the K-A (cf. Bisset, 1939; Roberts, 1940) on grounds of their lithology. Therefore it's not possible to draw any reliable conclusions as to the original limits of the K-A system. The great development of arenaceous formations in northern Buhweju may suggest an approach to the margins of the area of deposition in a NW direction, but a not dissimilar development in Isingiro passes laterally into argillaceous formations in all directions.

Thus the K-A system in southwestern Uganda has rocks like mudstones, shales, slates, phyllites, grits, schists, quartzites and intrusive rocks such as granites and granodiorites. Granites form eroded domes are referred to as arenas since they are easily weathered.

1.8.5 Tectonic evolution, intrusion and Metamorphism of the K-A.

The Kibaran belt evolved as a result of the movement between continental plates i.e. the Kibaran Event that proceeded the Pan-African Event between the 1400 and 900 Ma (Pohl and Gunther (1991)). The area was basically made up of sediments (both clayey and sandy) mixed up with volcan-ic rocks and in a few instances carbonate rocks. Early tectonic forces then led to thrusting and a large mass of rock thrust over other rocks. A major folding phase in the Kibaran event (about 1200 Ma) which produced a wide anticlinorium and a narrow synclinoria.

The anticlinoria were then intruded by the G1 and G2 granites causing contact metamorphism of the country rocks thus formation of a contact aureole with the degree of metamorphism increasing towards the intrusive body. G1and G2 (two-mica) granites are the oldest granites and formed through muscovite and minor biotite dehydration melting of a greywacke source at moderate temperatures and pressures (731-806°C, >5 kbar).

This was followed by the intrusion (1100 Ma) of Alkaline biotite granites (G3). G3 (biotite) granites are younger and formed by biotite-dominated melting of a similar source under slightly higher temperature but decreased pressure conditions (768- 847°C, <4 kbar) consistent with the ongoing emplacement of mantle-derived melts and crustal melting during lower plate exhumation. e.g. Burundi-an – Tanzanian ultramafic belt in NW Tanzania and SW Uganda.

The country rocks within this belt were later intruded by numerous small bodies of the granites, pegmatitic granites and pegmatites (G4). G4 granites (Sn granites) formed at 986 ± 10 Ma (Tack et al., 2006)and they are associated with most of the mineralization in this belt.

The intrusive granites metamorphosed the country rocks mainly allochemical due to their extremely high temperatures. The K-A rocks are metamorphosed to various degrees i.e. There is a progressive increase in metamorphism towards the base, from shales or slates, through phyllites (sericite-chlorite) to mica schists (muscovite and finally biotite-bearing). At the same time this progression corresponds to increasing proximity to the granitic rocks of the arena.

In the west, basal rocks have undergone high-grade metamorphism to phyllites and fine muscovite schists. The sandstones have been metamorphosed to form hard quartzites and conglomerates have been metamorphosed and pebbles flattened. The quartzites have also been sheared and mylonitized.

1.8.6 Mineralization and economic potential.

The Kibaran belt is best known for its richness of different granite-related rare element deposits that contain cassiterite, gold, columbite-tantalite (coltan), wolframite, beryl, spodumene, amblygonite , monazite e.t.c The Sn-Nb-Ta-W mineralisations mainly occur in pegmatites and quartz veins, which are interpreted to be related to the 'Sn- or G4-granites' the last of the intrusive bodies in the K-A system. The occurrence of tin as Cassiterite was discovered and documented (1924) in NW Tanzania by J.S. and D.S Kargarotos at Kyerwa (Barnes 1961).

The central part of Rwanda in the K-A system has tungsten deposits occurring as mineralised quartz veins that are hosted by graphite-rich black shales. Wolframite minerals formed after the precipitation of the main quartz vein. The pegmatites are dated at 968 ± 8 Ma and the Nb-Ta mineralisation in the pegmatites at 962 ± 2 Ma (Romer and Lehmann, 1995), they are sometimes crosscut by mineralised quartz veins (Varlamoff, 1972; Pohl, 1994).

The tin-mineralised quartz veins formed at 951 ± 18 Ma (Brinckmann et al., 2001) can be realized at the cassiterite deposit near Kikagati where small scale artisanal mining is being carried out along sub-parallel to parallel quartz veins.

The system also consists of potash rich soils derived from the weathering of shales thus encouraging agriculture e.g. bananas, maize and also animal rearing like cattle. The quarrying actively occurs throughout the whole region for attaining of various construction materials and minerals applied towards industrial and economic use.

In conclusion, the K-A system has a high economical potential based on the different minerals present and the activities carried out in the area such as quarrying which encourage economic growth ofthis areas within the system.

1.9 MATERIALS AND METHODS USED

1.9.1 Materials

- ***Geological map:*** It was applied to locate current positions relative to other locations on the map using the coordinates obtained from the GPS.
- ***Geological Compass:*** It was used to determine directions and the strike and of dips of the different structures like beddings.
- ***Hand lens:*** It was used to enhance the rock samples obtained so as to correctly determine their textural characteristics using the naked eye.
- ***Hammer:*** It was used to obtain rock samples from the outcrops so to make observations using fresh parts.
- ***Sample bag:*** It was used to carry and store the obtained samples for later analysis such as laboratory analysis
- ***Tape measure:*** It was used to standardize the pace length, used in the estimation of the extent or dimensions of outcrops and features of interest.
- ***Camera:*** It was used to take the image of geologic structures and features observed in the field.
- ***Pens and pencils:*** They were used as scales for the geologic pictures and also to note the observations made in the field.
- ***GPS:*** It was used to determine our positions. It provided the latitude, longitude and elevation readings of the location.

1.9.2 Methods

The following are the various methods used to collect and record data during the mapping exercise;

- ***Pacing*****:** It helps estimate the extent of various outcrops and features, here standardized pacesdone prior to the actual mapping activity are used as reference.
- ***Observation of area A*****:** Changes in vegetation cover break in slope, difference in soil cover, floats, different rock types and the different structures were observed.
- ***Measurements*****:** The strike and dip readings of different structures such as faults were obtained using the geologic compass.
- ***Data analysis*****:** Data obtained from all the stations was statistically analyzed using different soft-wares e.g. Stereonet and ArcGIS
- ***Sample analysis*****:** Both macroscopic (texture and mineralogy) and microscopic (thin section) anal-ysis of the obtained samples were done to observe the different characteristics of the grains.
- ***Report writing:*** This is the final step in the project, it digitizing the map, drawing a cross section of area, analysis of structural data, research with relevant literature and making a final neat reportfrom the collected data.

CHAPTER TWO: STRATIGRAPHY AND LITHOLOGY

2.1 Stratigraphy

This is a branch of geology that deals with the study of stratified rocks. A stratum is a layer or rock characterized by unifying properties that distinguish it from adjacent layers. (Atugonza, 2020). It is divided into various *categories* each depending on what the geologist is interested in determiningabout the rock outcrop, they include;

- ***Biostratigraphy*:** It involves organizing strata according to the fossils they contain
- ***Lithostratigraphy*:** It involves organizing strata according to its lithology characteristics e.g. tex-ture, colour, grain size sorting and roundness etc.
- ***Chronostratigraphy*:** Strata is arranged according to the geologic time of their formation. Thisdepends on the fossils present within the rock itself.
- ***Magnetostratigraphy*:** During deposition of sediments, certain minerals that contain magnetic properties may get aligned with the magnetic dipoles hence the rock attaining magnetism.
- ***Sequence stratigraphy*:** It involves the study of rock relationships within a time-stratigraphic framework of repetitive, genetically related strata bounded by surfaces of erosion or their correlative conformities.

However, all these arms of stratigraphy operate on definite *principles* which were defined by Nicholas Steno in 1669, they are as follows;

- ***Principle of horizontality*:** It states that in an undisturbed sequence of rock strata, the beds of sediment deposited form a horizontal/near horizontal) layer, thus helps in the analysis of tilted or folded rock strata.
- ***Principle of superposition*:** In an undisturbed stratum, the oldest layers lie at the bottom and theyoungest on top thus used in deducing strata age.
- ***Lateral continuity*:** Horizontal strata extend laterally until they thin to zero thickness (pinch-out)at the edge of their basin of deposition or unless they are cut by younger rock units.
- ***Principle of cross-cutting*:** It states that rocks that cuts across existing rock are younger than thatrock, this principle aids in the relative age dating of the rocks.
- ***Principle of inclusion*:** Fragments of rock that are contained (or included) within a host rock areolder than the host rock.
- ***Fauna succession*:** This is also known as the **Smith-Cuvier discovery, it** states that fossils and groups of fossils exist for limited amounts of time, and that fossil plants and animals appear in the rock record in a definitive pattern hence the older the rock, the more primitive the fossil forms that were present. In area A, no fossils were observed.

