MAKERERE UNIVERSITY

COLLEGE OF NATURAL SCIENCES

SCHOOL OF PHYSICAL SCIENCES
DEPARTMENT OF GEOLOGY AND PETROLEUM STUDIES

THE SEMLIKI BASIN FIELD STUDY PROJECT REPORT

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

BY;

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Submission Date: 23RD September 2022

DECLARATION

I, **Musiime Alvin** do declare that this report is a record of my work in Karugutu and has never been submitted anywhere else for a degree or diploma award.

This report has been submitted with my authority to the Department of Geology and Petroleum studies in partial fulfillment for an award of a degree in Petroleum Geosciences and Production.

.... 19th Sept 2022

Signature Date

DEDICATION

I dedicate this report to my parents, Mrs. Kamuntu Ruth and Mr. Mujuni Lawrence, my siblings, friends and relatives as well. Thank you for believing in me and always bolstering me up

Deep gratitude and appreciation to the entire department of geology and petroleum studies in Makerere University. Thank you so much.

ACKNOWLEDGEMENT

I would like to acknowledge and thank the Department of Geology and Petroleum Studies and especially the lecturers: Dr. S. Echegu, Dr. Nagudi Betty and Dr. J.M Kiberu for the guidance during the field trip and subsequent follow up during report writing.

A special mention to my group members in mapping area I; Ngobi Benjamin, Aleer David Leek, Dut Marial Thuc, and Godi Kelvin for the hard work they invested in accomplishing the project, and for the great cooperation and discussion throughout the project period.

Special thanks go to the members of the support staff at the department for support and provision of extra research material during the field trip.

MAY GOD BLESS ALL OF YOU ABUNDANTLY.

Approval

This report is submitted with approval of the project supervisors namely Dr. S. Echegu, Dr. J.M Kiberu and Dr. B. Nagudi.

Project Coordinator: Dr. Betty Nagudi

Signature.....

Date....19th/Sept/2022

Abstract

This report details the observations made during the field excursion conducted from 2nd to 10th January 2022 and post-field data analysis and interpretation. The study was done in the Semliki Basin located within the Albertine Graben South and East of Lake Albert basin in Ntoroko District, Western Uganda. The Semliki basin is a rift basin and a half basin formed by tensional tectonics. The general stratigraphy of The Semliki basin consists of Kisegi, Kasande, Kakara, Oluka, Nyaburogo, Nyakabingo and Nyabusosi formations in that order.

The fieldwork was carried out in areas of Kichwamba, behind Kisegi hill at the quarry, along seasonal the Kisegi River, along Kibuku road cut, and Sempaya hot springs.

The main objective of the field work was to study the environment and processes of deposition of sediments and make deductions about the petroleum potential of the area. The specific objectives of the fieldwork were; to identify lithologies in the Semliki basin, to identify and relating structures observed in the basement and in the sediments, to identify different elements of the petroleum system and to identify the facies and depositional environments.

Different materials like GPS, geologic compass used were to measure, record and store geological data. The manuals provided to each group were used to guide group members in the study process. Most of the activities done were in groups though some of the activities like presentation of results were individual work.

Vast structural and stratigraphic data was collected and then analyzed to make conclusions about the petroleum potential of Semliki basin. The study area comprised of fluvial, deltaic and lacustrine sediments, all affected by intensive tectonic activity. This led to the formation of different structures with in the basement and sediments that we observed. Examples of these structures include faults, joints, folds, veins and banding. Sedimentary structures observed include cross bedding, unconformities, faults, and mud diapir and deformation bands. Mud diapirs, faults, plunging folds would be good structural seals.

The presence of hot springs with in the area indicated the presence of a high geothermal gradient which is important factor for source rock maturation. Sedimentology, stratigraphy and tectonics are applied to develop a full understanding of the rocks and the sediments that fill Semliki sedimentary basin and this information was used to interpret the geologic history and evaluate the economic importance of these rocks.

The general stratigraphy of The Semliki basin consists of Kisegi, Kasande, Kakara, Oluka, Nyaburogo, Nyakabingo and Nyabusosi formations in that order.

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CHAPTER ONE: INTRODUCTION

1.0 PROJECT BACKGROUND

This field study is aimed at equipping with various fieldwork skills the students of Bachelors of science in Petroleum Geoscience and Production at Department of Geology and Petroleum Studies, School of Physical Sciences- College of Natural Sciences, Makerere University. The study is designed for students that have completed third year students of the aforementioned program during the recess term. The study is carried out in the Albertine Graben, South and East of the Lake Albert basin with major focus on the Kichwamba and the Semliki basin. This report therefore contains the details of the field study and submitted for examination in partial fulfillment of the requirements for attainment of the aforementioned degree at the named department.

1.1 Location of the Study area

The study area (kichwamba and semliki basin) is found in Karugutu-Ntoroko district, Southwestern Uganda. This area is in the Albertine Graben, South and East of the Lake Albert basin. It forms northern part of the western arm of the East African Rift System (EARS). The Semliki basin occupies an area of approximately 1200km^2 with 740km^2 in the Ugandan portion of the Albertine graben and the rest in the Democratic Republic of Congo. The study are is specifically found in Block 3 of the Albertine Graben**(Fig1.1**) and consists of the Semliki flats and the adjacent Toro Plain, Southwest of Lake Albert. It is bordered to the southeast by a steep fault escarpment rising almost 1000m to the northernmost spur of the Rwenzori mountains. The area is quite different from the surrounding areas of Uganda and Democratic Republic of Congo (DRC) given its low elevation of about 650m above mean sea level compared with about 1100 to 1500m for the adjoining rift shoulders to the east and 1500 t0 1800m to the west. Up to 700m of Neogene sediments are thought to be exposed in tributary valleys to the Semliki River the area, although estimates have varied between Wayland and Pickford et al, who suggested around 600m, and Bishop with at least 1300m.

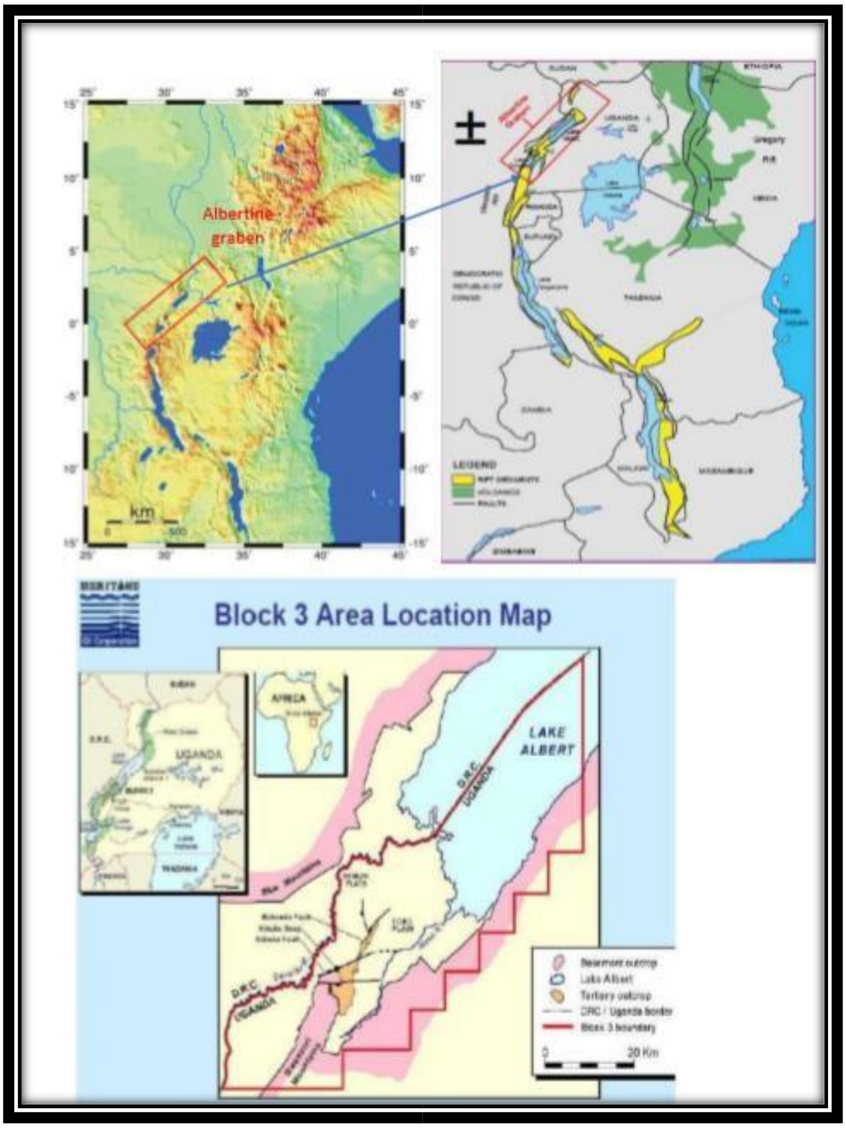


Figure1. 1: Maps showing the Location of the Albertine graben in Africa and in Uganda (top). Block 3 exploration area showing the location of the Albertine graben (bottom) (Source; geoexpro.org)

1.2 Accessibility

The study area is accessible by road from Kampala through Mubende district, Kyenjojo and Fort-Portal up to Ntoroko district. A highway is followed from Kampala through Mubende, Kyenjojo to Fort-portal (about 290km) and then to karugutu Town in Ntoroko District (25.6km from Fort-Portal) along the Fort-Portal-Bundibugyo highway.(Fig1.2).

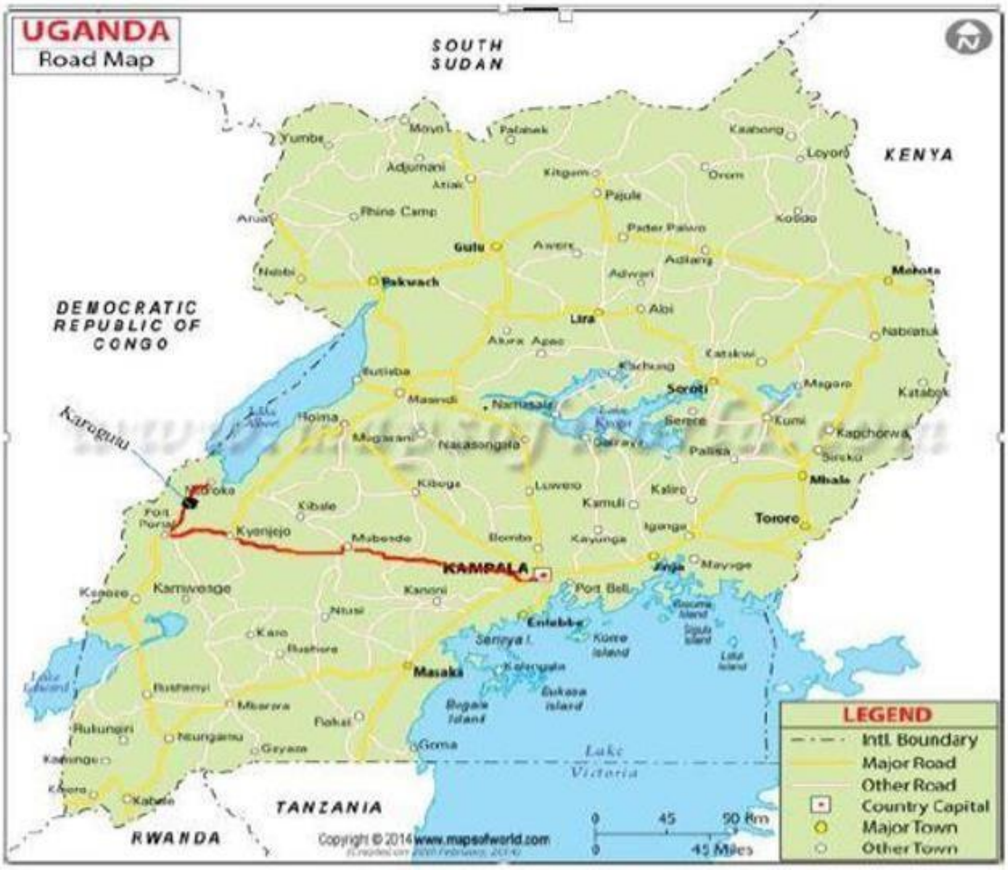


Figure1. 2. A map of Uganda showing the road used to access the Study Area.(indicated by the red line) *(Source; mapsofworld.com)*

1.3 Objectives of the study

- **Main Objective:** Field training on how to collect and interpret stratigraphic, petrographic, sedimentologic and structural data; which are very important in hydrocarbon exploration.
- **Specific Objectives:**
    - ✓ To identify the lithologies in Semliki Basin.
    - ✓ To identify and relate structures observed in the basement and sediments.
    - ✓ To study the lithologies and environments in order to identify the different elements of the petroleum system.
    - ✓ To Identify facies and depositional environments.

1.4 Geologic Setting Of The Study Area

Overview of Formation and evolution of the Albertine Rift

The Albertine Graben is part of the Northern-most extension of the Western arm of the East African Rift System (EARS). The Graben stretches from the border between Uganda and Sudan in the north to Lake Edward in the south, a total distance of over 500km with a variable width of 45 km. The evolution of the Eastern arm began at around 30 Ma with initial fracturing in the Afar region and the Ethiopian plateau and first volcanism at 20 Ma**(Fig.1.3).** The thermal up-doming and faulting in the Western arm branch did not begin earlier than Early Miocene and volcanism is thought to have started in the Middle Miocene, 12.6 Ma in the northern Virunga province (Bellon and Pouclet, 1980). At around the 12Ma, a shallow down-warp initiated a basin that filled up with fluviatile and evaporite deposits named the Kisegi Formation (Pickford et al., 1993). The timing for the first rifting phase in Uganda is constrained by the initial lacustrine conditions (Pickford et al., 1993) and began about 11–10 Ma with formation of Lake Obweruka, a 550km long basin that filled the valley formed by this rifting phase. Lake Obweruka became permanent when the rate of downthrow exceeded sedimentation rates about 8 to 7Ma when the first major rifting episode occurred. Rift shoulders were uplifted and were climatically significant at 4 Ma (Pickford et al., 1993). At around 2.6Ma, there was renewed rifting (Schlueter, 1997) during which the Albertine rift became more compartmentalized due to the emergence of the Rwenzori mountains. It resulted in division of Lake Obweruka into smaller lakes that is; Lake Edward and Albert (Pickford et al. 1993). At around 14,000-12,000 years ago, there was another phase of rifting which caused a shift of drainage direction to the north (Aanyu, 2011). The throws of the major normal faults in the Western Rift are estimated to amount between 1 and 6 km and the polarity of the rift structure changes repeatedly along strike (approx. 100 km long asymmetric segments).

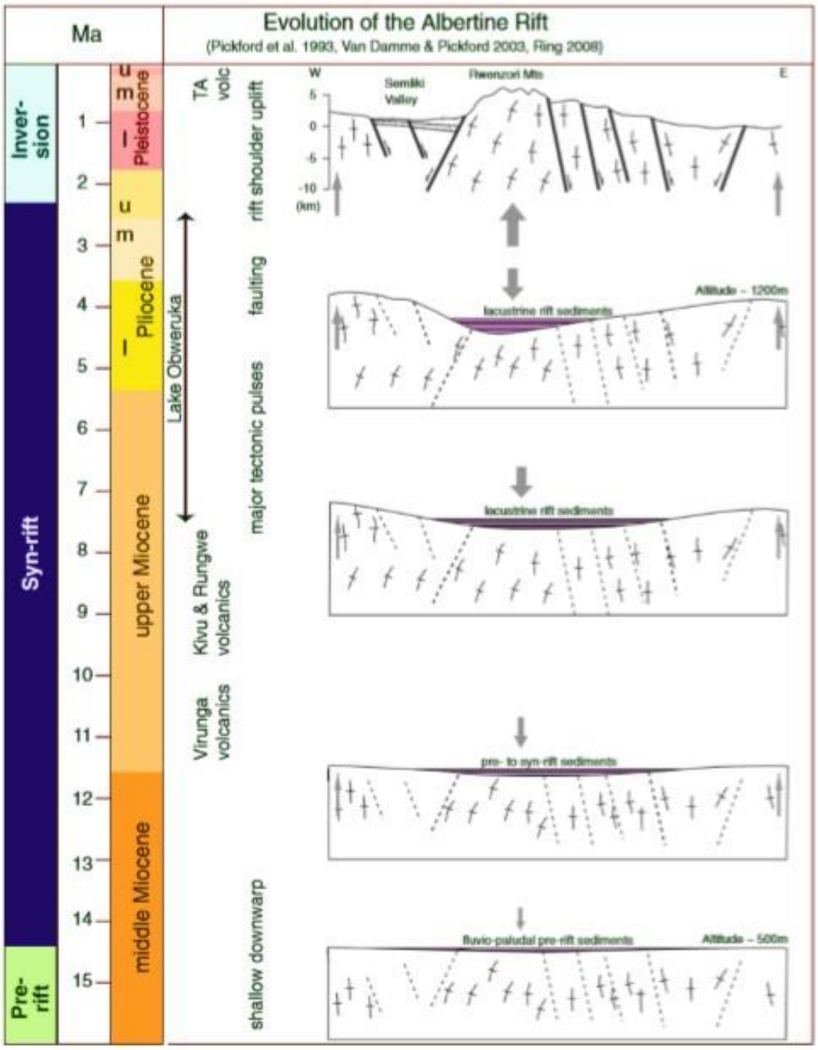


Figure1. 3 A diagram showing Evolution of the Albertine Graben(modified after Pickford et al1993, Van Damme and Pickford 2003, Fling 2008).

STRUCTURAL SETTING

The Graben is a Cenozoic rift basin formed and developed on the Precambrian orogenic belts of the African Craton. Rifting started during the late Oligocene/Early Miocene. The Graben has been affected by many tectonic episodes of both extensional and compressional regimes. Evidence of stress regimes oblique and perpendicular to the boundary faults is seen through the geometry and orientation of the fault systems defining the basins in the Graben. The Albertine Graben terminates at a known sinistral strike slip shear zone, namely; the Aswa shear zone. Other shear zones can be interpreted in the south of the Graben, around Kivu and Rukwa areas in the Tanzania part of the East African Rift. The Albertine Graben is therefore believed to have evolved in a strike slip dominated regime similar to the other basins developed in the Central African Rift System (Figure 1.4).

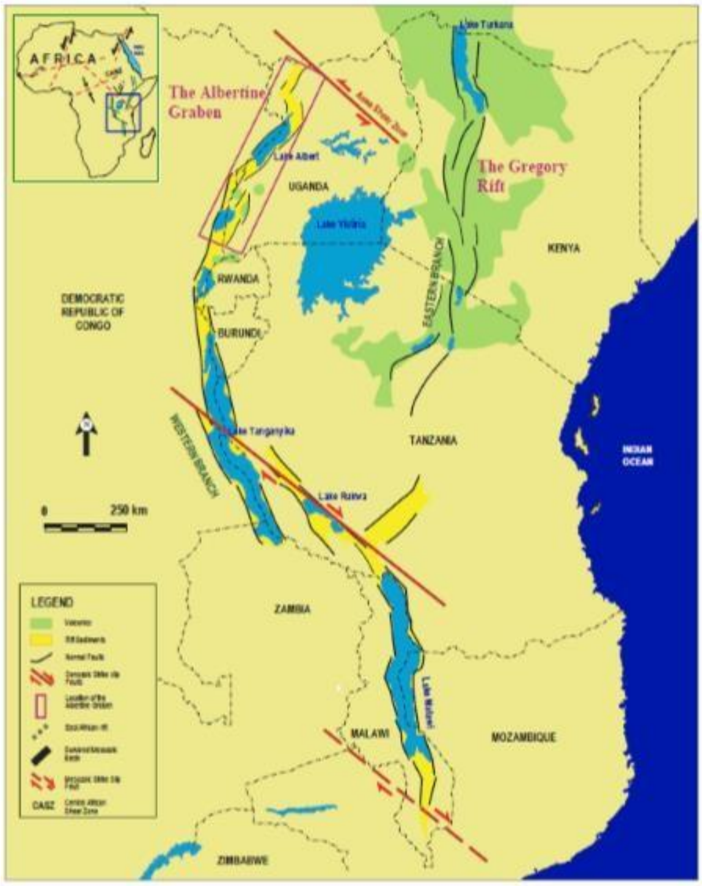


Figure1. 4: A Map of East Africa showing the three strike-slip shear zones along which the Albertine graben formed(Source: Lukaye, et al 2016)

Structurally, the Albertine Graben is divided into three domains**(Figure 1.5):** the northern domain that trends in the NNE-SSW direction and encompasses the Rhino Camp and Pakwach basins, the central domain in a NE-SW direction where the Lake Albert (Butiaba- Wanseko and KaisoTonya areas) and Semliki basins are located and the southern domain in a NNE-SSW direction where the Lakes Edward-George basin is found. The Graben trends in a NE-SW direction through most of its length, probably following the preexisting basement fabric.

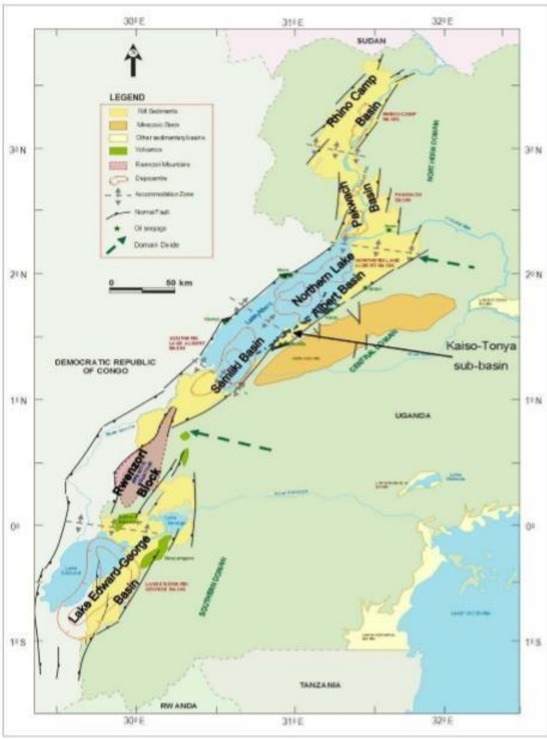


Figure1. 5: A map of Uganda showing the three structural domains of the Albertine graben(modified after Lukaye, et al 2016)

Overview of Topography Albertine Graben

According to Grotzinger et al., (2007) topography is the general configuration of varying heights that gives shape to Earth's surface. The shape of the Graben was studied by Jarrett (2014) using a digital elevation model designed with help of satellite imaging**(Figure 1.6).** The shape across the Semliki basin can be seen in cross-section "D" of the same Figure.

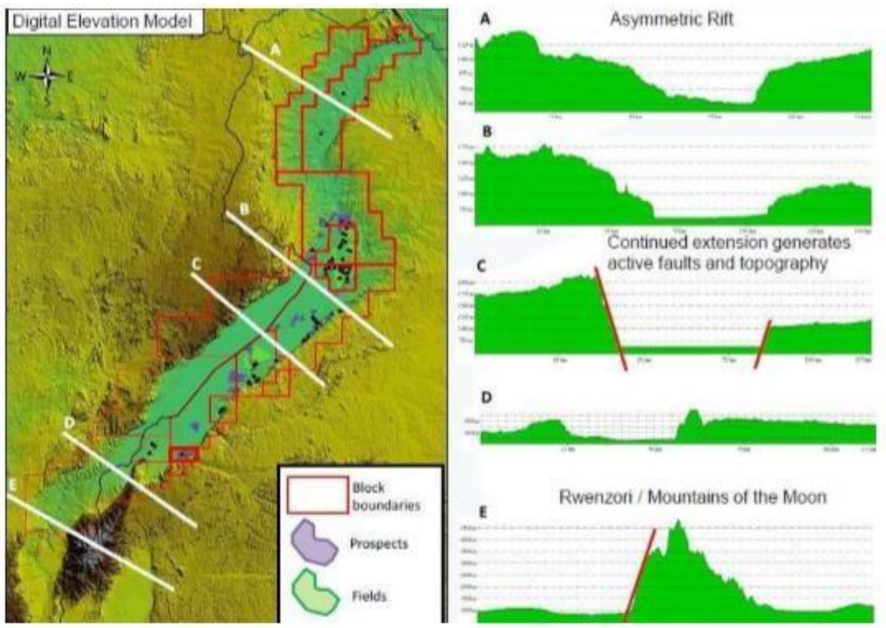


Figure1. 6: Topographic profiles along the Albertine graben (left) and the resultant cross sections (right).(Source: Jarret, 2014).

Overview of stratigraphy of Albertine Graben.

The stratigraphy of the Albertine Graben majorly consists of fluvial-deltaic and lacustrine deposits. The stratigraphy of the area has been greatly affected by tectonism, climate and Lake level fluctuations.

A number of geologists including Wayland (1925), Bishop (1965) and Pickford (1993) have given varying accounts of the stratigraphy. Studies by PEPD and the oil companies operating in the country have been carried out in an attempt to harmonize the variations in descriptions of the past and produce a unified stratigraphy for the Graben.

Generally, the oldest units, the Proterozoic is well exposed on the rift flanks and shoulders of the Albertine Graben. It comprises mainly high-grade metamorphosed and igneous rocks of Pre-Cambrian age. Seismic data points to a Pre-Cenozoic rift sedimentary section in some parts of the Graben, mainly restricted to the Lake Albert depocenters. The syn-rift section of the Albertine Graben was first recorded in the **Waki- 1B well,** which was drilled in 1938. This well penetrated both the Mid and Upper Cenozoic syn-rift sections which are characterized by conglomerates and sandstones. The well went through the Mesozoic pre-rift section before reaching basement. The Kisegi and Kaiso formations of the Cenozoic are also quite well exposed in the Graben, consisting mainly of intercalation of conglomerates and sandstones deposited in fluvial and shallow lacustrine environments. The Kisegi Formation in some cases overlies the meta-quartzite Basement. Although the Lower Cenozoic may overlie the crystalline basement in many parts of the Graben, there is a possibility that it overlies a Mesozoic section (Karoo) in some parts of the Graben.

Physiography of the Semliki Basin

The area comprises of the Semliki flats and the adjacent Toro plains South-west of Lake Albert. The largest part of the Semliki flats has a flat or very gently undulating surface with savannah vegetation. The undulating areas of the Toro plain are separated from the flood plains on the Eastern banks of the Semliki River by the major Makondo fault. The Semliki River meanders within the Semliki flats and forms the boundary between Uganda and the DRC. The Semliki Basin covers about 340 km^2 of the Northern Rwenzori Block. The Rwenzori Mountains are seen to plunge northwards beneath the Semliki Flats, with steep, fault-controlled escarpments on both sides of northernmost spur of the Rwenzori Mountains. The Semliki basin is bordered to the South-east by a steep fault escarpment rising almost 1,000 m to this spur. It is also is bordered on its western side by two major faults namely, the NNE-SSW trending Semliki fault and the NE-SW trending Bunya faults**(Figure 1.7).** These two separate the Congo escarpment and the basin.

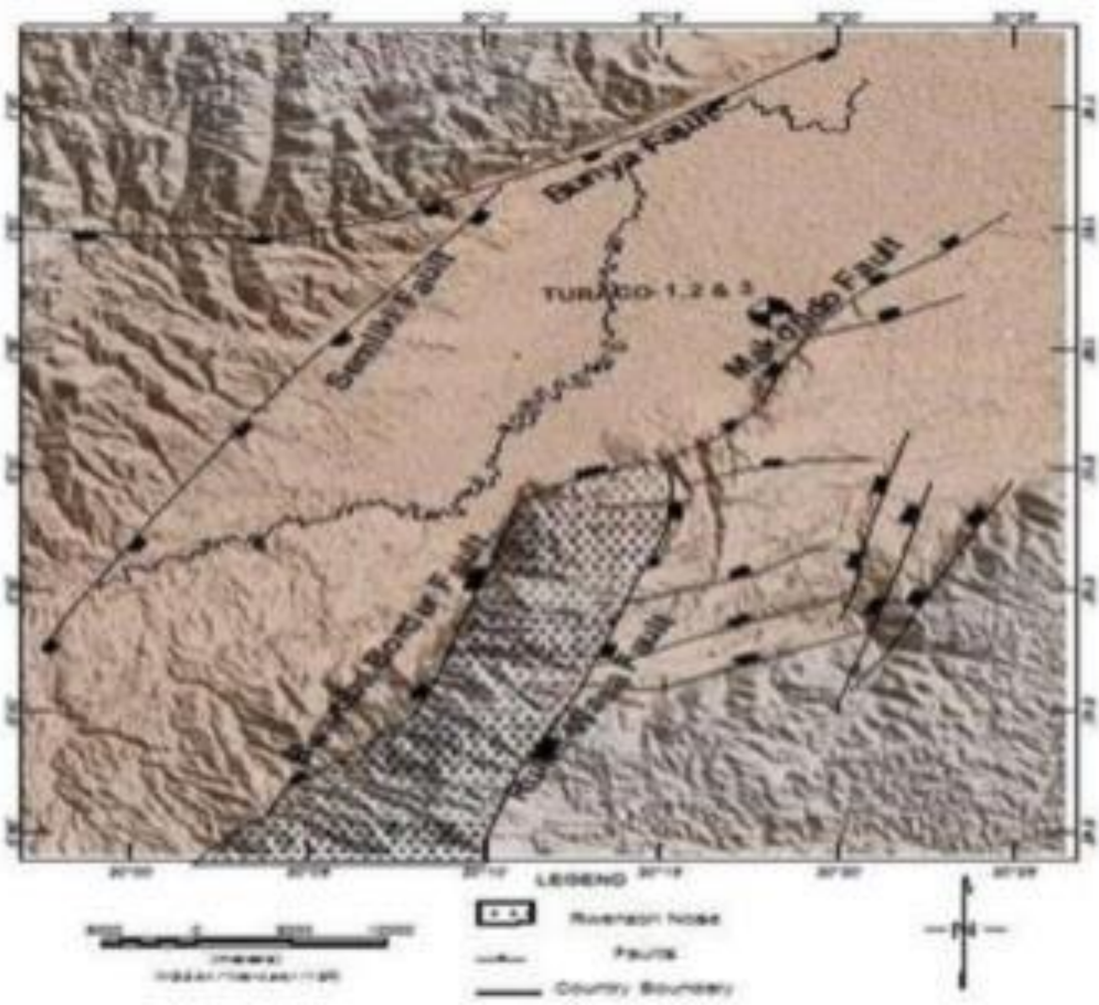


Figure1. 7: Physiography map of Semliki area showing the major faults oriented mostly in NE-SW direction (Source: Semanticscholars.org and Lukaye et al 2016)

The Semliki has a topography characterized by low elevations throughout the area with altitude ranges of approximately 630-750m above sea level(Figure 1.8).

Figure1. 8: Cross section of the topography of Semliki Basin (Source: PEPD, 1995)

At the margins, the valleys are used for agriculture since they have some reasonable soil thickness as compared to the hill slopes. The relative displacement of the Semliki fault at the western boundary of the basin is much greater than the corresponding fault displacement at the Eastern margin. After sediment in-fill, this resulted into an asymmetric basin with the Western side (in the DRC) much deeper than the eastern side (in Uganda) of this Semliki plain. This is therefore a Half-Graben.

2.0 CHAPTER TWO: MATERIALS AND METHODS

This chapter describes how the various equipment and materials(Table 1) were used in the field to achieve different aims like measurement of bedding thickness, structural trends, gauging grain-sizes among others. It contains the different methods applied to achieve different aims like carrying out facies analysis, treatment of collected data.

This chapter also gives information about the visit to Sempaya hot springs within the Albertine Graben which was aimed at investigating the effect of temperatures on the hydrocarbon occurrence within the rift. Other information contained in this chapter is geophysical tools, procedure and methods applied.

2.1 Equipment and Materials

Table 1: Equipments and materials used in the field

Material/Equipment	**Purpose**
GPS	used for locating ourselves on the base map, and determining the elevation of the different stations visited
Jacob's staff	It is a pole with length markings and stabilization features. This was used to measure vertical bedding-thickness during stratigraphic logging.
Base maps (topographic and geologic).	These were used for locating and orienting ourselves in the field and show the type of geologic structural framework to expect in a given location.
Geological Compass	We used this to measure structure trends like dip and strikes of the various structure. It was also used for base map orientation since it gives the compass directions.
Hand lens	Used to magnify the grain sizes of especially fine to very fine materials that cannot be readily distinguished by the naked eye.
Pair of binoculars	Used to view places/outcrops that were inaccessible by foot for example outcrops behind thickets and those very far.
Phones and digital cameras	We used both to take pictures of outcrops and structures.
Tape measure	Used to measure bedding-thickness and extent of structures.
Shovel and hoe	Used for cleaning sediment surfaces so as to clearly view beds to be logged.
Geological Hammer	Used for breaking off samples of rocks from in situ rock outcrops especially in the basement
Wentworth grain scale	Used for gauging grain-sizes, shapes and the types of grain sorting while in the field
Field notebooks	Used for taking field notes that is brief descriptions done on the basement rock and sediments in the field as well as other geologic features were recorded in the notebook. Sketching structures and recording of structural readings taken. All this information is useful in making interpretation and report writing
Graph paper	Used for drawing sedimentological logs
Backpack	Used to carry notebooks, pencils, pens, food, water bottle.

Well logs	Used for petrophysical analysis

2.2 Methods

2.2.1 Desk Study

A desk study is a phase of project planning that outlines all the activities to be undertaken during the field study. A desk study was conducted at the camp, where the different lecturers briefed us about the detailed plan and appropriate methods to be applied and mechanisms for carrying them out were discussed through literature review. The teaching staff gave guidelines regarding field data acquisition, recording and syntheses and how to use the various field equipment and material. Students were divided into groups and supplied with all the materials and equipment to be used in the field. This was conducted for a few hours on day 2.

2.2.2 Field Work Methods

Fieldwork took the largest part of the study since it is the major point of significance. The fieldwork was carried out by observing and describing outcrops, survey stations, identifying lithologies and structures, taking measurements of structure trends and bedding-thickness, basement studies, sedimentary logging exercise, discussions, analysis and interpretation of facies and depositional environment in order to get information on such factors as paleocurrent direction, petroleum potential of the area as discussed below.

