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School of Physical Sciences

DEPARTMENT OF PETROLEUM AND GEOLOGY STUDIES (DPGS).

A DETAILED FIELD PROJECT REPORT ABOUT THE SEMLIKI BASIN IN NTOROKO DISTRICT, ALBERTINE GRABEN.

Compiled by;

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Presented to Department of Geology and Petroleum Studies as a requirement for the completion of the Bachelors of Science in Petroleum Geoscience and Production (BPGP) Degree Program at Makerere University.

Project Coordinator; **Dr. Denis Mutebi** **Date of Submission: 13th June 2026**

Declaration.

I **KISOMBO GEORGE** declare that the information in this report presented to Makerere University, Department of Petroleum and Geology Studies is based on real field work study, Literature review and research work compiled together to paint a better picture of the Semliki Basin.

Sign...

Date....13th JUNE 2026..............

Project Coordinator

Dr. Denis Mutebi

Sign...

Date....13th/6/2026.......................

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Dedication and Acknowledgement

I dedicate this work to my parents who continuously support me in all my academic endeavors, my lecturers for their selfless service to ensure that we students understand all the taught concepts and to everyone else who supported me along the journey.

My sincere appreciation goes to the Department of Geology and Petroleum Studies for organising this field trip to the Semliki basin thus availing an opportunity for the us to put knowledge acquired during lectures into practice.

I would also like to acknowledge the lecturers who accompanied us on this journey; Dr. Simon Echegu, Dr. Betty Nagudi, Dr. John Mary Kiberu and Dr. Denis Mutebi and the support staff for the guidance and support offered to us during the course of the trip and beyond. Thank you so much.

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Abstract.

This report presents the findings of a field study conducted between 8th and 19th June 2025 in the Semliki Basin, located within the Albertine Graben of the East African Rift System (EARS), Ntoroko District, southwestern Uganda. The study was carried out by third-year students of the Bachelor of Science in Petroleum Geoscience and Production programme at Makerere University, under the coordination of the Department of Geology and Petroleum Studies.

The Semliki Basin is a half-graben rift structure covering approximately 1,200 km^2, bounded by the Rwenzori Mountain escarpments to the southeast, Lake Albert to the north, and the Semliki and Lamia rivers to the west. Fieldwork focused on the Kichwamba, Kisegi Hill, Kibuku roadcut, Turaco well sites, and Sempaya Hot Springs, employing methods including stratigraphic logging, structural measurements, grain size analysis, paleocurrent determination, facies analysis, and geophysical data interpretation.

Basement lithology consists primarily of high-grade Proterozoic metamorphic rocks including granite gneisses, migmatites, and quartzites, which are heavily jointed and fractured. Overlying these basement rocks are seven Miocene-to-Recent sedimentary formations; the Kisegi, Kasande, Kakara, Oluka, Nyaburugo, Nyakabingo, and Nyabusosi formations; comprising sandstones, siltstones, mudstones, conglomerates, and clays deposited in fluvial, deltaic, and lacustrine environments.

Structural analysis revealed NE-SW-trending normal faults, joints, foliations, and folds consistent with the extensional tectonics of the Albertine Graben. Primary sedimentary structures including cross-bedding, laminations, ripple marks, and mud cracks were used to reconstruct paleocurrent directions and depositional environments. Geophysical studies, including Bouguer gravity anomaly maps, total magnetic intensity maps, seismic section interpretation, and petrophysical wireline log analysis from the Turaco 1, 2, and 3 wells, confirmed the basin's asymmetric half-graben architecture and the presence of hydrocarbon-bearing intervals.

The Semliki Basin demonstrates all the critical elements of a viable petroleum system: lacustrine source rocks with significant organic content (Kasande Formation), porous and permeable sandstone reservoir rocks (Kisegi Formation), impermeable clay top seals, and structural and stratigraphic traps associated with the basin's fault architecture. Evidence of active oil generation is provided by the Kibuku oil seep, while the Sempaya Hot Springs in the Buranga Geothermal Field indicate elevated geothermal gradients that accelerate source rock maturation. Overall, the Semliki Basin holds substantial potential for hydrocarbon exploration, warranting continued geological and geophysical investigation.

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CHAPTER 1. INTRODUCTION

1.0. Background

This report contains findings of a field study conducted in the Albertine Graben from 8^{th} June to 19^{th} June, 2025 over the Kichwamba and Kibuku areas in the Semliki Basin to the south and east of the Lake Albert Basin. The field study is designed for students pursuing a Bachelor of Science in Petroleum Geoscience and Production who have completed their third year at the Department of Geology and Petroleum Studies, School of Physical Sciences, College of Natural Sciences, Makerere University. The focus areas for the study included Kichwamba, Kisegi hill, the Turaco wells, Sempaya hot springs, and the Semliki Basin. Throughout the field study, activities such as stratigraphic logging, geological analysis, and description were carried out, leading to interpretations of depositional environments and their history, paleo flow, basin and facies analysis, and other related concepts. The study embraced some of the geological aspects including the East African Rift System, drainage and reversal, braided river environment, interpretation of petrophysical and geophysical data, depositional environments, and facies analysis.

1.1. Study Area

1.1.1. Location.

The study areas (Kichwamba and Semliki basin) are 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 part of the Albertine graben with the rest in the Democratic Republic of Congo and it is bounded by the steep escarpments of the Rwenzori Mountains to the South East, Lake Albert to the North, rivers Lamia and Semliki to the west.

The Ugandan portion of the Semliki basin covers the southern part of the Ugandan portion of the Lake Albert, plus a landward area to the south of the lake. This includes the eastern part of the floodplain of the Semliki River and Lake Albert, known as the Semliki flats and the adjacent Toro plain, a slightly more elevated escarpment area to the east of the flood plain. It is bordered to the South East by steep escarpments rising almost 1000m to the northernmost spur of the Rwenzori Mountains. The low-lying undulating areas of the Toro plain are separated from the Semliki flats, flood plains on the Eastern banks of the Semliki River by the major Kibuku and Makondo fault.