2.2 Stratigraphy of K-A System

The K-A system rocks cover more than 250000 km^2 extending on both sides of Lake Tanganyika in the west, penetrating both Shaba and Kivu provinces of Zaire bounded by the Kasai craton. A NNW- SSE terrane of Paleoproterozoic Ruzisian belt separates the eastern and western parts of the belt, Mporokoso basin (SE of the western segment) comprises sediments of the Muva group extending in- to SW Tanzania (Daly M. C., 1982). A *threshold subdivision* has been generally established and ac- cepted for all areas having same lithologies;

The lower Kibaran has a thickness of about 4000-6000 m with lithologies such as pelitic rocks, graphitic in some occurrences having quartzitic alterations, calcareous and itabiritic formations. Grey- wacke layers with sedimentary structures of turbiditic origin are seen intercalating with pelitic layers later undergoing metamorphism of different grade to produce phyllites, micashists, gneisses, migmatites and kinzigites (Schluter, 1997).Granitoids, granulites, metagabbros and other metamorphosed basic rocks are found at the base of this unit.

The middle kibaran *(2000-3000 m)* is composed of large quartzitic bodies having intercalations of pelitic rocks with minor conglomerates (Ruvmegeri, 1991). This is overlain by shists and quartzo-shists with calcareous sediments and itabiritic layers on top.

The upper Kibaran is composed of a conglomeratic quartzite, overlain by pelites and quartzite having many conglomerates int the order. Combe (1932) used six (6) quartzite horizons in an attempt to correlate the successions between two areas of the and as a basis of assigning lower, middle and upper units. For Shaba and Kivu, Rwanda and Burundi recent work has been done to assign stratigraphic columns of the Kibaran in these areas (Cahen et al., 1984). Few notes have been written on the strati-graphic division of the Kibaran system in Uganda and Tanzania.

Nevertheless, in Uganda, the K-A system borders the Buganda-Toro system and the Gneissic-Granulitic Complex. A relatively thin narrow strip of sandstones of the Bukoban system separate the K-A rocks from Lake Victoria in the East. The rocks of the K-A continue further West and East into Rwanda and Tanzania (Schluter, 1997). Rock units are characterized by massive argillaceous units intercalated with thinner arenaceous bands of quartzites and quartzitic sandstones with granite intrusions. From the works of Combe (1932) who used quartzites as marker horizons (q1-q6), the K-A of Uganda has been grouped into three divisions.

The argillaceous rocks of the K-A system in Uganda show an increase (progressively) in metamor-phism towards the base, with a transition from shales and slates, to phyllites and finally to either mus- covite or sericite shists (Schluter, 1997). The effect of granite emplacement superimposed onto the re- gional metamorphism a narrow zone of contact metamorphic aureole, having mica schists, with little garnet, andalusite and staurolite (Barnes, 1956). Barnes (1956) made the reservation that only five of Combe's quartzitic horizons are persistent and identifiable over any distance, from Combe's work in Western RukungiriMpalo where he had set up a section (Schluter, 1997). In Ntungamo-KafunzoDwata, Combe (1932) recognized only four arenites.

2.3 Stratigraphy Description of Area, A

In general, area A was made up of quartzites, shales and conglomerates rock units. The quartzites are abundant on the hilltops and ridges while the shales occupy the lowlands (valleys, gentle slopes) of the area. The evidence of banana plantations in the lowlands, together with grey soils was enough proof towards the presence of grey shales in those areas.

The quartzites are a result of metamorphism of sand sized particles, sediments or rocks like sand- stones. Brecciated quartzites possibly resulted from compaction of weathered quartzite clasts, ce- mented by either clay minerals or iron-rich minerals specifically hematite giving it a reddish-browncolor. Conglomerates appear as intercalations in quartzites, evidence that they are younger than thequartzites within which they are interlaced.

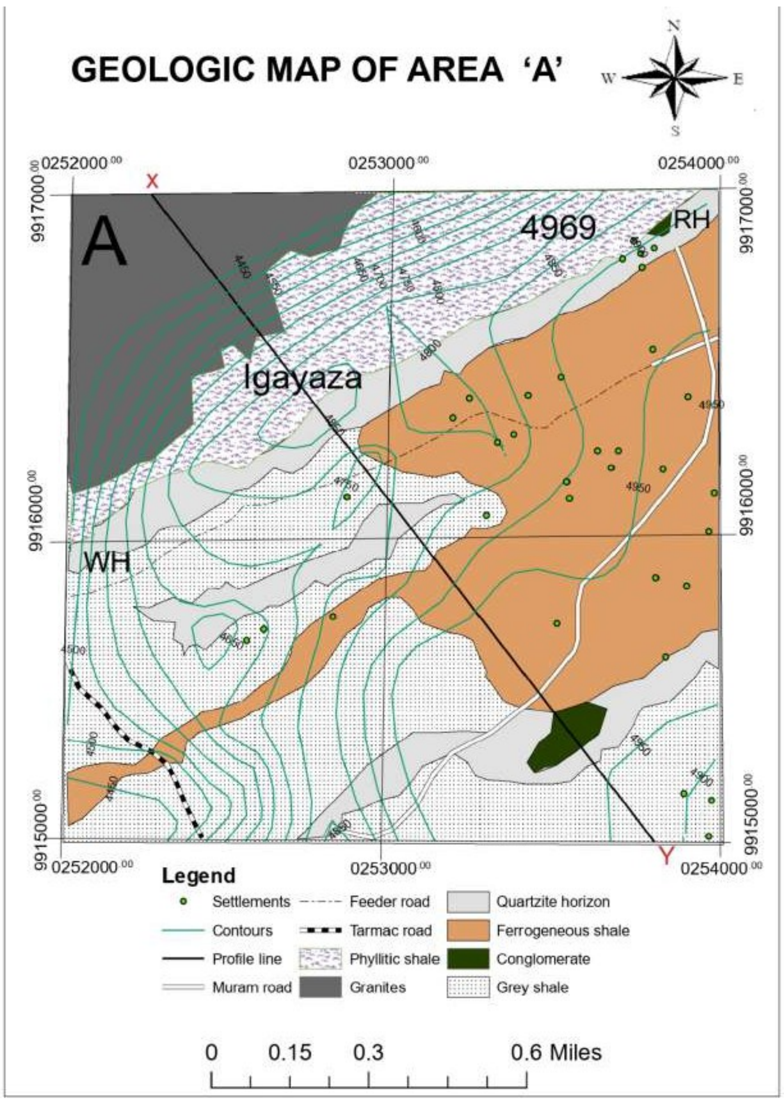
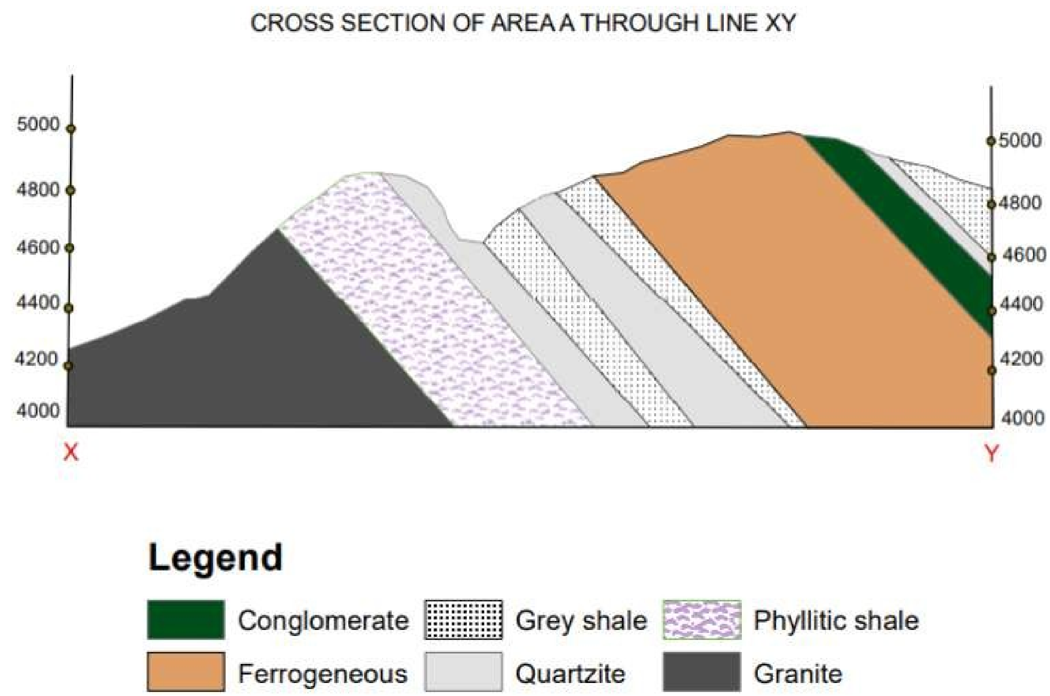


Figure 5 : A digitalised ArcGIS geologic map of area A showing the lithology and stratigraphy.