2.2.2.1 Basement studies

The basement consists mainly of granitic gneiss and amphibolite observed along foothills of the Rwenzoris immediately after Kichwamba trading centre towards Bundibugyo. Structures present included joints, foliation and faults. Structural measurements involved the use of a compass to obtain the strike and dip of the different structures in the basement.

A contact between the basement and loose sedimentary layers is seen next to the Kibuku quarry and we described the sediments immediately overlying the basement including the dynamics of the depositional mechanisms and processes and we created a stratigraphic log of the sediments including the contact.

The other methods used under these studies include;

- **Mineral analysis**

This was mainly done in basement studies in order to identify different minerals present in the basement rocks based on color and their characteristics using an unaided eye and a hand lens for the minerals that are not very visible with a naked eye. This helps us to identify the lithology and interpret depositional processes and environment.

- **Structural measurements**

This method was used both in basement and sediment studies. The strike, dip, plunge and trend of structures were measured using instruments like a geologic compass for in situ rocks. Other parameters like thickness of beds a Jacob's stuff or tape measure were used especially in the sediments. The structural measurements obtained during this study have been attached in Appendix 1, 2 and 3 and a detailed discussion of their implication given in Chapter Five. For strike and dip direction the right-hand rule is the preferred method in this study. Structures measured included the joints [strike, dip and spacing], bedding and faults [strike and dip] and foliations.

Use of Geological Compass: In order to obtain strike of a fracture, the compass (facing upwards) was placed on the clean surface of the fracture with the compass parallel to the horizontal plane. To obtain the dip direction, the compass was placed on the fracture surface in such a way that it is parallel to the vertical plane. The edge of the compass should be parallel to the surface of the fracture and the required measurements read off and recorded from the compass.

From the analysis of the different structures, structural measures and rock types, a deduction was made concerning the geologic history and tectonic evolution of the area. The structures in the basement also gave an important insight on the structures that can be found in the sediments.

2.2.2.2 Sediment study

Lithostratigraphic logging: This was done from the bottom to the top of sediments layers along the Kibuku road cut. The information in the log included structures within the beds, sediment colors, grain size, sorting, type of lithology, grain size distribution and type of contacts between the lithological units. These logs helped in analysis, interpretation and understanding of the Semliki basin.

Logging procedure:

i. Cleaning and clearing of the outcrop using a hoe and shovel to remove vegetation and to expose a fresh surface
ii. Measurement of vertical thickness of the outcrop using a tape measure or Jacob's stuff
iii. Description of the sediment layers in terms of grain size, sorting, color among others.
iv. For outcrops whose basement is not seen or not clear, we use an erosional contact at the base of the log when constructing it on the graph paper.
v. Indicate facies on the log, determine and interpret the likely depositional environment and depositional processes.

The log produced was characteristic of the types of sediments that is fluvial/deltaic/ lacustrine and so on. It also helped in determine the hydrocarbon potential of the sediments for example in identifying potential source rocks and reservoir rocks or seals.

Determination of grain size and shape.

Determination of grain shape is based on observation of the clasts/grains with help of a hand lens to estimate sphericity, roundness of clasts, sorting and cementation at the exposures, road cuts and outcrops. The grain size was determined using a Wentworth Grain size scale**(Table 2).**

i. **Roundness:** During the transportation process, grain shapes changes due to abrasion resulting in the eventual rounding off of the sharp corners and edges of grains. Thus, rounding of grains gives clues on the amount of time the sediment has been in the transportation cycle. The different categories of roundness include very angular, angular, sub-angular, sub-rounded, rounded and well-rounded
ii. **Sorting:** Particles become sorted on the basis of density, because of the energy of the transporting medium. The degree of sorting may indicate the energy, rate, duration of deposition, as well as the transport process like river, debris flow, wind which are responsible for laying down the sediments.
iii. **Cementation:** occurs as dissolved minerals deposited in the spaces between the sediments. These minerals act as glue or cement to bind the sediments together.

Table 2: Wentworth Grain size scale

Grain Diameter: millimeters	microns	phi	Wentworth Size Class		
				Boulder	Gravel
256		-8.0		Cobble	
64		-6.0		Pebble	
4.0	4000	-2.0		Granule	
2.0	2000	-1.0	vcU	Very coarse sand	Sand
1.41	1410	-0.5	vcL		
1.0	1000	0.0	cU	Coarse sand	
.71	710	0.5	cL		
0.5	500	1.0	mU	Medium sand	
0.35	350	1.5	mL		
0.25	250	2.0	fU	Fine sand	
0.177	177	2.5	fL		
0.125	125	3.0	vfU	Very fine sand	
0.088	88	3.5	vfL		
0.0625	62.5	4.0		Silt	Mud
0.002	2.0	9.0		Clay	

Determination of paleocurrent flow direction.

Sedimentary structures within the layers were used to interpret and deduce the paleocurrent direction at the time of sediment deposition since they reflect environmental conditions that prevailed at, or very shortly after, the time of deposition. More specifically, the dip direction of cross-bed (tangential and angular) foresets encountered in the sand layers was used to determine this direction. The foreset laminae in cross-beds were generated by avalanching on the down-current side and therefore these foresets are deposited downdip. The dip direction was measured by a compass, on cross-beds that were well exposed in three dimensions on the outcrop. The readings were recorded and used to plot rose diagrams as discussed in details in Chapter 5.

Interpretation of the depositional environment.

A depositional environment can be defined as describes the combination of physical, chemical and biological processes associated with the deposition of a particular type of sediment and, therefore, the rock types that will be formed after lithification, if the sediment is preserved in the rock record. Deposition in the Semliki Basin is characterised by fluvial and lacustrine sediments. These sediments were noted to include sandstones, basal conglomerates, clays and silts. The distribution, orientation and internal geometry of fluvial/deltaic deposits is controlled by a number of factors; including but not limited to climate, water discharge, sediment load, river mouth processes, waves, tides, currents, winds, shelf width and slope and the tectonics and geometry of the receiving basin (Selley, 1978). Evidence of lacustrine environment was confirmed by presence of invertebrate fossils such as freshwater bivalves and oysters as encountered in Makondo area (201157, 110303). The depositional environment in the Kisegi formation is mainly fluvial, with meandering, alluvial, inter-channel, flood plain and over-bank deposits. In the observed outcrops, alluvial fan conglomerates pass up into fluvial channels and minor floodplain deposits all thought to have been deposited in semi-arid conditions. The outcrops show a series of meandering channels downcutting into each other with the uppermost abandoned channel filled with mixed silt and sandstone. In the subsurface, specifically in the Turaco3 well, the penetrated 300 m of the formation suggest a dominantly fluvial environment in a relatively quiescent tectonic regime, with low energy small scale channel systems.

Additionally, we used some few minerals present in sediments to interpret the conditions in the depositional environment for instance, the gypsum that has precipitated in the joints and within layers of sands and clays at the Kibuku road cut is indicative of conditions of semi-aridity in the environment of deposition.

Textural and mineralogical maturity of the rock units were used to deduce proximity of the provenance, strength of the paleocurrent for example the basal conglomerate of well-rounded quartzitic cobbles indicated a phase of strong current probably in a fluvial environment. Furthermore, episodes of a lacustrine environment are supported by presence thick layers of clay at Kibuku road cut(Group 6 area) and evaporates (gypsum) present in Kisegi and Kibuku.

Facies Analysis and Interpretation

Facies are used mostly to establish different units of rock from adjacent units within a contiguous body of rock by physical, chemical, or biological means. Facies analysis was conducted in the field through sedimentary logging of the encountered outcrops. Different facies groups were identified on the basis of factors such as sediment colour, grain size, structures, grading sequences, and fossil content.

Field discussions and presentations

Each group presented and discussed their findings after the stratigraphic logging to the entire class and lecturers and questions were asked where necessary.

Visit to the Sempaya hot springs

The Sempaya hot springs are located in the Semliki national park in Uganda. This national park covers an area of $220km^2$ and is bordered by Mt. Rwenzori in the South-east, DRC in the West, and the Semliki flats to the North. Buranga in which the Sempaya hot springs fall along with Katwe-Kikorongo and Kibiro are the three geothermal fields in Uganda. The Park is endowed with rich wild life which includes; nine species of primates/monkeys, 460 species of which 35 are endemic and many more. The Sempaya hot springs consist of a female and male hot spring named Nyansimbi and Bamaga respectively by the locals who believe that the couple disappeared from these hot springs. The temperature of the hot springs ranges between 98^0C-103^0C and this temperature is believed to be caused by the low altitude between 670m and 760m. The area is also in close proximity with the Bwamba fault that is approximately seven miles from the surface of the super-heated rocks. The hot water gushed out is based on the rain water which percolates into the porous sedimentary rocks. It percolates through the rock dissolving a variety of materials, from radium to Sulphur. As this water and groundwater moves further beneath the surface, it heats up from the primal heat of the earth, the mantle which is closer to the surface than in other areas. When it encounters a weak zone such as a fault or crack, it then ascends along it to surface as a hot spring. The female hot springs consist of a series of steamy water jetting out of the subsurface with a strong pungent smell of hydrogen sulphide (H_2S) gas, carbon dioxide gas, carbonates and other salts. It occupies an area of about 60 x 40 m. There is a travertine cone formed, about 1m in height. Average water temperature is 98.4°C. The male hot springs on the other hand are a pool of steamy hot water with a strong pungent smell of sulphur. The pool diameter is about 30m and average water temperature is 86°C, down to a depth of 5m and has a carbonate cone formed from carbonates precipitating out of the water.

Figure 2. 1: Sempaya Hot Springs(Female)

Effect of Temperature on Hydrocarbon Occurrence in the rift:

The highest temperatures ever recorded were 106°C and 103°C for the male and female hot springs respectively and thus are thought to contribute to the geothermal gradients that have accelerated the thermal maturation of source rocks in the Albertine Graben as one of the youngest rift basins in the world. However, a suitable oil window is defined by the temperature range of 60-120°C. This means that the hot springs temperatures are higher than the lower limit of the oil window and therefore, the effect is twofold that is, it is useful in formation of hydrocarbons from thermal transformation of organic material to kerogen to hydrocarbon since high temperatures accelerate thermal maturation. It is however detrimental through thermal alteration/cracking as there is good chance of "overcooking" or cracking the oil to form thermogenic gases like methane.

Geothermal potential of the area

Geothermal energy can be used to generate electricity. Geothermal potential is analogous to petroleum potential in such a way that, to generate from a geothermal field, it must have all the system elements in place. These include; a source rock, a localized plume; a reservoir rock that can carry heat and retain it like granites and sandstones; a cap rock (also called a seal rock) to provide a blanket to impede the escape of heat from the reservoir rock , clay and hydrocarbons; and finally, a plumbing system that allows water to move from one point to another, more like migration pathways. Presence of hot springs generally shows high geothermal potential in this field. This is because the hot springs translate into presence of a localized heat source and a viable plumbing system, while the sandstones and clays mapped in the region can efficiently work as reservoirs and caps respectively.

Makondo and Turaco field study

The Makondo area (201070/110311) is located within the Semliki national game park. Within this area exists the Makondo fault which was of great interest to geophysicists in early explorations. From literature, in 1983, Kenting Earth Sciences carried out an airborne survey which was followed by a gravity and radiometric survey. The data obtained from the surveys indicated an interesting flower structure at the Makondo fault. In 1998, seismic data was acquired and showed that the Makondo fault was striking in the NE-SW direction. The hanging wall of this fault was also of great significance in petroleum exploration and the drilling had to commence.

The Turaco wells (199697, 114170) are located on the Hanging wall of the Makondo fault. The Turaco wells were first drilled in 2001 with an aim of encountering oil in the Kisegi formation. The target was to reach 2500m but only 2400m depth was achieved due to drilling problems encountered (Bottomhole Assembly got stuck). Turaco well 2 was then drilled as a sidetrack but was unable to reach the target. Turaco well 3 was drilled 100m away from Turaco well 1 and reached a target of 2900m. Unfortunately, carbon dioxide with natural gas contaminants was encountered and thus the objective of drilling the wells not achieved. The well site was the decommissioned, abandoned and the area restored to its natural state. There are controversies on the source of the carbon dioxide as to whether it was as a result of vulcanism that took place in the area or due to over maturation of hydro carbons that could have been present in the subsurface.

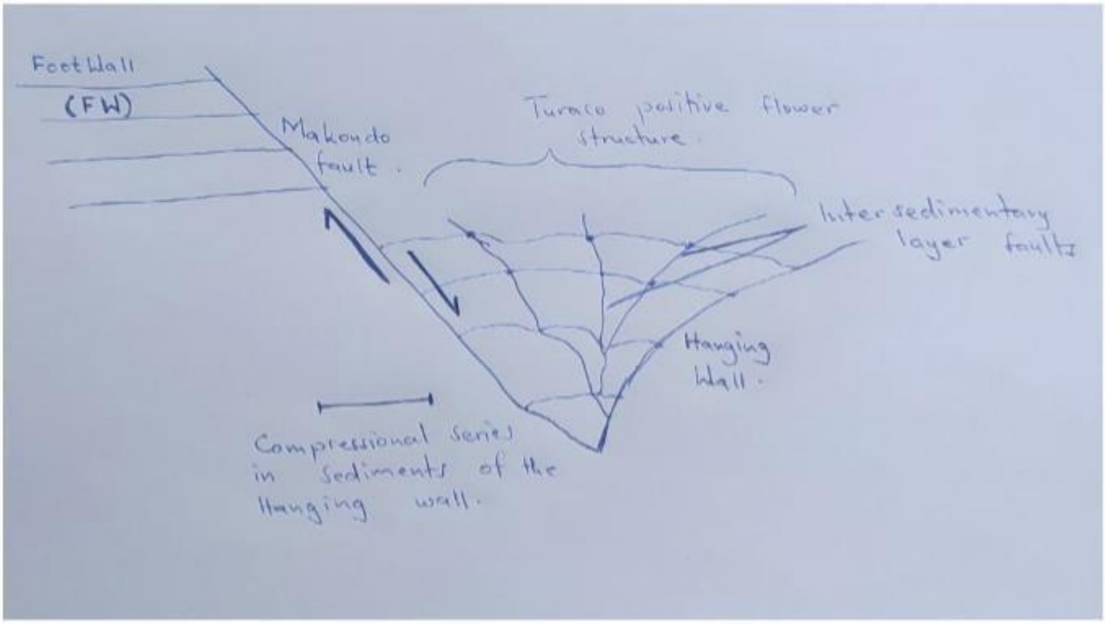


Figure 2. 2: Positive flower structure at Turaco

2.2.3 Post-field Methods

Field data analysis.

Data obtained while in the field, both geological and geophysical was analyzed using various techniques to aid the overall understanding of information presented in this report. The structural measurements of dip and strike were plotted on the stereographs using stereonet software to obtain stereographic plots. Stratigraphic logs included in this report were digitized using Sedlog software The maps of gravity bouguer and magnetic anomalies were obtained using specialized software called Oasis Montaj(Geosoft), to allow for interpretations regarding the nature of the subsurface.

Usage of seismic images basically relied on horizon tracking in order to obtain discontinuities and come up with the different subsurface structures such as faults, roll-over anticlines among others **Field report write-up**

This report marks the climax of the field project in which all data, skills, knowledge and interpretations made during the project are documented. The report is a result of research, data analysis, literature review and interpretation of all the collected data. It consists of seven chapters that include Introduction; Materials and Methods; Lithology and Stratigraphy; Basin and Facies analysis; Structures; Geophysics; and lastly Discussions, Conclusions, and Recommendations.

CHAPTER THREE: LITHOLOGY AND STRATIGRAPHY

3.0 INTRODUCTION

This chapter looks at a variety of rock properties and features for example the type of sediments deposited in the Semliki Basin, depositional processes/agents and the deposition environment of the environment.

Lithology refers to study of rocks with special emphasis on description and classification. This involves the study of physical characteristics visible at outcrop, in a hand lens or core samples or with low magnification microscopy, such as color, texture, grain size, or composition. The Semliki basin comprises two major types of lithologies; syn-rift (clastic and non-clastic sediments) and pre-rift lithology (Pre-Cambrian basement rocks). At the time of deposition, sediments are laid horizontally in layers called strata(**Principle of original horizontality)**.

Stratigraphy is the study of rock layers and the layering. The stratigraphy of the Semliki Basin as a whole has been divided into a number of formations. Based on age relationships of strata and succession of beds, Pickford et al. (1994) classified the sedimentary rocks of Semliki Basin into seven formations as discussed under basin analysis in Chapter four.

The study of stratigraphy is based on the Principles established by Nicolas Steno known as 'principles of Stratigraphy". They include the following:

- ✓ **Principle of superposition:** In an un-deformed state, a sequence of strata will have the younger strata overlying older strata. It is very useful in relative age dating of layers that have undergone minimal or no tectonic impacts.
- ✓ **Principle of original horizontality:** Layers of sediment are originally deposited at their angle of repose, which is horizontal under the action of gravity. It is important to the analysis in identifying and explaining folded and tilted strata.
- ✓ **Principle of lateral continuity**: Layers of sediments extend laterally in all directions unless obstructed by a physical object or topography
- ✓ **Principle of cross-cutting relationships:** A geologic feature that cuts another is the younger of the two features. It is useful in relative age dating of rock layers which have gone through various tectonic episodes.
- ✓ **Principle of faunal succession:** Sedimentary rock strata contain fossilized flora and fauna that succeed each other vertically in a specific, reliable order that can be identified over wide horizontal distances.
- ✓ **Principle of inclusions:** If a rock fragment is enclosed in another rock, then the fragment is an inclusion that represents fragment of older rock.
- ✓ **Principle of uniformitarianism** also known as the "principle of actualism"; All geologic processes/events taking place presently have ever occurred in the past.

3.1 BASEMENT LITHOLOGY

Basement rocks occupying the study area belong to the rock systems of Buganda-Toro and KaragweAnkolean. They are mainly encountered along the flanks of the Graben and comprise high-grade metasedimentary and metamorphic rocks such as gneisses, granitic gneisses, dolerite dykes, amphibolite intrusions, mica schists and in some areas, quartzites and granites. Intense shearing and metamorphism that affected rocks in particular parts can be attributed to active faulting. There is an extensive weathering(chemical) in the fault zones due to percolation of water into the faults which results into weakening of the rocks. The major lithologies forming the basement include;

3.1.1 Amphibolite

This occurs along the Kichwamba road cut as an intensely fractured intrusion(Figure 3.1). The formation of amphibolite came after the formation of the granite through vulcanicity, tectonism occurred leading to fracturing of the rocks and later dolerite dyke intruded along lines of weakness(fractures) in the granite and leading to shearing. This dyke may have metamorphosed the granite into a granitic gneiss as a result of contact metamorphism. Later episodes of tectonism could have metamorphosed dolerite dyke into an amphibolite. This intrusion may have contributed to further fracturing of the granitic gneiss given its brittle nature. This notion is evidenced by the presence of similar trend of joints (NE-SW) in both the granitic gneiss and amphibolite dyke. The fracturing of the amphibolite could have been caused by margins of the dyke cooling faster than the middle parts hence leading to greater friction at the margins and consequently fracturing. The amphibolite colors observed include; dark-green, black and brown. Minerals included amphiboles (>90%), plagioclase, pyroxenes and to a small percentage, biotite and quartz (<10%).

Figure 3. 1: A large amphibolite outcrop encountered near Kichwamba Technical college

3.1.2 Granitic Gneiss

A massive outcrop of this rock type was exposed at the road cut near Kichwamba Technical College (186824/79600)(Figure3.2). The rock is banded with different mineral colors including white, grey, pink and black and some brown colors brought about by weathering processes. The rock is heavily fractured with some joints filled with quartz minerals possibly from the hydrothermal fluids that rose into the joints during the different tectonic episodes. Tectonism also led to foliation and banding in the rocks. The presence of minerals like quartz, feldspars, muscovite, biotite and albite is evidence that the rock underwent high grade metamorphism.

This same lithology occurs at the Kibuku Quarry (192486/102083) at elevation of 675m**(figure 3.2)** with similar properties except the addition of the muscovite mineral in the Granitic gneiss at the quarry and the gneisses are being highly metamorphosed to schists. This rock is heavily jointed with most of the joints oriented in the NE-SW direction and has quartz veins. The abundance of structures like joints was used to discuss the potential of the Semliki basin. These joints would act as migration pathways for the hydrocarbons.

Relationship to Petroleum: The intense fracturing makes this rock a potential reservoir. However, the is poor due to compartmentalization caused by a thick layer of clay running from top to bottom. This could have resulted from shearing of rocks along weakness lines such as the joints, creating void space which was later filled by the sediments. The oil, if present, would likely have been water-washed or biodegraded hence affecting quality and production since biodegraded oil is heavy and expensive to produce.

In terms of Health, Safety and Environment, the outcrop was poorly quarried leaving some of the blocks hanging which is a threat to man and animals. Different methods of making this area a safe space were discussed and include the following; quarrying from top to bottom while following lines of weakness and opposite to the direction of dip of the joints, constructing gabions to prevent hanging blocks from falling, revegetation after quarrying, benching mining instead of blasting, improved decommissioning plans.

Figure 3. 2: A photograph showing quartz vein in a granitic gneiss in Kichwamba area (left)(186824/79600) and Granitic gneiss at quarry behind Kisegi hill(Right) (location: 192486/102083).(Heavily jointed, banded and foliated).

3.1.3 Quartzite

Quartzite is a hard non-foliated metamorphic rock composed almost entirely of quartz(Figure 3.3). Quartzites are derived from metamorphism of sandstones. In the study area, quartzites occur in form of quartz veins within the country rock (granite gneiss mostly. As temperatures and pressures reduced, the magmatic intrusions were continuously reworked to form more stable mineral such as the quartz, that later cooled and solidified to form the quarzitic veins. Generally, their color varied from white to faint-pink. However, some trace-quantities of mafic minerals such as biotite and micas were observed in these quartzitic veins.

Figure 3. 3: Heavily jointed Quartzite outcrop

3.1.4 Granites

The granite is massive, pink to grey colour and with a weathered portion of brown to grey colour. It is medium to coarse grained and comprises K-feldspars, quartz, biotite, muscovite. Most of the minerals have been altered due to active faulting in the area.

3.2 Lithology of the Sediments

It is believed that in the Albertine Graben, the sediments deposited until the middle Miocene were up to 6km thick (Van Damme and Pickford, 2003; Abeinomugisha, 2010). Based on age relationships of strata and succession of beds, Pickford et al. (1987 and 1994) classified the sedimentary rocks of Semliki Basin into seven Formations (Nyabusosi, Nyakabingo, Nyaburogo, Oluka, Kakara, Kasande and Kisegi Formations.). Different factors that aided this classification included the geometry, degree of consolidation, fossil content and radiometric dating of surface outcrops. Provenance of sediments in Semliki basin is believed to be the basement rocks in the highlands/ Mt. Rwenzori ranges (basing on the color and mineralogical characteristics of the sediments) and Lake Obweruka; the present day Lake Albert. The sediments were transported by rivers into the basin and deposited. The different sediment lithologies in the Semliki basin are discussed below.

3.2.1 Conglomerates

Conglomerate is a clastic sedimentary rock composed of substantial fraction of rounded to subangular gravel-size clasts(>2mm in diameter). In the Semliki Basin, The conglomerates are of polymictic and monomictic types and have both matrix-supported and clast-supported fabric, mainly made up of sub-angular gravel and pebbles of varying grain sizes and color. The pebbles and cobbles are of quartzite and granite gneiss rocks. From example in the Kisegi formation at location 192788/101978 and elevation of 707m exists a polymictic conglomerate made up of angular to subangular pebbles and cobbles of quartz and the fabric is clast-supported(Figure 3.4). The source of these pebbles and cobbles is believed to be in the basement rocks in the Rwenzori mountains. Additionally, the sub-angularity of pebbles and cobbles indicates that the clasts were transported through a short distance from their provenance thus the minimal textural reworking.

The conglomerates are poorly sorted, this is evidence of very high energy water, laden with large masses of sediments, moving from an uphill provenance and suddenly losing all its energy and dynamism leading to an instantaneous settling of the sediments. This situation occurs mainly in alluvial fans.

Figure 3. 4: A polymictic Conglomerate made up of angular to sub-angular pebbles found at the contact between sediments and basement in the Kisegi Channel

3.2.2 Sands

Sands are the most dominant sediments at the basin. They are of various sizes ranging from very fine to very coarse, and degrees of sorting from poor to well sorted. The sands were originally deposited in lateral layers with thickness range of 18-120cm. They are of different colors namely; grey, white, yellow to reddish-brown. The yellow sands are a result of coating by iron(iii) oxides. The white color was dominant in quartz-rich sands. The sands are cemented by iron minerals and colorless gypsum flakes, while other sands are unconsolidated. Majority of the sand layers show a uniform size within the beds and a few exhibit grading within the beds. The sequences consisted of blocky layers(example is the kasande formation) and graded sequences. The fining-upward sequences are indicative of a fluvial system where varying energy levels deposit different grain sizes and coarsening upwards sands indicate deltaic settings while the blocky sequences are evidence of lacustrine deposition.

Most sands were deposited in cyclic layers(Figure 3.5).

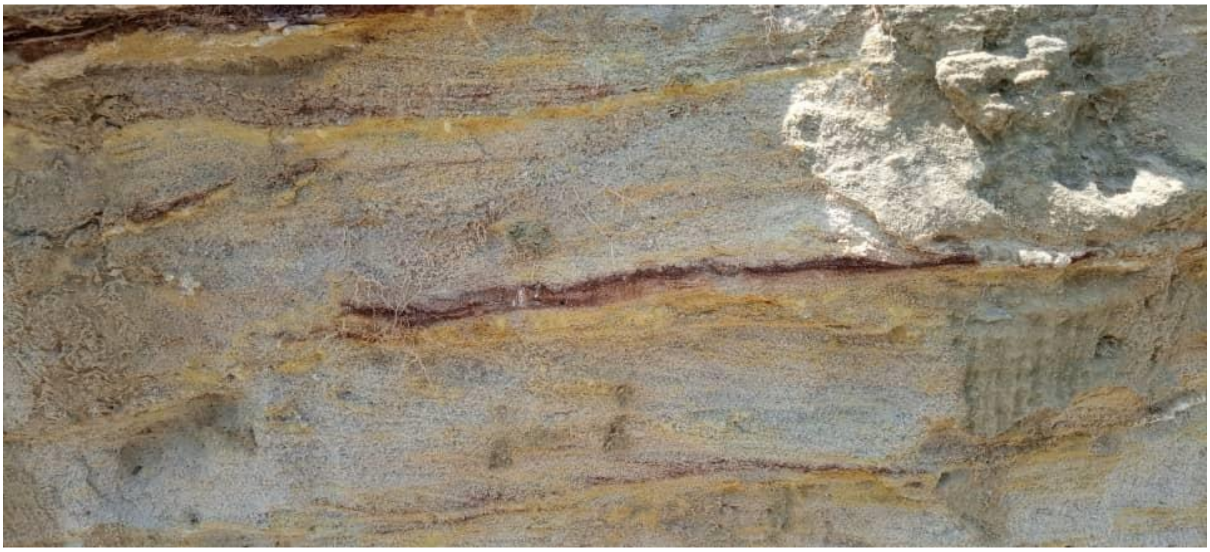


Figure 3. 5: Sand layers encountered along Kibuku Road Cut

Petroleum Potential: the coarsening upward sequence would be ideal for reservoirs because the hydrocarbons would accumulate in the upper parts of the reservoir that are thicker and coarser(hence more porous) due to buoyancy. This implies great storage capacity and permeability leading to high recovery factors compared to fining upward sequences with low permeability. However, although these sands would make good reservoirs, the gypsum present in them would lead to compartmentalization by sealing the fractures and poor communication in the reservoir.

Structures present in the sands include cross-beds, planar beds, load casts, joints, folds and faults In some sections, the sands were observed to be inter-bedded with clays. This cyclicity in deposition results into compartmentalization of potential reservoirs a fact which greatly impairs recovery of hydrocarbons. The clays that overly the cyclic sequences would form as good cap rocks.

3.2.3 Clays

Clays are very fine grained sediment that occur in various colours. In most parts, the occur as very thin layers(5-10cm) between thicker layers of sands(Figure 3.6). While in area logged by group 6 in the Kasande formation, clay was deposited in thick layers of upto 300cm. The clays have grey, yellow and reddish brown colours and contain gypsum. The presence of the reddish-brown colour is attributed to iron(iii) oxides and this together with gypsum signify semi-arid paleoenvironment.

Generally, clays may have been deposited during periods of transgression when the waters were calm, whereas sandstones could have been deposited during periods of regression by high energy and dynamic waters. Furthermore, clays can be deposited during periods of flooding when the rivers overflowed their banks, deposited silts and clays. Most of the clays in the basin are discontinuous and even pinching out in some areas. The structures present in the clays included laminations, faults. The gypsum sheets in clay beds resulting from precipitation from calcium sulphate-rich waters and desiccation marks that could have formed as the clay layers lost moisture.

In terms of petroleum potential, the clays would form good source rocks and cap rocks given the fact that some layers contained dark brown material believed to be organic matter which is vital in hydrocarbon formation and their very fine nature makes them good seals.

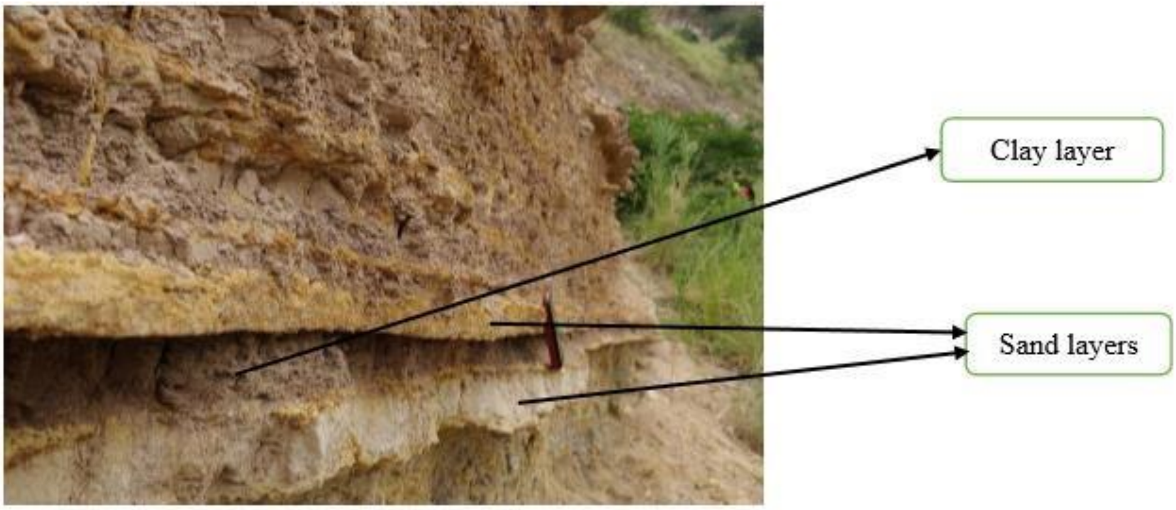


Figure 3. 6: Intercalations of clay and sand layers encountered along Kibuku Road cut

3.2.4 Silts

These are fine to very fine sediments, a few milimetres in grainsize diameter. In the Semliki basin, They form thin, less extensive layers and less common than sandstones and clays. Silts encountered are continuous. The silts encountered contained clay minerals, feldspars and quartz. Colour of the silts ranged from grey, white, yellow and reddish-brown, due to presence of iron oxides. They are wellsorted and fine grained.

3.2.5 Evaporites

Gypsum ($CaSO_4.2H_2O$) is the main evaporite mineral associated with the sedimentary rocks in the study area(Figure 3.7). The paleoclimatic conditions were favorable for evaporation and leading to formation of gypsum. The gypsum flakes are white-colorless in colour, brittle and acts as a cementing agent along with the iron oxide cement in the sediments of the logged road cut of Kibuku area. The presence of gypsum is evidence of semi-arid conditions.

Figure 3. 7: Gysum crystal found in most sands Along the Kibuku Road cut

3.2.6 Travertine

Travertine is a chemical rock, formed by chemical decomposition and the sediments transported in solutions to the sites of deposition where chemical changes due to evaporation occur. Travertine deposits are encountered at the Sempaya hot springs(Figure 2.1) where groundwater containing dissolved calcium and bicarbonate ions precipitate calcite to form a chemically precipitated limestone.

3.3 Contact between basement and sediments

The contact between sediments and basement in the study area is found at location **192593/102087** and elevation of 712m. This contact is marked by a layer of conglomerate with matrix-supported fabric of sands and made up of angular to sub-angular pebbles(indicating short distance of transport)(**Figure3.8).** The lithology includes granitic gneiss in the basement which is overlain by conglomerates and unconsolidated and consolidated sands cemented by gypsum and iron(iii) oxides. The structures present include cross-stratification. The basal conglomerate is poorly-sorted, polymictic, clast-supported and comprising subangular cobbles, pebbles and coarse sands.

About three cycles of fluvial deposits**(Figure3.8)** with conglomerates higher in the sequence havig smaller pebbles than those at the contact at the bottom. This could be due reduced energy of the river in the later episodes of deposition. These different cycles of deposition can be attributed to rejuvenation of the river. Rejuvenation can be caused by change in climatic conditions(i.e. increase in rainfall and amount of water) and tectonic activity which can increase in uplift which leads to higher gradient between the source and depositional site and consequently increasing flow rate, energy and the river deposits heavier sediments.

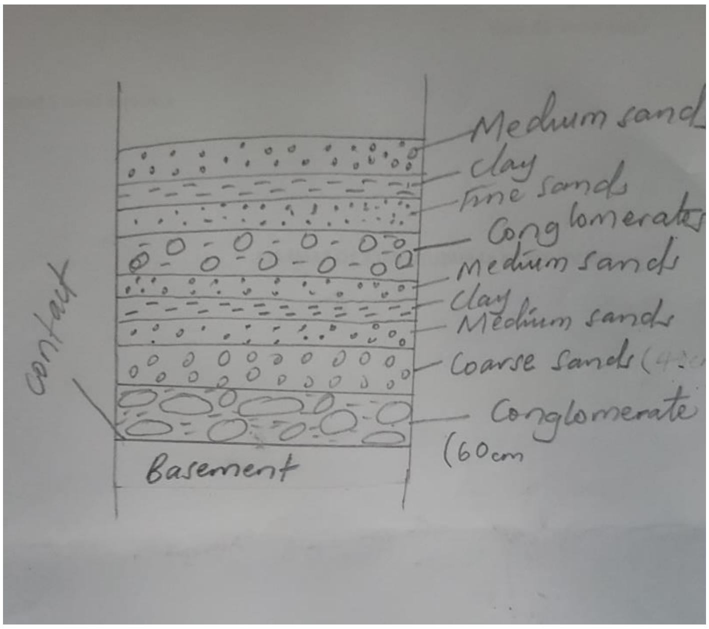


Figure 3. 8: A sketch of contact between sediments and basement in Semliki basin(location: 192593/102087 and elevation of 712m).