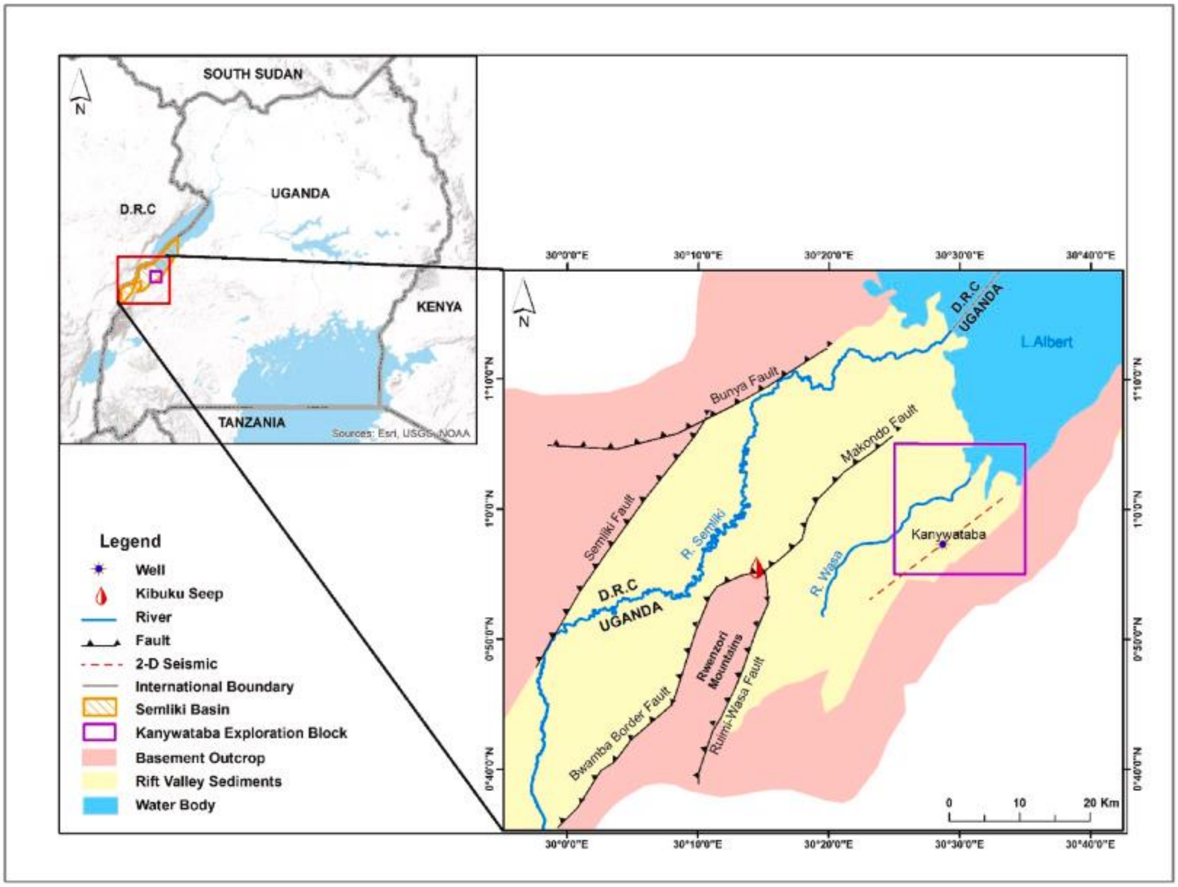


Figure 1.Shows the location map of the Semliki basin South of Lake Albert.

Source; https://www.sciencedirect.com/science/article/pii/S1464343X23000493

1.1.2. Accessibility.

The area was accessed by road transport from Kampala to Ntoroko district using the Kampala-Mubende Road, to Fort Portal (290km) and then to Ntoroko (study area) using the Fort portal – Bundibugyo highway for about 78km. The camp was set up about 44km from Fort Portal town at Karugutu Secondary School, in Karugutu town. The different study areas (Kibuku area at Kisegi hill behind the quarry & South of Kisegi hill, North end of Kisegi hill road cut) were accessed by bus from the camp and while at the Kisegi hill area, the Kisegi river channel was accessed by foot.

1.2. Objectives.

1.2.1. **Main objective**: To collect and interpret stratigraphic, petrographic, sedimentologic and structural data; which are very important in hydrocarbon exploration.

1.2.2. Specific objectives:

- Identify different lithologies.
- Describe all the contacts and structures in different lithologies.
- Identify and relate structures observed in the basement and in sediments.
- Identify and explain depositional processes based on textural and structural characteristics of sedimentary rocks.

- Describe the main process and facies that characterize particular environments.
- Apply facies analysis to interpret sedimentary succession.
- Study the lithologies and environment, in order to identify the different elements of the petroleum system

1.3. Geologic setting of the study area

1.3.1. Regional geology of the area.

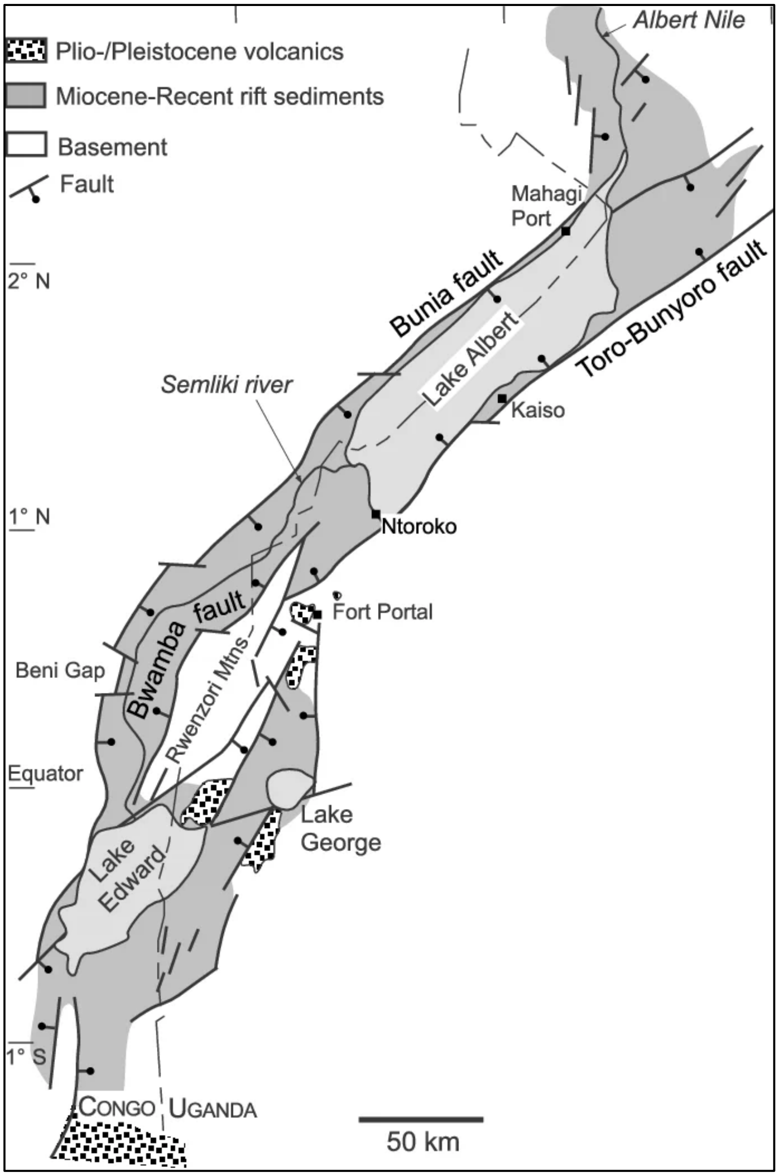
The Albertine Graben comprises the Northern extremity of the western arm of the East African Rift system. It runs for 550km from Rwanda in the South, to the Uganda/Sudan border in the north, straddling the border between Uganda and the Democratic Republic of the Congo (DRC). The Graben contains the lake George – Edward Basin, in the South, bounded on the northwest by the Rwenzori Mountains which rise to over 5000 metres above mean sea level. The Graben is offset to the West and continues beyond the North end of the Rwenzori Mountains in an echelon trend comprising the Semliki and Lake Albert (Kaiso – Tonya Area) Basins and the Rhino Camp Bassin.