2.4 A geologic Cross-section of Area, A across Line XY on the map

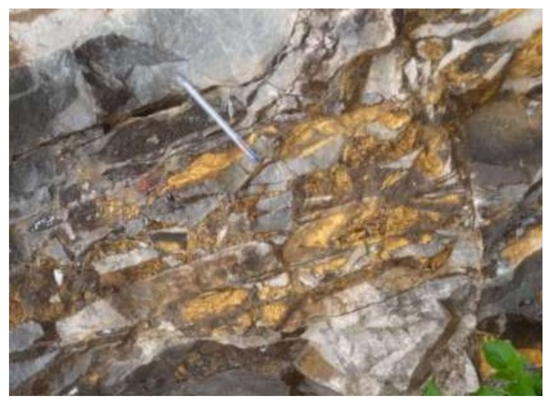


2.5 Stratigraphic Units

Quartzites

They are hard, non-foliated and low grade metamorphic rocks as they have relict structures, mainly derived from metamorphism of sandstones or sand-sized sediments at high temperatures and pressures due to the regional tectonic activity in the area. These conditions recrystallize the sand grains as well as the silica cement that binds the grains together resulting into an interlocking network of quartz grains of great strength. This interlocking crystalline structure makes the quartzite hard, tough, and with great durability. The quartzites, due to their stability and resistance to weathering and erosion formed ridges that stretched for several kilometers with a few discontinuities like faults.

They are fine to medium grained rocks composed of silica and quartz with pure quartzites usually white or grey in color although but they can occur with shades of red due to the presence of iron oxide. Many of the quartzites have structures such as faults, fractures, folds and some have quartz veins that cross-cut the quartzite. In some areas the rocks are intensely weathered forming lateritic soils.



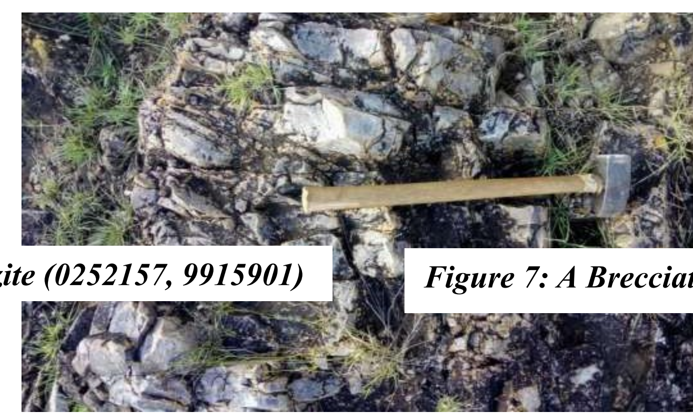


Figure 6*: Dark Grey Quartzite (0252157, 9915901)*

Figure 7: A Brecciated Quartzite

Figure 7*: Highly Fractured Quartzite (0252032, 9915889)*

Conglomerates

These are siliciclastic consolidated coarse-grained clastic sedimentary rocks predominantly of gravel-size (> 2 mm) clasts cemented together by fine grained matrix. They are polymitic composed sub rounded clasts. They show imbrication i.e. a preferred orientation of sediments to direction of currents.

The clasts are of varrying compositions i.e. quartz, chert, vein quartz, limestone, shales and may also contain various amounts of matrix, which commonly consists of clay- or sand-size particles or a mixture of clay and sand. In area A, the conglomerates were made up of quartzite clasts essentially pebbles (>2mm) that are well-rounded and extra-formational. They rest uncomfirmably over the quartzite, which may indicate a period of erosion or non-deposition before the sediments were deposited from outside the basin to form the conglomerates.

Figure 8: A Conglomerate at Station 8 (0253458, 9915692) on top of Quartzite.

Shales

These are fine grained clastic sedimentary rocks that consist of clay minerals and silt sized particles of other minerals like quartz, found on the ridges below the quartzites. It is fissile and brittle in nature hence distinguishing it from the other clay particle sized sedimentary rocks. They have variations in color and composition thus the varying categories such as phyllitic, grey and ferruginous shales.

They exhibit structures such as bedding, lamination, foot marks, burrows and tracks in most areas. Due to their texture, they easily weather to form soils which favour plant growth and the reddish color of the ferruginous shale is a result of oxidation of the iron.

The various categories of shales are distinguished as below based on the degree of metamorphism and the sediment color;

- **Phyllitic shales**: They are foliated metamorphic rocks created from partly metamorphosed shales, here the fine-grained white micas have a perfect orientation and are lustrous in nature. The phyllitic shales observed were hard and grey in color indicating low- grade metamorphism but one that's higher than that of ferruginous and grey shales.

- **Grey shales**: These are soft, fine grained grey shales containing a high percentage of clay minerals e.g. kaolinite, chlorite, iron oxide and little amounts of organic matter. They contain very little or no iron solutions recrystallized within the lines of weakness present in them. Structures like beds, laminations and folds exist within the shales. The folds are due to the action of tectonic forces on the shales and their ductile nature which were exposed as a result of weathering.

- **Ferruginous Shales**: These are low grade meta-sedimentary rock that contain large amounts of iron oxide hence the reddish brown color which evidences an oxidizing environment. They were found on the gentle slopes of the ridges and appear to be less competent than grey shales evidenced by the fact that most of the encountered outcrops appeared to be shattered. Floats of ferruginous shales were abundant in low-lying gently sloping areas especially in plantations and areas with thick vegetation.

Granites

These are felsic intrusive igneous rocks with granular texture hence phaneritic found below the shales on the lower areas of the hills. In area A, their outcrops were found in the NE part and appeared to be greatly weathered whose products provide well-conditioned soils facilitating plant growth. They were predominantly pink, white and grey in color therefore suggesting a mineralogy composition of quartz, alkali feldspars and micas. Also the shales in the intermediate vicinity showed a higher degree of metamorphism.

2.6 Weathering

According to the rock types present like quartzites, granites and shales, the weathering types active in the area are chemical and mechanical weathering. The latter because of quarrying activities in the area facilitated by the joints and fractures present in the quartzites. The outcrops with no quarrying activities, their surfaces were either eroded clean by rain water, covered by lichens or have a rusty brown color due to chemical weathering of the iron minerals especially in dark- grey quartzites.

In the shales, it's not always possible to see fresh surfaces on the outcrop without first clearing it due to chemical weathering which makes them more prone to erosion by water thus the valleys and slopes contain weathered debris washed from uphill. The granites and conglomerates were also chemically weathered. In weathered conglomerates, weathering rinds and sub-rounded quartz clasts with a brown coloration around their edges were observed.

2.7 Rock succession and Deposition Environment In Area, A

2.7.1 Rock succession

There was early deposition of the clay sized particles followed by the sand sized particles, this deposition was also cyclic i.e. alternating. The clay sized particles were compacted and lithified into shales whereas the sand sized particles into sandstones which were then metamorphosed to form shale-slates-Phyllite and quartzites respectively in the presence of high temperature and pressure conditions.

This nature of metamorphism was enhanced through the intrusion by granitic bodies into the country rocks hence *contact aureole* formed around these bodies. In area A this is evidenced by the Masha arena where there is progressive increase in metamorphism of the rocks towards the granitic body.

2.8 Deposition Environment

In area A, due to the changes in the energy or medium of transportation of the sediments, the area has intercalations of both arenaceous and argillaceous rocks. Here low energy favoured the deposition of fine suspended sediments like clay and silt in quiet water i.e the medium has low kinetic energy during these periods thus favourable for sediment deposition which were compacted and cemented as they underwent diagenesis to form sedimentary rocks like shales.

For the quartzites, the sediments were carried by high energy water which favoured transportation and deposition of the coarse sediments. Diagenesis occurred with compaction and cementation of the silt - sand sized particles forming sandstones. The sandstones underwent metamorphism to form low grade quartzites of medium sized quartz particles with no primary structures.

Conglomerates were formed when sediments of different clast sizes were carried by turbulent flow and deposited in a depositional area when the velocity of the current decreased as the energy of the water reduced. But this occurred on already present quartzite formation and was deposited over them in local basins which were compacted and cemented forming conglomerates that are hard rocks.

Microscopic observations revealed that quartz grains stored strain as indicated by the wavy extinction under cross polarized light. No fossils were found implying that deposition probably took place during the Precambrian times when life was scarce and small organisms such as algae, fungi and bacteria without hard parts were difficult to preserve. Alternatively, the rocks could have been subjected to intense tectonic forces which destroyed the fossils, though this is highly unlikely since it has already been established that the metamorphism in this area is generally of a low to medium grade.

2.9 Geologic History

Rock sedimentation is thought to have started after the lower Proterozoic and the related orogenesis probably around 1900 Ma and also after 2100 Ma and before 1800Ma and ceased with the Kibaran orogeny at 1250-1300 Ma (Clifford, 1970).

The main compressional deformation occurred when the granites intruded Syn-tectonically the upright folds that already existed in the area forming regional(NW-SE) and cross(NE-SW) folds. The volcanic interlude followed the swallowing of the basin leading to the formation of the major Igayaza synclinorium (Schluter, 1997).

There exists a significant geological phenomenon of topographic inversion in the K-A system which led to the formation of the arena. The unstable minerals in granites began to weather under surface conditions and were eroded rapidly thereby bringing about a peculiar topography in which the original anticline became a valley and the syncline now appears as ridges and roundedhills.

After deposition, the sedimentary rocks (shales and sandstones) were formed by lithification (compaction and cementation) to form beddings and laminations in shales. Compaction due to farther sedimentation led to increase in pressure and temperature which initiated regional metamorphism at depth. Shales began to turn into slates whereas sandstones were transformed into quartzites.