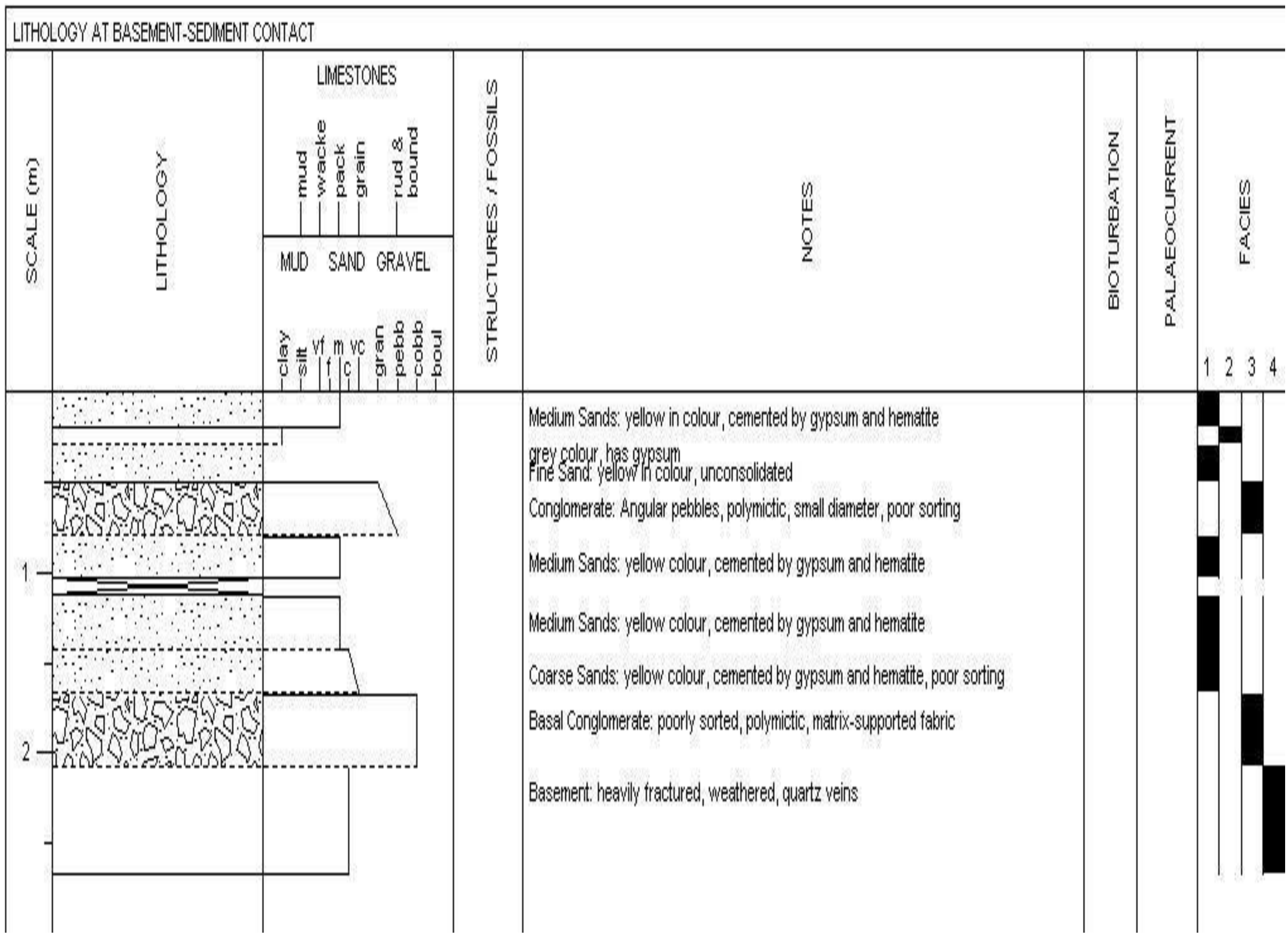
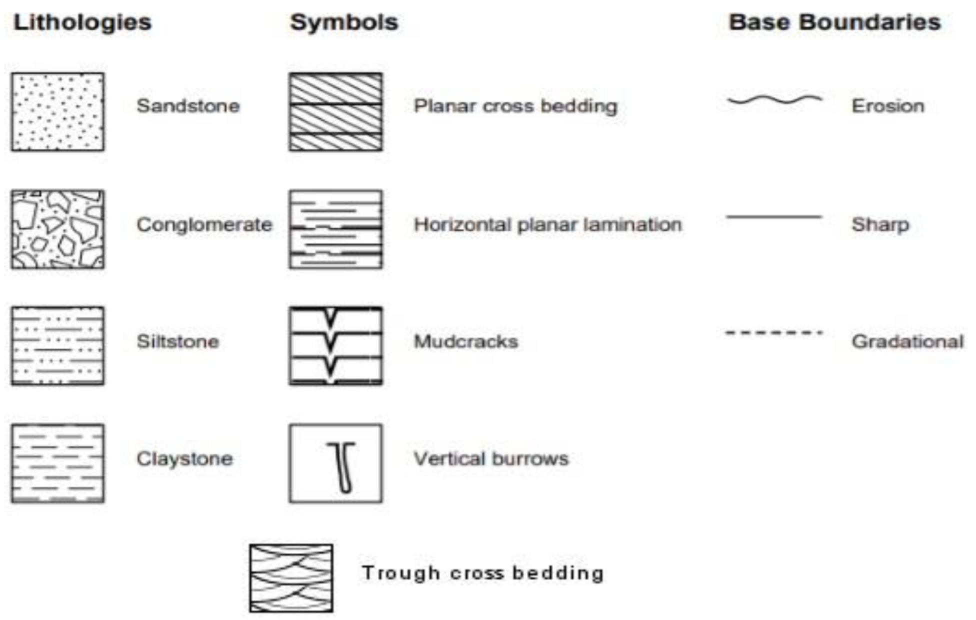


Figure 3. 9: A diagram showing Sedimentary log showing the lithology at the sediment-basement contact encountered next to the quarry behind Kisegi hill.

Table 3: Log key



3.4 Sedimentary Logs and Interpretation

3.4.1 Group 6 log

Figure 3.10 below shows the sedimentary log of area logged by Group 6 along the Kibuku Road cut. The log consists mainly of thick layers of clay and blocky Sand layers without major structures and a few layers of silts. This is indicative of lacustrine deposition environment. The beds exhibit cyclicity, this represents repetitive changes in the conditions(especially energy, sea/lake level or tectonic activity) of the depositing medium or the depositional environment. Seasonal changes in weather could have resulted in fluctuation of water levels in the lake leading to deposition of repeated layers of sands, clays and silts.

The sands layers vary in grain size from very fine to coarse with the fine-grained layers being more dominate. This is more characteristic of lacustrine deposits because fine-grained materials are deposited by low-energy media and lake is a low environment/medium. Most sands are yellow in color while a few layers are white. The yellow colour is due coating of the sands by iron(iii) oxides. Some sand layers are unconsolidated as described in the 'notes' column of the log while others are cemented by gypsum or iron mineral. The presence of iron(iii) oxide is an evidence of oxidation paleoenvironment and together with gypsum, they signify semi-arid conditions/paleoenvironment.

They clays contain some dark brown material believed to organic matter. This makes them potential rocks in this area. Past studies have associated this section of the road cut with Kasande Formation which overlies Kisegi formation(Reservoir rocks in the study area) and underlies Kakara formation. These clay layers can also act as seals to the generated hydrocarbon after expulsion to the lower sand layers. The clay layers also contain mud cracks which implies that they were exposed to the atmosphere at some point in time. This suggests that the lake must have dried up or its level fell.

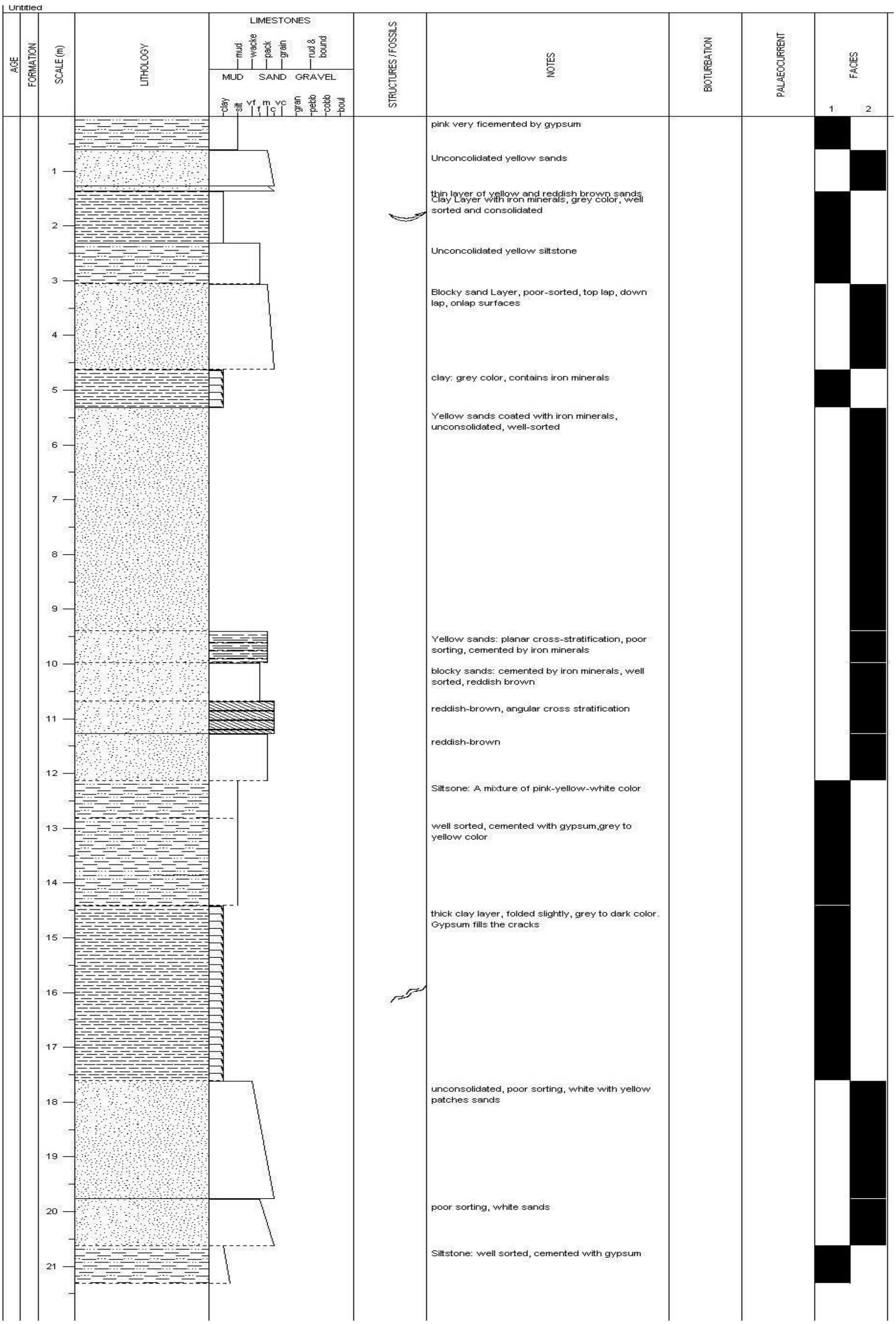
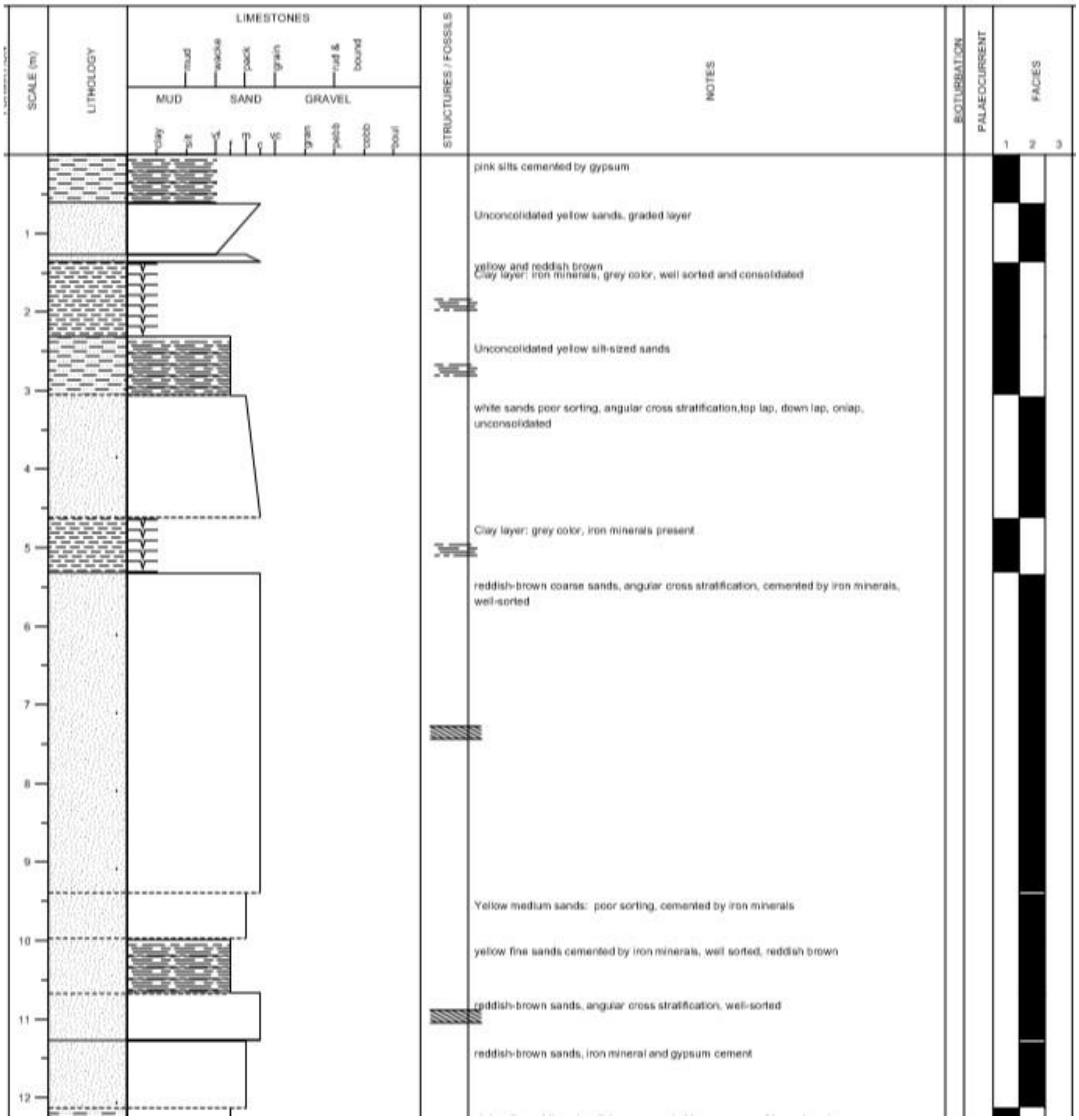
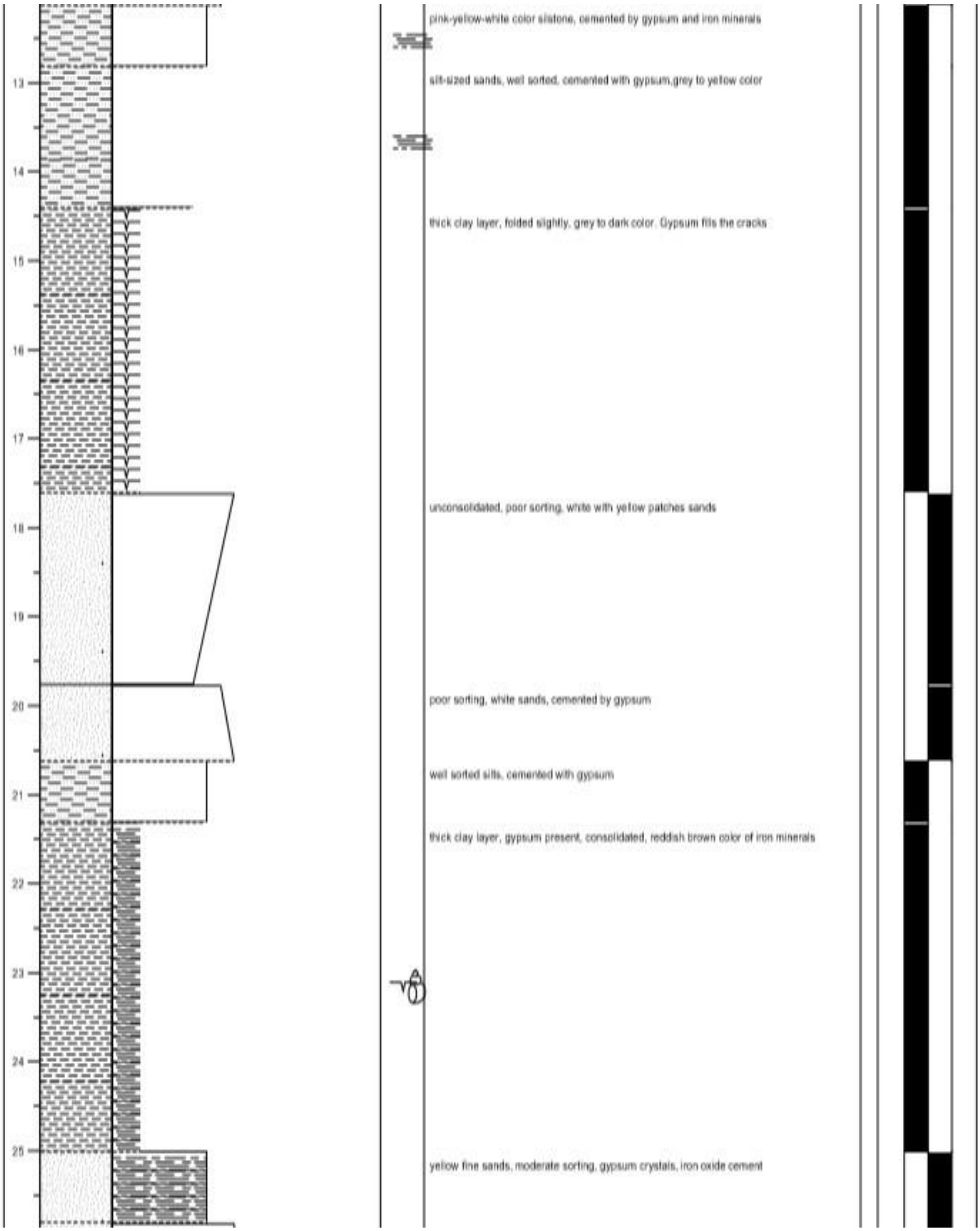


Figure 3. 10: Group 6 Sedimentology Log

3.4.2 Combined Sedimentary log

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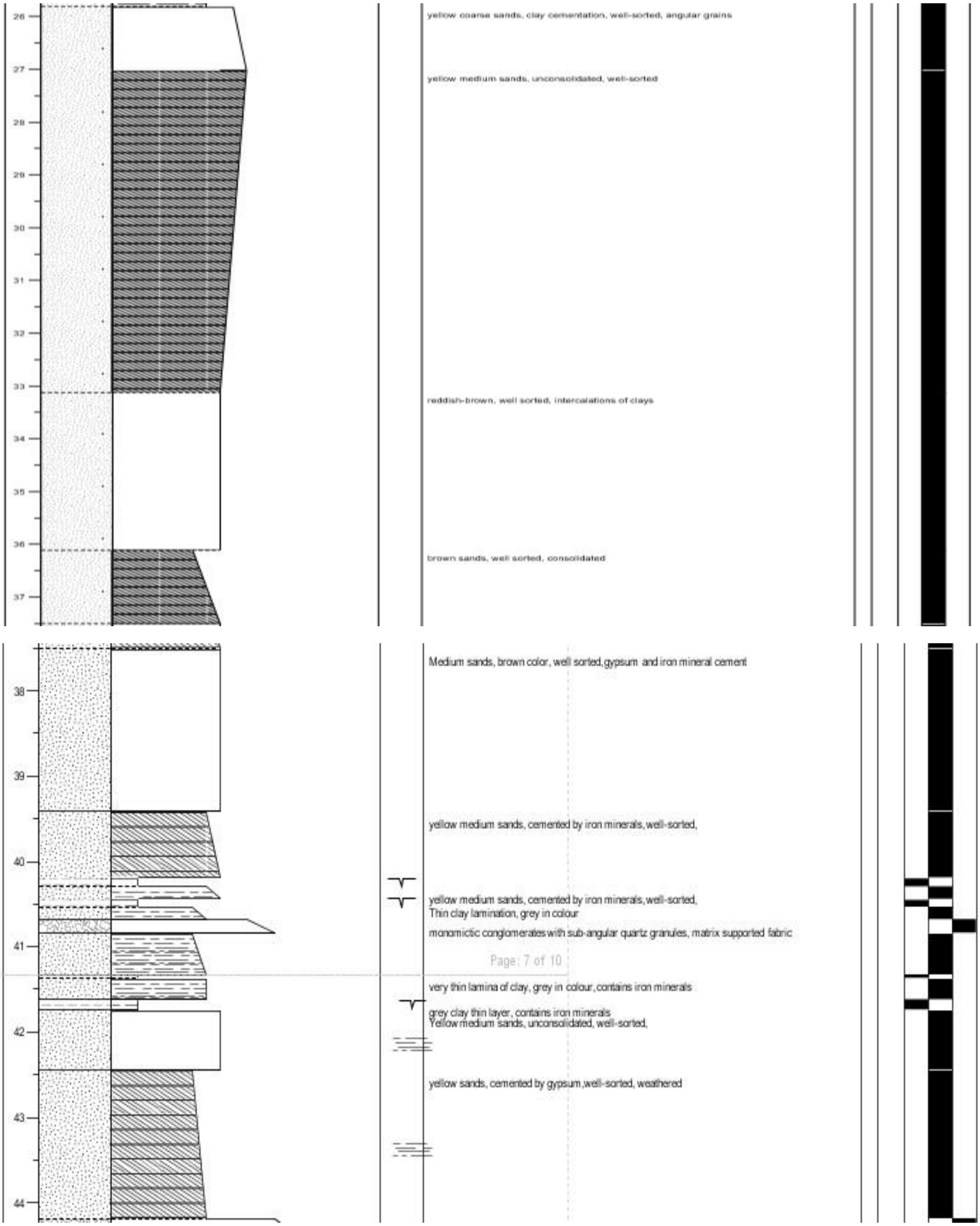
pink-yellow-white color silstone, cemented by gypsum and iron minerals
silt-sized sands, well sorted, cemented with gypsum,grey to yellow color
thick clay layer, folded slightly, grey to dark color. Gypsum fils the cracks
unconsolidated, poor sorting, white with yellow patches sands
poor sorting, white sands, cemented by gypsum
well sorted silts, cemented with gypsum
thick clay layer, gypsum present, consolidated, reddish brown color of iron minerals
yellow fine sands, moderate sorting, gypsum crystals, iron oxide cement



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yellow coarse sands, clay cementation, well-sorted, angular grains
yellow medium sands, unconsolidated, well-sorted
reddish-brown, well sorted, intercalations of clays
brown sands, well sorted, consolidated
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Medium sands, brown color, well sorted,gypsum and iron mineral cement
yellow medium sands, cemented by iron minerals,well-sorted,
yellow medium sands, cemented by iron minerals,well-sorted,
Thin clay lamination, grey in colour
monomictic conglomerates with sub-angular quartz granules, matrix supported fabric
Page: 7 of 10
very thin lamina of clay, grey in colour,contains iron minerals
grey clay thin layer, contains iron minerals
Yellow medium sands, unconsolidated, well-sorted,
yellow sands, cemented by gypsum,well-sorted, weathered

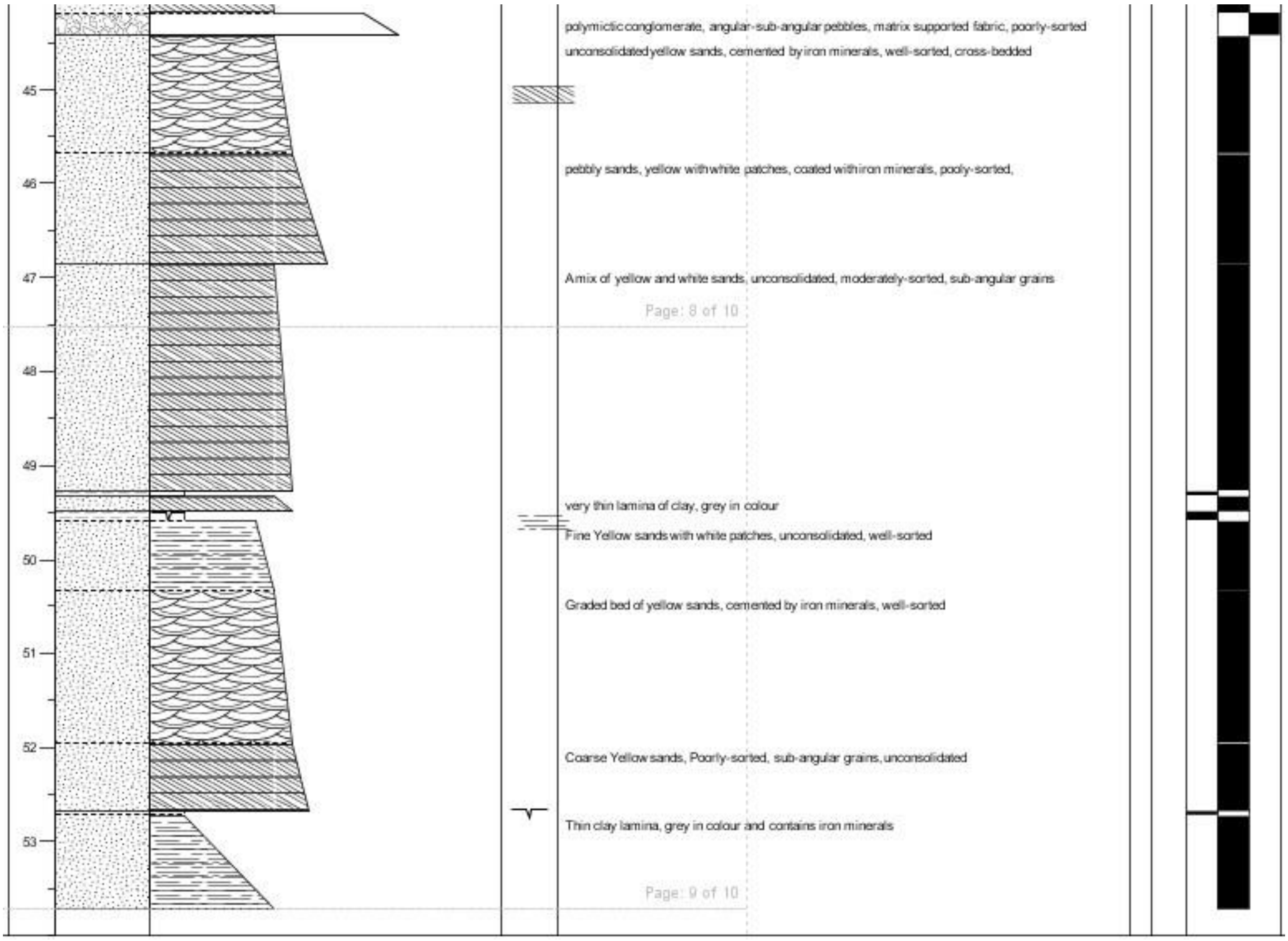


Figure 3. 11: Combined Sedimendary Log for Kibuku area(As logged by groups 2, 4 and 6)

Interpretation of the combined log

The figure 3.11 above shows a combined sedimentary log of Kibuku area as mapped by Group 2 from the base of the log upto about 39m, group 4 from 39m to about 21metres and group 6 from 21m to the topmost layer.

The area logged by group 2 consists of a series of fining upwards sequences/cycles, with sands of various grain sizes intercalating with very thin laminations of clays. Most sand layers in this area are cross-bedded with Angular, planar and trough stratification being the major structures observed. The presence of fining-upwards sequences and cross-stratification signify a fluvial paleoenvironment. The cyclicity is caused by deposition during the various episodes of sediment supply and river rejuvenation. The conglomerate layers higher up the sequence have smaller pebbles than those below them probably due to the reduced energy of the river in the Latter episodes of deposition. Most cross-beds dip in the Southeast and this could have been the paleocurrent direction. From the features observed, the sediments may have been deposited by a meandering river. Meandering rivers are mainly made up one channel that twists its way across the flood plain. A meandering river deposits sediment on the insides of the curves (point bar deposits) and erode the banks on the outside of the curves. Fine grained material is thus deposited on the flood plain whereas coarse materials are deposited along the channel. Intercalation of clays and sands are most likely flood plain or a meandering river with an ox-box lake deposits while medium to coarser sands are channel deposits. The sands are cemented by iron minerals and gypsum and as discussed, these indicate semi-arid paleoenvironment.

The section logged by group 4 comprises a fining up sequence at the start and a coarse-up sequence towards the end. The fining-up sequence is suggestive of a fluvial system while the coarsening upwards sequence is characteristic of deltaic environment. This coarsening upwards is caused by regression and transgression of the lake/ocean. Lake/ocean deposits fine beds and rivers deposit coarser sediments since they have higher energy. Therefore, this area could be a transition zone between a lacustrine and fluvial paleoenvironments. Most sands are yellow in colour and cemented by gypsum and iron minerals, conglomerates have a matrix-supported fabric.

The area logged by group 6 comprises thick layers of clay and blocky sand layers as already discussed in subsection **3.4.1.**

3.4.3 Base of Kisegi Formation

The basement of the kisegi formation is marked by contact between conglomerate and weathered granite gneiss basement rock(Figure 3.12). The conglomerate comprises monomictic quartz angular to sub-angular pebbles and pebbles with a matrix-supported sand fabric, this angularity of the pebbles indicates a short distance of transport, the conglomerate is overlain by very coarse to medium grain sands with trough and swash structures in these layers. The sand layers are poorly sorted possibly due to sudden drop in energy as a result of reduction in gradient, this is probably an alluvial fan region.

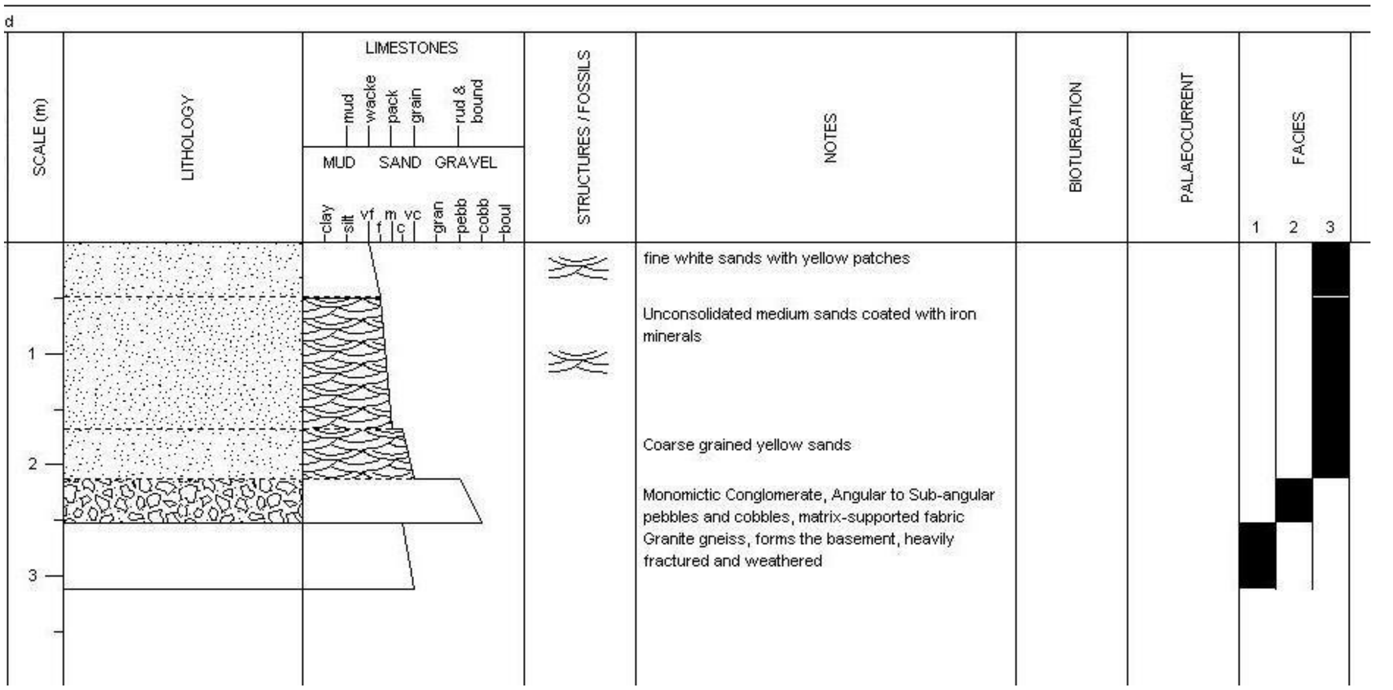


Figure 3. 12: Base of Kisegi Formation

CHAPTER 4 : BASIN AND FACIES ANALYSIS

4.0 Introduction

This chapter looks at the various concepts of basin and facies analysis and their application to the study and interpretation of Semliki sedimentary basin. From the small area studied, the results obtained were extrapolated to other areas using these concepts to understand and deduce the potential of the rest of the basin.