Traditionally, the Lake Albert Basin was thought to be an asymmetric half-graben that dipped to the northwest, where the Blue Mountains, which are 2100 meters high, were likely raised by the massive bordering Bunia fault system (Ebinger, 1989). The Toro Bunyoro and Tonya fault systems, which dip westward and govern the uplift of the 1200-meter-high topographic escarpment at the lake's eastern edge, make up the eastern boundary. Karp et al. (2012) demonstrate that the Lake Albert Basin is actually a whole graben that "has subsided symmetrically and continuously in the Late Cenozoic along two extensive boundary fault systems on either side of the basin" using fresh seismic data and gravity re-processing.

1.3.2. Structural Setting.

The African Craton's Precambrian orogenic bands gave rise to the Albertine Graben, a Cenozoic rift basin. The late Oligocene/Early Miocene saw the beginning of rifting. The Graben has seen multiple extensional and compressional tectonic episodes. The geometry and direction of the fault systems creating the basins in the Graben provide evidence of stress regimes oblique and perpendicular to the boundary faults. The Aswa shear zone, a recognized sinistral strike slip shear zone, is where the Albertine Graben ends. There are other shear zones in the Tanzanian portion of the East African Rift, near the Kivu and Rukwa regions, and south of the Graben. The Albertine Graben could, therefore have evolved in a strike slip dominated regime similar to the other basins developed in the Central African Rift System.

The Albertine Graben can be divided into three structural domains: the Southern Domain, the Central Domain and the Northern Domain. The northern domain that trends in a NNE- SSW direction encompasses the Rhino Camp and Pakwach basins, the central domain in a NE- SW direction where the Lake Albert (Butiaba-Wanseko and Kaiso-Tonya areas) and Semliki basins (where the study was conducted) are located in the southern domain trends in a NNE-SSW direction where the Lakes Edward-George basin is found. The central domain is an almost full graben while the southern and Northern domains are typically half grabens. The Graben trends in a NE-SW direction through most of its length, probably following the pre-existing basement fabric.



(Pickford et al., 1993; Ring 2008)

Figure 2 Shows some of the structures in the Albertine Graben

1.3.3. Evolution of the Albertine Graben

Based on sedimentary research done in the outcrops of the Kisegi-Nyabusosi area, a four-stage model for the evolution of the Lake Albert Basin has been developed. The first stage, which occurred between 14.5 and 10 million years ago (Ma), is associated with a sag basin that is mostly composed of river deposits and has little accommodation space. A distant fluvial plain gave way to a lacustrine environment during the second phase, which took place between 10.0 and 4.5 Ma and is characterized by the development of limited accommodation space and subsequent lake level rises. Changes in the accommodation/sediment supply ratio at this period signify the beginning of rifting activity.

The third stage, which spans 4.5 to 2 Ma, is a conventional rift governed by sediment supply rather than accommodation, indicating a change in the main geological processes that shaped the basin.

In the fourth stage, which lasts from 2 to 1.5 Ma, there is an overall rise in subsidence along with a substantial supply of sediment, which speeds up the uplift of the basin flanks. The dynamic interaction between tectonic and sedimentary processes that shape the landscape across geological timeframes is highlighted by this phase's stacked transgressional cycles from a fluvial to a lacustrine environment.

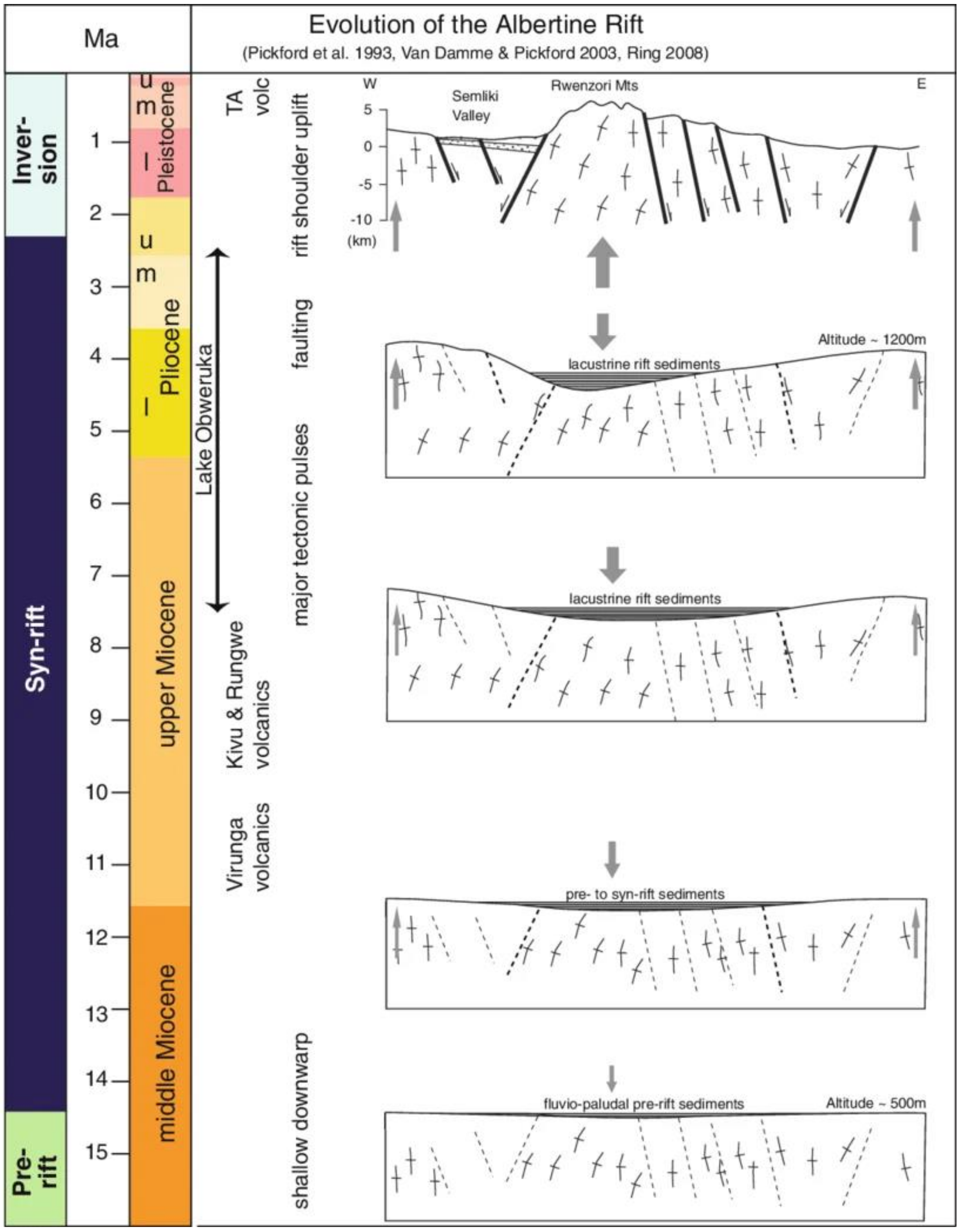


Figure 3 Shows the stages and processes in the evolution of the Albertine Graben.