Folding of the shales was accompanied by formation of an axial planar cleavage at shallow levels (Schluter, 1997), only in argillaceous rocks and to a less extent in the less arenaceous ones. The numerous faults are evidence of tectonic forces that affected the area leading to intensive jointing common in quartzites.

Metamorphism was enhanced by the increase in temperature and pressure due to burial of sediments and also by the heat released by magma that intruded older sediments to form granites. The metamorphic grades vary with depth and also with the distance from the arena, being highest at the greatest depth and also next to the arenas (evidenced when shales were metamorphosed to slates and phyllites) and reducing with greater distance from the arena as evidenced by the presence of relict bedding in quartzites. Schists were recorded at the point of contact with the granites in the arena.

CHAPTER THREE: STRUCTURES IN AREA, A

3.1 Introduction

Structures refers to features on rocks that are formed by deformation due to tensional, compressional or shear forces although they can also form as a result of differences in stress fields acting on country rocks, when there is thermal contact with magma (contact aureoles) and rubbing motion of rock blocks against each other.

They are of special interest to geologists as a tool for interpreting aspects of ancient sedimentary environments e.g. transport mechanisms, paleocurrent flow directions, and relative current velocity. Some sedimentary structures can be used to identify the tops and bottoms of beds thus deter- mining if the sedimentary sequences are in depositional stratigraphic order or have been over- turned by tectonic forces.

The sedimentary structures are categorized into primary and secondary structures as detailed below;

3.2 Primary structures

These developed in the rock at the time of sediment deposition e.g beddings, laminations, sole marks and mud cracks etc. They are used to reconstruct the conditions that were present during the time of rock formation, right order of deposition of the sediments hence important in absolute age dating of the rocks. In area A, the following structures were observed;

- **Beddings**

These are large scale lithostratigraphic units whose thicknesses range from a cm to several meters, they differ from one another in terms of grain size, mineral type, color, thickness and texture. The beds are marked by well-defined divisional planes separating them from layers above and below. In area A the beds were found mainly in the shales and some of them were folded dueto the tectonic forces that acted on them. Most of the folded beds were plunging in the NW-SE direction and trending in the NE-SW direction thus conforming to the trend of the cross fold while others were trending in the NW-SE direction conforming to trend of the regional fold.

- **Laminations**

These are small scale sequences of fine layers that occur in sedimentary rocks whose con- cept is similar to that of beds.

Figure 14: Bedded Shales

Figure 15: Laminated Shales

3.3 Secondary structures

These formed after deposition of the rock body due to external stresses in the presence of high temperatures and pressures as well as chemical reactions within the rock or with its environment e.g. folds, faults, joints, striations and fractures etc. Contrary to the primary structures, these ones are important in relative age dating and correlation of geologic events that have taken place during the existence of the rocks. These structures are explained as below;

- **Joints**

These are fractures along which there is little or no displacement along the plane of deformation. They are mainly formed in brittle rocks especially metamorphic rocks when the applied stress exceeds the rock strength. They might be linked to the fact that as applied stress increases and rocksare bent, the brittle ones break in order to the release stress thus creating fractures.

In the area two joint sets were mapped, with the major set trending in the NW-SE(regional) and the minor set in the NE-SW(cross fold) direction. They were most dominant in quartzites that were located along the ridges and are non-systematic i.e. irregular in form, spacing and orientation.

Figure 11: Shows both the major and minor joint sets in the mapped area

- **Faults**

These are fractures on the earth's crust along which there is relative displacement on the either side of the fracture whose formation is similar to that of joints. They are grouped into normal, reverse, or strike-slip faults depending on the movement of the hanging wall relative to the foot wall. In the mapped area, evidence of faulting was seen through the presence of the fault breccia, linear vegetation seen in certain areas.

- **Folds**

They are distortions of a given volume of rock material which occur when a stack of originally flat and planar surfaces is bent or curved as a result of permanent deformation. Folds can range from microscopic to hundreds of kilometers across. The K-A system is dominated by two-fold sets i.e. the regional folds trending NNW and cross folds trending NNE (Barnes, 1956). In the area mapped the folds were found to occur in argillaceous rock units like shales which are ductile in nature and so are easily bent when acted on by the compressional forces.

Figure 12: Folded layers

- **Veins**

They are formed as a result of fluid phase where silica-minerals are deposited into faults, joints or other raptures present within the rocks. The veins within the area include quartz and iron rich veins, the former were cut across by joints in the quartzites showing that the veins are older. Some of the veins were fractured showing that the rock hosting them underwent some period of deformation.

Figure 13*: Shows Iron-rich and Quartz veins respectively*

3.4 Micro structures

These are observed through thin sections analysis of rocks for various structures that could notbe observed with the unaided eye thus aided in the description of the history and nature of the rocks and they include;

- **Elongation.**

This is very evident especially within the quartzites where by the grains are seen to attain a particular alignment of their longer axis. Ideally, quartz grains are equidimensional but in cases where the elongation is observed, it suggests that these grains underwent some strain which might have even cased the metamorphism. Therefore, the elongation in the quartz grains in quartzite is evidence that the quartzites underwent metamorphism.

- **Twining**

This is also a feature observed in the phyllite. When crystals are stressed, they may be deformed plastically by gliding or sliding along planes between rows of atoms within the crystal structure. This may take the form of 'translation gliding', whereby one or more rows of atoms may be displaced laterally along the glide plane, or 'twin gliding', where a smaller displacement is taken up by each row within the lattice. This leads to what is referred to as twins and it can be observed in thin sections using XPL whereby they exhibit undulose extinction

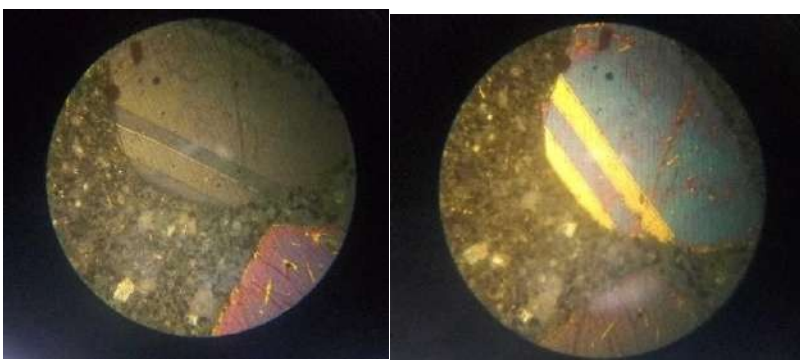


Figure 14: Twinning as observed in a phyllite sample.

3.5 STRUCTURAL DATA AND ANALYSIS

3.5.1 Obtaining and analysis of Macro structural data.

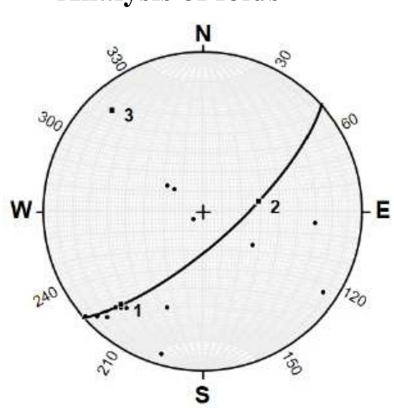
Various parameters of the different structures such as the plunge, trend, strike or dips of structures like joints, beds, fault, veins and folds were taken using a diverse collection of equipment majorly a compass and ruler. This data was then analyzed using various software such as GIS and stereo-net to obtain digitized maps, contour diagrams and rose diagrams.

FOLDS			
No	Strike	Dip	Dip Quadrant
1	286	82	N
2	034	80	N
3	038	18	S
4	036	22	S
5	006	60	W
6	318	88	E
7	312	70	N
8	214	31	N
9	318	6	N
10	318	88	N
11	312	78	N
12	290	54	E
13	308	66	E
14	310	68	E
15	315	82	N

3.5.2 Sterographic Analysis

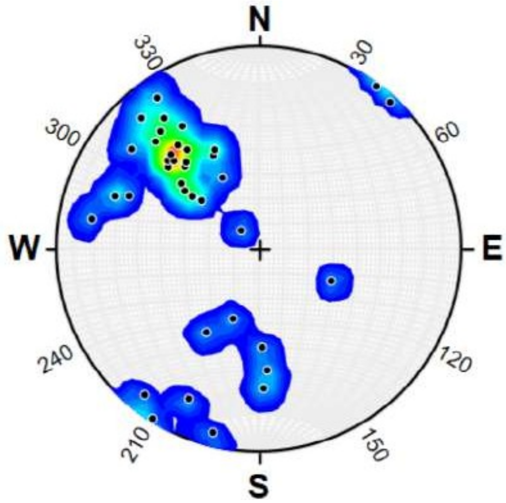
Stereonet/ Wulff net are a descriptive phrase of equal-angle or equal-area used to display used to display the geometries and orientations of lines and planes without regarding their spatial relations. The data obtained from macroscopic analysis and measurements during field mapping were input into the software and deductions were made through development of contour(density) and rose diagrams for the different sets of structures each of which aid in forming a fairly conclusive result. Below are the equal-area stereo nets plotted, plus contoured stereograms indicating areas with highest and lowest densities.