Basin analysis is a geologic method by which the formation and evolution history of a sedimentary basin is revealed, by analyzing the sediment fill and subsidence(Duppenbecker and Eliffe, 1998). Sedimentary basin analysis is largely conducted by two types of geologists who have slightly different goals and approaches. The petroleum geologist, whose ultimate goal is to determine the possible presence and extent of hydrocarbons and hydrocarbon-bearing rocks in a basin, and the academic geologist, who may be concerned with any or all facets of a basin's evolution.

Facies analysis is the description and classification of any body of sediment followed by the interpretation of its processes and environments of deposition(unacademy.com).

4.1 Integration of basin analysis concepts in interpretation of Semliki sedimentary basin

Sedimentary basins are regions of Earth's crust where subsidence has occurred and a thick sequence of sediments have accumulated to form a large three-dimensional body of sedimentary rock. They form when long-term subsidence creates a regional depression that provides accommodation space for accumulation of sediments. Subsidence of sedimentary basins generates the spatial distribution of accommodation infilling sediments. Aspects of the sediment, namely its composition, primary structures, and internal architecture, can be synthesized into a history of the basin fill. Such a synthesis can reveal how the basin formed, how the sediment fill was transported or precipitated, and reveal sources of the sediment fill. From such syntheses, models can be developed to explain broad basin formation mechanisms.

Formation and Evolution of Semliki basin

Semliki basin is a rift basin. Rift basins are elongate sedimentary basins formed in depressions created by tectonically-induced thinning (stretching) of continental crust, generally bounded by normal faults that create grabens and half-grabens(Burke,1985). Semliki sedimentary basin is a half-graben rift segment which is a geological structure bounded by a fault(listric) along one side of its boundaries. Semliki sedimentary basin is located in the central domain of the western arm of the Albertine graben. It is a pull apart basin formed when the Albertine graben, a product of active rifting, underwent transtensional strike-slip deformation that was controlled by already existing NE-SW graben-forming normal faults. The formation of the Semliki basin is complex multi-phase structural evolution consisting of three syn-rift episodes(Figure 4.1). The first episode (Mid-Miocene to Late Miocene) is characterized by intense fault activity with extension. The second episode (Late Miocene to Early Pleistocene) is characterized with transpression and creased rift shoulder uplift. In contrast, the third episode (Early Pliocene to present day) is characterized by transpression and continued reactivation of older faults. Extensional and transpressional (compression and strike slip) tectonics associated with these episodes have had a decisive influence upon sediment source areas and topographic contrasts within the Semliki basin.

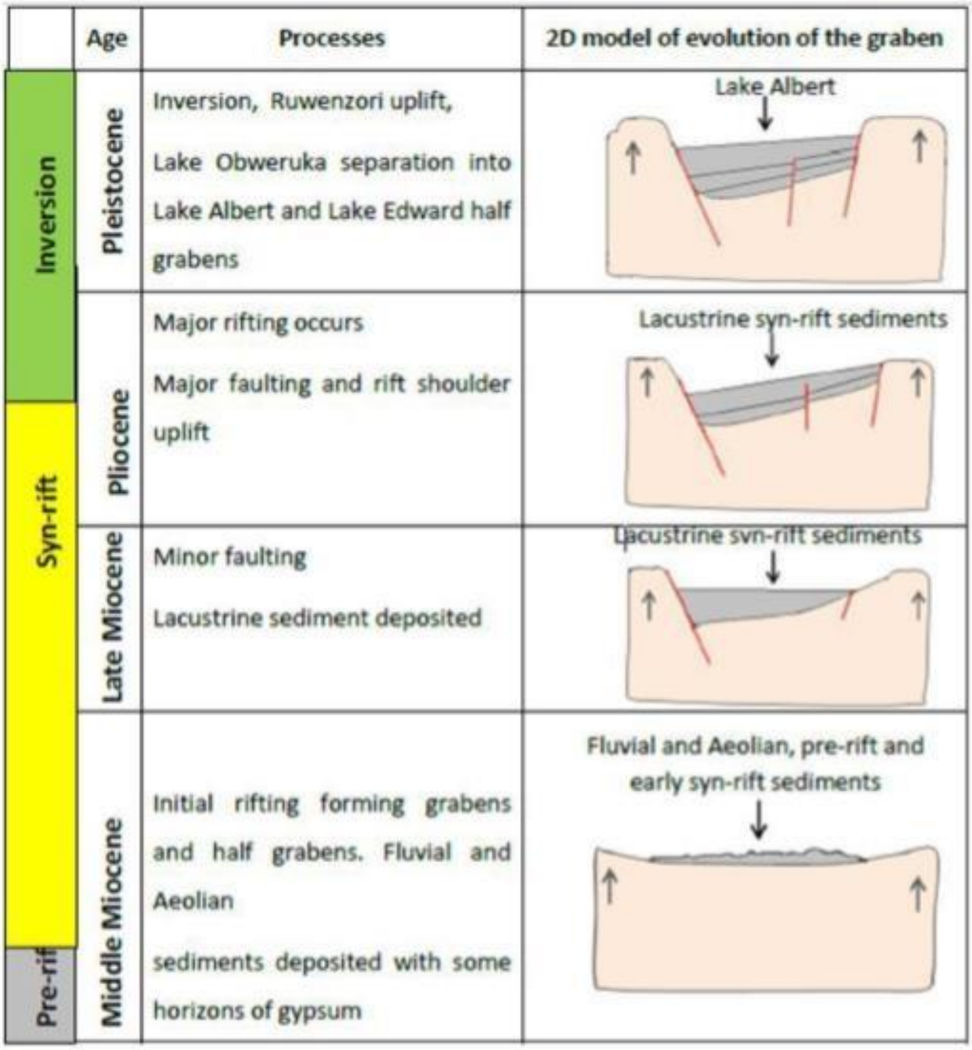


Figure 4. 1: Stages of the evolution of the Semliki basin(modified after Pickford et al 1993; Van Damme and Pickford 2003; Ring 2008)

Sediment deposition generally accelerates subsidence. At the center of this graben, fine sediments and alluvial fan deposits are deposited while the shallower parts contain coarse sediments and this shallower section is where the Semliki Basin falls.

Basin Structure.

The Semliki basin is made of a wedge shaped structure (half graben) basin containing mainly deposits of fluvial, deltaic and lacustrine sedimentary systems(Figure 4.2). The geometry of the basin has been deduced from lithology and structures. It is believed that source rocks developed mainly during the syn-rift, in deeper portions while reservoir rocks developed in shallow lacustrine and flexural areas as well as in deep lacustrine zones in form of sub-lacustrine sands or turbidites encased in mudstones or clays. The sediments right atop the basement are fluvial-deltaic and some deep sub lacustrine 'turbidite' sands. Alluvial fan sediments deposited as far as almost 6 km appear to pinch out into deltaic sandstone formation (later cut by faults on the right side) and partly into the lacustrine mudstone/clays. The lower most sediments immediately above the non-conformity are fluvial-deltaic. The basin fill also has lacustrine clays interbedded with fluvial-deltaic deposits. Sedimentary facies are laterally discontinuous with strong facies contrasts. These features are typical of freshwater sedimentation where precipitation outstrips evaporation resulting in fluvial-lacustrine facies association (Carroll and Bohacs, 2001).

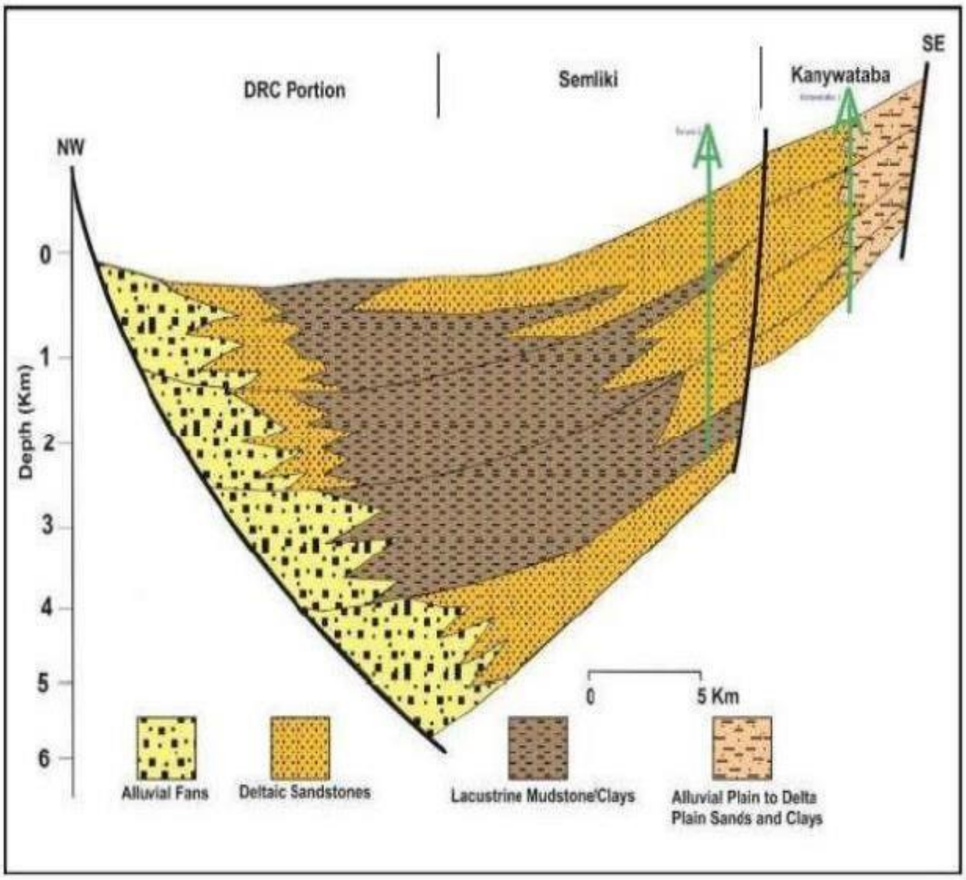


Figure 4. 2: The structure of the Semliki basin showing major sediment deposits and their location(Source: association (Carroll and Bohacs, 2001).

Stratigraphy of Semliki basin

Based on age relationships of strata and succession of beds, Pickford et al. (1987 and 1994) classified the sedimentary rocks of Semliki Basin into seven Formations namely Nyabusosi, Nyakabingo, Nyaburogo, Oluka, Kakara, Kasande and Kisegi Formations as shown in Figure 4.3 below.

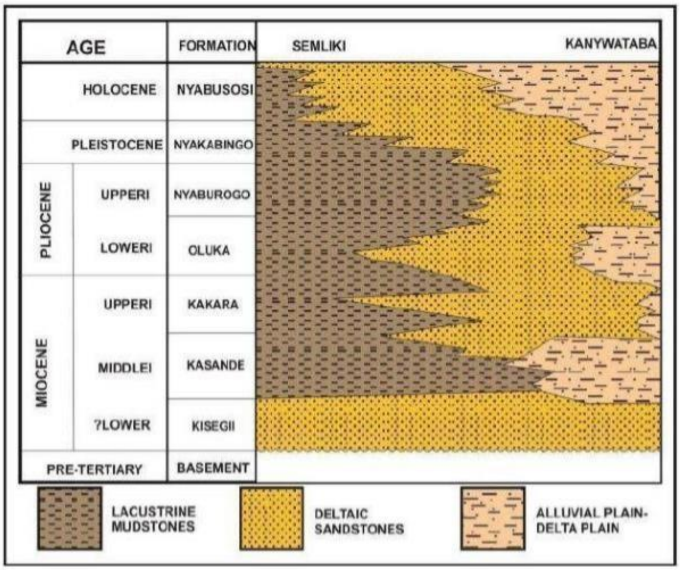


Figure 4. 3: Arrangement of the Formations in the Semliki basin from the youngest (Nyabusosi) to the oldest (Kisegi)(Source: Pickford et al 1987 and 1994)

Detailed discussion of the different formations

Kisegi Formation

Kisegi formation is considered the oldest formation of Semliki basin and hence sits on the basement. It rests unconformably over the basement complex granite gneisses and Buganda-Toro metaquartzite, with the contact marked by a basal polymictic conglomerate. The formation's basal conglomerates near the Kibuku seep generally pass up into a thick friable yellow, well-sorted, medium to fine-grained sandstone which is mainly composed of intercalations of conglomerates and low-angle cross-bedded sands. Part of the Kisegi Formation was logged at the Kibuku road cut(Group 6 area) and act as the reservoir rocks. Gypsum is common as veins and thin interbeds throughout in exposures. The upper portion of this formation comprises a cyclic sequence of sands and clays. Kisegi could have been formed by a combination fluvial, deltaic and lacustrine systems. The presence of gypsum and yellow sands(from coating by iron(iii) oxides) indicates a semi-arid paleoenvironment where evaporation and oxidation prevailed. In outcrop, alluvial fan conglomerates pass up into fluvial channels and minor floodplain deposits believed to have been deposited in semi-arid conditions. Part of this formation is exposed at the North end of the of Kisegi hill cut behind the Kibuku quarry where the contact between the sediments and basement is exposed and also along the Kibuku road cut.

The hydrocarbon seeps in surface exposures of the basal strato-type at Kibuku show sandstones impregnated with oil and it is waxy because of its lacustrine source or biodegradation. The seep is inactive because of likely biodegradation or due to tectonism which could have changed the migration path. The formation was estimated as 110 m thick in its type section by Pickford et al. (2003), much less than the 300 m suggested by Bishop (1998).

Kasande Formation

The formation attained its name informally from Heritage Oil & Gas plc in 2002 after Mr. Robert Kasande, then Principal Geologist at PEPD, based on field mapping carried out by the company in the area. The kasande formation overlies the Kisegi formation(Figure 4.3) and acts as the source rock and seals. The formation is characterized by dark brown to yellowish brown mudstones, with channelized sandstones up to several meters thick. Thin black coaly shales are seen uppermost in the unit. The well sections contain grey, dark grey to reddish-brown claystones and mudstones. RPS Energy (2008) suggested lacustrine conditions that pass up into a wet delta plain with fluvially derived marsh or swamp vegetation for the sequence.

Based on information from the Journal of Earth Science and Engineering, 2016, Kasande Formation is 31 m thick in exposures and 115 m thick in the Turaco-3 well. Its thickness is however uncertain elsewhere in the subsurface although a 76 m thick development is interpreted in the Kingfisher wells, approximately 55 km NE of Turaco wells. The formation is expected to have a great lateral extent in the deeper western subsurface of Lake Albert in the hanging wall of the main western border fault. Thick clay and channelized sand sequences are characteristic of lacustrine conditions. Similar suggestions were made by Lukaye (2009) who noted a change in palynofacies assemblage about 100m under the formational base, marking a transition to warm and wet open lacustrine environments.

Kakara Formation

This Formation was studied and named by Pickford et al. (1993) and was observed along the massive roadcut exposure in Kibuku and overlies the Kasande formation. Along the road cut the formation is made up of mainly intercalations of unconsolidated, yellowish brown poorly sorted, medium to coarse grained sandstone, sand-matrix conglomerates and brown to red pebbly and muddy sandstones. These are interbedded with grey soft silty claystones. The bulk of the Kakara Formation's exposed section was deposited on a coastal plain, with the intermittent coarse-ferruginous sandstones introduced by crevasse splay from nearby channels. The contact with the underlying Kasande formation is not seen in outcrops, but Pickford et al. (2003) believed it to be marked by the first development of ferruginous sandstones in the succession. However, Lukaye et. al (2016) observed great lateral change of lithofacies belonging to this Formation from outcrops to the subsurface. The authors also reported that Late Miocene age was assigned to this Formation on the basis of mollusc assemblages and mammalian finds and also suggested that the bulk of the Kakara Formation's exposed section was deposited on a coastal plain, with the intermittent coarse-ferruginous sandstones introduced by crevasse splay from nearby channels.

The contact with the underlying Kasande formation is not seen in outcrops, but Pickford et al. (2003) believed it to be marked by the first development of ferruginous sandstones in the succession. The entire formation was penetrated by the Turaco-2 and 3 wells, with its basal stratotype being defined in Turaco-3 at the first marked sandstone appearance at 2425 m. The base is defined by a sudden reduction in gamma ray, with corresponding changes in Spontaneous potential (SP), porosity, density and sonic log responses. The reference section is shown in the new road-cut exposure at Kibuku but the development here is totally sand-dominated and not typical of the formation otherwise. Log patterns in the Turaco-3 well suggest a coarsening and shallowing upwards sequence. The section's lowermost 57 m display coarsening upward rhythms, followed by a 185 m thick sandy section with erratic gamma ray response. This is then followed by 166 m with repetitive coarsening upward rhythms, and then 20 m of lacustrine shales. The formation is topped by interbedded sands and shales with a thickness of 104 m. In natural exposures, the much thinner 40 m development of the formation is developed as a dominantly dark claystone, with well-defined, mainly laterally continuous, thin ferruginous coarse sandstone beds. The formation's top in exposures is marked by a 40-50 cm thick bench of conglomeratic polymictic ferruginous sandstones. The Kakara Formation is 542 m thick in Turaco-3; its thickness is uncertain elsewhere although a possible 500 m development is also seen in the Kingfisher wells, approximately 55 km NE of Turaco.

Oluka Formation

This Formation was named after Mr. John Oluka, a Game Ranger in the Semliki game Reserve, by Pickford et al. (1993) while undertaking field mapping in the area. The formational base in the type section is exposed on the ridge between Nyaburongo and Kisegi rivers and in the Valley. The base is defined by dark shales overlying well-developed widespread conglomeratic ironstone with large smooth, rounded quartz pebbles as described by Pickford et al. (2003). The basal hypostratotype is defined in the Turaco-3 well at 1,883 m at the development of a thick shale unit marked by a rapid increase in gamma ray, with corresponding changes in SP, porosity density and sonic log responses. Exposures comprise an association of interbedded claystones, shales, siltstones and sandstones. The claystone units are of various colors, light to dark grey. A suspected tuff bed has been mapped in exposures assigned to the formation. Several thin beds of very hard, grey-green silica cemented sandstones and concretionary ironstone beds occur through the formation. About 15 to 16 concretionary ironstone horizons have been observed in natural outcrop, some of which thin and pinch out laterally. The subsurface lithology is characterized by a 23 m thick shale with high gamma ray character at the base, followed by a thinly interbedded sand/shale interval of about 100 m. This is then followed by thicker sandstones with somewhat erratic coarsening upward cycles. The top is marked by clear coarsening upward cycles. The formation is over 390 m thick in Turaco-3 and about 50 m thick in exposures. Pickford et al. (2003) suggested an age close to 7-8 Ma (Late Miocene), "perhaps a little older" for the middle part of the exposed unit of the Oluka Formation. This interval to be of Miocene/Pliocene transition.

Also, Roller et al. (2010) for the depositional environment, they suggested dominantly lacustrine to nearshore/coastal mudflat environments, while the upper parts of the outcropping formation suggest mainly distal fluvial to delta plain regimes, with minor nearshore lacustrine intercalations.

Nyaburugo Formation

The formation was named by Pickford et al. (1993) after exposures in the Nyaburogo River valley. It consists of thick sequences of claystones with numerous rusty browns to yellowish siltstones, pisolitic ironstones, paleosols and fining upward sandstones at the top. Large ironstone concretions with typical 'iron-skin' weathering are common in this formation. The iron manifestation in parts of the Formation indicates that this part of Formation was deposited in regimes of humid tropical climates. Lukaye et. al (2016) reported that exposures of this Formation were dated late Miocene. to middle Pliocene on the basis of mammalian biochronology and molluscan assemblages supported by tuff correlations.

Generally, this formation consists of a lower arenaceous sequence with stacked fluvial-channel sandstones sequence, that fine-upwards into more clayey sequences with subordinate channel-fill sandstones. This fining-upward sequence confirms fluvial environment of deposition. The sandstone units are fine grained and display plane parallel and cross bedding structures. The channel-fill sandstones at the base of Nyaburogo display lateral and vertical accretion surfaces indicating possible deposition in a meandering river environment. The stratotype is proposed in the Turaco-1 well where the base is placed at an apparent log break at 1,492 m immediately above a silicified sandstone bed at 1,500 m. The base seems to be marked by a rapid reduction in gamma ray log response, although log patterns are somewhat obscured by the "5 1/2" casing shoe also at this level.

Nyakabingo Formation

The formation was named by Pickford et al. (1993) after exposures in the Nyakabingo river valley. The type section is defined in the Turaco-1 well and is 207 m thick. The basal stratotype is defined by the base of a thick lacustrine shale unit at 1,055 m, marked by a rapid increase in gamma ray with corresponding increase in spontaneous potential (SP), porosity density and sonic log responses. The partial exposures are seen east of the Nyakabingo river valley close to the Semliki Flats. Log response through the formation in Turaco-1 suggests four repetitive coarsening-upward cycles. Exposures show light grey to light greenish grey claystones, iron-stained siltstones, pebbly and coarse sands/sandstones and carbonate nodules. A massive amalgamated ironstone about 1 m thick, consisting of several individual thin beds of both concretionary ironstones and ferruginous sandstones, is found uppermost in exposures suggest late Pliocene age in outcrops on the basis of mollusk associations. Exposures have been interpreted as interbedded flood plain and/or lagoonal.

Pickford et al. (1993) suggested late Pliocene age in outcrops on the basis of molluscs associations with flood plain/inter-lagoonal fcaies indicating lake level fluctuations. However, Lukaye et. al (2016) suggested late Miocene and late Pleistocene ages on the basis of palynomorphs in cutting from wells, and a significant break in deposition between this Formation and the overlying Nyabusosi Formation.

Nyabusosi Formation

The formation was first named by Pickford et al. (1993) after localities in the Nyabusosi river valley (Nyabusosi meaning "hilly place" in Lutoro). The boundary between the Nyakabingo and Nyabusosi formations is not clear in outcrop as they are juxtaposed across the major Makondo Fault zone near Makondo village. Lukaye et. al (2016) reported that it is dominated by series of alternating clays and silts punctuated by 7 to 8 distinctive ironstone horizons which formed the basis for the tripartite member division described by Pickford et al. (1993). The basal Makondo member without ironstones, overlain by ironstone-containing Behanga member and the top most Kagusa member also lacking ironstones. The authors also suggested late Pleistocene age on the basis of palynomorphs in cuttings from the Turaco wells. However, Pickford et al. (1993) dated this Formation to be 1.5Ma using correlation of a thin tuff near the base of the uppermost Kagusa member with a tuff from Turkana basin dated to the same age.

They also suggested coastal to near-shore lacustrine environments of deposition with considerable lake-level fluctuations; lake strandline deposits indicated by shell-beds of the oyster-like Etheria in the Kagusa Member, while flood plain environments clearly indicated by levels in the Behanga and Kagusa members, the latter with Oldowan artefacts suggesting hominid habitation.

4.2 Elements of facies analysis and facies analysis interpretation from observed lithologic units

Facies is a body of rock characterized by a particular combination of lithology, physical and biological structures that bestow an aspect that is different from the bodies of rock above, below and laterally adjacent. Facies analysis is the interpretation of strata in terms of depositional environments (depositional systems), commonly based on a wide variety of observations. Every depositional environment puts its own distinctive imprint on the sediment, making particular facies. The result of sedimentary facies analysis is the recognition that they help control hydrocarbon accumulation. Sedimentary facies and other lithological characters play a major role in the process. Once the favourable facies are identified, they help identify the distribution of favourable exploration areas. Reservoirs emerging from different sedimentary facies are different from each other. This difference is made based on structure, composition, particle size, sorting, thickness, etc.

The sedimentary facies present in the study area along the kibuku road cut are discussed below; **Lithofacies**

This is classification of facies based on lithology of the sediments. Four different lithofacies were encountered in the field; sandstones, conglomerates, silts and clays.

- **Sandstone:** The sands vary from poorly sorted to well sorted, fine to coarse-grained in terms of grain size and the colour observed include white, grey, yellow, pink and brown. The brown colour is interpreted to be due to precipitation of iron (iii) oxide. This is an evidence of an oxidation environment and the gypsum present in sands signifies semi-arid paleoenvironment. The sands have angular beds and tangential beds mainly dipping in the NW-SE direction and hence used to deduce paleocurrent flow direction.
- **Clays**: The clays observed in the field study are very fine grained in size, and their colour varies from brown, grey or dark green. Some clay beds are continuous and persistent while others are discontinuous. Thickness varied from bed to bed, some beds are very thick up to 2m thick while others are very thin that is few centimetres and some clay beds are massive and blocky especially in the Kasande formation and this indicates low-energy lacustrine depositional environment.
- **Silt**: These are very fine-grained and appear grey to white in colour, although some exhibited a yellow colour due to coating by iron(iii) oxides. They are well sorted, fine grained, most of the silt beds were thin and continuous, there are low scale cyclicity observed in silts.
- **Conglomerates**: The conglomerates observed were poorly sorted, with varying colour but mostly brown due to the presence of iron rich minerals, they are mainly of matrix-supported fabric of coarse sands and made of pebbles and cobbles. It forms the contact between the basement and sediments.

Biofacies

Biofacies is defined as a part of a stratigraphic unit in which the fossil fauna or flora differs significantly from that found elsewhere in the same unit and are described based on fossil assemblages. The biofacies present in the semliki basin contain either preserved flora or fauna remains, or both in the environment of deposition. In Makondo, fish bones, bivalves and white oyster shells are found. These fossils provided a diagnostic evidence of freshwater lacustrine environments of deposition in the Semliki Basin. Other biofacies can be found in Kisegi river channel and comprise plant roots, fossil wood, gastropods and snail shells.

Summary of the depositional environments in the Semliki basin from facies analysis

Fossils give vital clues on the depositional environment, because particular fossil occurrences or suites are characteristic of a particular environment, and often the specific depth range. Clayey facies, fine to medium to coarse sand facies and conglomeratic facies are present. The fluvial system deposits are interpreted from the fining-upwards sequences(see logs in chapter 3), point bar deposits found at the Kisegi river channel, floodplain deposits (fine sediments), cross beds, a meander channel observed in the coarse sands in the Kisegi formation and water fossils such as bivalves. Structures such as cross beds, ripples give information on local paleocurrent directions. Intercalations between sands and clays indicate changes in the deposition conditions with regards to energy and environment. A river deposits clays and finer sands during times of low energy or flood events in flood plains and when water energy is rejuvenated, it can carry and deposit coarser material.

Thick layers of clays and blocky sand layers around area logged by group 6 indicate lacustrine deposition environment. The shift from fluvial to lacustrine may have involved a delta as a transition zone of deposition. The deltaic environment is inferred from the presence coarsening upwards sequences in some parts of the kibuku roadcut.

Semi-arid conditions are deduced given the presence of red sands and gypsum which occurred in association with the clays and sands. Gypsum is as a result of high rates of evaporation and red sands are a result of oxidation of iron oxides.

Presence of organic matter in some layers is indicative of anoxic conditions. Hence the depositional environments/systems of the sediments in the Semliki Basin are fluvial, lacustrine and deltaic.

Paleocurrent flow and paleocurrent analysis

A paleocurrent or paleocurrent indicator is a geological feature (typically a sedimentary structure) that helps one determine the direction of flowing water in the geologic past. This is an invaluable tool in the reconstruction of ancient depositional environments(Prothero and Schwab, 1996).

In the study, the features used in determination of the paleocurrent direction include crossstratification, imbrication parting lineation. And from these, it concluded that the paleocurrent direction was in the NW-SE.

Hydrocarbon potential of Semliki Basin

Semliki basin contains elements of a good petroleum system evidenced by the abundance of excellent reservoir type sands, mature source rocks(clays), traps, intraformational and regional seals as well as hydrocarbon migration pathways in the basin. These elements are discussed below in relation to the semliki bain. **Source rocks**

source rock is an organic-rich rock which has generated hydrocarbons or which could generate hydrocarbons. Organic matter is observed in clays and some fine sands of the Semliki basin thus potential to form good source rocks provided sufficient conditions for maturation to prevail, these conditions include temperature and this is present in the basin evidenced by presence of hot springs like Sempaya hot springs. Additionally, the basin contains a huge sediment pile thick enough to provide necessary temperature and pressure for organic maturity to the oil window leading to generation of hydrocarbons.

Evidence of oil generation and migration is seen at the kibuku seep(Figure 4.4). This seep is waxy due to its lacustrine nature or it could have been biodegraded and it is inactive probably due to biodegradation or tectonism which would alter migration path.

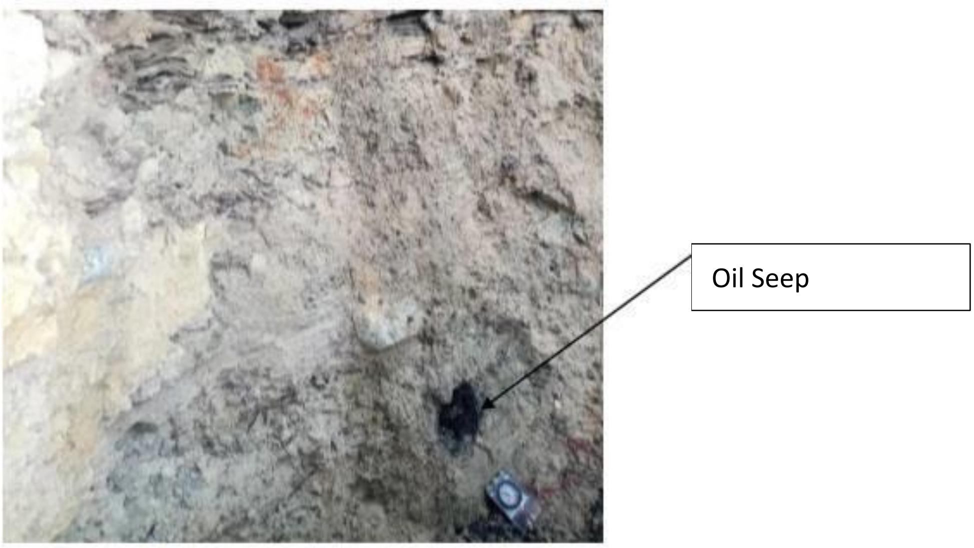


Figure 4. 4: Kibuku Oil seep(location: 192687/102879. Elevation: 688m)

The kasande formation forms the source rock in the semliki basin.

Reservoir rock

A reservoir rock, or simply petroleum reservoir may be defined as a rock with sufficient porosity and permeability to store and allow flow of hydrocarbon reserves in commercial quantities. Potential reservoir rocks occur in the Semliki Basin as medium and coarse sands. The reservoir rock is mainly sandstone(medium to coarse sands) reservoirs. A wide range of sandy sediments occur at the Kisegi and Nyaburogo formations. In the Kibuku area, the Kisegi Formation consists of loose sandstones with a thickness of about 140 cm in outcrop. The sandstones quality is however affected by presence of fine sands, pore-filling cement, gypsum. Generally, reservoir quality rocks are present, since porosities of over 22% have been reported in sandstones outcropping in Kibuku. In the sandstone formation logged, most reservoir quality sands have been compartmentalized by gypsum and clay layers. This is not desirable since it reduces on communication between productive zones, leading to production problems.

Since the kasande formation(source rock) overlies the kisegi formation(reservoir), the lithostatic pressure from the overburden increases the hydrostatic pressure of the hydrocarbons(if generated) and this creates cracks that enable these fluids to escape in several directions(this is primary migration) and some hydrocarbons go into the kisegi formation. Once the hydrocarbons have been expelled, the fractures in the source rock close up and hence the Kasande formation can act as seals for the Kisegi reservoir.

In the semliki basin, the intensely fractured basement rocks are also good potential reservoirs.

Traps

A trap is a stratigraphic or structural feature that impedes further migration of hydrocarbons, allowing for accumulation within the reservoir. Examples of structural traps in the semliki basin include faults sealed by gypsum, while stratigraphic traps include unconformities and pinch outs. Minor faults of NE trend in the lower section along Kibuku road cut are associated with major normal faults and can be good petroleum traps especially if they form sealing faults. Most of the potential hydrocarbon traps in this basin are fault-controlled since it contains many fault structures such as Kichwamba, Makondo and more. The faults could also act as adequate lateral seals when a reservoir is juxtaposed against a seal and there exist sealing material (fault gouge).

Seals

In the study area, the Kasande clays provide good sealing geometry for the underlying Kisegi formation. The shales of Transgressive systems tracts form good seals for the underlying low stand systems tracts. The presence of oil seeps such as Kibuku oil seep indicate that there are intervals which are inadequately sealed. Also, the hydrocarbon column height can affect the integrity of the cap rock that is if the cap rock is thin, a high hydrocarbon column can breach the integrity of the cap rock or even break compartmentalization due to high buoyancy force.

Migration pathways

The presence of numerous faults and fractures provide potential migration pathways for hydrocarbons from source rocks to reservoir rocks.

Maturation and hydrocarbon generation

There exist high temperatures in the Semliki basin evidenced by hot springs and these can facilitate and accelerate maturation of organic matter and consequent generation of hydrocarbons provided low conductivity rocks exist to accumulate enough heat.

However too much heat can destroy the produced hydrocarbons.

CHAPTER FIVE: STRUCTURES.

5.0 Introduction

Geologic structures are rock features formed by various processes affecting sediments during deposition or due to post-depositional powerful tectonic forces that occur within the earth and deform rocks. The study of these processes that result in the formation of geologic structures and how these structures affect rocks is known as structural geology. Structural geology can help us interpret the stratigraphic succession of the area, the paleocurrent flow directions as well as the energy of the transporting medium among others. The Semliki basin has syn-depositional structures (commonly known as primary structures) and post-depositional structures resulting from tectonic activity or metamorphism (secondary structures). Primary structures include beddings, laminations, and secondary structures such as joints, faults, foliation, and veins.

This chapter focuses on the description of the various structures observed in the study area(both in the basement and sediments), plots of the structural data, interpretation and comparison between the different plots, relationship between paleocurrent directions obtained from the plots(rose diagram) and the Albertine Rift trend and geomorphological features.

5.1 Structures In The Basement

The basement of the Semliki basin is made up of rocks of both the Basement complex and the Buganda-Toro rock systems. These are well observed at the margins of the basin by quarries as well as road-cuts and in some areas the contact between the sediments and the basement is clearly seen.