Schematized evolution of the Albertine Rift basin with major phases of tectonic and volcanic activity and indicated sedimentary evolution (modified after Pickford et al. 1993; Van Damme and Pickford 2003; Ring 2008). Volcanism in the Western Rift started at *12 Ma in Virunga, *8-9 Ma in the Kivu and Rungwe volcanic fields, and *70 ka in the Toro-Ankole province (TA volc.) (Kampunzu et al. 1998; Boven et al. 1998).

1.3.4. Stratigraphy of the Albertine Graben.

It is crucial to remember that many geologists have studied the stratigraphy of the Albertine Graben throughout the years, which has resulted in some differences in descriptions. Organizations like Uganda's Petroleum Exploration and Production Department and local oil corporations have worked to balance these differences and create a cohesive understanding of the strata.

The Proterozoic rocks, which are prominently displayed on the rift flanks and shoulders, start the stratigraphic sequence in the Albertine Graben. High-grade igneous and metamorphosed formations from the Pre-Cambrian era make up the majority of these rocks. In some areas of the Graben, especially near the Lake Albert depocenters, seismic data indicates the presence of a Pre-Cenozoic rift sedimentary layer.

According to data from the 1938 Waki-1B well, the syn-rift section includes both the Mid and Upper Cenozoic syn-rift phases, which are distinguished by sandstones and conglomerates. This well also passed through the Mesozoic pre-rift section before arriving at the basement. The Graben contains well-exposed Cenozoic strata, particularly the Kisegi and Kaiso formations, which are composed of sandstones and conglomerate intercalations that were deposited in shallow lacustrine and riverine settings. The metaquartzite Basement is sometimes covered by the Kisegi Formation. Although the Lower Cenozoic frequently covers the crystalline basement in most of the Graben, in some places it might also cover a Mesozoic layer, especially the Karoo formation. The complex stratigraphy of the Albertine Graben underscores the dynamic geological processes that have shaped the region over millions of years, highlighting the significance of ongoing research and exploration efforts in understanding its subsurface structures and resource potential.

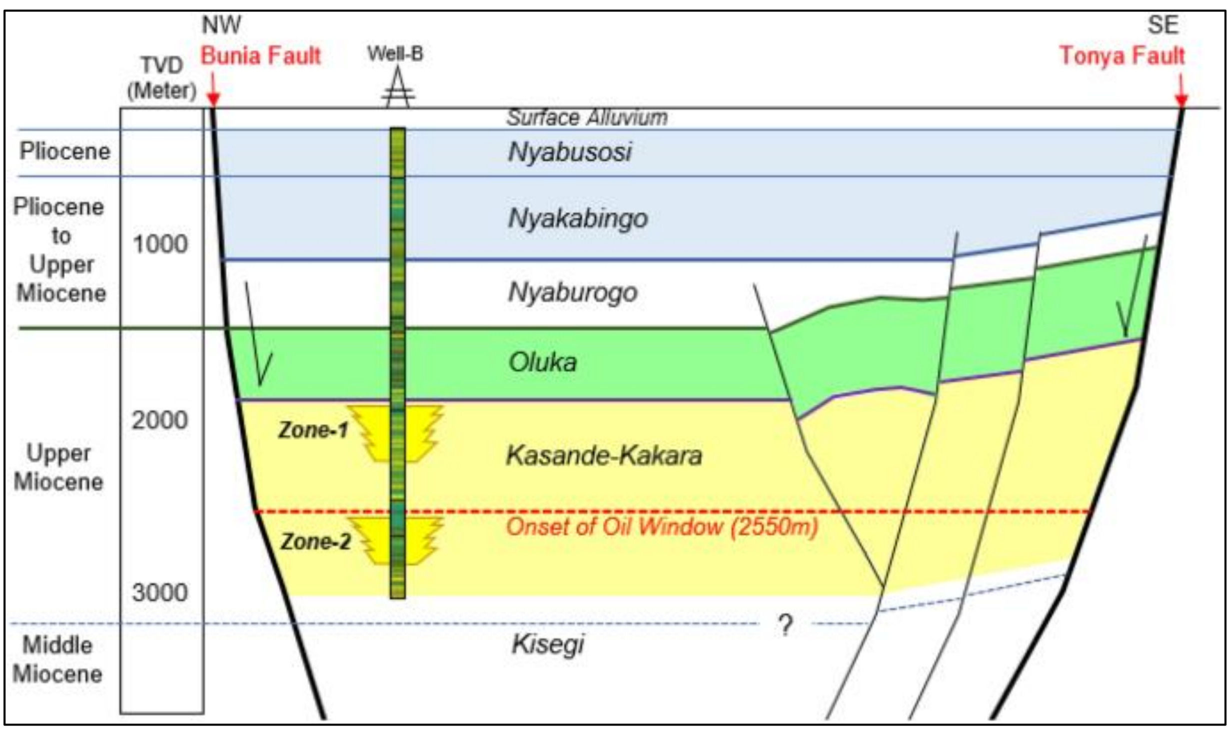


Figure 4. Shows the Stratigraphy of the Albertine Graben obtained by drilling in the area bound by Bunia and Tonya Faults.

According to Pickford et al. (1993), the Semliki basin's stratigraphy consists of seven formations, each of which represents a different geological and depositional phase. The Kisegi, Kasande, Kakara, Oluka, Nyaburongo, Nyakabingo, and Nyabusosi formations are listed in order of age. From the middle Miocene, or roughly 15 million years ago, to the present, they provide a thorough record of sedimentary development within the Albertine graben.

Fossiliferous sediments from the middle Miocene are plentiful in the sedimentary succession that has been preserved in these formations, which is noted for its significant thickness. A protracted period of deposition and sediment buildup is indicated by evidence that the sedimentary strata continue even farther into the lower Miocene.

Understanding the geological past and environmental shifts that have molded the Semliki basin over millions of years is made possible by this stratigraphic framework. Geologists can decipher the intricate tectonic and depositional processes that have shaped the basin's evolution by examining the age relationships of strata and bed successions within these formations.

1.3.5. Physiography of the Semliki Basin.

The Semliki basin, which includes the Semliki flats and the nearby Toro plains southwest of Lake Albert, has a diverse physiography that is influenced by fault-controlled features and geological processes. The majority of the basin is made up of the Semliki flats, which have a mostly flat or gradually sloping terrain covered in savannah flora. On the other hand, the large Makondo fault separates the flood plains along the eastern banks of the Semliki River from the undulating portions of the Toro plain.