- **Analysis of folds**



***Interpretation*:** Poles of the various axial planes were plotted using the stereonet software to provide the Pi diagram shown. From the plot it is observed that the folds generally dip in the SW direction and strike in NE direction hence correlating with the cross fold trend of the K-Asystem.

- **Analysis of bedding planes n=38 poles to imported planes**



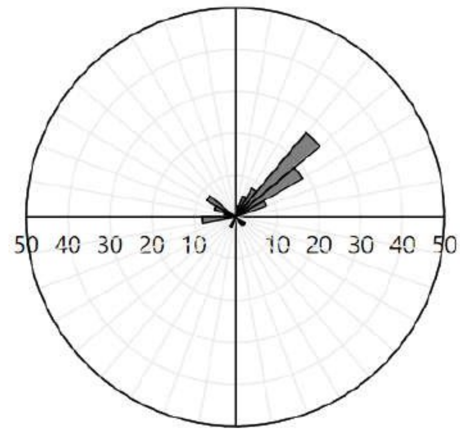


Figure 15*: Shows the density and rose diagrams respectively*

Interpretation

From the analysis, we found that the beds show a general trend in the NE-SW and the different colors in the contour diagram indicating the different poles of the bedding planes in the area. The concentration of the poles decreases outside towards the color blue with red containing the highest concentration of poles whereas the blue color, the least poles.

Since the poles are perpendicular to planes, the region with the highest density of poles is considered to have the least number of planes oriented in that direction thus from the density diagram above it's deduced that planes increase outwards from the red color towards the blue hence generally trending in the NE-SW direction.

From the rose diagram the length of the petals gives the frequency of the bedding planes in an area and are directly proportional hence in this case showing that most of the bedding planes were oriented in the NE -SW as shown by the petals while a few trended towards the NW-SE. This general orientation of the beds can later aid in the determination of direction of transportation of the sediments that were later deposited there.

- **Analysis of joint planes n=103 poles to imported planes**

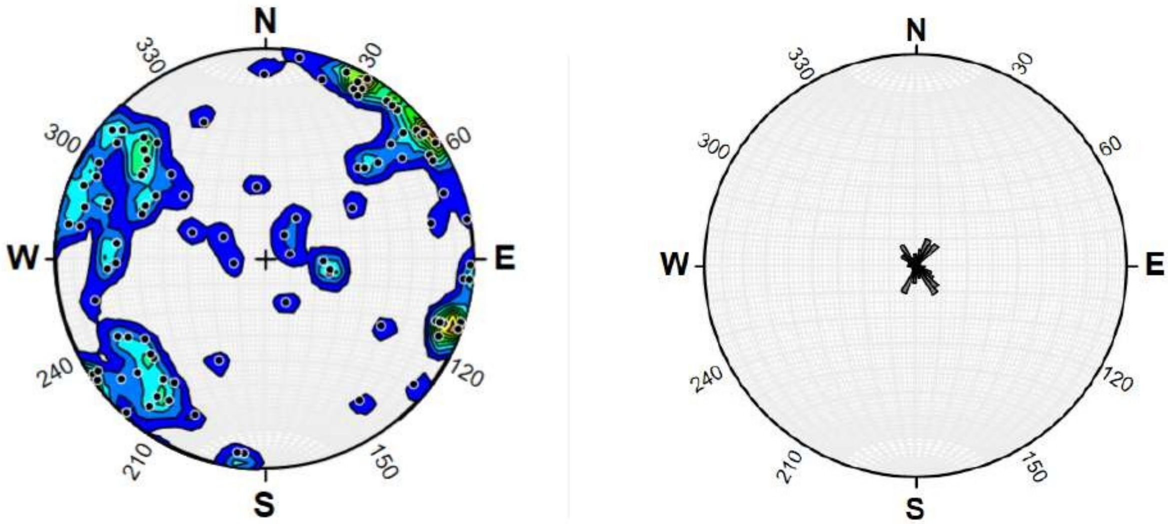


Figure 16*: Shows the density and rose diagram of joints* ***<u>Interpretation</u>***

The joints have a general trend of NW-SE shown by the contour diagram with a few trending NE-SW, the red color shows the area with the highest number of poles all the way up to the blue with a smaller number of poles.

The general direction of the joints, NW-SE relates to the direction of the regional folding hence it may be deduced that the same event or nature of forces that caused the folding led to the formation of these joints as well. The ones that trend in the NE-SW direction correspond to the region- al fold trend hence might have been due to the event that led to the formation of this folds as well.

3.5.3 Discussion

The compressional forces acted on the area leading to the formation of regional folds(NE-SW) and cross folds (NW-SE). Structures like folds, joints, faults, beds and quartz veins with the associated mineralization were probably triggered by the compressional and tensional forces that affected the area. Plastic deformation usually occurs first especially in the K-A system rocks resulting into rupture thus suggesting faulting within this system following the folding

Due to the increase in pressure and temperature changes that might have been caused by the burial or the intrusive granite body, there was low grade metamorphism. This is evidenced by the presence of relict structures such as relict beds within the quartzites and also elongated of the quartz was observed during the analysis of the thin sections.

The age relations within these structures can only be distinguished in the cases where the actual structures are being observed and they vary from locality to locality hence no general relation- ships. The principles of stratigraphy aid a lot in these comparisons for example in the sketch be- low, the faulting occurred after the formation of the quartz veins.

CHAPTER FOUR: PETROGRAPHY AND METAMORPHISM.

4.1 PETROGRAPHY

Introduction

It's a branch that focuses on the detailed description and classification of rocks, useful in establishing the mineral content and textural relationships within the rock. It started from the field with the filed notes at the out crop including macroscopic description in the hand specimens.

The chapter gives the description of the samples obtained and the thin sections got from representative samples in the laboratory. The analysis is majorly divided into two major types as explainedbelow;

- ***Macroscopic analysis***

It involves fresh sample description obtained in the field by use of a hand lens and the naked eye e.g. mineralogical compositions, color, grain shape, texture, structures present, and field name.

- ***Microscopic analysis***

Sample thin sections are studied under a microscope for detailed analysis of minerals, micro texture and structure. Microscopic properties were obtained both under plane polarized light e.g. pleochroism, colour, habit, inclusions, cracks and relief or under crossed polars e.g. birefringence, interference colors, extinction, sign of elongation.

4.2 Sample Analysis

DESCRIPTION	IMAGE
Sample: A4 (0253082, 9916160, 1463m) Name: Shale Type: Sedimentary Colour: Reddish-Brown , brown Mineralogy: Iron-rich(30%), silt(60), quartz(10) Grain size : Fine grained. Shape: N/A Type: Sedimentary rock. Structures: laminations. Deduction: It's a laminated ferruginous shale that has undergone a very low-grade metamorphism	

DESCRIPTION	IMAGE
Sample: A1 (0252032, 9915889, 1372m) Type: Metamorphic Precursor rock: Sandstone Colour: white, grey Mineralogy: Quartz, feldspars, sodium Grain size: Medium to Coarse Shape: Subhedral Structures: Quartz vein Deduction: A1 is a quartzite that has undergone very low-grade metamorphism	

DESCRIPTION	IMAGE
Sample: A5 Location: (02523096, 9915625, 1509m) Colour: grey (85%) , brown (5%) , Redish-brown (10%) Mineralogy: iron-rich , clay minerals Grain size : fine grained shape: N/A Type: sedimentary rock Precursor rock: Shale Structures: laminations Deduction: A5 is consolidated grey shale that has undergone a very medium-grade metamorphism	

DESCRIPTION	IMAGE
Sample: A7 Location: (0252718, 9916471, 1463m) Color: grey (95%) Reddish-brown (5%) Mineralogy: clay minerals , iron rich mineral Grain size : fine grained and shape: N/A Type: sedimentary rock Precursor rock: shale Structures: lamination , micro-folds Deduction: It's a laminated consolidated shale that has undergone low-grade metamorphism	

4.3 METAMORPHISM

Introduction

It is the sum of all changes that take place in a rock as a result of changes in the rock's environment i.e temperature, pressure (directed as well as lithostatic), and composition of fluids. The changes in the rock may be textural, mineralogical, chemical, or isotopic which proceed at varying rates making time an important factor. These reactions take place at >150 to 200 °C, where at highest temperatures it gives way to magmatic processes i.e. partial melting producing migmatites, mixed igneous– metamorphic rocks.

Prograde metamorphism is one that occurs during heating or burial, the heat is introduced into the crust by bodies of magma which on cooling liberate their heat content, and on crystallizing liberate the latent heat of crystallization. Metamorphism resulting from this heat that is localized around igneous intrusions is referred to as *contact metamorphism*. Heat can also be introduced over much larger areas e.g. when sedimentary rocks are buried either through subsidence or filling of sedimentary basins their temperature rises due to the geothermal gradient and in part to the blanketing effect of crustal rocks. This type is associated with plate margins and occurs on a regional scale, thus termed *regional metamorphism*.