5.1.1 Joints.

A joint is a break (fracture) of natural origin in a layer or body of rock that lacks visible or measurable movement parallel to the surface (plane) of the fracture(Davis et al, 2012). Although joints can occur singly, they most frequently appear as joint sets and systems. Joints arise from brittle fracture of a rock or layer due to tensile stress. This stress may be imposed from outside; for example, by the stretching of layers, the rise of pore fluid pressure, or shrinkage caused by the cooling or desiccation of a rock body or layer whose outside boundaries remained fixed.

In the Semliki basin, two sets of joints can be observed in the basement rocks, namely those trending in NW-SE and NE-SW directions with the NE-SW trend being the more dominant trend. The strike and dip attitudes measured at the basement outcrop near kichwamba Technical College(location: 186950/79653) and that at the quarry behind the kisegi hill are recorded in Appendix 1. These joints are of systematic type and they are planar, parallel and can be traced for some distance, and occur at regularly, evenly spaced distances on the order centimeters to a few meters. The basement rocks Kichwamba are heavily jointed**(Figure 5.1).** The aforementioned joint sets can be observed here with the average fracture spacing of 15 cm for NE-SW trend and about 19 cm for NW-SE trend. Some of the joints have been filled with siliceous material to form veins.

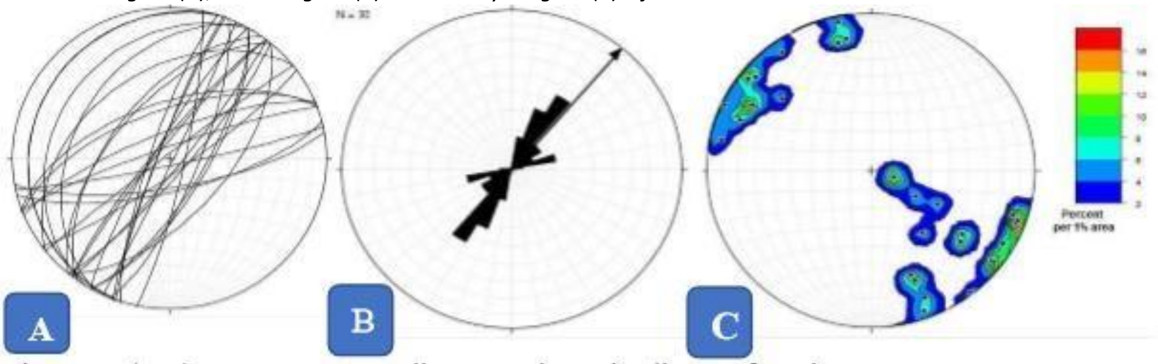
Relationship with Albertine Rift: The dominant joint set (NE-SW trend) trends in the same direction as the Kichwamba fault. This implies that the features were formed by similar forces oriented in the same direction. Similarly, at the quarry in Kibuku behind Kisegi hill (192486/102083, 675m) the major set of joints observed in undifferentiated granites (basic and acidic) trends in the same direction as the Kichwamba faults.

Figure 5. 1: A photograph showing a heavily jointed granite gneiss rock near Kichwamba Technical College.(location: 186824/79600, elevation: 1613m).

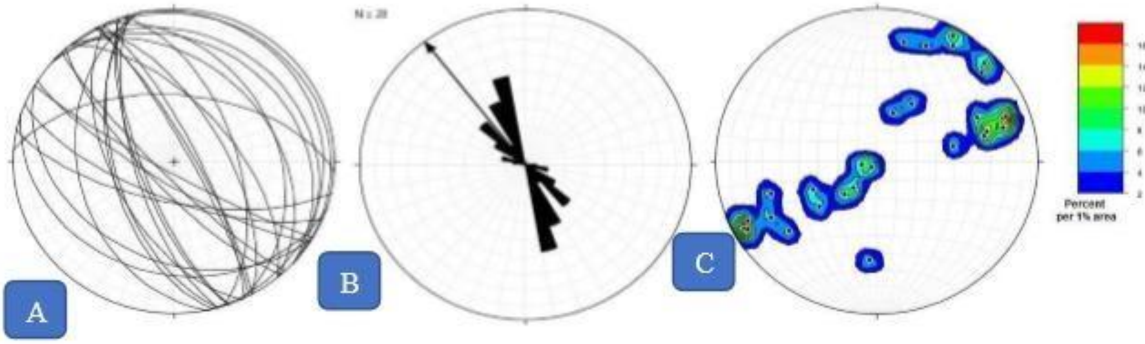
Stereographic analysis of joint measurements

The structural measurements obtained from the field are plotted using a Stereonet software to give plots of stereographic projections, rose diagrams and contour diagrams which are analysis and draw conclusions.

Table 3: Stereogram(A), Rose Diagram(B) and Density Diagram(C) of Joints encountered in the basement F



Set 1



Set 2

From table 4 above, the major trend of the joints(Set 1) is in the NE-SW direction. This implies that the tectonic forces that affected the rocks were oriented in the NW-SE directions and a minor trend in the NW-SE direction. The contour diagrams (Part C) show joint measurements plotting close to the periphery of the great circle therefore their planes lie almost at the centre. This indicates that the joint planes dip steeply. Also, sigma 1 and sigma 2 plot near the periphery and sigma 3 near the centre of the circle. Since the sigma 1 is always the strongest, the tectonic forces that caused the deformation of joints could have been compressional forces and they were very strong. Set 2 shows a trend of NWSE hence the tectonic forces that affected the rocks were from NE-SW directions. Therefore, for the two sets of joints, the tectonic forces were compressional. It is also observed from the rose diagram that two sets of joints (NW-SE and NE-SW) occurred in area Semliki basin (basement rocks) hence two episodes of deformation.

5.1.2 Faults

In geology, a fault is a planar fracture or discontinuity in a volume of rock across which there has been significant displacement as a result of rock-mass movements. A fault is formed in the Earth's crust as a brittle response to stress. Generally, the movement of the tectonic plates provides the stress, and rocks at the surface break in response to this.

The type of faults in the Semliki basin are dip-slip normal faults resulting from tensional forces that affected the area. They are oriented in the NE-SW direction and include both large scale faults and minor faults. The trend of faults in the Semliki basin is consistent with the general trend of faults in the Albertine rift.

The major faults include the Makondo fault between the Semliki flats and the Toro plains. The Semliki basin is bordered to the South-east by a steep fault escarpment rising up to 1,000m to the northernmost spur of the Rwenzori Mountains. It is also bordered on its western side by two major normal faults namely, the NNE-SSW trending Semliki fault and the NE-SW trending Bunya faults which separate the Congo escarpment and the basin. The normal faults in the Semliki basin are conjugate in nature, that is to say, they have similar magnitudes of dip but opposing directions and thus able to form the graben architecture. The NE-SW trending Kichwamba normal fault with a Western dip, controlled the escarpment (exposed by roadcut) along which several measurements of structures in basement rocks presented herein were made. It was also observed that the major faults manifested in form of discontinuous faults that are shorter and somewhat off the overall orientation. These faults influence drainage because the brecciated and weathered rocks along faults are easily removed by water to form seasonal streams gullies(Figure 5.3).

Figure 5. 2: Fault zone in the Semliki basin

5.1.3 Foliation

Foliation in geology refers to repetitive layering in metamorphic rocks(Marshak, 2009). Foliation is usually formed by the preferred orientation of minerals within a rock. This is the result of some physical force and its effect on the growth of minerals. It is caused by shearing forces (pressures pushing different sections of the rock in different directions), or differential pressure (higher pressure from one direction than in others). The planar fabric of a foliation typically forms at right angles to the maximum principal stress direction. In sheared zones, however, planar fabric within a rock may not be directly perpendicular to the principal stress direction due to rotation, mass transport, and shortening.

In the study area, foliation is evident in the gneisses near Kichwamba Technical College and trends in the NE-SW direction. This is similar to trend of major joints and faults and hence they could have been caused by the same forces. The measurements of foliations are recorded in Appendix 3.

Figure 5.3: Foliated granitic gneiss at Kichwamba with the foliations trending in the NE-SW direction(Location: 186950/79653, elevation: 1615m)

Stereographic analysis of foliation measurements

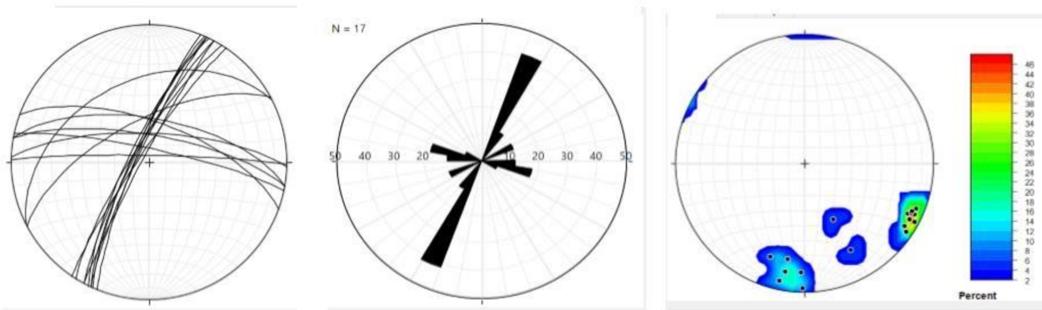


Figure 5. 4: Planes for foliations (L), Rose diagram for strikes (C) and contour diagram for dips (R).

Interpretation

The Rose diagram shows that most foliations trend NE-SW direction and a few oriented in the NW-SE direction. In comparison with the general fault trends in the Albertine rift, The major strike direction of the foliation is similar to that of the faults in the basement rocks and that of major faults like the Kichwamba fault and Semliki fault. Therefore, it is believed that the foliations could have been formed by the same tectonic stress episode that formed the faults and the two structures could have formed probably around the same time while the minor foliation trend must have been caused by a different episode of stress. The contour/density diagram shows one maximum which means that we have one preferred dip direction. Since poles are plotted perpendicular to planes and most of the poles concentrate in the SE direction, it means that the planes from which the poles were plotted dip in the NW direction. Therefore, it can be deduced that the most preferred dip direction is NW and strike direction is SW.

5.1.4 Banding

Banding is a separation of light (felsic) and dark (mafic) minerals in higher grade metamorphic rocks like gneiss. In the study area, Banding is observed in the granitic gneiss near Kichwamba Technical College(Figure 5.5). The banding is usually due to the presence of differing proportions of minerals in the various bands.

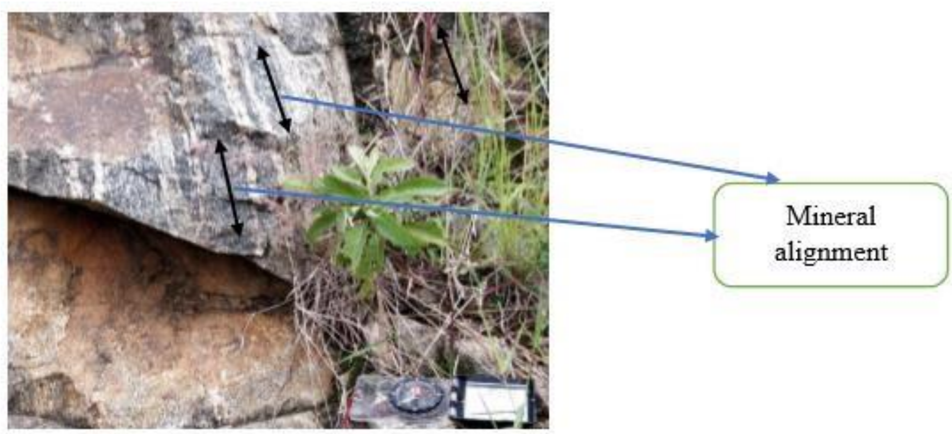


Figure 5. 5: Banded Gneiss at Location: 186950/79653 and elevation: 1615m.

5.1.5 Veins

In geology, a vein is a distinct sheet-like body of crystallized minerals within a rock. Veins form when mineral constituents carried by an aqueous solution within the rock mass are deposited through precipitation. The hydraulic flow involved is usually due to hydrothermal circulation.

The study area, the vein structures are quartz veins that are pink to white in colour(Figure 5.6) and iron-rich veins which are reddish brown in colour. The quartz veins are more common and measure a few centimeters to meters in length and measure a few centimeters in diameter while iron-rich veins run only a few centimeters and are a few millimetres in diameter.

The trend of the veins (NE-SW) is similar to the trend of the joints in the area implying the hydrothermal fluids rose through these fractures at a much later date after the formation of joints. This means that the veins are younger than the host rocks in which they are emplaced.

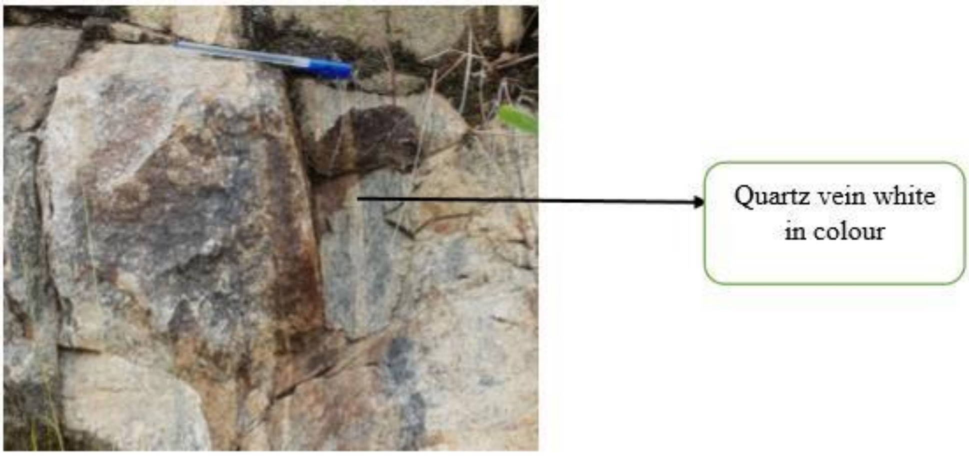


Figure 5. 6: Quartz veins in the granitic gneiss At Kichwamba

5.2 Structures in Sediments

Sedimentary structures include all kinds of features in sediments and sedimentary rocks, formed at the time of deposition. These structures represent physical, biological and sometimes chemical conditions that prevailed at the time the sediments were deposited or soon after deposition. Varying hydraulic conditions result in assemblages of structures that often bear diagnostic features of specific sedimentary environments, and therefore an understanding of the origin of sedimentary structures and their assemblages is a prerequisite for any geoscientist.

The structures in sediments in Semliki Basin are mainly of primary origin formed during the formation of rocks, either through depositional processes or deformational processes. The primary sedimentary structures observed within the sediments included cross-beds, load casts, mud cracks and fossils such as bivalves, oysters, and fish bones. The secondary structures in sediments included intra-sedimentary faults, soft sediment deformation structures and biogenic sedimentary structures such as bioturbations, dwelling and trails. The sedimentary structures give useful insights about the depositional environment in terms of processes, depositional energy and direction of younging, paleocurrent patterns and paleogeography. The structures are described in details below.

5.2.1 Primary structures

5.2.1.1 Bedding/stratification

According to Neuendorf et al, 2005, a bed is a layer of sediment, sedimentary rock, or pyroclastic material bounded above and below by more or less well-defined bedding surfaces usually more than 1cm thick.

Conversely, a lamina is a coherent layer of sedimentary rock, sediment, or pyroclastic material less than 1 cm thick.

Beds can be differentiated from the other by looking at the sedimentary structures, grain size, color, texture, fossil content of the components.

In the study area, three categories of beds are encountered namely planar bedding (layers of sediment with flat, parallel bedding planes that were deposited nearly horizontal), massive beds without any structures and cross-beds (strata in which internal layers dip at a distinct angle to the surface that bound the sets of the cross beds).

- **Planar stratified beds**

Planar bedding (or parallel bedding) is the simplest sedimentary structure. It occurs when bedding planes are parallel to each other. In undisturbed (undeformed) sedimentary sequences, planar bedding continues laterally as horizontal beds at the scale of kilometers to hundreds of kilometers. In the study area, the thickness of these beds a few centimeters to a meter. The beds are differentiated in terms of color (e.g., white and yellow)**(Figure 5.7**), nature of the boundary(i.e parallel) and grainsize. Another essential feature of planar laminae is that their lateral extent is much greater than their thickness. Planar laminations are usually formed wherever there is fallout of sediment onto a planar sediment surface in the presence of currents that are too weak to transport the newly arriving sediment over the bed (Allen, 1984). Such a scenario usually occurs in fine sediment. Most of the beds strike in the NE-SW direction similar to the trends of structures in the basement and Albertine rift faults.

Figure 5. 7: Planar beds of sands

- **Graded Bedding**

A graded bed is one in which there is a vertical change in grain size. Normal grading is marked by an upward decrease in grain size (fining upwards), reverse grading is where the grains coarsen upwards. This type of grading is produced as sediments settle out of suspension, normally during the waning phase (weaker strength) of a turbidity flow. This type of bedding was observed in almost all sand sediments of the study area.

- **Cross beds**

In geology, cross-bedding, also known as cross-stratification, is layering within a stratum and at an angle to the main bedding plane. The sedimentary structures which result are roughly horizontal units composed of inclined layer. Cross-bedding is formed by the downstream migration of bedforms such as ripples or dunes in a flowing fluid(Boggs, 2006). The fluid flow causes sand grains to saltate up the stoss (upstream) side of the bedform and collect at the peak until the angle of repose is reached. At this point, the crest of granular material has grown too large and will be overcome by the force of the moving water, falling down the lee(downstream) side of the dune. Repeated avalanches will eventually form the sedimentary structure known as cross-bedding, with the structure dipping in the direction of the paleocurrent.

The types of cross beds mapped in the sediments include;

✓ **Tabular(Angular) cross beds**: In this type of bedding, the units terminate at a high angle to the bounding surfaces(Figure 5.8). The angular cross beds rest on truncated areas of underlying sets and their cross strata are themselves truncated beneath the underlying sets. These beds were most likely deposited by moderately energetic waters carrying medium to coarse sandstones. Most of them trend in the NW-SE direction (figure 5.9(L)).

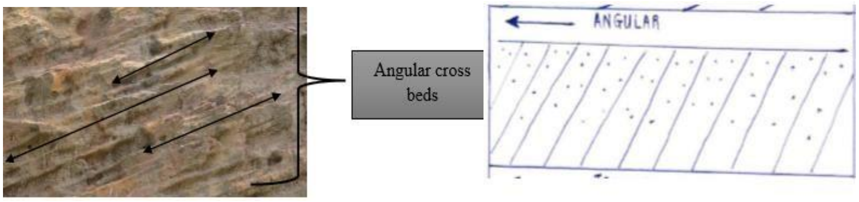


Figure 5. 8: Angular cross beds(L) and Sketch of the Angular crossbeds(R)

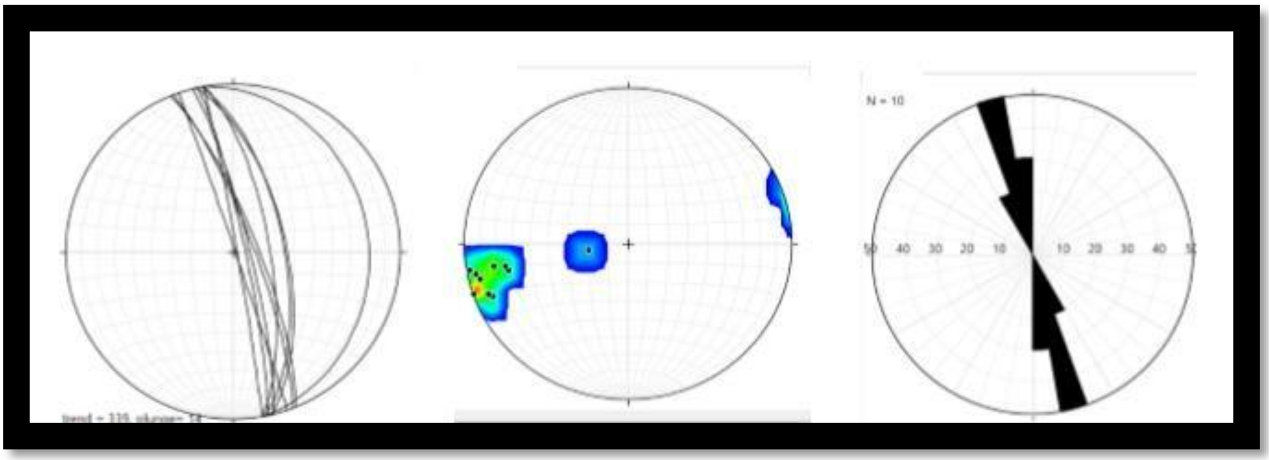


Figure 5. 9: A stereogram showing preferred trend of bedding(L), contour diagram of poles to the planes(C) and a rose diagram potraying paleocurrent direction(R).

Interpretation of structural data

From Figure 5.9 above, the contour/density diagram shows that the poles of the beddings are concentrated in the southwest quadrant and dips steeply since the poles are towards the periphery of the stereogram. Using the planes and contour diagram, the most preferred dip direction is NE. The rose diagram shows a preferred orientation in the NW- SE direction for these beds and from the rose diagram, it is most likely the paleocurrent direction was in the Northeast.

- ✓ **Tangential cross beds**

This a type of cross-bedding in which beds/foresets terminate onto the bottom bounding surface at nearly asymptotic angle or at a tangent(Figure 5.10). These crossbeds features form mainly as a result of the migration of large scale straight-crested ripples and dunes. In the study area, these are evident in medium to coarse-grained sands and are formed during moderate flow regime conditions. The individual beds ranged in thickness from about 5-15cm and extend laterally up to a few centimeters.

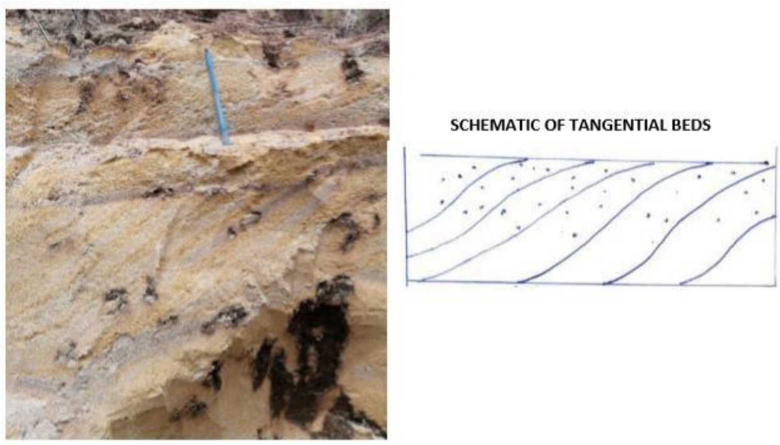


Figure 5. 10: A photograph showing tangential cross beds

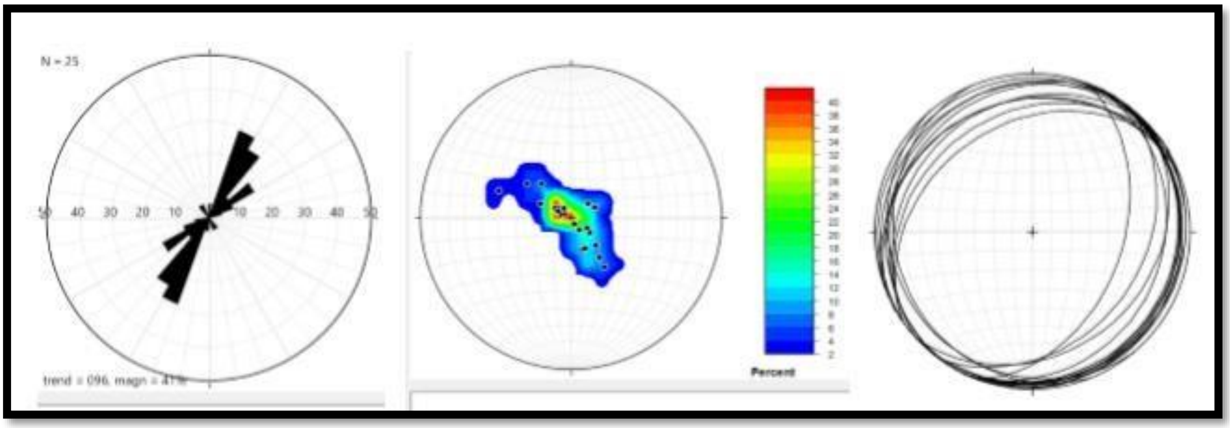


Figure 5. 11: Rose diagram portraying paleo-current direction(L), contour/density diagram(C) and stereogram showing preferred trend(R) for tangential beds.

Interpretation

From contour plot (Figure 5.11(c)), the beddings preferentially dip in the SE because majority of the poles plotted lie in the NW quadrant. This can further be confirmed by the dipping of a large number of planes in the SE. The rose diagram shows a preferred orientation in the NE-SW direction. The tangential beds were mainly dipping in SE direction, this implies that the current flow was towards the South East direction.

Paleocurrent analysis using rose diagrams

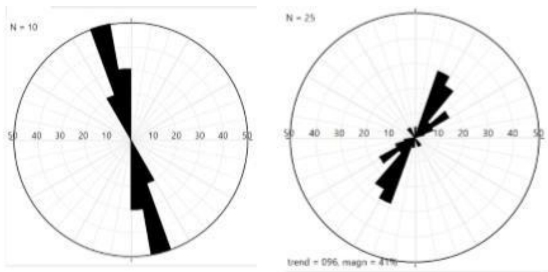


Figure 5. 12: Rose diagrams for angular beds(Left) and tangential beds(Right).

The angular and tangential cross-beds were used to interpret derive the paleocurrent direction. The angular beds have a Northwest-southeasterly trend while the tangential beds have Northeasterlysouthwesterly trend as seen in Figure 5.12. The two directions clearly show that there was a change in the course and direction of flow of the river as it was depositing sediments. Therefore, it can be deduced that the river depositing the sediments was majorly meandering type, however, at some point the river could have been braided when it had not changed course. The dips discussed above in the structural measurement interpretation show that paleocurrent flow was both in the SE and NE directions.

Relationship of the paleo-flow direction to Albertine rift trend.

According to Kashambuzi, 2006, the Albertine graben was strongly shaped by continental extension in the NW-SE direction along a strike slip fault. During this period, the river depositing the sediments could have followed this trend. However, during Pliocene-Pleistocene transition, there was a rift inversion stage especially during the uplift of the Rwenzori mountains which could have changed course of the river to the NE-SW direction. This can further be supported by the structural trends of the Albertine graben where structures in the norther domain are oriented in the NNE-SSW, structures in the central domain are oriented in the NE-SW and finally structures in the southern domain are oriented in the NNE-SSW, (Pickford and Senut, 1994). Therefore, the discussion above could be a reason for the change in paleocurrent flow direction.

- ✓ **Trough Cross-beds**

Trough cross-beds have lower surfaces which are curved or scoop shaped and truncate the underlying beds(Figure 5.13). The foreset beds are also curved and merge tangentially with the lower surface. They are associated with sand dune migration. They are produced by migration of strongly threedimensional dunes by strong paleocurrents (McLane and Michael, 1995). Generally, It is difficult to tell paleocurrent direction using trough beds because their three-dimensional shape makes measurement of foreset dip directions at local planes quite challenging even though two dip directions are successfully obtained.

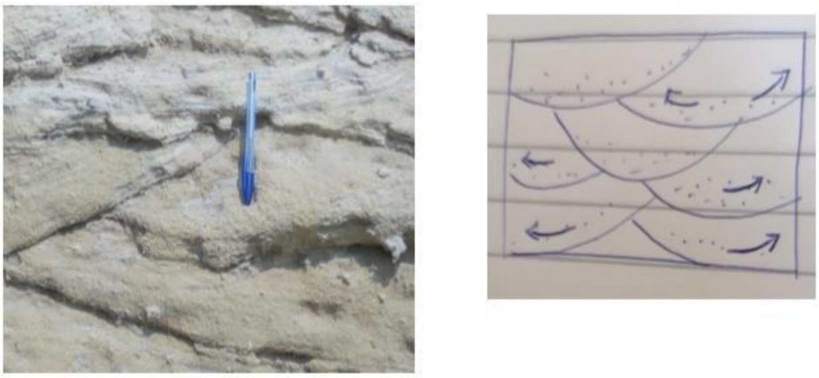


Figure 5. 13: Trough bed foresets within sands (left). Schematic on the right show two paleo flow directions obtained from the beds.

In the study area, the thickness of these beds is only a few centimeters and they are not laterally extensive.

- ✓ **Herring bone cross-stratification**

This is a type of cross stratification formed in tidal areas where the currents periodically flow in the opposite direction(Figure 5.14). This is very common in shallow lacustrine environments, bimodal dipping foresets reflect the "to and fro" movement of ebb and flood currents.

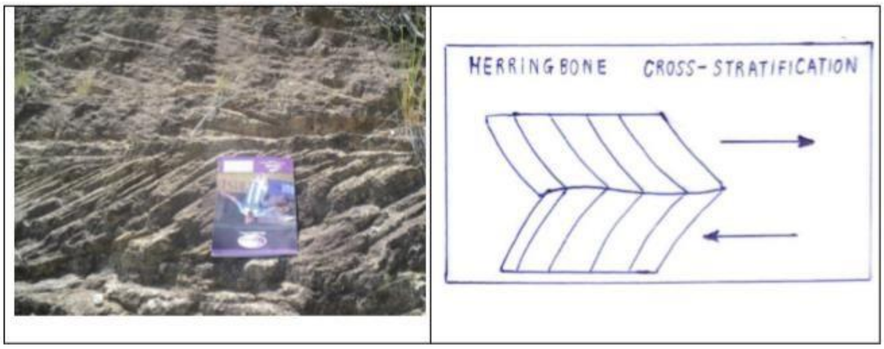


Figure 5. 14: A photograph of Herringbone cross stratification in the field(L) and a Sketch of Herringbone cross stratification(R)

- **Laminations**

Lamination is a finer scale sedimentary layering that occurs as internal structures of a bed. They are normally very small and less pronounced than bedding layers and they are often regarded as planar structures 1cm or less in thickness(Figure 5.15). They are caused by cyclic changes in the supply of sediments. Laminations occur as parallel structures or in different sets that make an angle with each other. The laminations in the field were mostly observed in clays and silts. Laminations develop in finegrained sediments when fine-grained particles settle from suspension, this possibly occurs in quiet waters like deep lacustrine environments.

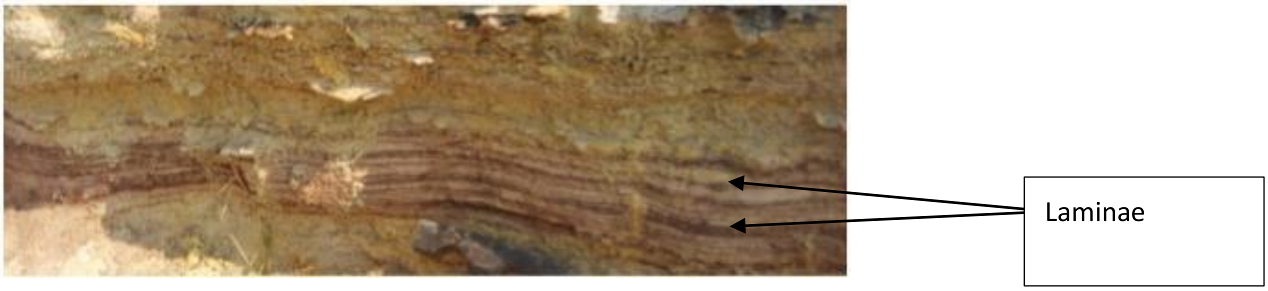


Figure 5. 15: Laminations

- **Mud cracks**

These are polygon-shaped cracks developed in mud which has dried out terrestrial environments(Figure 5.16). These form when mud is dewatered, shrinks, and leaves a crack. This tells you that the mud was saturated with water and then exposed to air. Mud cracks curl upwards, so they can be used as geo-petal structures. In the study area, they are encountered in clays and this implied that the lake responsible for the deposition of clays dried up at some point and the sediments were exposed to the atmosphere.

Figure 5. 16: Mudcracks in clays of kisegi channel

- **Fossils (body fossils)**

Carbonate fossils like bivalves(Figure 5.17), gastropods and oysters are found in the Makondo This is indicative of freshwater (lacustrine/fluvial) paleoenvironments of deposition in the Semliki Basin.

Figure 5. 17: A bivalve shell found at Makondo area(area (location 0110299N, 0201157E).

- **Load casts**

Load casts are bulges, lumps, and lobes that can form on the bedding planes that separate the layers of sedimentary rocks(Figure 5.18). The lumps "hang down" from the upper layer into the lower layer, and typically form with fairly equal spacing. These features form during soft-sediment deformation shortly after sediment burial, before the sediments lithify. They can be created when a denser layer of sediment is deposited on top of a less-dense sediment. In the study area, this scenario is found where sands overlie clay layers.

Figure 5. 18: Load Casts observed in the field (location: 192965/101750) and a sketch of load cast on the right.

- **Stratigraphic Pinch out**

A pinch-out is a point where a stratum or other lithologically distinct body of rock thins to a feather edge and disappears, so that the underlying and overlying strata separated by the pinching out stratum come into direct contact(Jackson&Julia, 1997).(Figure 5.19).

Pinch-outs are of a great significance in petroleum geology since they can act as traps for example if a sand layer acting as a reservoir is pinching into a low porosity rock like a Shale which will act a seal in this case. Petroleum migrating through a porous stratum is trapped where the stratum pinches out between impermeable underlying and overlying strata.