The Semliki River is the natural border between Uganda and the Democratic Republic of the Congo (DRC) as it meanders through the Semliki lowlands. The Rwenzori Mountains stretch northward beneath the Semliki Flats, and the basin encompasses around 340 km2 of the Northern Rwenzori Block. The northernmost spur of the Rwenzori Mountains has steep, fault-controlled escarpments on either side, giving the basin a striking geological backdrop.

Low altitudes are a defining feature of the Semliki basin's morphology, with altitude ranges often falling between 630 and 750 meters above sea level. Because of their comparatively heavier soil than the surrounding hill slopes, valleys along the basin's edges offer rich agricultural land.

The basin's western limit is defined by two large faults that separate it from the Congo escarpment: the Semliki fault, which trends NNE-SSW, and the Bunya fault, which trends NE-SW. Interestingly, the Semliki fault's relative displacement on the western edge is greater than its comparable displacement on the eastern edge. The Semliki plain features a Half-Graben morphology as a result of this discrepancy, which has led to an asymmetric basin shape with the western side (in the DRC) showing higher depth than the eastern side (in Uganda).

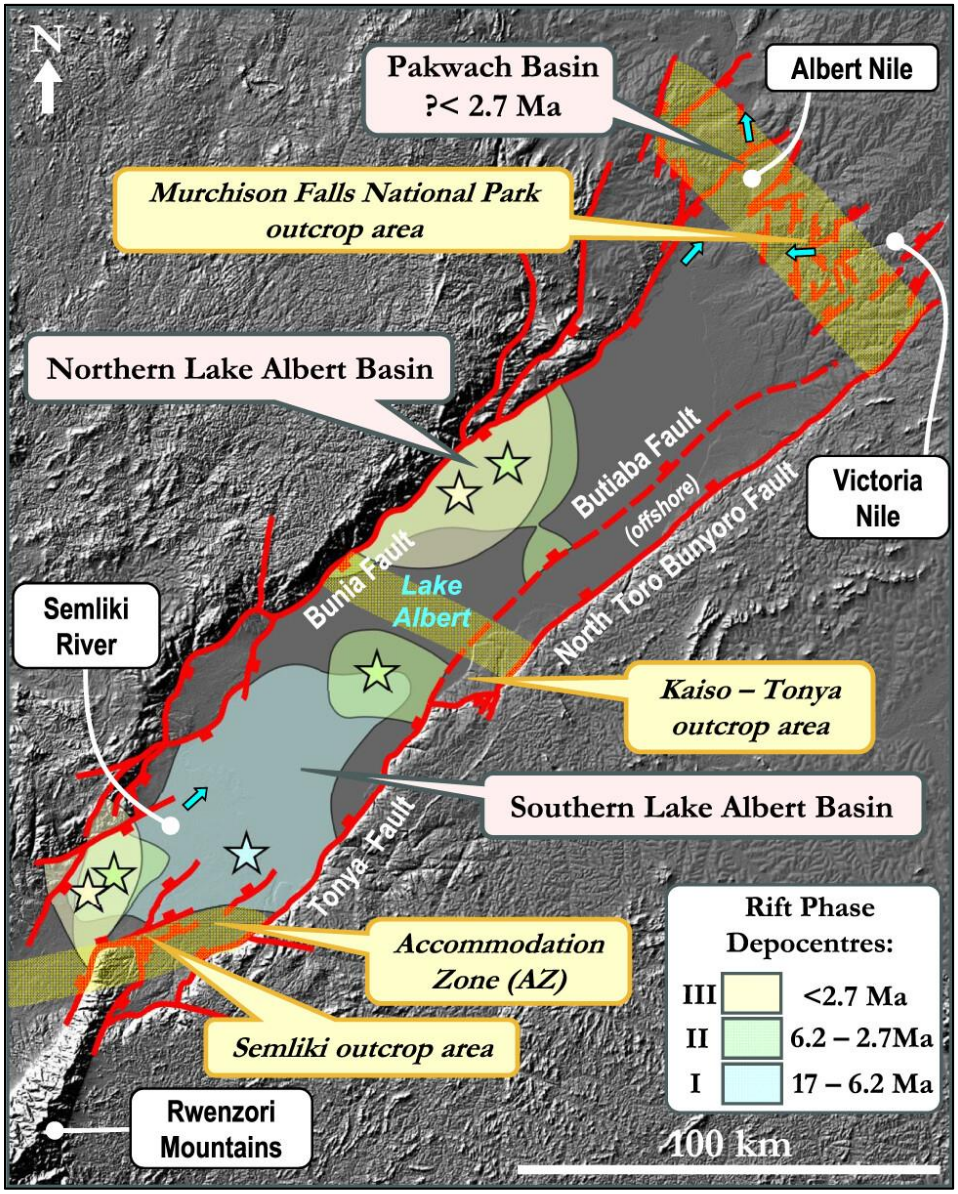


Figure 5. Shows the extent of the Bunia and Tonya Faults bounding the Semliki and the Albertine Graben

Digital elevation model (DEM) at 90 m for the Lake Albert basin, with main structural elements, depocenters and key onshore outcrop areas shown. Principal subsiding areas (depocenters) in each sub-basin are shaded blue (17–6.2 Ma), green (6.2–2.7 Ma) and yellow (2.7 Ma), with stars indicating the point of maximum subsidence. The sub-basins are separated by accommodation (or transfer) zones. Significant offshore faults are represented by dashed lines. The blue arrows indicate the drainage directions for the long-axial rivers draining into and out of the lake.

Simon *et al.* (2017), with additional information from Lukaye *et al.* (2016) and Rubondo (2005)

Geological map of the Kisegi–Nyabusosi area (after Pickford et al. 1993) with division of the sedimentary column into 8 formations, based on biostratigraphy dating of mollusk associations (Gautier 1970, Van Damme and Pickford 2003)