4.3.1 Metamorphism of rocks in Area A

The metamorphism in the area progressively increases from the top to the base ranging from shales/slates at the top through phyllites, to muscovite schist and finally biotite schists at the bottom. It also increases with proximity to the granite intrusions hence rocks closest to them have been metamorphosed to a higher degree as compared to those farther from the granite intrusions e.g. sandstones have been metamorphosed to form hard quartzites which are sheared and mylonitised.

Regional metamorphism has affected the area since quartzite is mapped in the area with it's presence as evidence of low-grade metamorphism deduced basing on the relict beddings in shales and quartzites. The absence of structures like proper alignment of minerals (foliation) proves the absence of high grade metamorphism.

The metamorphic grade increases towards the arena since shale samples were picked further from the arena and the lithology changes gradually to slates and phyllites as one approaches the arena. Secondary metamorphic structures such beddings in shales are seen to become more pronounced towards the arena.

The mere fact that there were no fossils in the rocks is proof of excessive temperatures during metamorphism because they were decomposed thus not preserved. Evidence of faulting may prove that probably hot waters percolated out of the Earth's surface to cause hydrothermal metamorphism but it could be on a very small scale.

CHAPTER FIVE: REGIONAL SYNTHESIS

Introduction

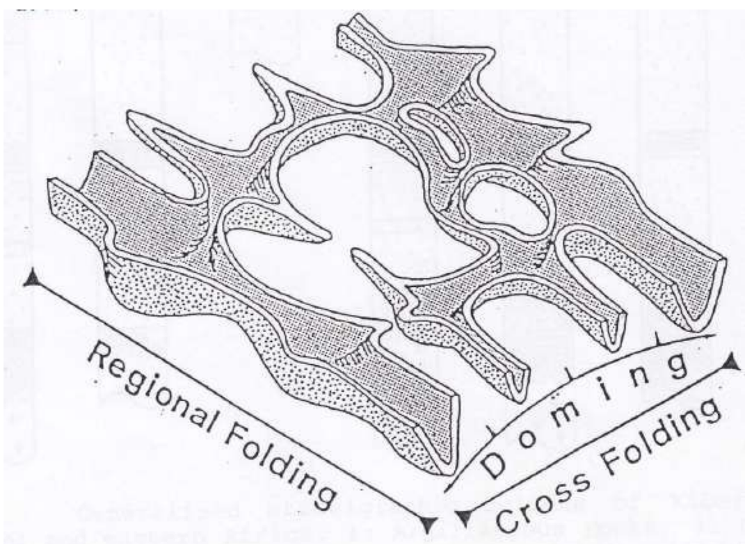
This chapter compares results of the mapped area and those of the neighboring areas including theoretical data obtained by other geologists with a *major aim* to correlate the results from our observations to those in other areas for proof and clarity thus this chapter entails observations from hot-spots of other groups mapping different areas and the entire areal geology.

5.1General Geology

The system comprises mainly argillaceous formations that have been slightly metamorphosed to argillites, phyllites and schists. There are also arenaceous formations represented by quartzite.

Ultramafic, mafic rocks and granites intruded the Karagwe-Ankolean rocks, which are majorly recorded in NW Tanzania comprising of rocks like peridotites, pyroxenites and norites e.t.c. The metamorphism in the Karagwe-Ankolean System is very low and mainly increases towards the base of the system.

The general structural trend of the Kibaran belt is in the NE-SW direction in the south. In Tanzania the belt trends in N and NE direction. The prominent Kibaran trend in SW Uganda is NW called Ankole fold trend (Barnes, 1956).



Fold trends in the K-A

- Regional folding (NW- SE)
- Cross folding (NE-SW)
- Minor folding (Argillites)

Other structures

- Cleavage
- Faulting
- Jointing
- Bedding

Mineral resources include; cassiterite, nickel, copper, gold, silver, magnetite, talc, mica, uranium, thorium, beryllium, lithium, cobalt, platinum, chromium, titanium, vanadium and iron e.t.c

The system unconformably terminates into Buganda-Toro (1800Ma) system which stratigraphically overlies the gneissic-granulitic complex. Wayland (1921) used the term 'Argillite series'/ar-gillaceous to describe the K-A rocks as well as other similar formations in Uganda.

Ucakuwun (1989) noted that the earth in Isingiro is formed of non-fossiliferous rocks of the Pre-cambrian age thus stratigraphic hierarchy of Igayaza relies on the criteria indicated by depositional structures available i.e crosscutting relationships of lithologies, structures and geochronology e.g In area A, there are phyllites at the base, shales on slopes and quartzites on ridge tops.

5.2 Topography

The area is made up of hills with intervening lowlands that are occupied by granites and granitic gneisses, which is controlled by erosion and weathering processes and also the underlying geology. Quartzites and conglomerates can be found near or at hilltops and generally on steeper hill slopes whereas claystones and shales were rarely at the hilltop but were found on hill slopes and in low-lying areas such as swamps.

5.3 Granite and Arena Phenomena

An arena is a broad stadium-like topographic low ground structures surrounded by country rocks topped by boundary quartzites (Schulter, 1997). This term was used by Wayland in1920 to describe these features that were very common in the K-A system of southwest Uganda. He realised each structure was an anticlinal dome which was intensely eroded to expose the underneath gran-ite

There are two main theories that suggest about the granites which led to the formation of the arena;

i) The granites invaded the already formed anticlines which then underwent uniform weathering and then differential weathering resulting into the formation of these features.

ii) The granites are older than the cover formations and there was just an episode of thrust faulting, which remobilized the granite to where it invaded the cover formations to fill the void created by doming which squeezed the cover rocks causing mylonitization and low-grade metamorphism.

This was then preceded by the uniform erosion and then differential weathering which exposed the granite intrusion leaving the un-metamorphosed rocks standing higher than the created low lying area. Further action of the processes resulted into the formation of the arena..

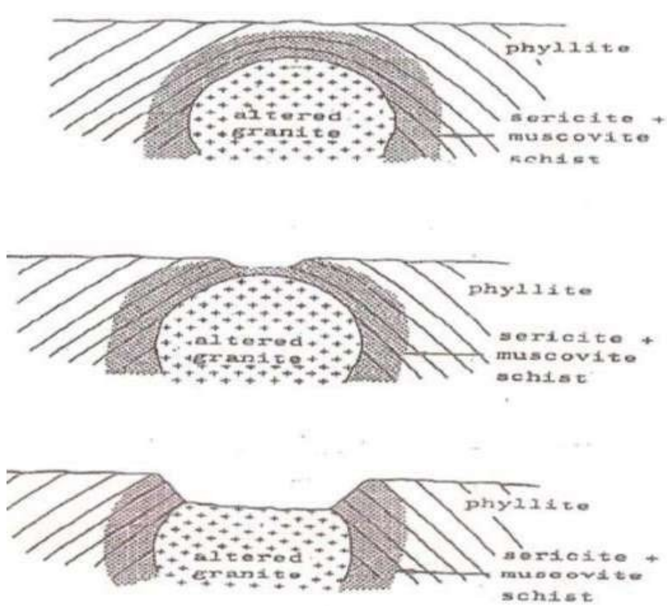


Figure 17: Shows the formation of the Arena. (After Schulter, 1997)

5.4 Drainage Patterns

They are majorly controlled by the area's the topography i.e. drainage features like streams are only found in narrow valleys between hills and most are seasonal, flowing into swamps. The swamps in turn are located in wider relatively flat valleys which enable water to accumulate for the formation of a swamp environment. Thus, the drainage pattern is dictated by the location and patterns of valleys. The drainage pattern in the area can however be described as dendritic, where smaller seasonal streams flow into larger streams whose flow lasts longer eventually draining into swamps.

5.5 Stratigraphy

We discovered about five rock types in the area during the field study i.e. quartzites, shales, clays, conglomerates, brecciated quartzites and granites. However, there was no outcrop fromwhich the entire stratigraphy could be seen.

The succession of rocks appeared to vary from place to place based on the stratigraphy of the K-A system; the combined study area by all groups spans almost the entire stratigraphic column. Areas A, B, G and I are most probably found in the lower division of the Karagwe-Ankolean.

Rock type	Occurrence	Topography
Quartzite	All groups	Hill tops or steep slopes
Shales	All groups	Near the base of mountains and in valleys
Phyllitic shales	All groups	Hill slopes
Conglomerates	A, G	Hill tops interbedded with quartzites
Granites	I, A, B	Low-lying areas in valleys

5.6 Geo-tectonic Evolution

According to Ucamuwun, the tectonic development of the Karagwe-Ankolean started prior to 1400 Ma as an extensional tectonic event probably over a region of mantle upwelling. Crustal thinning formed a asymmetrical basin with the deepest parts located along the NW-SE trend passing through SW Ankole and NE Kigezi. This was followed by an initial rapid deposition of sediments.

The sediments later underwent low-grade metamorphism depending on the depth of the burial; those at the bottom being more metamorphosed. However, the conditions were not adequate for the formation of gneisses or even to trigger anatexis. (Ucamuwun, 1989)

The sediment pile was then disharmonically folded between 1300 and 1200 Ma as a result of a compression deformation style occurring along the NE-SW direction. In this folding, the major anticlinorial and synclinorial structures in Southwestern Uganda were formed. (Ucamuwun, 1989)

The final episode was the formation of arenas as a result of granitic intrusions between 1200and 1100 Ma.