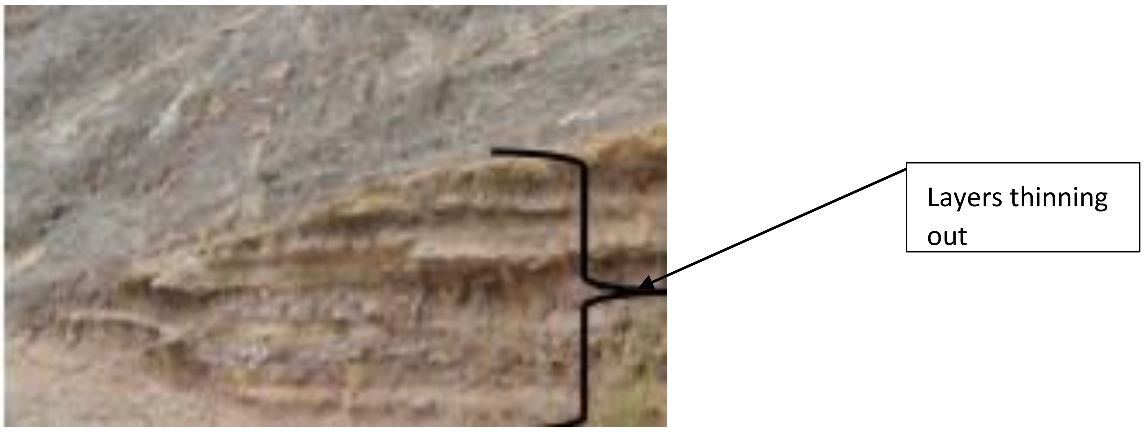


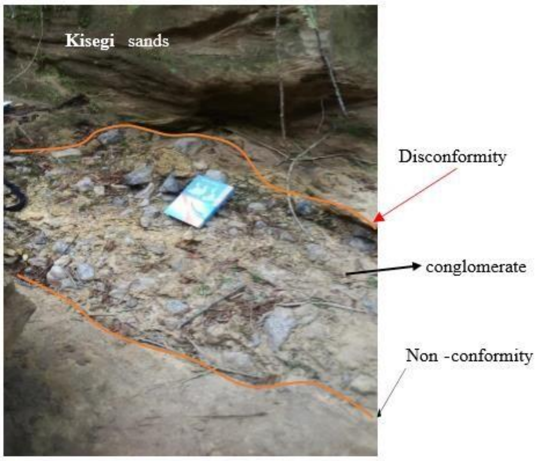
Figure 5. 19: layers pinching out

Pinch outs occur only in a few areas in the study area especially along the kibuku roadcut area.

- **Unconformity**

An unconformity is a buried erosional or non-depositional surface separating two rock masses or strata of different ages, indicating that sediment deposition was not continuous.

The type of unconformity in the study area are non-conformity and disconformity. A non-conformity exists between sedimentary rocks and metamorphic or igneous rocks when the sedimentary rock lies above and was deposited on the pre-existing and eroded metamorphic or igneous rock, it is evidenced by presence of conglomerates at the contact between basement and sediments (Figure 5.20) while a disconformity is an unconformity between parallel layers of sedimentary rocks which represents a period of erosion or non-deposition.



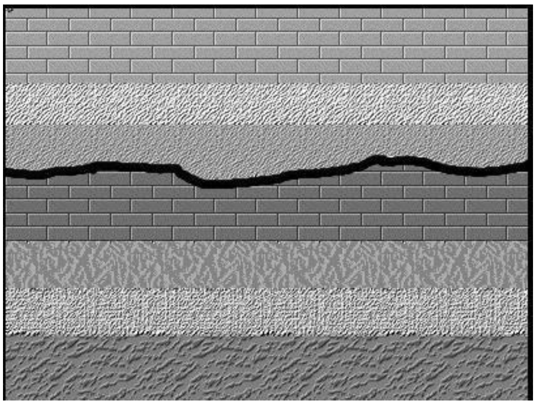


Figure 5. 20 Unconformity observed at location: 192593/102087, 712m and a sketch of disconformity(right)

5.2.2 Secondary Structures

A secondary structure is a structure formed in response to an applied stress that results from plate movement, (Wilkerson, 2019). Therefore, these structures are tectonic, as they develop after lithification of sedimentary and igneous rock, and after crystallization of metamorphic rocks. For the case of sediments encountered in the field, most of the secondary structures were formed in response to tectonism in the basement rocks below the sediments. This means that the structures formed in the sediments are most likely the same structures in the basement rocks in the basin. The secondary structures encountered in the sediments include;

- **Faults**

In the study area, only minor faults that are present in the sediments. The faults mapped in the area are dip-slip normal faults (hanging wall moves down relative to foot wall) and dip-slip reverse faults (hanging wall moves up relative to footwall) and were mainly oriented in the NE-SW direction and relative displacement of about 4cm and run for a few centimeters in length(Figuren5.21). They have a similar trend to the general major faults in the Albertine rift implying that the sediments were affected by the same tectonic forces that affected the basement and formed the major faults.

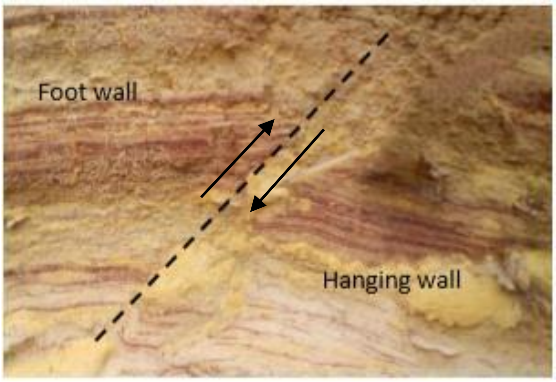


Figure 5. 21: Normal fault

✓ **Intra-sedimentary faults**

These are minor faults in sediments associated with the major faults and were formed after deposition of sediments as a result of tectonic movements(Figure 5.22). The minor faults generally trend in NE direction and can form good traps for hydrocarbon accumulations provided they are sealing faults.

Figure 5. 22: Intra-Sedimentary faults

- **Joints**

Joints are observed in consolidated sands and occupied mostly by gypsum and iron minerals. The joints in the sediments are oriented in the NE-SW direction which is a similar direction to that of the joints in the basement rocks and general trend of the Albertine rift. Hence, the tectonic events that formed the joints in the basement rocks extended to the sediments must have also affected the sediments.

- **Veins**

The veins occupied some bedding planes between the sediments, as well as joints. The veins are filled with gypsum ($CaSO_4.2H_2O$) mineral(figure 5.23). This indicates to presence of conditions favoring evaporation and precipitation. Depositional environments that are interpreted from the presence of these gypsum veins include; ephemeral lakes and supratidal flats in hot arid settings. Since these veins cut through beds as well as occupying bedding planes between loose sediments, it can be concluded that the gypsum veining is younger than the sediments.

Figure 5. 23: Gypsum filled veins within clay beds.

- **Flower Structures**

Positive flower structures have been mapped on the seismic data acquired in the Turaco area by previous scholars in the Albertine Graben. Fault systems diverge upwards and form positive flower structures as shown in the figure 5.24 below. Closer inspection of these structures reveals that the section within the boundary faults of the flower structures forms anticlines suggesting that they were formed by trans-compressional tectonics. The formed anticlines can be good structural traps for hydrocarbons accumulation.

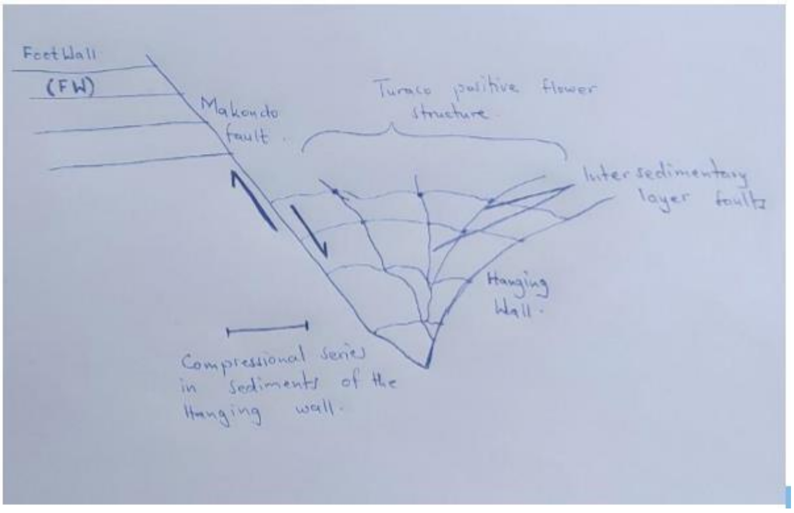


Figure 5. 24: Positive flower structure at Turaco

5.3 DISCUSSION

Tectonic history and Relationship of structures

Initially, the basement rocks were acted upon by regional extensional forces oriented in the NW-SE direction and ended up rifting the basement rocks. This tectonic regime is responsible for the NE-SW trending fractures that include joints as well as normal faults present in the study area. This notion is evidenced by the fact that observed fractures in the basement correlate with the known general structural trend of the Albertine rift. The presence of the different joint sets gives us a clue that the area was affected by different episodes of tectonism oriented in different direction.

After sediment infill, it is believed that the basin was reworked by a strike-slip tectonic regime that was trans-tensional in nature. This is evidenced by the presence of a steep transversely- consistent faults with similar dips seen in the interpreted seismic section. This regime was controlled by the existing NE-SW faults and therefore this strike-slip movement (also characterized by a slight component of extension) was along the NE-SW trend. It can be seen that the folds, with a general NESW axial trend, within basin (observed in the seismic data) were formed by shearing caused by this strike-slip regime. The folds formed as a result of uplifting due to compression at constraining bends occurring at zones that connect adjacent segments of the en echelon NE-SW fault segments. This mechanism can as well be used to explain the formation of the reverse dip-slip intra-sedimentary faults observed.

The Semliki basin is believed to have formed as a pull-apart basin at a large releasing bend. This discussion considers joints oriented in NE-SW direction.

Petroleum potential of the structures

The structures in the Semliki basin whose petroleum potential is discussed below include; faults, flower structures and rollover anticlines (discussed in chapter 6) and Pinchouts.

- ✓ **Faults:** The faults observed in the sediments were filled with Gypsum which is a nonpermeable material therefore giving the faults a good potential for trapping hydrocarbons as sealing faults.
- ✓ **Flower structures:** These consists of several faults that form a flower-like structure and this would act a potential trap in the case where the faults are sealing faults. Rollover anticlines; These are syn-depositional structures developed within the downthrow block of large normal faults. They form a fold like structure which can be a potential trap especially in the presence of a nearby cap rock
- ✓ **Pinch-outs**: These form traps when the reservoir like a sand is pinching into a potential cap rock like clay/shale which has a low permeability hence preventing hydrocarbons from escaping.
- ✓ **Joints**: the intense fracturing in the area is an evidence of potential for hydrocarbon storage.

CHAPTER 6 : GEOPHYSICS OF SEMLIKI SEDIMENTARY BASIN

6.0 Introduction

This chapter discusses the geophysical aspects of the Semliki Basin, with particular interest on potential field date i.e. gravity and magnetic data. These datasets have been interpreted to attain a better understanding of the petroleum system of the Albertine Graben. Geophysics is the application of physical principles in studying the earth. It is a science that applies the laws of physics to study the earth's interior. Geophysical exploration methods exploit the fact that there is a variation of lithology and physical properties of the rocks involved within the earth. For every standard physical property, there is a corresponding geophysical property, for instance, for density contrasts, the gravity method is used, for magnetic susceptibility the magnetic method is used etc.

There are two broad types of geophysical methods, namely; the passive and active methods. The active geophysical methods involve injection of some form of energy into the subsurface in order to measure the physical properties of the rock for example the electric and seismic methods. On the other hand, passive methods measure spatial variations of naturally occurring fields for example the gravity and magnetic methods. The passive methods are also referred to as Potential methods.

Acquisition of potential field data in the Albertine graben and Uganda at large.

Over the years, airborne geophysical coverage of the entire country was carried out. In 1980, the onshore portion of the southern part of the country (South of 10 00' N) was surveyed with a magnetic and gamma-ray spectrometry system at 1 km line spacing by Geo-survey. Aeromagnetic surveys were done by Kenting Earth Sciences in 1983 as part of the “Great Lakes” program, covering Lake Victoria with spacing of 40 km, and the western part of Uganda, including the Albertine graben at 5 km line spacing. The survey blocks in the North and Northeast were flown by Hunting in 1959, and incorporated electromagnetic and radiometric, as well as magnetic surveys. The magnetic data from these surveys were recompiled as part of the African Magnetic Mapping Project (Barritt, 1993), and released in 1992. It should be noted that some of the areas were not covered as a result of the safety and security risk they posed.

The African Magnetic Mapping Project identified five sedimentary basins in Uganda; the Albertine Graben, Hoima Basin, Lake Kyoga Basin, Lake Wamala Basin and Kadam-Moroto Basin. Still in 1992, Kenting flew an aeromagnetic survey over the Kidepo valley-Moroto-Mt. Elgon region focusing on petroleum exploration. The aircraft was flown at an altitude of two kilometers due to safety reasons across the Karamoja region at the time, a factor that affected the resolution of the data. According to MEMD, Kenting obtained 15,454 line-kilometers of raw aeromagnetic data over the entire Albertine graben which was processed by a company called Edcon. Interpretation of this data revealed 3 significant sub-basins (shown in Appendix I) with depth to basement of over 3km. The graben was subsequently divided into three exploration areas. In 1991, the Petroleum Unit in the Geological Survey and Mines Department (GSMD) of MEMD was transformed into the Petroleum Exploration and Production Department (PEPD) with a main role of establishing and promoting the petroleum potential of the country. From 1991 onwards, PEPD embarked on acquisition of ground geophysical data over the Albertine graben. The gravity surveys revealed significant structuring, improved depths to basement, and subsequently enabled further subdivision of the graben into 5 exploration areas from the previous 3. This is how the data used for this study was obtained. Actually, PEPD has now shifted priority to the Moroto-Kadam basin obtaining more geological and geophysical data. This is after registering great success in the Albertine graben.

6.1 Potential Field Survey Method

6.1.1 Gravity Survey Method

The gravity field on the surface of the Earth is not uniformly the same everywhere. It varies with the distribution of the mass materials below. This lateral change can be measured and interpreted in terms of likely causative geology. A Gravity survey is an indirect (surface) means of calculating the density property of subsurface materials. The higher the gravity values, the denser the rock beneath. In most cases, ground-based gravimeters are used to precisely measure variations in the gravity field at different points. Gravity anomalies are computed by subtracting a regional field from the measured field, which result in gravitational anomalies that correlate with source body density variations. Positive gravity anomalies are associated with shallow high-density bodies, whereas gravity lows are associated with shallow low-density bodies. Thus, deposits of high-density chromite, hematite, and barite yield gravity highs, whereas deposits of low-density halite, weathered kimberlite, and diatomaceous earth yield gravity lows. The gravity method also allows for prediction of the total anomalous mass (ore tonnage) responsible for an anomaly. Applications of gravity to mineral deposit environmental considerations includes identification of lithologies, structures, and, at times, orebodies themselves (Wright, 1981). Small anomalous bodies, such as underground workings, are not easily detected by gravity surveys unless they are at shallow depth. In petroleum exploration, gravity survey can help the exploration geologists to narrow down on the target and also give information about thickness of the sediments and depth to the basement.

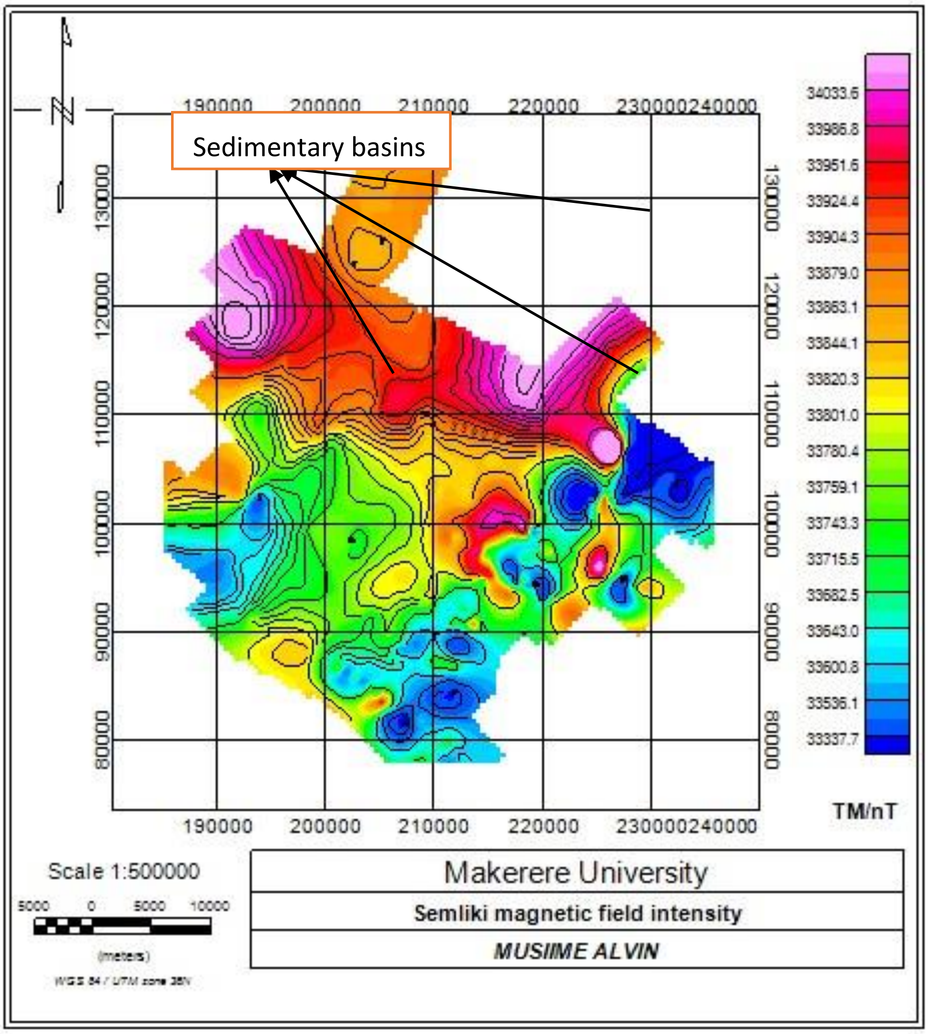


Figure 6. 1: A bouguer anomaly map of Semliki basin.

Interpretation

A Bouguer gravity anomaly map of the Semliki basin(Figure 6.1) was produced for use in the gravity interpretation of Semliki basin. The Bouguer gravity anomaly shows that the values are negative and vary from below -221.3 to above -111.3 mGals indicating that they are associated with local deficiencies in mass that result from volumes of rock less dense than the average density. The base of the Semliki basin is made up of igneous or metamorphic rocks that are overlain by sediments. The gravity low values range from below -221.3 to -203.0 mGals (blue to green zones) and are concentrated in the centre to northern part of the map in grids the regions A2, B2, B1, C1 and C2 and parts of A3, B3, C3 and in the central part of grid B4 of the Bouguer map. Gravity highs are associated with the rocks of high density and range from -203.0 to above -111.3 mGals (Yellow to pink zones), as concentrated in the southern part of the map in grids in regions A4, B4, C4 and the southern parts of grids A3, B3, C3. The yellow line in cells A3, B3 and C3 could be the area of contact between the sediments and basement because south of this line are gravity highs and north of this line are gravity lows.

The regions of gravity highs imply the thickness of sediments is low(very thin layers) and hence the dense basement formations with high-density minerals are shallow and have huge positive effect on the gravity reading. The gravity lows are due to the density deficiencies resulting from thick sediment within the basins. The magnitudes of these low gravity values reflect the thickness of the sedimentary section that overlies the Pre-Cambrian rift floor. Therefore, a conclusion can be made that the Semliki depocenter is in the North-western part of the area (around grid B2) that has a relatively low Bouguer anomaly range (blue zones on the map).

Positions of geological bodies

Gravity maps can be used to locate horizontal positions of geologic bodies that have a different density than the surrounding rock. The gravity lows in grid cells C2, C1 and B4 may be due to the density differences resulting from igneous intrusions or even salt domes.

6.1.2 Magnetic Survey Method

The magnetic method detects changes in the earth's magnetic field caused by variations in the magnetic properties of rocks. A magnetometer is the instrument used for measuring these local variations of earth's magnetic field and indirectly, the thickness of sedimentary rock layers where oil might be found.

The area with relatively low susceptibility readings are usually areas with the thickest sequence of non-magnetic sedimentary rocks. Magnetic surveys can be used for locating grabens or other basins beneath miles or sedimentary rocks hidden columns of salt rising through heavier overlying strata or basement rock associated with buried structural highs. However, magnetic contours give limited information of structure or stratigraphy. The method can also be airborne (plane or satellite) which permits rapid surveying and mapping with good areal coverage. Like the gravity technique this survey is often employed at the beginning of an exploration venture.

The magnetization of rocks has both direction and magnitude (thus magnetization is a vector quantity) and can be a combination of both remanent and induced magnetization. The induced magnetization depends on the rocks susceptibility while the remanent magnetization (remanence) depends on the history of the rock. Due to the dipole source nature of the magnetic field, the amplitude of a magnetic anomaly is unaffected by physical scale change. This in part is due to the magnetic effect not arising from the bulk volume of the magnetic material but from the surface area of the magnetic interface, and that magnetic fields decay more rapidly with distance. This causes magnetic maps to appear to favor the effects of shallow sources over deep ones. If no shallow volcanics (generally strongly magnetic) are present, the effects of the crystalline basement are seen in magnetic maps. Basic igneous and metamorphic rocks, iron ore, and banded iron formation give high readings of the magnetic anomaly. Acid gneisses and metamorphic rocks give relatively intermediate readings while sediments give the lowest values.

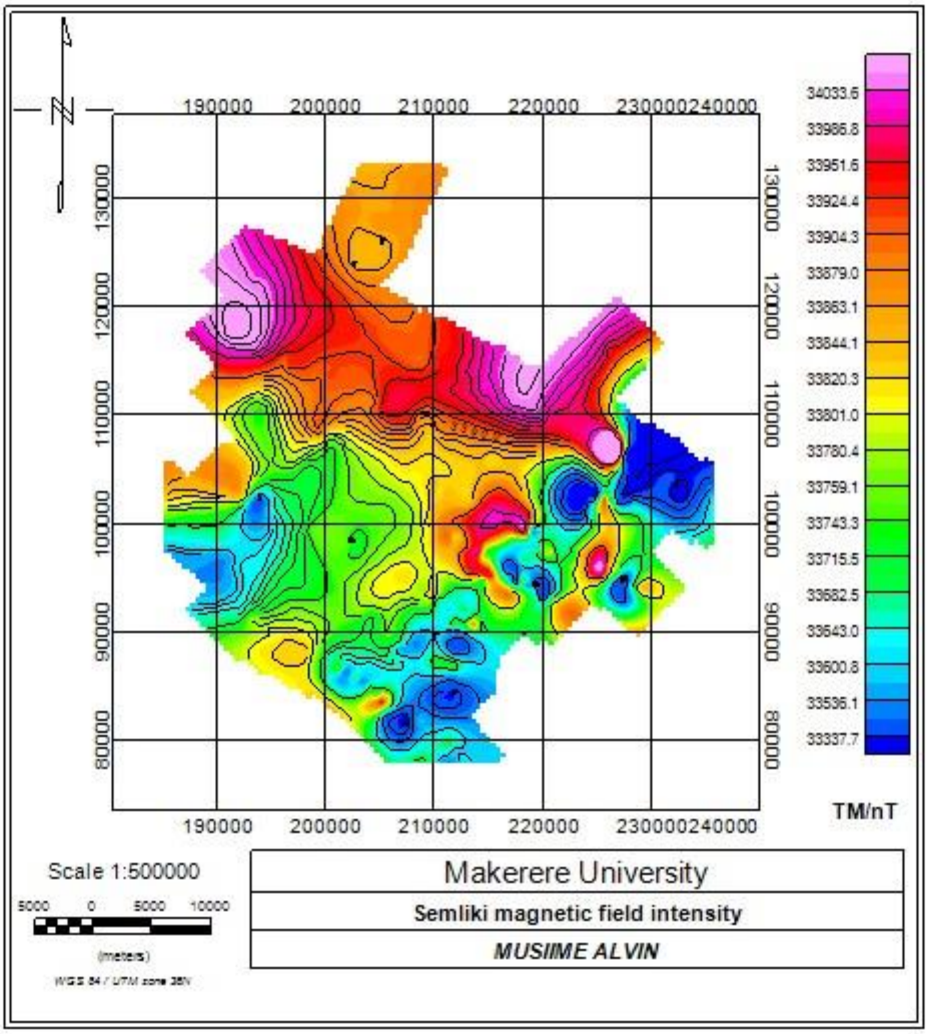


Figure 6. 2: A total magnetic intensity anomaly map of the Semliki basin

Interpretation of results

The total magnetic intensity map shows the variation of both highs and lows magnetic signature from 33,337.7 nT to 34,033.6 nT respectively including the IGRF model value of 33,000 nT; the regions of magnetic highs indicate sediment deposition basin that dominates the north- and north-west part of the study area(Figure 6.2) implying that the sediments contain magnetic materials eroded from rocks that were overlying the flanks of the rift valley and the Rwenzori host mountain.

The relatively low total magnetic values are interpreted as the basement which dominates the south- and south-east part of the study area. Before erosion, the rocks that form the basement were buried at great depth where the geothermal temperature exceeded the Curie temperature and the minerals lost their magnetic properties hence demagnetized. Therefore, hot rocks seldom contribute to magnetic anomalies.

The magnetic highs in the south could possibly be igneous intrusions that contain magnetic minerals like magnetite, hematite and magnetite.

The analytic signal filter is widely used as a magnetic interpretation. It eases location determination of the causative sources of the magnetic anomalies, where its maxima are mainly positioned over the edges of the sources, regardless of their magnetization direction (Cheyney et al.2011). This filter converts data which have been recorded in the inclined earth's magnetic field to what the data would have looked like if the magnetic field had been vertical.

Also, derivatives in both the horizontal and vertical directions of the TMI maps alongside with the Tilt Derivative (TDR) were used to map and delineate structures (lineaments or faults) present in the Semliki basin(Figure 6.3). These derivatives sharpen the edges of magnetic anomalies, give clearer contrast between geologic units and causative structures such as lineaments/faults (Macleod, Jones, Dai, 1993).

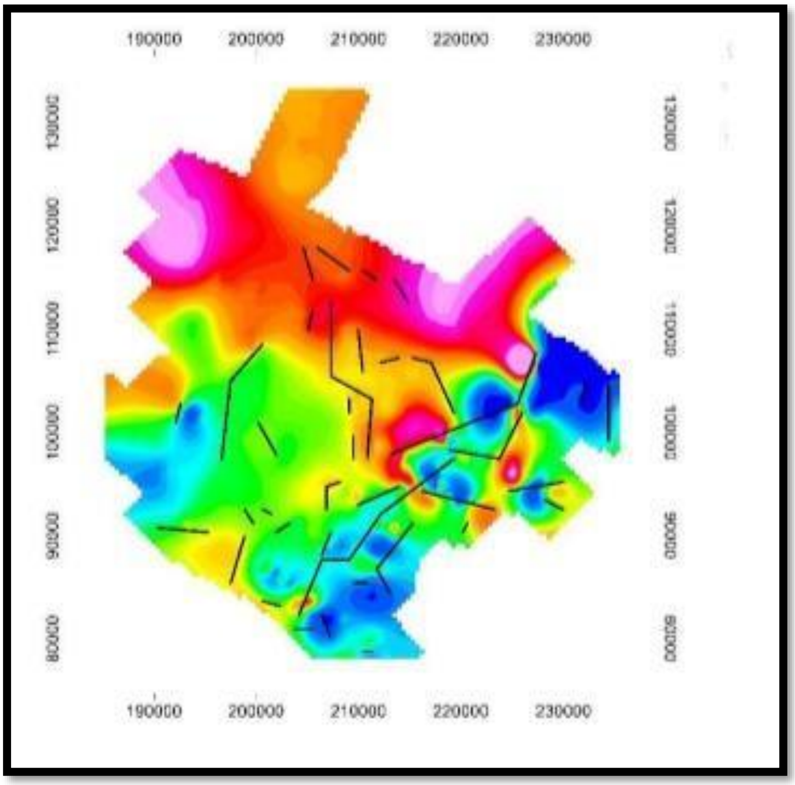


Figure 6. 3: Structures delineated from magnetic intensity data.

6.2 SEISMIC SURVEYS

Seismic methods provide a clearer image of the subsurface than other geophysical methods. The basic principle is to initiate a seismic pulse from a seismic source at or near the Earth's surface, using a vibroseis, airgun or an explosive, and record the amplitudes and travel times of waves returning to the surface after being reflected or refracted from the interface(s) of one or more layers. When a seismic source emits a pulse that propagates through the sedimentary layers, the sound waves travel between the layers with different velocities. The results are recorded either using a geophone for land seismic or hydrophone (marine), and are later interpreted for search for oil and gas. Seismic methods are widely applied to exploration problems involving the detection and mapping of subsurface boundaries of, normally, simple geometry. The methods are particularly well suited to the mapping of layered sedimentary sequences and are therefore widely used in the search for oil and gas. Seismic interpretation, whether for hydrocarbon exploration or geotechnical studies, is the determination of the geological significance of seismic data. Reflections evident on a seismic section have a time and a character.

6.2.1 Results of Seismic Study and Interpretation of Structures for Semliki Basin

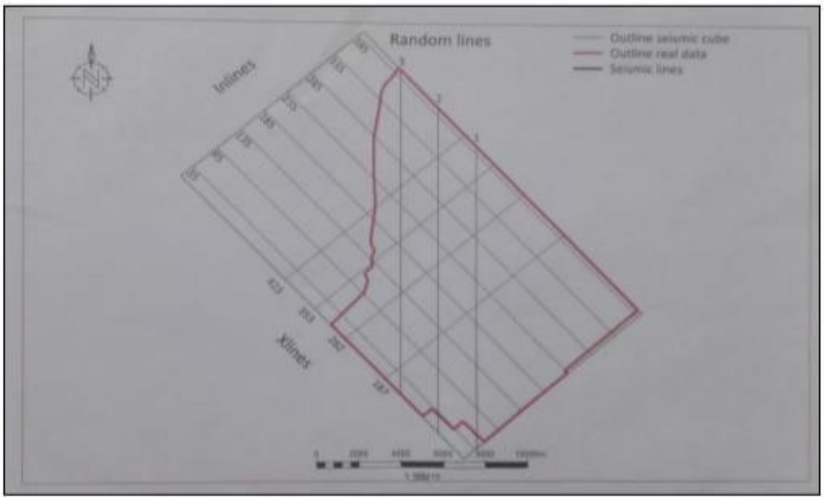


Figure 6. 4: The random lines from which the seismics were shot.