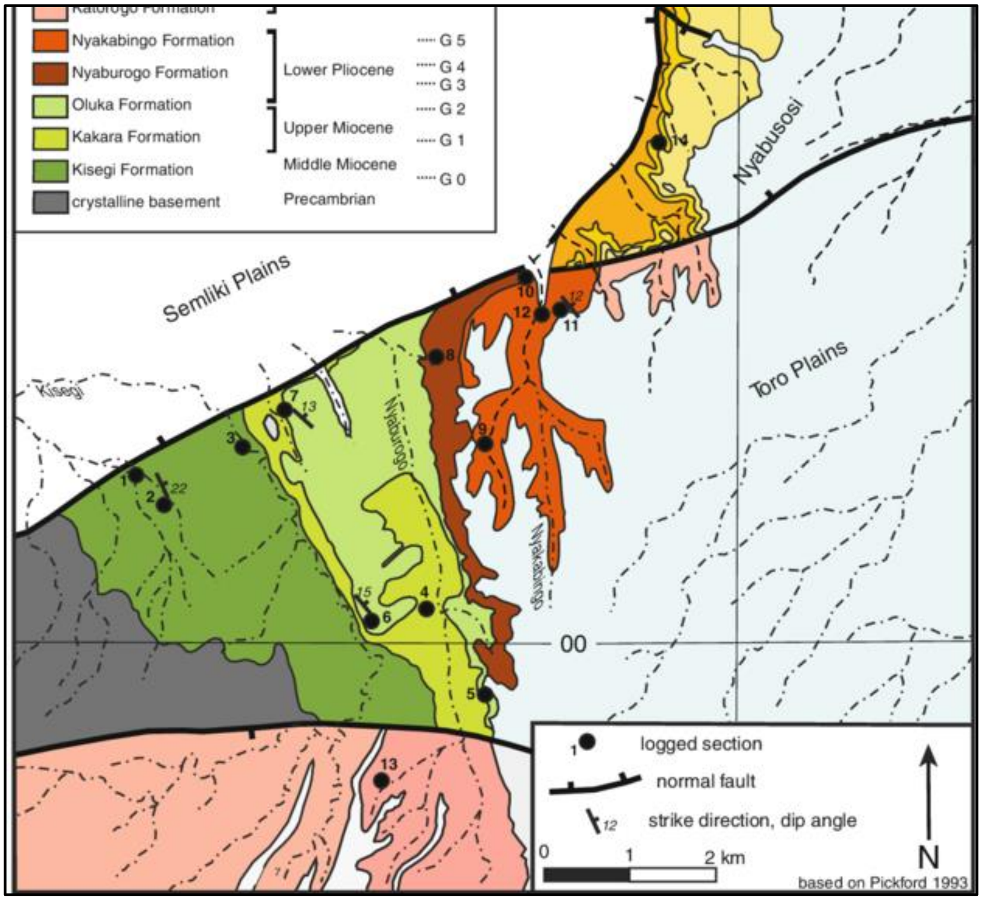


Figure 6 Map showing some of the geological formations of the Semliki plain

Chapter 2. Materials and Methods.

This chapter outlines the materials, equipment, and methodological approaches employed during the petroleum and geoscience fieldwork in the Semliki Basin, located within the Albertine Graben of the East African Rift System. The fieldwork was conducted to assess sedimentary facies, structural features, paleocurrent directions, and potential hydrocarbon systems, guided by standard geological protocols for sedimentary basin analysis in rift settings. Activities included outcrop mapping, stratigraphic logging, sample collection, and geophysical surveys. A specific visit to the Sempaya Hot Springs in the Buranga Geothermal Field was incorporated to evaluate subsurface thermal regimes and their implications for hydrocarbon maturation.

2.1. Materials.

The fieldwork involved the utilization of a variety of equipment and materials, each serving specific purposes essential for geological investigations. Here is a breakdown of the tools and their respective uses:

Jacob's staff: Used for measuring vertical thicknesses of beds during stratigraphic logging, providing crucial data for understanding sedimentary sequences.

Figure 7. Illustrates the Jacob's Staff used to measure thickness of lithounits.

Geological compass: Instrumental in determining direction and describing structures by enabling the measurement of strike and dip of joints and beds, as well as the trend of faults, aiding in structural analysis.

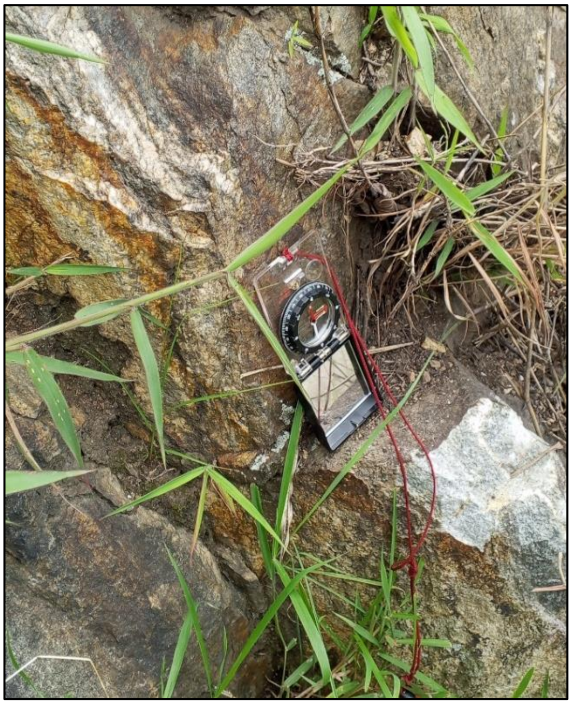


Figure 8. Shows a geological compass.

Geographic Positioning System (GPS): Employed for locating positions in the field and on maps, with readings configured to metric units and specific coordinate systems, facilitating precise mapping and elevation determination at various stops.

Base maps (topographic and geologic): Utilized for orientation in the field, providing context regarding the geological structural framework, such as the identification of faults like the Makondo fault, aiding in navigation and interpretation.

Figure 9. Shows a base map used to locate geologic features in the field.

Measuring tapes: Used for measuring bed thickness, providing quantitative data essential for lithostratigraphic analysis.

Hand lens: Provided close examination of rocks, sediments, soils, sand, minerals, and other materials with tiny features, facilitating detailed observation and identification of small fossils.

Hoes and spades: Employed for cleaning sediment surfaces to enable clear visualization of beds for logging purposes, ensuring accurate descriptions and observations.

Digital cameras/Phones: Used for capturing photographs of interesting geological features, providing visual documentation for further analysis and reference.

Field notebooks: Essential for recording field observations, including descriptions of basement rocks, sediments, and other geological features, as well as sketching exposures, serving as a basis for report writing and analysis.

Graph papers, pencils, and rulers: Utilized for the construction of lithostratigraphic logs, enabling the visualization and interpretation of sedimentary sequences and structural characteristics.

Hammers: Used for breaking rocks to obtain samples and exposing less weathered sediments, facilitating detailed examination and analysis of rock properties and composition.

Figure 10. Shows a geologic hammer used to collect samples.

Grain size scale. The Wentworth grain size scale was used to evaluate the grain size of the particles. The finest particles were designated clay, followed by silt, sand, granules, gravel, pebbles, cobbles, and boulders.

2.2. Methods

2.2.1. Desk Study.

During the desk study phase, all accessible literature and geological maps related to the Albertine region and the Semliki basin were thoroughly examined. The purpose of this thorough review was to provide the team an overview of the research region and acquaint them with the tools and supplies they would need for the field investigation.

2.2.2. Structural Measurements.

Many structural elements found in the field were meticulously measured during structural measurements. The researchers used the right-hand rule to determine the dip and strike of structures such joints, bedding, faults, and foliations using a geologic compass. Additionally, a Jacob's staff and tape measure were used to measure factors like bed thickness. The Appendix contains comprehensive structural measurements that were made at different locations in the area of study e.g. At Itojo, Kibuku, Kisegi hill, etc.