5.7 Hotspots

- ***Group B (0255689, 9918237, 1495m)***

This area consists of a large shale outcrop with a shiny surface. The rocks in this area underwent high grade metamorphism forming rocks like phyllites, phyllitic shale. The rocks have an axial planar cleavage because they are parallel to the fold axis.

Structures observed: minor folds (NE-SW), beds, mulions joints, cleavage, rods and boudins.

Explanation: The mulions were formed by tabular elongation, caused by lineation whose extension caused the deformation (elongation) of competent rocks overlain by incompetent rocks ***whereas*** Boudins consist of two incompetent rock overlying each other with a competent one in the middle which were formed during regional metamorphism which led brittle rocks to flow onsolidifying. Measurements; Bedding plane: N66E, 26SE, Fold Axis: N22E, 30SW

- ***Group I***

The group in area I presented two hotspots:

i) (0251158, 9916783, 1332m), here we observed weathered granites, shales, quartzites on a relatively steep slope. The general trend of the structures in area are beds(NE-SW) and joints(NW-SW). The minerals present include clays(grey coloured grains), quartz(coarse)

ii) (0251937, 9915762, 1358m), Quarry, we observed grey shales in the fracturing quartzites of low grade metamorphism.

The mined quartzites can be used for decorating houses and constructing roads. The quarrying carried out affects the locals both positively and negatively e.g employment and pollution respectively.

- ***Group G (0254455, 9916105, 1551.4m)***

They presented a conglomerate that had a sinkhole, the rocks in the area are shales (greys and ferruginous). The area is fault zone with a NE-SW trend aligned with that of the joints, evidenced by the breccia.

The conglomerate is composed of angular boulders and sub-rounded pebbles which are dark colored and cemented to the pebbles by iron oxide minerals like silica, bauxite and hematite. They are jointed and likely form very good seals because they hold water for a long time but can't make good reservoirs due to poor sorting and low permeability evidenced by the high degree ofcementation.

- ***Group H (0253301, 9914099, 1373m)***

- ***Group A***

We observed two hotspots in the area;

i. (0252032, 9915889,), a highly jointed brecciated quartzite, smoky black/grey in color caused due to tectonic forces which led to faulting where rocks more relative to each another cause grinding. This favors the passage of water and also vegetation growth, the rocks are fine grainedand consist of quartz and structures like faults, fractures.

ii. (0253923, 9915569), a large conglomerate outcrop underlain by a brecciated quartzite consistingof sinkholes. The outcrop is grey/white in color, zoned and highly jointed due to tectonic events. The surroundings of this location are vegetation and trees.

Figure 18: Group As' 2nd hotspot, A Brecciated Conglomerate.

5.8 Summary

In area A, group A mapped 9 stations within it, many of the stations mapped consisted of similar structures, rock types, colors, vegetation and trend direction etc. The mapped stations are explained as follows;

i) ***Station 1(0252032, 9915889):*** We observed highly jointed brecciated quartzites, grey/smoky in color with quartz as the main mineral. The presence of a breccia is a field evidence for faulting that occurred in the area and the area is a fault zone. The rocks consist of fractures and joints whose main trend is NE-SE. Some of the measurements included; N47E, 64SE N72E, 84SE and N26E, 78SE etc.

ii) ***Station 2(0252157, 9915901):*** Highly jointed grey quartzites and shale on the steep slopes which had undergone excessive erosion, the rock debris were transported to the valley. There exists a thin contact boundary at (0252238, 9915866) between the two lithologies, the shales are fine grained and consist of thin beds showing short periods of deposition. The minerals present are quartz, iron oxides, and feldspars. Measurements include; N02E, 40SE N50W, 60SW and N10W, 86SW etc.

iii) ***Station 3(0252286, 9915838, 1300m):*** We observed thin folded shales that enter into the ground thus short periods of deposition. They are laminated, soft and grey/reddish brown in color indicating that they were in contact with hydrothermal solutions hence the clay miner-also. The area has many quartzite floats of sub-angular shapes that were transported by erosionMeasurements include; N06E, 60SE N48W, 88SW and N42W, 70NE etc.

iv) ***Station 4(0252371, 9916003):*** Highly jointed quartzite with joints aligned in the same direction. At (0252057, 9915948) We observed ferruginous shales with a reddish brown color, and a highly jointed brecciated quartzite (0252068, 9915936), the soils within this region wereblack and brown in color.

v) ***Station 5(0252112, 9915839)*****:** Laminated folded grey shale with dark brown surrounding soils whose trend direction is NE-SE. The mineral are iron oxides and quartz.

vi) ***Station 6(0252210, 9915759)*****:** Gently folded grey shales made u of thin sheets of iron oxides.

vii) ***Station 7(0252098, 9915692)*****:** Brecciated quartzite, white in color and highly jointed. Measurements made were; N89W, 83SW N33W, 78SW etc.

viii) ***Station 8(0253923, 9915569)*****:** A conglomerate, It's the second hotspot.

ix) ***Station 9(0253314, 9915287)*****:** Highly jointed quartzite with a narrow and long depression filled with water. Animal grazing was the human activity taking place in the area. Measurements include; N24W, 86SW N42W, 84SW N30E, 54SE and NN16E, 78SE etc.

The overall observations made in the field agree with those expected from an area within the Karagwe-Ankolean system as described in literature according to Ucamuwun (1989) i.e. The presence of arenas, Granitic intrusions, Conglomerates near the base of the sedimentary pile, Alternating layers of quartzites and shales, the general structural trend, Low grade of metamorphismand limited extent of contact metamorphism.

CHAPTER SIX: CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

Igayaza falls under the K-A system which in some literature, place it under the Kibaran belt it's found to give rise to mountainous or hilly landscape with the lower lying areas containing metamorphosed rocks as a result of the granitic intrusion and the valleys containing the weathered granites themselves. Quartzites run along the summits of the ridges with the rest of the argillaceous rocks such as the shales and phyllites occupying the slopes of the ridges and the valleys within and between the ridges having granites.

The structures and granite phenomena of K-A in Uganda present features for which there is no close analogies in any described region elsewhere. Most notable are the widespread occurrence of two or more directions of folding with steep axial planes, the development of dome-like basement structures, often with associated later granite, and the progressive metamorphism of the sedimentary systems, increasing in general towards the basal portions of the successions, with proximity to the granite intrusions and towards the interior parts of their areas of development and often showing a dependence on regional migmatization

Mineral resources associated with the system include cassiterite, wolframite, nickel, copper, gold, silver, niobium-tantalum and magnetite etc. Some of the minerals occurring in the same system in neighboring countries have not been located in Uganda. The major economic activity carried out in this area is agriculture through growing of majorly bananas and maize and also rearing of animals such as cattle and goats.

Mining of aggregate through quarrying is also very commonly carried out especially on the quartzites to obtain construction materials.

Therefore, the dynamic and diverse nature of the structures and features present in Igayaza and the K-A system makes it ideal for purposes of learning and deeper understanding of geologic processes. In general, however, the K-A system is both less metamorphosed and less structurally complex so that over wide areas its stratigraphy can be ascertained.

6.2 Recommendations

Despite the successful field study carried out in the area, there are a few recommendations which if considered, could eliminate the few challenges encountered during the exercise and hence yieldbetter results.

- The students should be informed about and/or availed with the literature they are going to apply while in the field so that they read or research prior to the fieldwork. This fastens learningin the field and promotes better understanding.
- I recommend that the department should carry out continuous supervision and monitoring of students during and after the field work so as to encourage the students to perform the duties fully and also accurately.
- Adequate preparation and information of the relevant authorities in the areas whose resources are going to be tampered with prior to carrying out the field work to avoid inconveniences. This is also found to be parts of the field surveying preparations which must be adhered to.

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Appendix 1: Shows the fold measurements made.