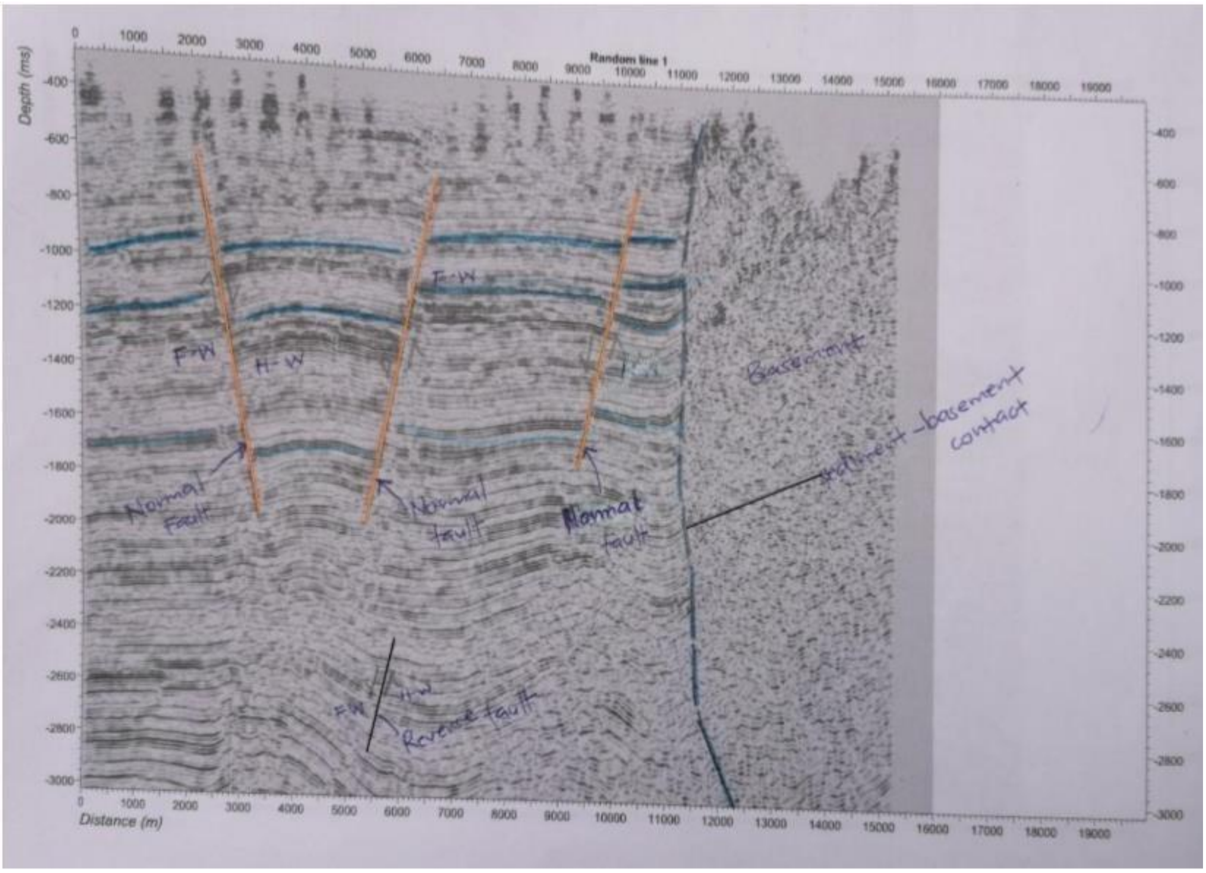


Figure 6. 5: Structures interpreted from Random line 1

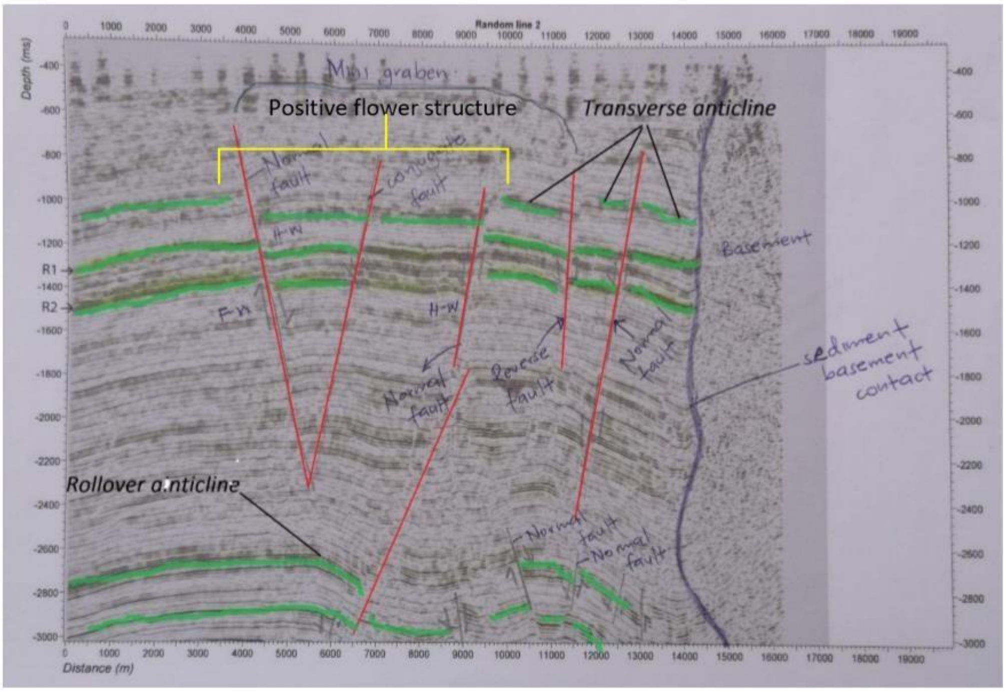


Figure 6. 6: Structures interpreted from Random line 2

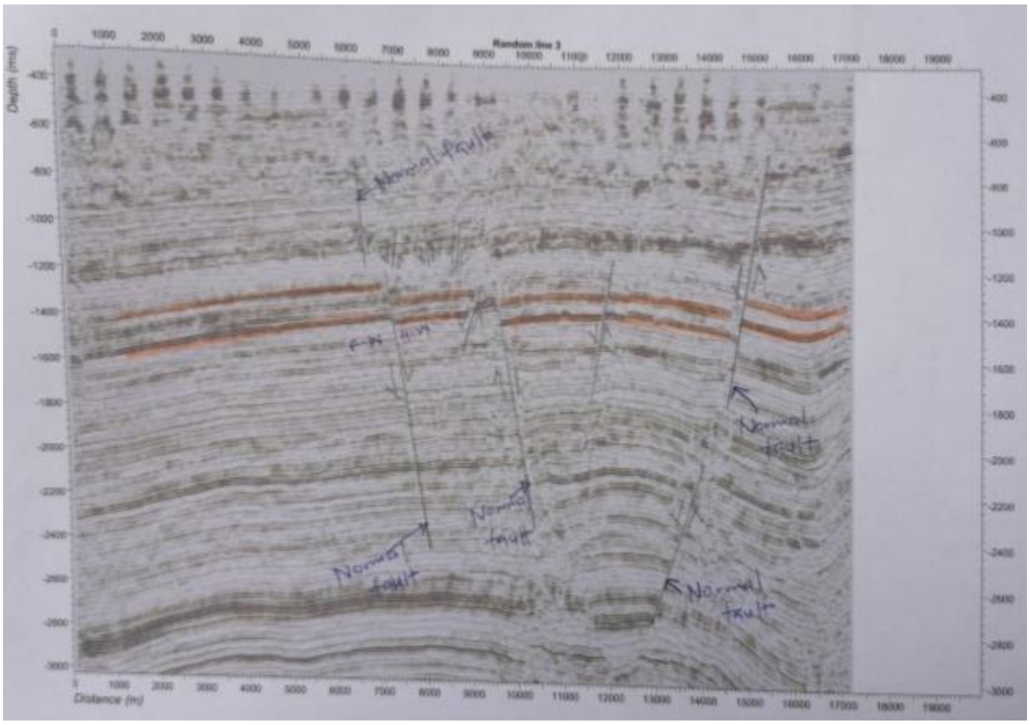


Figure 6. 7: Structures interpreted from Seismic Random line 3

The sections shown above (Figure 6.5, 6.6 and 6.7) illustrate high quality seismic data of Semliki basin since the horizons and structures can be clearly identified. The interpretation shows that the Semliki Basin has been affected by intense faulting evidenced by the lateral displacement of horizons where the faults are indicated by orange, red and grey colors lines. The faulting that has occurred indicates a regime in which the fault system diverges upwards to give a positive flower structure. Closer inspection of these structures reveals that the section within the boundary faults of the flower structures forms anticlines suggesting that they were formed by transpressional tectonics. The faults are mainly dip-slip normal faults while a few dip-slip reverse faults. The overall flower structure is associated with concave up or planar reverse faulting, and also this type of faulting leads to the compartmentalization of the reservoir which has been reported in several reservoirs in the Albertine graben. The transverse anticlinal structures are related to an accommodation zone between the principle border faults. Accommodation zones are long term critically stressed zones where fluid pathways are more likely to remain open in networks of closely spaced, fault breccias dominated fractures. Accommodation zones occur at fault intersections consisting of belts of interlocking, oppositely dipping normal faults. Multiple subsurface fault intersections in these zones can be favorable features for trapping hydrocarbons. Rollovers are anti-form structures developed in the downthrown blocks of growths faults are good for hydrocarbons trapping.

6.2.2 Results of seismic study and interpretation of facies/lithology for Gulf of Mexico

High resolution (150-200 Hz) seismic data with a vertical resolution of 3 m from an intra-slope salt withdrawal mini-basin in the Gulf of Mexico was availed by the field supervisor. This seismic data provides an excellent example of the seismic facies and the depositional elements common to many deep depositional systems. This data was derived from an Exon Mobil training exercise and includes eight 2D seismic lines (Line D1, which ties lines S1-S7). The main aim of providing this data was to enable students gain experience of interpreting structures, sequences, the key stratal surfaces around the grids of the seismic lines and understand how uncertainties related to seismic data are realized. The procedure involved locating and marking reflection terminations on D1, tying strike line S6 to seismic line (dip line) D1 and extending the surfaces and facies interpretation defined on to line S6 through D1. Features on D1 are tied back onto S6. This procedure was repeated for lines S1, S2, S3, S4, S5, and S7.

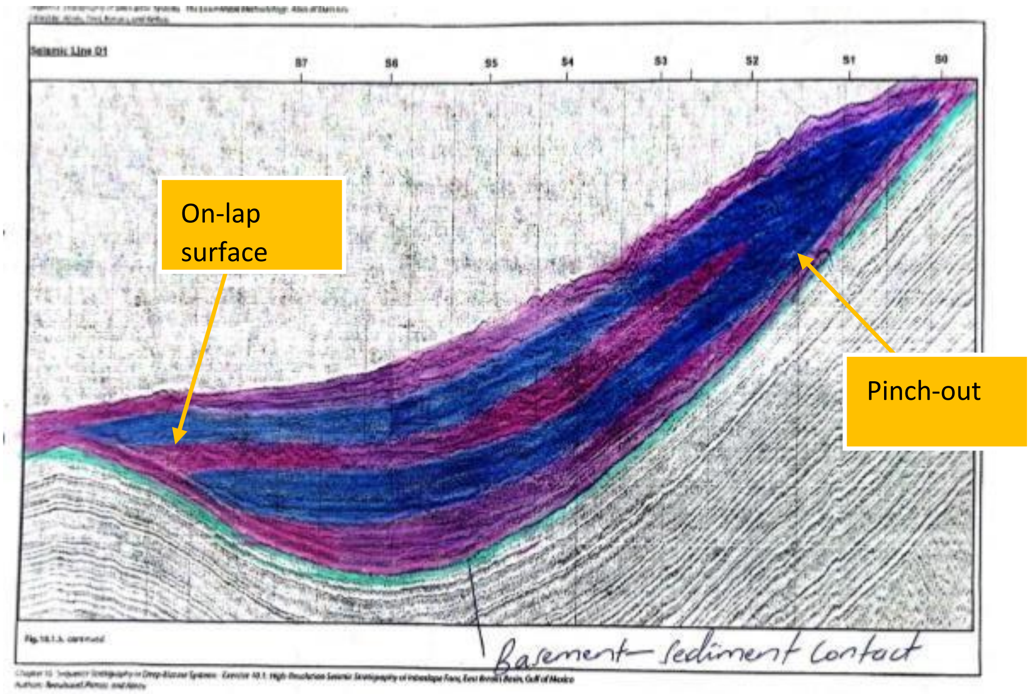


Figure 6. 8: Seismic line D1

Interpretation

The figure 6.8 above shows cyclic sedimentation with two major facies shown by blue and purple colours. It also shows a pinch-out and layers on-lapping onto a surface.

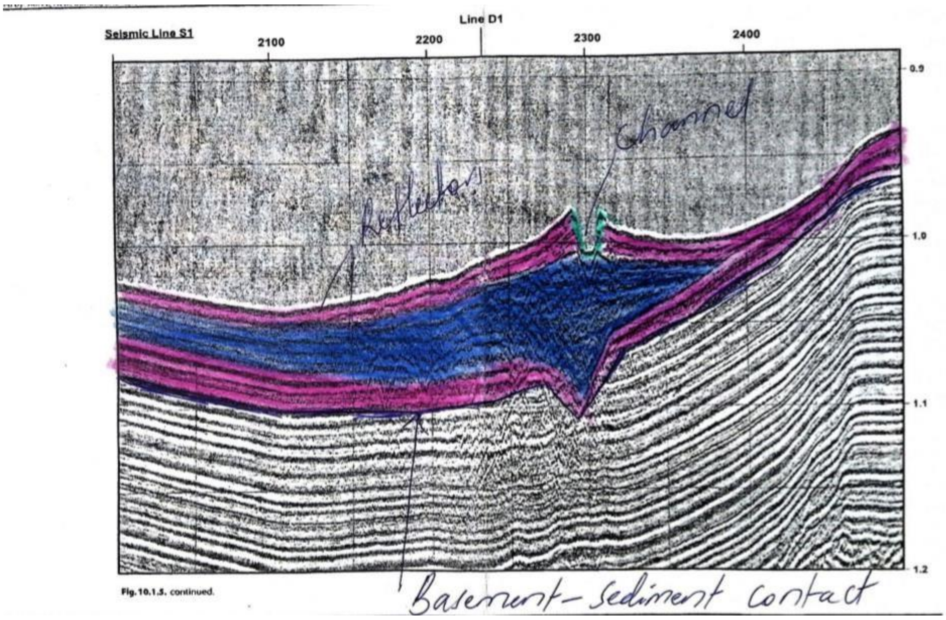


Figure 6. 9: Seismic line S1

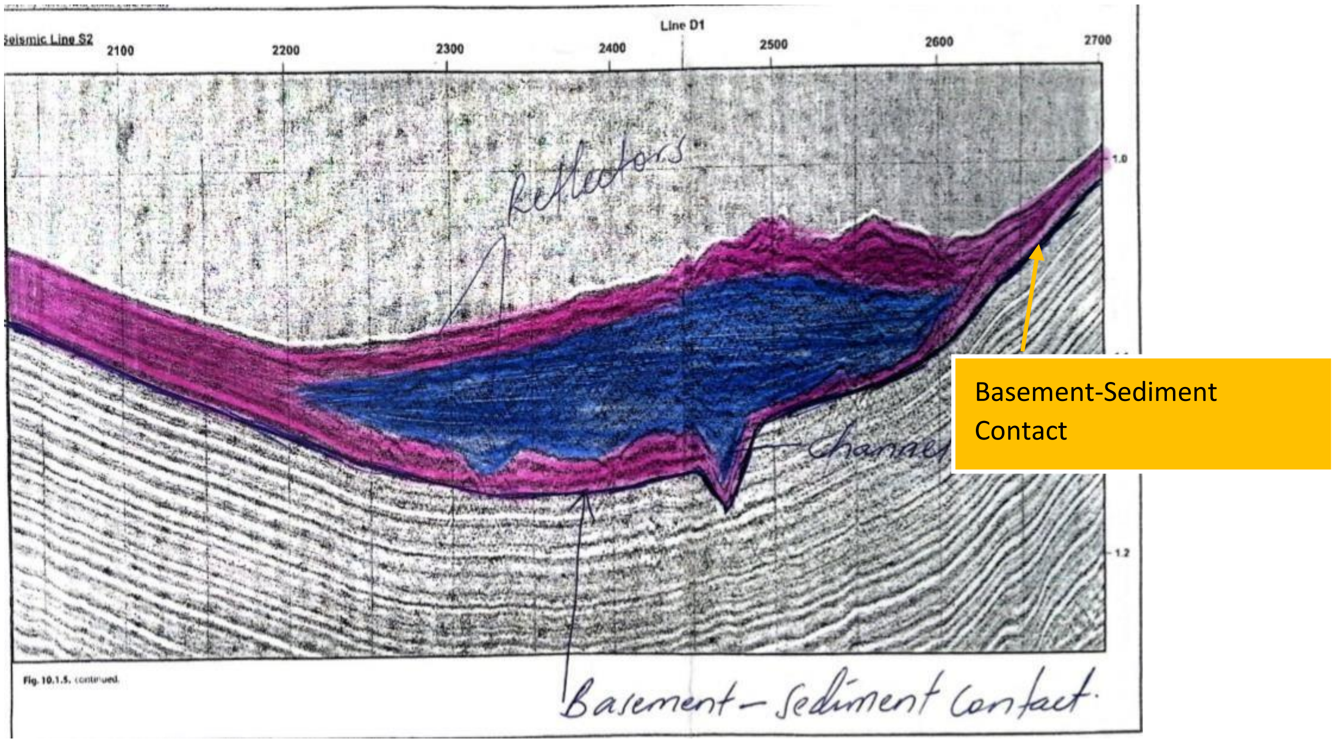


Figure 6. 10: Seismic line S2

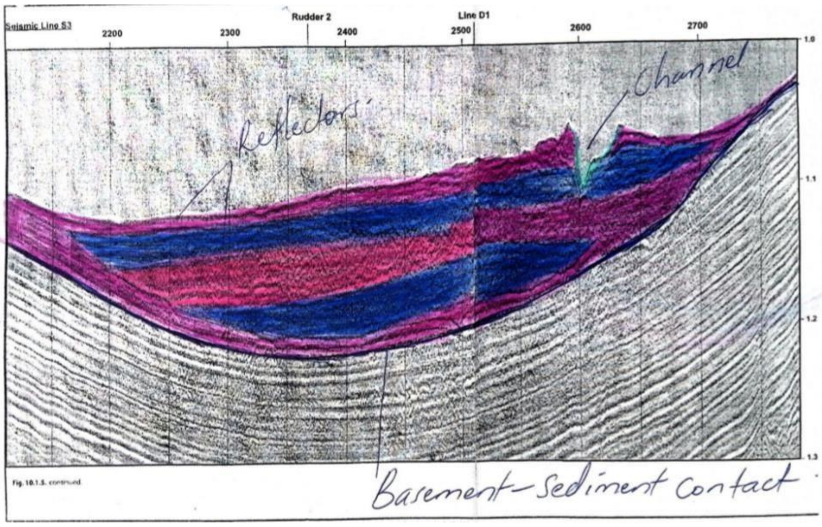


Figure 6. 11: Seismic Line S3

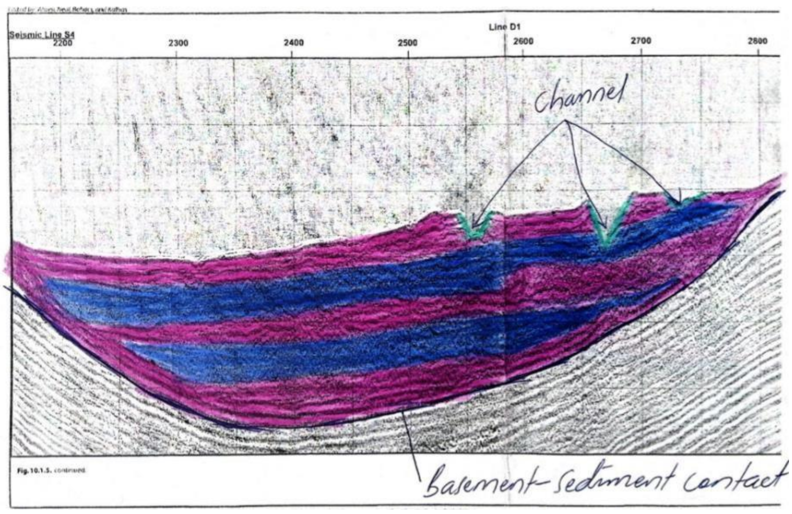


Figure 6. 12: Seismic line S4

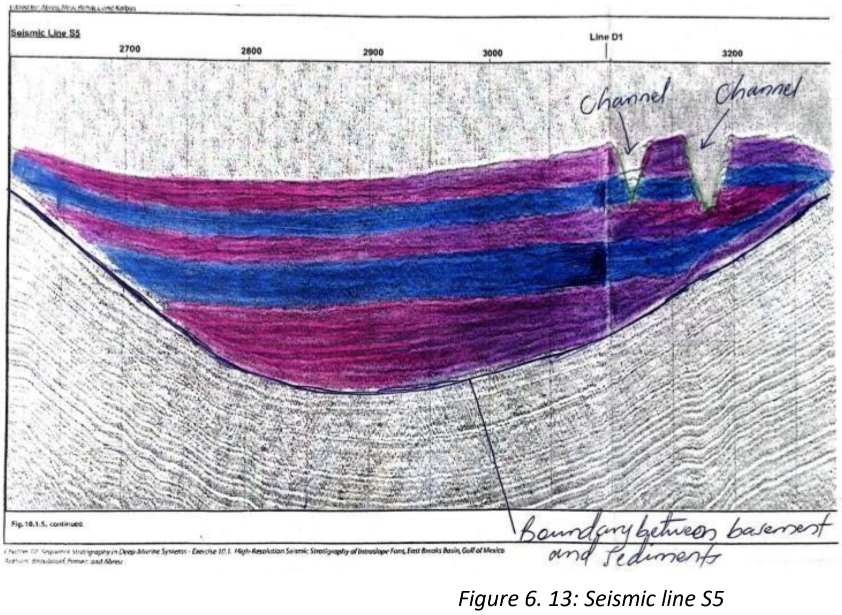


Figure 6. 13: Seismic line S5

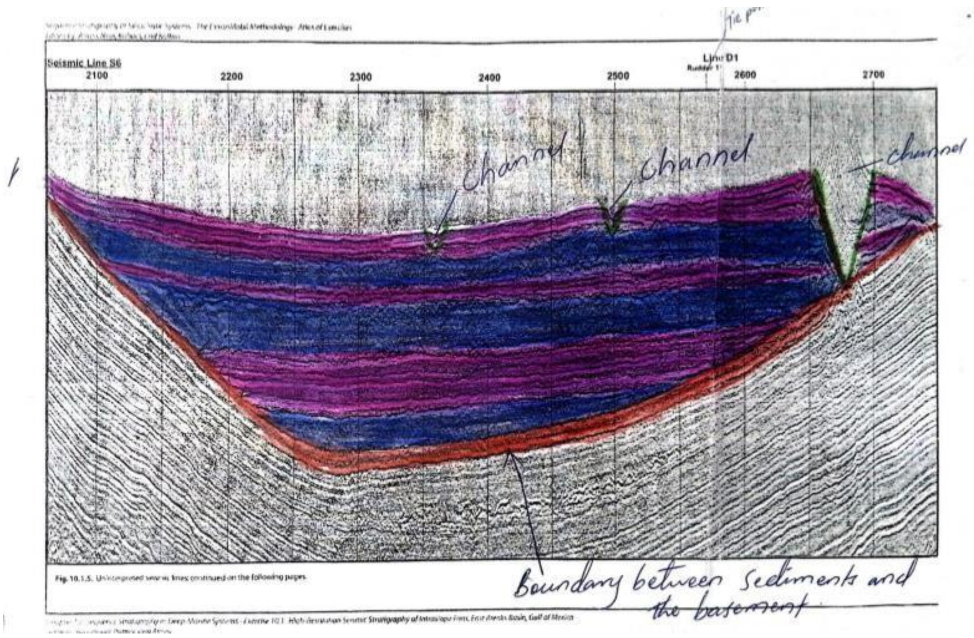


Figure 6. 14: Seismic line S6

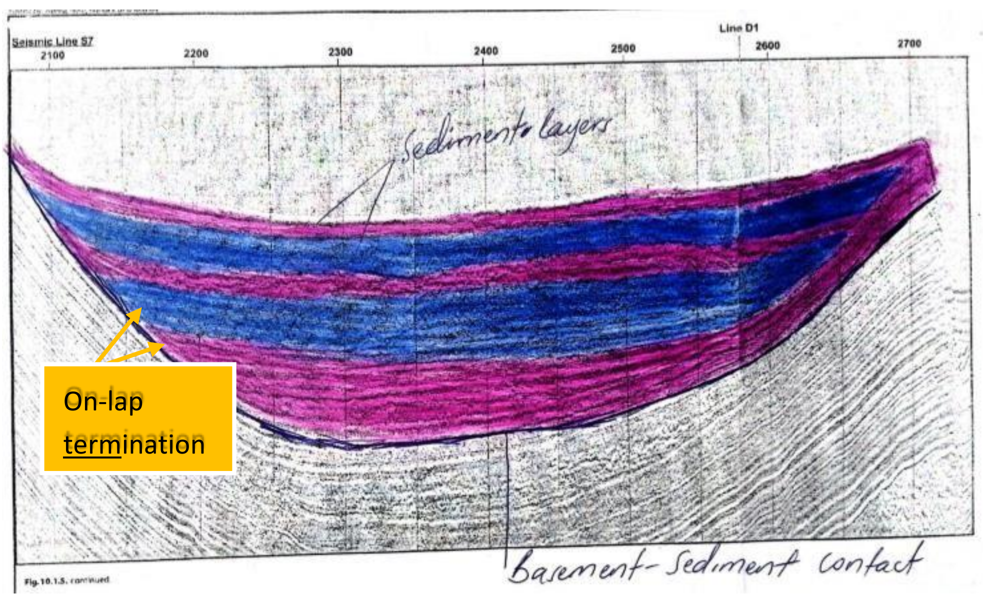


Figure 6. 15: Seismic line S7

Interpretation of results

The diagrams from figure 6.8 through figure 6.15 shows that two facies with cyclic sedimentation appear in seismic sections of lines S1 through S7. The facies are shaded with blue and purple colours respectively. The facies in purple are characterized by continuous parallel reflections indicating that these facies were deposited in environments where uniform conditions were laterally extensive like in deep water environments with low energy.

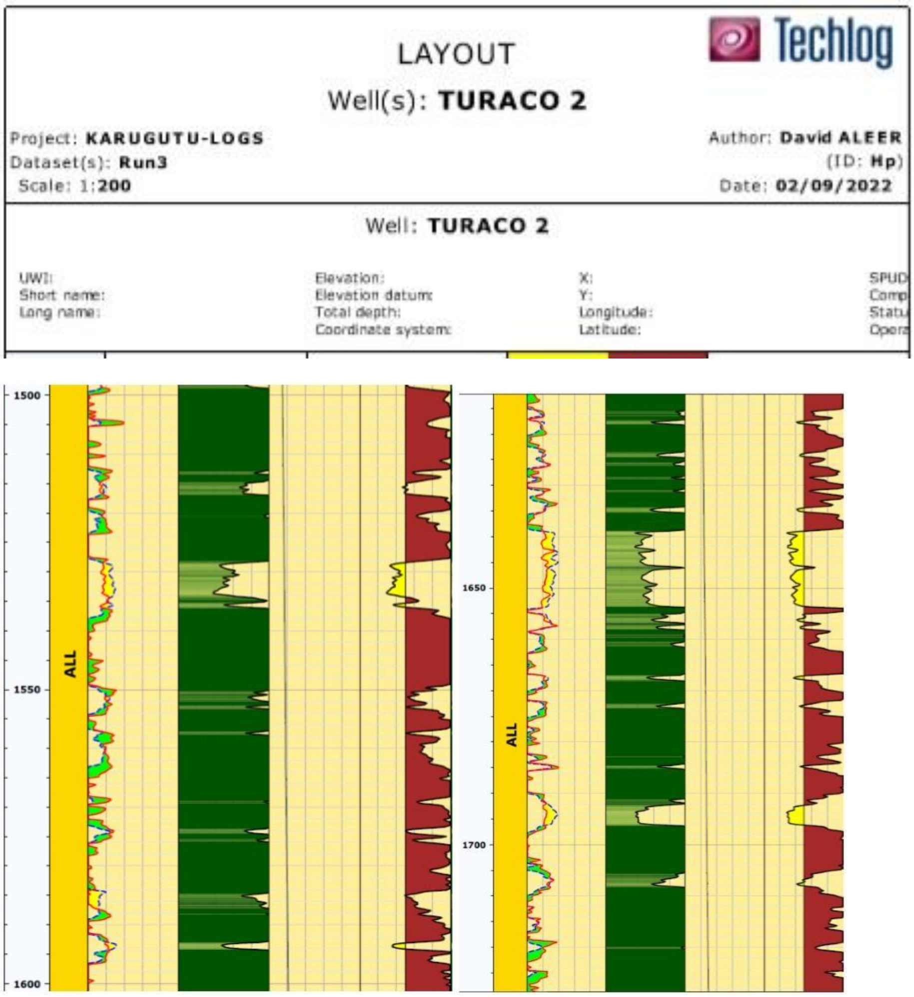
The facies shaded in blue are characterized by somewhat discontinuous reflections that suggest that the facies are characteristic of an environment where there was a lateral change in facies such as fluvial and alluvial environments with high energy.

The sequence boundaries observed in seismic line S1 to S7 included various conformable surfaces (gradational) between facies and a possible unconformity on which the seismic facies are onlapping. The onlapping stratal terminations are recognized on seismic line by the termination of low-angle reflections against a steeper seismic surface.

Geometric observations; Seismic line 1 shows only two types of seismic facies and these appear to pinch out towards the right. They probably represent fluvial channel deposits at the mouth of the river entering into the basin. As we move towards seismic line 2,3,4,5,6,7 the basin widens and deepens, cyclicity and thickness increase, maximum depth of the basin is best seen along seismic line S7, this shows that the geometry of these deposits is more like a cone shape.

From the interpreted geometrical information and seismic attributes observed, it can be deduced that the sediments were deposited in a fluvial system particularly in a fluvial/alluvial fan depositional environment. Furthermore, the sediments that were deposited in the basin were later cut through by river channels, probably during periods of regression. The river eroded the sediments leading to truncation of strata and then became an abandoned channel.

6.3 Petrophysics For Formation Evaluation



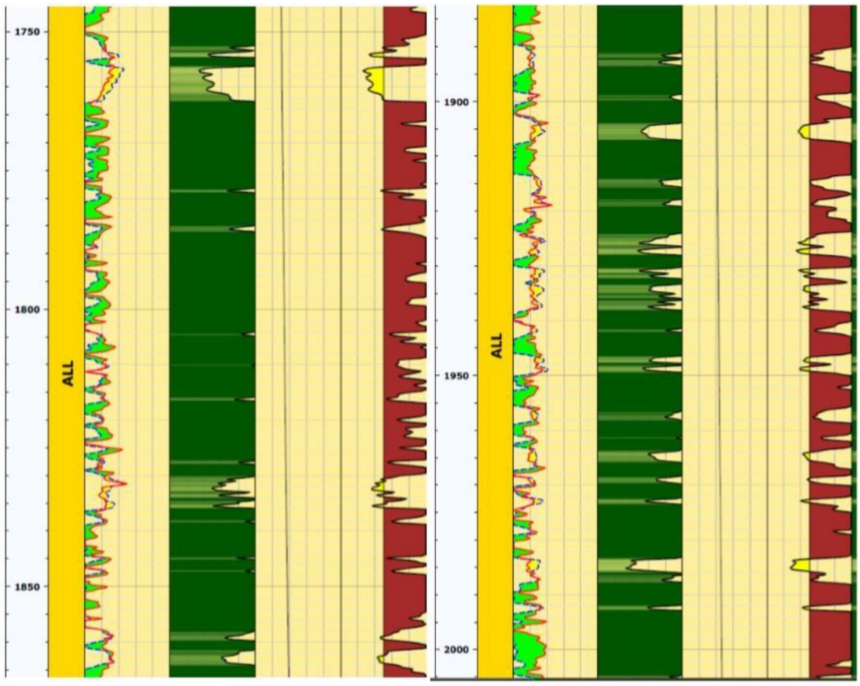


Figure 6. 16: Wireline log for Run 3 Turaco 2 from depth 1500ft t0 2000ft

Interpretation

The interpretation of the wireline log above has been made from an eye-catching section of 1500ft to 2000ft for the Turaco 2 well. The rest of the log can be viewed in Appendix 4

Neutron and Density porosity logs

These logs are shown in track 1. The Neutron porosity log (blue line) is used to measure hydrogen concentration a formation while the density porosity log (red line) measures the electron density of a formation. Low readings of the neutron log readings indicate the presence of gas since it has low concentration of hydrogen as compared to oil/water. On the other hand, the density log will give a high reading when gas is present. Therefore, a wide separation of the two logs on the wireline log shows presence of gas. When the neutron and density porosity logs track each other or are supper imposed it signifies the presence of oil or water. From the sections above, it can be observed that Turaco well 2 has more gas than oil/water. This is not very economical for a company whose major interest is oil.

These logs can be used to calculate porosity where;

$$\emptyset = \frac{\rho(matrix) - \rho(density\log)}{\rho(matrix) - \rho(fluid)}$$

Where, Φ =porosity,

$\rho\ (matrix)$=the density of the matrix (g/cc),

$\rho\ (density\ log)$= the corresponding density read from the density log (g/cc) and $(fluid)$ is the density of the fluids (g/cc).

Average Porosities obtained for Turaco-2 well include 31%, 21%, 36%, 26%, 22%. These are very good porosities implying that the reservoirs with in this area are good.

V-Shale log

This is shown in track 2. This log can be used to calculate the amount of shale in a formation. From the log. Low volumes of Vshale mean that the formation at that point has low shale content and thus porous. The sections are common hydrocarbons are present especially oil/water. The volume of shale can be calculates using a gamma ray log as shown below;

$$Vshale = \frac{GRlog - GRmin}{GRmax - GRmin}$$

Where, GRlog = reading of the gamma ray log,

GRmin = clean sand and GRmax is Shale.

Gamma ray Log

This is shown in track 3, High gamma ray readings a characteristic Shales because shales contain a number of radioactive minerals(like potassium) whereas low gamma readings are indicative of Sands which are deficient in radioactive materials,

Presence of a reservoir is shown as a negative reading also known as mud cakes that form due to the interaction of the reservoir fluids and drilling fluids. From the log, it can be seen that the Turaco well was mostly Shaly due to the high gamma readings probably as result of encountering the Kasande, Oluka to Nyakabingo formations that have a fair share of shales/clays in the semliki basin.

Makondo and the decommissioned Turaco Well sites

We did not physically visit these sites, however information from literature and visits by previous geologists indicates that Makondo is located at 201157/110303) with an elevation of 678m. The geophysics history of the area indicates that Kenting Earth Sciences carried out aeromagnetic surveys in 1993. In 1998, Heritage oil and gas carried out seismic data acquisition along the Makondo fault. The Makondo fault is an intra-sedimentary fault which forms the eastern flank of the Turaco positive flower structure(Figure 6.17). The basin consists of fossils of animals such as fish, bivalves, white oysters and hematite minerals which could have been present in the paleolake, Lake Obweruka before it dried up.

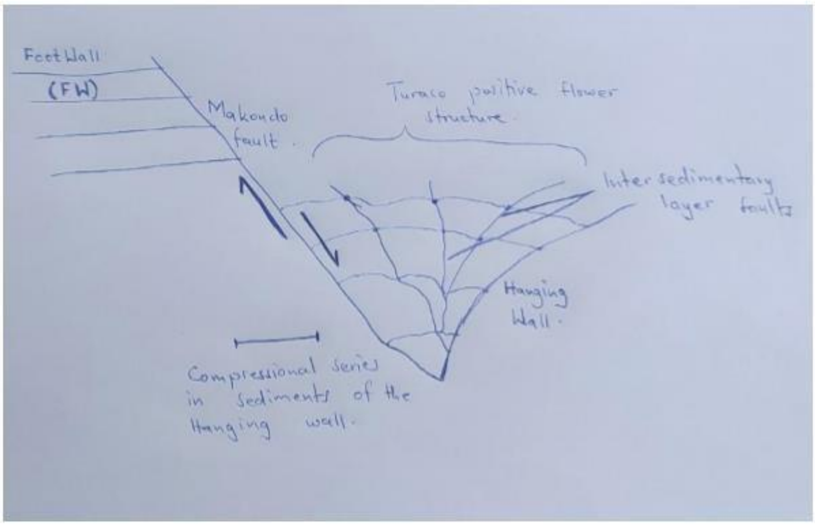


Figure 6. 17: Positive flower structure at Turaco(Source: Tukei, 2019)

The Turaco well is located at 199697/114170 and it is the hanging wall of Makondo fault. Figure 6.19 shows the site location of Turaco wells. Previous drilling history has it that the Turaco-1 well drilled in 2002 hit some hydrocarbon but not in quantities large enough to be commercial while Turaco-2 well drilled in 2003/2004, 10 m away from Turaco-1 showed significant volumes. The three dimensional (3D) seismic surveys in the area in 2004 led to drilling of Turaco-3 well 300 m from Turaco-2 and encountered gas with carbon dioxide contamination. Another well drilled at Kanywataba turned out to be dry. Turaco area still stands as an important hydrocarbon prospect within the Semliki Basin if exploration is heightened in future.

Figure 6. 18: Figure 6.19; Decommissioned Turaco well site(Courtesy of Tukei, 2019)

6.4 Results of study of Geophysical methods for geothermal exploration.

A geothermal field is an area of the earth characterized by a relatively high heat flow and the elements are similar to those of a petroleum system include;

Heat source: localized thermal plume or a rock having radiactive minerals.