2.2.3. Outcrop Rock Description.

Using a hand lens and the unaided eye, rock descriptions were performed to macroscopically describe the characteristics of observed rocks. The rock's name, grain size, color, minerals present, and structural characteristics were among the important characteristics mentioned.

2.2.4. Lithostratigraphic Logging.

On fresh rock exposures, lithostratigraphic logging was carried out methodically from bottom to top. Variations in color, grain size, structural orientation, and bed thickness were used to identify contacts between several lithologies. Using this data, large-scale stratigraphic logs were created in the field using graph paper and Sedlog software. Following analysis and interpretation, important information on the deposition environment, sediment flow direction, and rock grading was extracted from these logs.

There were multiple steps in the logging process:

- Using a hoe to clear any weeds or obstacles off the outcrops.
- Using Jacob's staff or a tape measure to determine the outcrop's vertical thickness.
- Using the characteristics of the rock and sediment layers to describe the outcrops.
- If the basement was not visible or clear, erosional contacts might be used at the base of the log.
- Building lithostratigraphic logs with structures and lithologies on graph paper.
- Differentiating between different types of rocks by interpreting the depositional environment and other rock attributes through analysis of the logs.

2.2.5. Grain size Determination.

A hand lens was used to observe the clasts in order to estimate factors such sphericity, roundness, sorting, and cementation during the measurement of particle size and form. To learn more about the kind of depositional environment and the circumstances that prevailed during deposition, these observations were made at exposures, road cuttings, and outcrops. The grains' sphericity and roundness were especially helpful in determining the kind of carrying agent and calculating the distance traveled. They also supplied important data regarding sediment maturity, which is essential for assessing petroleum potential.

A spectrum from extremely coarse sand to extremely fine sand was found via grain size analysis. The characterization of sediment grading within beds was made possible by the use of a grain size scale in this investigation. Important information about the deposition environment and the energy of the deposition agent was revealed by determining whether the silt coarsened upward or downward.

2.2.6. Determination of Paleocurrent direction.

Analyzing sedimentary features such cross-stratification, pebble imbrications, and current ripples was necessary to determine the direction of paleocurrent flow. The direction of the ancient currents that deposited the sediments can be inferred from these structures.

Specifically, the paleocurrent direction of sediment transport was inferred from the dip direction of angular and tabular cross beds found in sand layers. Researchers were able to determine the direction in which the sediments were carried by ancient currents by looking at the orientation of these sedimentary structures.

Further proof was offered by the fact that the majority of ripples on flood plains were asymmetrical. Usually pointing downstream, the shorter, steeper side of these ripples corresponds with the direction of flow of the currents that created them.

2.2.7. Interpretation of Depositional environments.

Several important characteristics found in the sedimentary rocks were necessary for the interpretation of the depositional environment. Grain sorting, grading within beds, the presence of particular minerals, and the kinds of structures seen in the rocks were some of these variables.

For example, stages of semi-aridity in the deposition environment were suggested by the presence of minerals such as gypsum that had precipitated inside joints discovered in sands and clays at the Kibuku road cut exposure. Changes between fluvial and lacustrine ecosystems may be reflected in variations in bed thicknesses across sediments, which suggested variations in depositional circumstances.

Additionally, the grading found in sedimentary strata offered important hints. Environments like fluvial or lacustrine settings exhibit normal grading, in which coarser sediments settle away more quickly than finer particles. In a similar vein, the existence of extremely fine-grained and well-sorted clays and sandstones indicated deposition in serene lacustrine settings.

2.2.8. Geophysics.

Magnetic and gravity measurements were gathered in the Semliki Basin. The obtained seismic data was printed on a sheet of paper with two sections: structures and facies. Exercises conducted at camp and on personal computers at the university served as geophysical studies. During these exercises, magnetic and gravity survey field data from Semliki basin, seismic sections of data from Semliki basin and Gulf of Mexico were provided.

By identifying seismic facies and designating stratal terminations and important stratal surfaces, the Gulf of Mexico seismic lines were interpreted. The following process was used to interpret the seismic lines from the Gulf of Mexico: Taking into account strike/seismic line S6 (which has discernible facies).

- Reflection terminations were identified and labeled, including truncation, onlap, and downlap.
- They were faintly colored on the section after the varieties of seismic facies were identified and their primary characteristics listed.
- The sorts of chronostratigrahically relevant seismic surfaces that connected units with various seismic facies were then identified and color-coded.

2.2.9. Sempaya Hotsprings.

A hot spring is a place where the water's temperature is much higher than the area's average yearly air temperature. The Sempaya hot springs are situated 40 kilometers from the DRC border in Semliki National Park in Sempaya, Bundibugyo district, western Uganda. The park is roughly 220 km^2 and located inside the Albertine Graben. It shares borders with Lake Albert and the Semliki Flats to the north, the Democratic Republic of the Congo to the west, and the Rwenzori Mountains to the southeast. The Sempaya hot springs are located in the Buranga geothermal field and are connected to the Rwenzori mountains (Bahati, 2016). Volcanic activity produced the hotsprings.

The male and female Sempaya hot springs are located in two marshy areas surrounded by a thick rain forest and boil at temperatures as high as 95–990 degrees Celsius. The female hot spring has a jet-like structure that shoots water above the surface, whereas the male hot spring is hotter and bigger. The Bwamba fault, which is about seven miles away from the surface of the extremely hot rocks, is close to the location of the hot spring. Rainwater seeps into the permeable sedimentary rocks, causing the heated water to spill forth. As it moves through the rock, it dissolves a range of substances, including sulfur and radium.

The primordial heat of the earth, the mantle, which is closer to the surface than in other places, heats the water and groundwater as it descends more below the surface. Hot springs are created when the pressure pushes this extremely hot water back to the surface through fissures and fault lines. The male hot springs are a pool of steaming hot water that smells strongly of sulfur. The pool had a diameter of roughly 30 meters, an average water temperature of 86 degrees Celsius, a depth of 5 meters, and a carbonate cone made of calcium carbonates (travertine) that precipitated out of the water.

The female hot springs, on the other hand, are made up of a series of steaming water jets that emerge from the subsurface and smell strongly of carbon dioxide gas, hydrogen sulfide (H2S) gas, carbonates, and other salts. It is roughly 60 by 40 meters in size, and the water's average temperature is 98.4°. These hot springs are located close to the rift flanks in a faulty area. They are the outcome of the Albertine Rift's active tectonism. The geothermal gradients that have hastened the maturity of source rocks in the Albertine graben are believed to be a result of the region's high temperatures. Nevertheless, thermal cracking of the hydrocarbons would result from raising these temperatures above the oil window (60–1200C).

Fractures and faults that serve as conduits or migration routes for hydrocarbons from source rock to reservoir may be found in the active fault system connected to the seismic activity in the Graben. Water contains a variety of minerals, including calcium, salt, fluorine, and lithium. These minerals build up and eventually obstruct water passageways, which raises underlying pressure and forces the water to surface somewhere else. The Semliki River, which empties into the Nile, receives this hot spring water via channels.