FOLDS			
No	Strike	Dip	Dip Quadrant
1	286	82	N
2	034	80	N
3	038	18	S
4	036	22	S
5	006	60	W
6	318	88	E
7	312	70	N
8	214	31	N
9	318	6	N
10	318	88	N
11	312	78	N
12	290	54	E
13	308	66	E
14	310	68	E
15	315	82	N

Appendix 2: Tables showing the Joint measurements

Joints_final * - PlanMaker

No	Strike	Dip	Quadrant
1	047	64	S
2	040	84	S
3	020	80	N
4	026	78	S
5	030	80	S
6	010	84	S
7	006	60	S
8	042	80	S
9	018	68	S
10	318	60	E
11	324	70	W
12	320	60	W
13	276	82	E
14	280	86	S
15	018	88	W
16	010	78	S
17	330	64	N
18	300	82	S
19	350	10	S
20	045	70	S
21	002	88	N
22	090	76	S
23	066	60	S
24	038	40	S
25	036	60	S
26	330	40	S
27	056	70	N
28	030	50	S
29	310	12	S
30	020	68	S
31	038	78	S
32	040	62	S
33	034	60	S
34	042	66	S
35	042	50	S
36	020	52	S
37	022	82	S
38	024	52	S
39	084	28	S
40	028	18	S
41	020	30	S
42	298	80	S
43	300	88	S
44	298	80	S
45	300	78	S
46	318	78	S
47	350	12	N
48	294	44	N
49	006	85	N
50	016	78	S
51	030	54	N
52	040	82	N

54	52	040	82	N
55	53	020	80	N
56	54	020	76	N
57	55	006	88	N
58	56	024	80	N
59	57	020	78	N
60	58	312	84	S
61	59	326	58	N
62	60	308	84	S
63	61	310	84	S
64	62	294	86	S
65	63	304	70	E
66	64	278	82	E
67	65	356	64	E
68	66	308	78	E
69	67	312	88	E
70	68	308	72	E
71	69	310	64	E
72	70	020	88	N
73	71	294	70	N
74	72	306	62	N
75	73	320	78	N
76	74	346	72	N
77	75	318	70	N
78	76	318	70	S
79	77	332	68	N
80	78	326	88	N

	A	B	C	
81	79	320	84	S
82	80	322	86	S
83	81	324	88	N
84	82	316	52	S
85	83	322	84	S
86	84	318	54	S
87	85	326	88	S
88	86	328	82	S
89	87	322	86	S
90	88	326	85	N
91	89	298	84	S
92	90	006	60	S
93	91	178	60	N
94	92	320	60	N
95	93	160	80	S
96	94	150	82	S
97	95	169	88	S
98	96	128	20	S
99	97	108	78	S
100	98	168	70	W
101	99	200	78	W
102	100	193	26	W
103	101	244	19	N
104	102	190	26	N
105	103	183	23	N

Appendix 3: Tables showing the bed measurements

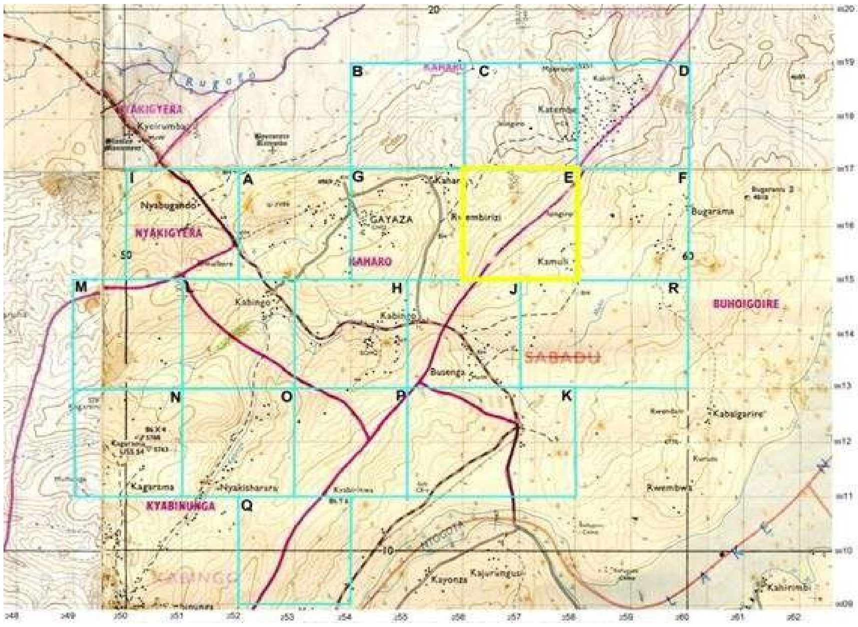
No	Strike	Dip	Dip Qu
1	290	30	N
2	302	40	N
3	268	40	N
4	266	50	N
5	268	58	N
6	52	54	S
7	48	45	S
8	46	10	S
9	204	32	W
10	284	82	N
11	10	72	E
12	38	68	E
13	42	50	E
14	40	30	E
15	44	52	E
16	54	68	S
17	46	62	S
18	63	32	S
19	64	42	S
20	50	46	S
21	66	44	S
22	54	50	S
23	58	60	S
24	38	34	E
25	22	58	E
26	20	64	E
27	50	64	S
28	132	86	S
29	295	70	N
30	308	80	N
31	302	88	N
32	38	38	E
33	40	41	E
34	126	88	S
35	56	78	S
36	46	50	S
37	48	75	S
38	47	53	S

Appendix 4: Tables showing the locations/Contours used

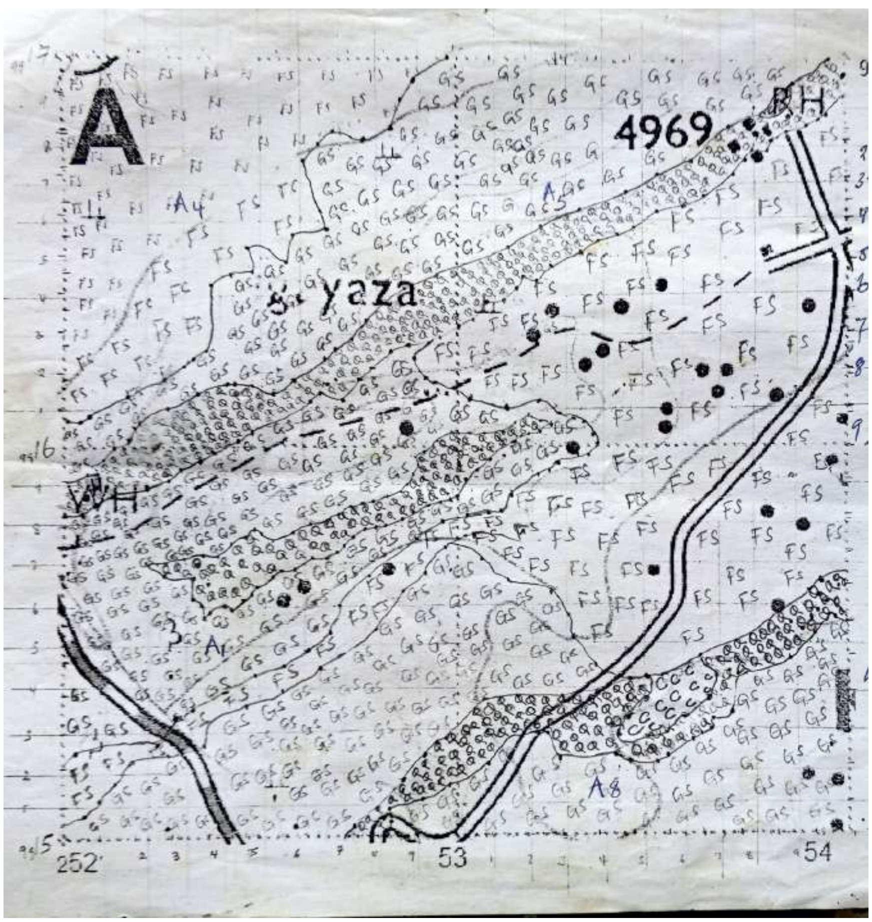
Contours_final_A * - PlanMaker

	X	Y	Elevation (ft)
2	252864	9916991	4400
3	252098	9916595	4400
4	252023	9916457	4400
5	252000	9915080	4400
6	252245	9915000	4400
7	253194	9916977	4500
8	252410	9916626	4500
9	252080	9916221	4500
10	252000	9915316	4500
11	252174	9915280	4500
12	252312	9915285	4500
13	252464	9915100	4500
14	253363	9916991	4600
15	252452	9916578	4600
16	252117	9915949	4600
17	252434	9915669	4600
18	252357	9915324	4600
19	253326	9916882	4700
20	252642	9916556	4700
21	252217	9916017	4700
22	252932	9916153	4700
23	252307	9915664	4700
24	252651	9915678	4700
25	252434	9915343	4700
26	252651	9915062	4700
27	252525	9915795	4750
28	252647	9915877	4750
29	252796	9915922	4750
30	252674	9915800	4750
31	253647	9916990	4800
32	252977	9916655	4800
33	252316	9916112	4800
34	253036	9916248	4800
35	253271	9916370	4800
36	253285	9916266	4800
37	253362	9916162	4800
38	252977	9916044	4800
39	253000	9915777	4800
40	252688	9915374	4800
41	252778	9915152	4800
42	252887	9915000	4800
43	253964	9916958	4900
44	252774	9916357	4900
45	253394	9916583	4900
46	253484	9916012	4900
47	253203	9915940	4900
48	253203	9915678	4900
49	252959	9915664	4900
50	252851	9915000	4900
51	253891	9915000	4900
52	253896	9915143	4900
53	254000	9915275	4900
54	253017	9915000	4900
55	253977	9916262	5000
56	253403	9915809	5000
57	253366	9915551	5000
58	253059	9915596	5000
59	253104	9915248	5000
60	253248	9915000	5000
61	253448	9915000	5000
62	253412	9915293	5000
63	253661	9915465	5000
64	254000	9915574	5000

Appendix 5: Maps of the Area



Map 1: Shows the location of area, A (yellow box)



Map 2: Shows the litho-logic units mapped in area, A

Legend

- *F.S: Ferruginous shales*
- *G.S: Grey shales*
- *Q: Quatzites*

Appendix 6: Shows a Combined map of the mapped areas