Reservoir: good conducting rock such as granite or sandstone

Seal: thermal blanket/ insulator and should be regional such as shale

Plumbing system: cold water moves through the hot reservoir, turns hot, percolates to surface, becomes cold, sinks back top reservoir due to high density and the cycle continues.

There are three geothermal fields in Uganda that is; Katwe-Kikorongo, Buranga and Kibiro. During the field study in the Semliki basin, Sempaya hot springs were visited. The Sempaya hot springs locally named by the natives of the area as female and male hot springs, lie within the Buranga geothermal field in, Semliki National Park, Bundibugyo district. Geothermal surface activity is intensive in this area. The hot water gushed out is based on the rain water which percolates into the porous sedimentary rocks. It descends through the rock dissolving a variety of materials, from radium to Sulphur. As this water and groundwater moves further beneath the surface, it heats up from the primal heat of the earth, the mantle which is closer to the surface than in other areas. When it encounters a weak zone such as a fault or crack, it then ascends along it to surface as a hot or warm spring.

Impact of Sempaya Hot springs on Petroleum potential of Albertine Graben

The Albertine Graben(15ma) is still young, but contains hydrocarbons. This is because it has a high heat flow evidenced by the Sempaya Hot springs as a result of crustal thinning. For a source rock to mature, it requires a certain Time-Temperature Index(TIT) threshold value above which the rock is considered mature to produce hydrocarbons. The temperatures at Sempaya hot springs are as high as 106°C and 103°C for the male and female hot springs respectively and thus are thought to contribute to the geothermal gradients that have accelerated the thermal maturation of source rocks in the

Albertine Graben as one of the youngest rift basins in the world. However, a suitable oil window is defined by the temperature range of 60-120°C but since the hot springs' temperatures are higher than the oil window, then there are greater chances of "overcooking" or cracking the oil to form thermogenic gases like methane. Higher temperatures of about 150°C to 200°C or very high TIT can destroy the hydrocarbons and can result in almost total transformation of kerogen into carbon. At these temperatures, methane or dry gas is evolved along with non-hydrocarbon gases such as CO_2, N_2 and H_2S.

CHAPTER SEVEN: DISCUSSION

7.0 Introduction

This chapter discusses the results obtained in the preceding chapters. It examines the interpretation of facies and depositional environments, gives summary of geological history of the study area, hydrocarbon potential of the study area, effect of high temperatures and structures observed on hydrocarbons.

7.1 Facies and Depositional Environments

Facies analysis and structures are used to give information about depositional processes and environments. The facies recognized in the field are categorized into lithofacies based on lithology and bio-facies based on fossils content. The depositional framework of the Semliki Basin is dominated by clastic and non-clastic sediments deposited in lacustrine, deltaic and fluvial systems.

The major rocks interpreted from the study area based on facies and facies association include conglomerates, sandstones, mudstones, clays and silts. Most of these can be seen along can be seen at the Kibuku road cut and along the Kisegi channel. The presence of organic matter within most clays suggests an anoxic paleoenvironment probably deep lake environment. Also, coals are found in Kisegi and have a paraffinic smell, high hydrogen Index(HI) and this could be due to rapid burial of organic matter limiting exposure to oxidation environment. On the hand, the presence iron(iii) oxide is an evidence of oxidation environment and the presence of gypsum indicates that the paleoclimatic conditions were favorable for evaporation. Therefore, the iron(iii) oxide and gypsum signify semi-arid paleoenvironment.

The major sedimentary environments recognized in the field are lacustrine, fluvial and deltaic environments as discussed below.

Fluvial environments: Fluvial environments were characterized mainly by thick sand beds with coarse to medium to fine grains and a generally fining upwards sequence. The fining up sequence is because the river deposits coarse materials during periods of high energy and the grainsize reduces with progressive reduction in river energy. Another diagnostic feature of fluvial system observed in the field is cross-bedding(discussed in chapter 5, Figure 5.10). The fluvial sediments could have been deposited by a meandering river, also, alluvial fan, inter-channel, flood plain and over bank deposits exist in the study area. The change of dip (SE to NW) bedding structures in some areas(Figure 5.14) suggests the river must have changed course at some point in time.

How rivers form long and wide sequences: The river deposits normally through its channel until mouth bars are formed, these mouth bars impede the passage of the river through the channel. This forces the river to change its channel and it deposits sediments in the new channel until the gradient(between source and deposition site) becomes very low and the river may change course again. This is known as Avulsion and hence, in this way, the river is able to deposit wide and long sequences. Tectonism can also affect the course of the channels. Rivers also deposit over their banks during floods which cause rivers to overflow their banks.

Lacustrine Environments: Lacustrine sediments are widespread throughout the Semliki Basin and are dominated by clay stones, siltstones. In the study area, lacustrine environment is evidenced by presence of thick layers of clays and blocky sands that lack sedimentary structures as observed along Kibuku road cut especially in the Kasande and Kisegi formations. Furthermore, The presence of invertebrate fossils such as freshwater bivalves, oysters at Makondo area (201157/110299) suggests a paleolake.

Deltaic environment: Delta is a regressive feature and it is recognized in the study area by presence of coarsening upwards sequence as seen towards the end of area mapped by group A. The coarsening sequence is caused by regression and transgression of the lake/ocean. Lake/ocean deposits fine beds and rivers deposit coarser on the already deposited sediments since the rivers have higher energy. This implies there was a transition environment in the Semliki Basin.

According to Pickford et al, 1993, provenance pattern shows that sediments were derived mainly from a widely branched, continental-wide river network that delivered sediment from northern, central and southern sources in Uganda with major input from Archean cratonic terrains and more distal Neoproterozoic Pan-African belt near the Kenyan margin.

7.2 Summary of the geologic history of the area

Semliki area is mainly a flat land bounded by NE-SW normal fault escarpment and the Rwenzori block (Kasande, 2006). The basement rocks in the Albertine graben were affected by different episodes of tectonism. The first episode was an extensional episode and was responsible for the formation of the main rift flanks striking NE-SW on both Uganda and Congo sides with the evolution of the graben. Later, a compressional regime leading to folding of the rocks came into play (Rev. Frank Tukwasibwe, 2007). The evolution of the western branch is attributed to thermal doming. There was extension(due to continental crustal thinning) during the Carboniferous leading to formation of a series of predominantly north or NE trending grabens. These grabens formed under continental conditions and were filled with fluvial and alluvial sediments.

The depositional history and stratigraphic succession of the Semliki basin is derived from the knowledge of various facies following from the oldest facies to the youngest facies based on wireline data, outcrops and seismic profiles. The stratigraphic record indicates that the sediments of the Permo-Triassic Karoo supergroup lie at the base, progressively overlain by Tertiary fluvial lacustrine and deltaic deposits towards the top. Stratigraphic interpretation of seismic data from the basin has been used to reconstruct the depositional history (Kiconco, 2005).

The basement rocks crop out over much of Uganda and are predominantly high grade metamorphic and igneous rocks of the Precambrian age.

At the base of the Early Tertiary sediments, a sharp boundary was mapped. The basement was thrust upwards, possibly causing erosion of the thrust sediments that formed a marked angular unconformity. The basement was juxtaposed against the sediments and then the Early Tertiary sediments were deposited basin-ward. These sediments are suggested to be siliciclastic, with continuous reflectors, associated with lacustrine settings rather than fluvial. These sequences onlap the Pre-Cambrian Basement highs and the delta sequences are seen to prograde and retrograde in this section with channel incisions (Kiconco, 2005).

Rapid increased subsidence and formation of a rift caused extremely rapid sedimentation which filled the graben with continental and lacustrine sediments in a more tectonically relaxed environment. Most of the siliciclastic sediments are deposited in the transfer zone, sands are tunneled along fault valleys into the basin and lacustrine conditions were widespread in times of low seismic activity.

7.3 Hydrocarbon Potential of the Semliki basin

Semliki basin has a good chance of containing oil and gas given the presence of petroleum system elements such as excellent reservoirs, regionally mature source rocks, traps, intra-formational and regional seals as well as hydrocarbon migration pathways in the basin. These elements are discussed in detail below. The Semliki Basin represents a suitable petroleum play for hydrocarbon accumulations.

Source rocks: In There were extensive lacustrine clays deposited in the study area that could form very good source rocks given time for burial and increase in temperatures. Some of these clays were probably rich in organic matter due to the dark colors for example dark brown colors in clays of Kasande formation and act as the source rocks in the Semliki basin.

Reservoir rocks: A reservoir rock is any rock that has both sufficient pore volume to store hydrocarbons and high permeability to enable flow/recovery of the hydrocarbons. In the Semliki basin, rocks of the Kisegi and Kakara Formations are good reservoir targets. This is because they are dominated by medium to coarse grained well-sorted sandstones with sufficient porosity to hold oil/gas and permeable enough to allow their flow. This means they have high porosity and permeability allowing them to act as reservoirs. The exploratory drilling in the Turaco wells encountered oil and gas in the Kisegi sands which makes this formation the main reservoir target in the basin. This is evidenced by presence of oil-impregnated Kisegi sands seen at the Kibuku oil seep(Figure 4.4). Similarly, it is reported that the flow in Sempaya hotsprings is about 10-15 litres/second, another indication of relatively high permeability of the subsurface rocks in the area. However, presence of cementing materials (clays and possible iron oxides) impairs the reservoir quality because it reduces both the porosity and continuity in pore throats. Additionally, intercalations of sand and clay layers in the basin would causes reservoir compartmentalization which would production expensive and challenging. Reservoir compartmentalization refers to a situation where parts of the same reservoir are disconnected and do not “communicate”. This means that development of such a reservoir system would require an expensive strategy of separately tapping into the different parts.

The intensely fractured basement rocks in the study area can also form good reservoirs since fractures improve permeability and porosity.

Traps: A trap is a stratigraphic or structural feature that prevents further migration of hydrocarbons, allowing them to accumulate within the reservoir. Examples of structural traps in the study area include faults sealed by gypsum, while stratigraphic traps include unconformities and pinch outs. Minor faults of NE trend in the lower section along Kibuku road cut are related with major normal faults and can be good petroleum traps especially if they form sealing faults. Faults form the most of the potential hydrocarbon traps in the study area since it contains many fault structures like Kichwamba, Makondo and more. The faults could also act as adequate lateral seals when a reservoir is juxtaposed against a seal and there exist sealing material (fault gouge).

Seals: Kasande clays provide good sealing geometry for the underlying Kisegi formation. The shales of Transgressive systems tracts form good seals for the underlying low stand systems tracts. The closure of fractures in the kasande formation due to overburden after oil is expelled makes the formation a good seal. However, the presence of oil seeps such as Kibuku oil seep indicate that there are intervals which are inadequately sealed. Also, the hydrocarbon column height can affect the integrity of the cap rock that is if the cap rock is thin, a high hydrocarbon column can breach the integrity of the cap rock or even break compartmentalization due to high buoyancy force.

Maturation: There exist high temperatures in the Semliki basin evidenced by hot springs and these can facilitate and accelerate maturation of hydrocarbons provided low conductivity rocks exist to accumulate enough heat.

Migration pathways: The numerous faults and joints present in the study are can aid movement of the hydrocarbons from the source rock to the reservoir. Also, since the kasande formation(source rock) overlies the kisegi formation(reservoir), the lithostatic pressure from the overburden increases the hydrostatic pressure of the hydrocarbons(if generated) and this creates cracks that enable these fluids to escape in several directions(this is primary migration) and some hydrocarbons go into the kisegi formation. Once the hydrocarbons have been expelled, the fractures in the source rock close up and hence the Kasande formation can act as seals for the Kisegi reservoir.

7.4 Effect of high temperature on hydrocarbons

The Albertine Graben (15ma) is still young, but contains hydrocarbons. This is because it has a high heat flow evidenced by the Sempaya hot springs. The temperatures are as high as 106°C and 103°C for the male and female hot springs respectively and thus are thought to contribute to the geothermal gradients that have accelerated the thermal maturation of source rocks in the Albertine Graben. However, a suitable oil window is defined by the temperature range of 60-120°C. When the temperatures are higher than the oil window, there are greater chances of "overcooking" or cracking of oil to form thermogenic gases like methane. In essence, high temperatures(i.e. high TimeTemperature Index) can destroy hydrocarbons because according to Arrhenius' rate rule, oil will degrade twice as fast for every 10 degrees Celsius the temperature is increased after their base activation temperature has been reached.

7.5 How structures affect the hydrocarbons

The major structures of concern observed within the rocks include joints, faults and folds, these were formed by tectonic activity in the area. These structures can greatly affect the accumulation and migration of the hydrocarbons. When the hydrocarbons are expelled from the source rocks, they migrate to reservoirs which are areas of a lower pressure compared to the source rocks, these hydrocarbons can migrate along a fault plane or joint fracture into the reservoir. It should be noted that the hydrocarbons will continue migrating until they come into contact with a barrier to trap them, it is of great significance that there are lots of faults in the area that can trap the hydrocarbons from escaping from the reservoir. Rollover anticlines are also very important since they act as traps too. Therefore, as a result of the faults and anticlines, the accumulation of hydrocarbons in commercial quantities is very possible. The NE-SW trending fractures and faults are the most likely migration pathways in the Semliki basin since they are linked to the basin depo-center where generation of hydrocarbons can occur.

The basement in Semliki basin is heavily fractured and weathered in some parts and this gives it potential to host hydrocarbons. However, the requirement for extreme lithostatic and pore pressures to overcome buoyancy is a limiting factor to basement potential. Therefore, detailed study of pressure regimes within the Semliki basin is required in order to draw accurate conclusions on basement potential.

CHAPTER EIGHT: CONCLUSION AND RECOMMENDATION

8.1 Conclusion

The Semliki sedimentary basin is located in the central domain of the western arm of the Albertine graben. It is a pull apart basin formed when the Albertine Graben, a product of active rifting, underwent trans-tensional strike-slip deformation that was controlled by already existing NE-SW riftforming normal faults. The basin is asymmetric in nature with a thin layer of sediments in the southern and southeastern parts of the basin but increases in thickness towards the north-west in the DRC.

We were able to achieve all the objectives set out for the field trip. That is to say, we collected and interpreted stratigraphic, sedimentologic and structural and used the information to deduce the hydrocarbon potential of the area. The materials used in collection of the data included GPS, Geological compass, Jacob's staff, geological hammer, shovel among others.

The major lithologies identified in the study area include granite gneiss, amphobilites, quartzites existing mainly as veins and granites. These form the basement with granite gneiss being the most dominant. The Sediments identified in Semliki basin are of Middle Miocene to recent ages and the stratigraphic sequence comprises mainly clays, silts, sands and conglomerates. These sediments have been grouped into seven formations namely; Kisegi, Kasande, Kakara, Oluka, Nyaburogo, Nyakabingo and Nyabusosi , in order from the base to top.

The structures encountered in the study area include both primary and secondary structures in the basement and the sediments; in the basement mainly joints, faults, foliations, veins were identified. Most of these structures had a similar orientation in the NE-SW direction (Major trend) which is similar to the structural domains of the Albertine graben and a minor trend in the NW-SE direction implying that more than one episode of tectonism affected this area. Some of these structures like faults, minor folds, intra-sedimentary faults and joints are encountered in sediments while typical sedimentary structures like beddings, cross-stratification, laminations, load casts among others are evident in the sediments. The structural trend in the sediments (NE-SW) must have been influenced by the same major tectonic events that affected the basement and the entire Albertine graben.

The study area appears to have all the major elements of a working petroleum system as discussed chapter seven(subsection 7.3). The thick layers of clay of the Kasande formation and possible organic matter providing potential source rocks, medium to coarse sands of Kisegi act as reservoir rocks while clays on top of sands and faults filled with gypsum forming potential seals. The area has both structural (rollover & compressional anticlines, tilted fault blocks, etc.) and stratigraphic traps (unconformities, Pinchouts, etc.) as well as extensive fault arrays and joint fractures acting as migration pathways. The presence of high temperature evidenced by Sempaya hot springs must have acceleration transformation of organic matter in hydrocarbons in this young basin. The high temperatures are however detrimental in the long run since the they can destroy the hydrocarbons.

The provenance of sediments in the basin is believed to be the basement rocks of the Rwenzori Mountain and the adjacent escarpments. The sediments were possibly transported by streams and rivers and deposited in fluvial, alluvial and lacustrine environments. Clastic sediments form massive sands, cross bedded sandstones, conglomerates and clays. This process of deposition was controlled predominantly by tectonic activities like Faulting, rifting and subsidence and also climatic changes which affected the level of the lake through transgression and regression regimes. Therefore, the major depositional environments interpreted from the study area are Lacustrine environment, Deltaic and fluvial environment.

8.2 RECOMMENDATIONS

The field study trip is quite essential students since it equips students with basic and most important field skills of data collection, analysis and interpretation. It also helps the students to appreciate and apply the knowledge gained in class to real field scenarios. The Semliki provides students opportunity to take part in various field activities such as lithostratigraphic logging, stratigraphic and structural analysis, facies and basin analysis and geophysical data interpretation.

However, a few challenges were encountered given the limited time in the field, we could not reach all the areas of interest and it is on this note that I would recommend that; field trip period be extended to at least 14days so that students can get more exposure and acquittance and horn their skills more and all areas of interests.

The other challenge is connected to use of software to analyse and interpret the data collected. I would recommend the students are trained for these software packages like Geosoft, Sedlog, Techlog and Stereonet in order to allow for more accurate analysis and interpretation of field data.

Furthermore, I recommend that at least five lecturers accompany the students to the field so that the few lecturers are not overwhelmed and the Lecture to student ratio can be reduced, this will eventually improve the overall learning of the students as they shall have more people to consult.

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APPENDICES

Appendix 1: Joint Measurements in the basement rock

set two									
Strike (°)	Dip(°)	Strike(°)	Dip(°)	Strike(°)	Dip(°)	Strike(°)	Dip(°)	Strike(°)	Dip(°)
155	58	274	54	122	78	335	36	312	4
164	70	168	40	332	82	331	64	331	80
166	58	348	8	160	74	120	36	108	27
164	60	334	78	138	76	310	18	312	24
160	72	136	82	112	70	320	60		
342	58	120	84	102	68	320	38		

set one									
Strike (°)	Dip(°)	Strike(°)	Dip(°)	Strike(°)	Dip(°)	Strike(°)	Dip(°)	Strike(°)	Dip(°)
248	76	198	80	218	84	198	12	220	60
030	70	201	84	212	26	040	60	080	74
249	64	054	82	200	12	040	81	250	60
250	84	038	84	200	84	012	82	078	86
218	82	210	82	232	88	025	88	208	38
076	72	030	72	232	42	216	58	022	75

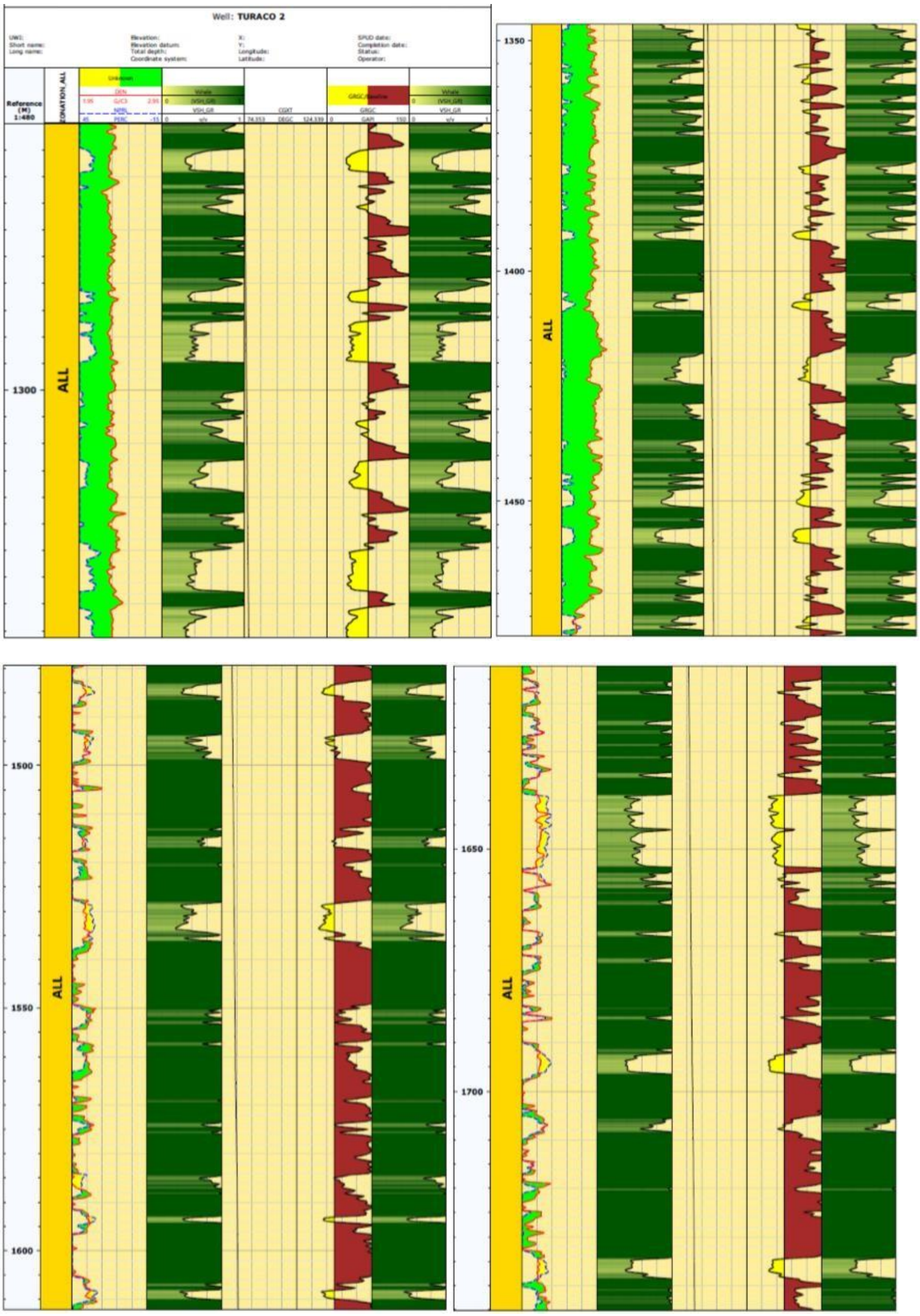
Appendix 2: Measurements of foliation in the basement rocks of the Semliki basin

Strike	dip
S80^{0}W	64^{0}NW
S60^{0}W	62^{0}NW
S63^{0}W	45^{0}NW
S30^{0}W	80^{0}NW
S22^{0}W	82^{0}NW
S29^{0}W	86^{0}NW
S26^{0}W	78^{0}NW
S24^{0}W	84^{0}NW
S34^{0}W	83^{0}NW
S28^{0}W	81^{0}NW
S25^{0}W	80^{0}NW
S24^{0}W	80^{0}NW
N88^{0}W	73^{0}NE
N78^{0}W	82^{0}NE
N89^{0}W	86^{0}NE
N70^{0}W	65^{0}NE
N82^{0}W	75^{0}NE
N80^{0}W	64^{0}NE
N85^{0}W	70^{0}NE

Appendix 3: Attitudes of cross-beddings

Tangential cross beds		**Angular cross Beds**	
Strike	**Dip**	**Strike**	**Dip**
N52^{0}E	6^{0}SE	N15^{0}W	88^{0}NE
S32^{0}W	10^{0}NW	N12^{0}W	85^{0}NE
S38^{0}W	15^{0}NW	N19^{0}W	87^{0}NE
S70^{0}W	19^{0}NW	N23^{0}W	76^{0}NE
S48^{0}W	21^{0}NW	N30^{0}W	89^{0}NE
S56^{0}W	8^{0}NW	N22^{0}W	80^{0}NE
N42^{0}E	5^{0}SE	N14^{0}W	82^{0}NE
S30^{0}W	4^{0}NW	N30^{0}W	75^{0}NE
N20^{0}E	7^{0}SE	N13^{0}W	64^{0}NE
N30^{0}E	10^{0}SE	N30^{0}W	20^{0}NE
N25^{0}E	19^{0}SE	N32^{0}W	65^{0}NE
N20^{0}E	42^{0}SE	N35^{0}W	72^{0}NE
N48^{0}E	23^{0}SE		
S55^{0}W	25^{0}NW		
S65^{0}W	20^{0}NW		
N35^{0}E	32^{0}SE		
N29^{0}E	6^{0}SE		
N25^{0}E	8^{0}SE		
N38^{0}E	10^{0}SE		
N23^{0}E	11^{0}SE		
S56^{0}W	32^{0}NW		
S40^{0}E	14^{0}SW		
S21^{0}E	15^{0}SW		
N9^{0}E	10^{0}SE		
N32^{0}E	8^{0}SE		
N24^{0}E	9^{0}SE		

Appendix 4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SPUD date:
Completion date:
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NPRL
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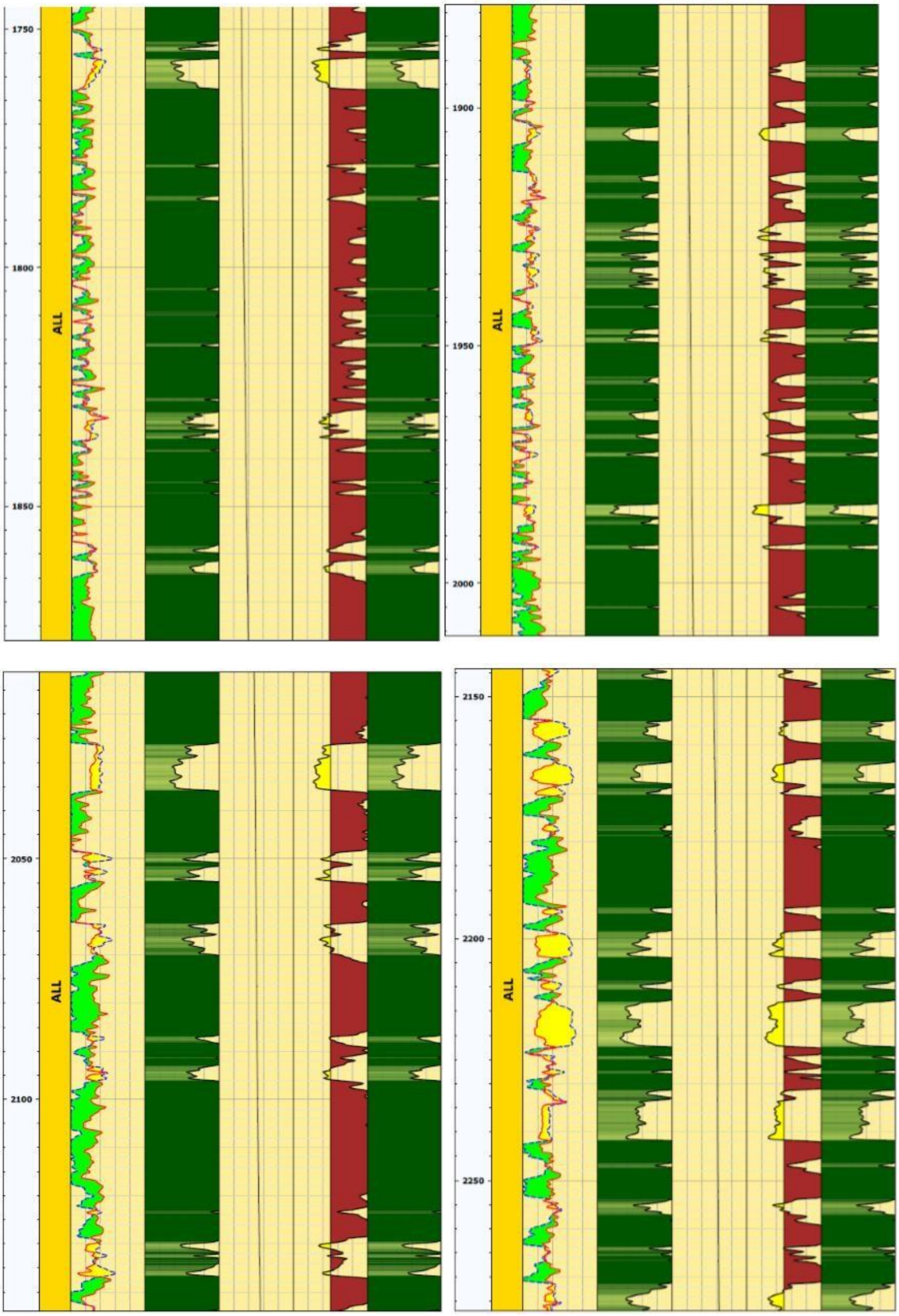
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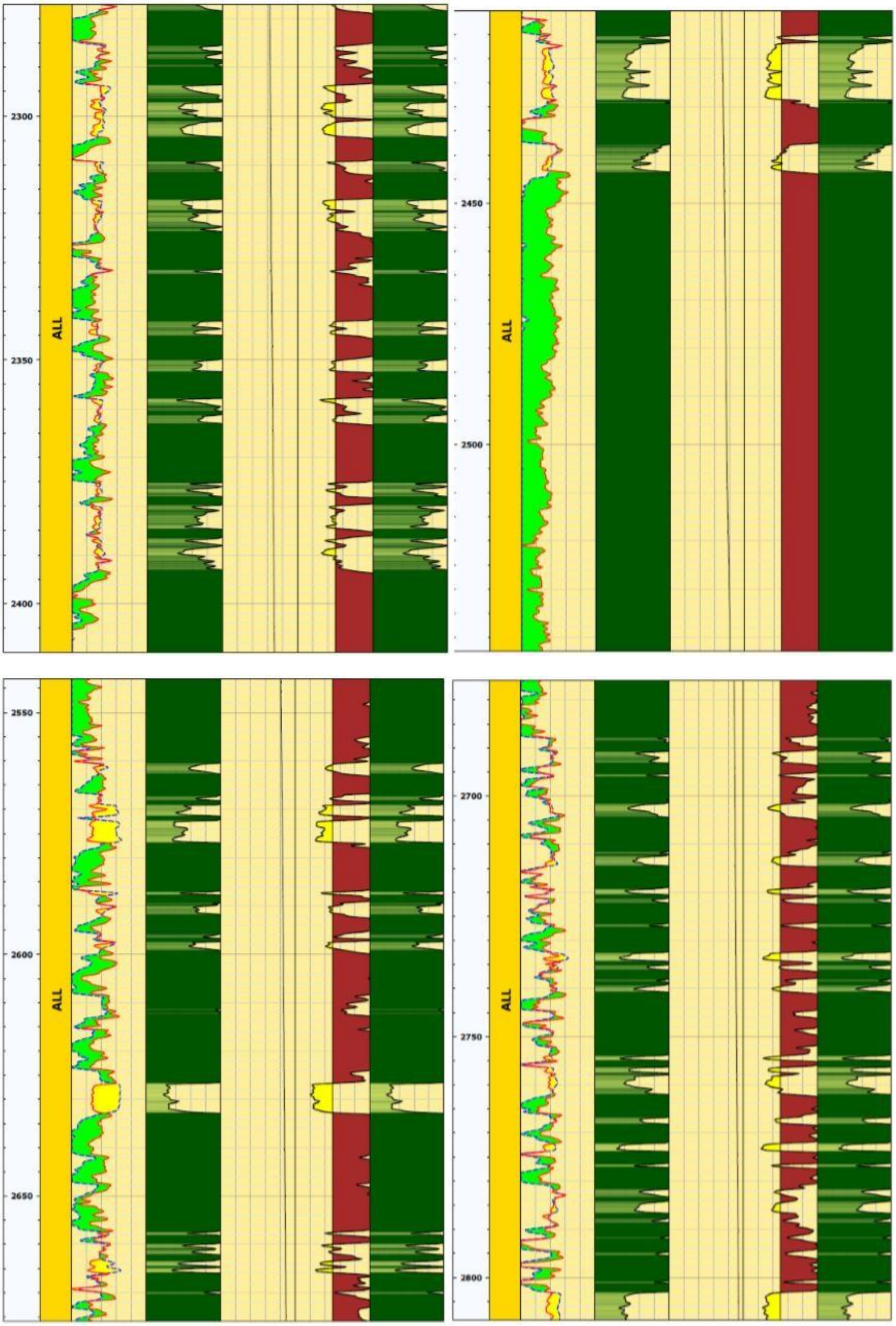

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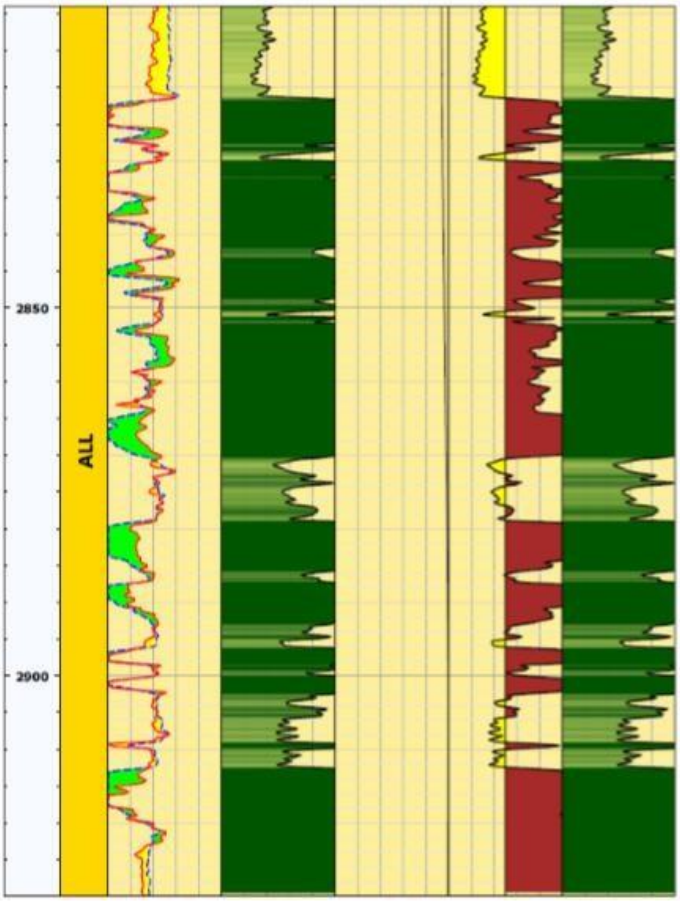
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