2.2.10. Laboratory Work.

Rose Diagrams.

When manipulating and analyzing structural data such as joints, beds, and foliations, stereonets and rose diagrams are crucial tools. By presenting data in a circular histogram shape, they offer a visual depiction of the structures' orientation. The length of each segment, or "petal," in the diagram represents a range of directions (usually strike or trend), and the number of joints within that range is indicated by its length. Rose diagrams and stereonets were created using spheristat software after the strike and dip measurements from the field were altered.

Sedlog was used to obtain the large-scale stratigraphic logs of the area. These logs were then analyzed and interpreted to obtain information about the environment of deposition, direction of sediment flow and the grading of the rocks.

Oasis Montaj software was used to process geophysical data, to obtain the gravity and magnetic data.

Techlog software was used to generate a petrophysical log from the petrophysical data obtained from the Turaco wells thereby evaluating the physical and chemical properties of subsurface rocks and fluids in a well. It helps identify rock types, estimate porosity, determine fluid saturation (oil, gas, or water), and locate permeable zones that may act as reservoirs.

CHAPTER 3. LITHOLOHGY AND STRATIGRAPHY.

The lithology of the Semliki Basin includes both sedimentary deposits and basement rocks. High-grade metamorphic rocks like gneisses, which are evidence of substantial tectonic and metamorphic activity, are found in the basement lithology. Sedimentary strata from the Miocene to recent epochs, which include formations like Kisegi, Kasande, Kakara, Oluka, Nyaburongo, Nyakabingo, and Nyabusosi, cover these basement rocks. Conglomerates, sandstones, clays, and fine-grained lacustrine deposits make up the majority of these sediments, which represent a range of depositional regimes from lacustrine to fluvial. Rich paleoenvironments and a variety of sedimentation circumstances across time are indicated by the sedimentary succession's well-preserved fossiliferous strata.

3.1. Basement Lithology

The Semliki Basin's basement lithology is mainly made up of high-grade metamorphic rocks that represent extensive tectonic and metamorphic processes, such as quartzites, gneisses, and amphibolites. These rocks are part of the Buganda-Toro system. These Proterozoic-era basement rocks show traits of deep crustal development and deformation. While other rocks exhibit noticeable schistosity as a result of the alignment of platy minerals, gneisses are frequently foliated, indicating strong directional stress. There are also quartzites, which are made from metamorphosed sandstones and demonstrate the tremendous pressures and temperatures that occurred during their development. The Semliki Basin's structural and geological framework is influenced by younger sedimentary layers that have been deposited on top of these old rocks, which are occasionally intruded by granitic masses.

3.1.1. Migmatite

The migmatite was located at Itojo (0191057,0094333 Elevation-1044m). It exhibits both solid-state and partial melting characteristics. Migmatites are associated to high-temperature metamorphic environments and commonly found in regions that have experienced intense geological processes such as mountain building or tectonic activity. The migmatite forms through the metamorphism of granites to form granite gneiss and subsequent partial melting. Therefore, migmatites have both metamorphic and igneous characteristics. The light-colored minerals, primarily quartz, melted first and make up the igneous component, while the dark minerals, with a schistose texture, represent the metamorphic component. The migmatite is characterized by folds, which are explained in the structures chapter.

Figure 11. Shows a folded migmatite at Itojo.

3.1.2. Granite Gneiss

The granite gneiss was initially a granite, which underwent high grade metamorphism, meaning that it has been subjected to higher temperatures and pressures than the schist. It is a migmatite formed by partial melting, hence having both igneous and metamorphic migmatites. Gneiss displays distinct foliation, representing alternating layers composed of different minerals, indicating significant directional stress. These basement rocks date back to the Proterozoic era and exhibit characteristics typical of deep crustal formation and deformation. These ancient rocks, sometimes intruded by granitic bodies, form the foundational bedrock upon which younger sedimentary layers have been deposited, influencing the structural and geological framework of the Semliki basin.

Granite gneisses are the most abundant rock type in the basement of the Semliki Basin, covering over 90% of the basement lithology. These rocks are primarily exposed in artificial outcrops created by human excavation during road construction (At Kichwamba; 0186953,0079664 Elevation-1604m and quarrying (at Kibuku; 192414;101902 Elevation-670m).

Figure 12. Shows the granite gneiss that belongs the basement rocks.

Figure 13. Shows a highly jointed granite gneiss exposed by quarrying at Kibuku Area.

The granite gneisses are generally white-grey in color, fine to medium-grained, and composed of K feldspars, quartz, and biotite minerals. Originating from granite, these rocks exhibit high-grade metamorphism, evidenced by the banding and foliation of minerals. The gneisses are heavily fractured, with some joints filled with quartz minerals from hydrothermal fluids during various tectonic episodes. The joints and foliations predominantly trend in the Northeast-Southwest direction, with joints dipping towards the Northwest. These granitic gneisses are highly jointed and fractured, making them potential reservoirs as the joints and fractures can serve as migration conduits for hydrocarbons.

3.2. Lithology and Stratigraphy of Sediments.

The basement rocks in the Rwenzori Mountains and the nearby escarpments are probably the main source of the sediments found in the Semliki Basin, based on the color and mineralogical features of the sediments found there as well as the basin's position. It is conceivable that the sediments came from sources like Lake Obweruka, which is now Lake Albert, as the uplift of the highlands happened more recently than the start of rifting. Rivers from the highlands most likely carried these sediments to the basin, where they were deposited. Sandstones, clays, silts, and conglomerates are among the sedimentary deposits that cover the basement rocks and provide evidence of the basin's lacustrine and riverine habitats.

3.2.1. Sandstones.

The Semliki Basin's most common sedimentary deposits are sandstones, which range in size from extremely fine to extremely coarse grains. These sandstones, which range in color from pale yellow to reddish brown, usually cover basal conglomerates. The presence of iron oxide, which is deposited in shallow water subaerial habitats, is responsible for the sands' yellow color. The sandstones are frequently intercalated with clay beds, conglomerates, and gypsum layers. They exhibit variable sorting, ranging from well-sorted to badly sorted, and extend laterally over considerable distances with varying thicknesses.

Figure 14. Shows an outcrop of the sandstone that belongs to the Sediments overlying the basement.

Reddish-brown iron minerals cement the matrix-supported sandstones, creating laminations in certain strata. Grain consolidation ranges from good to medium to weakly compacted, while grain morphologies range from sub-angular to sub-rounded. Quartz, iron (III) oxides, clay minerals, and gypsum are the predominant minerals. Many sands layers' uniform size grading indicates that they were deposited by a fluvial system, where differing energy levels cause varied grain sizes to be deposited. Fining-upward sequences, which show variations in energy levels, are also present in some strata. On the other hand, coarsening-upward sand layers indicate seasonal fluctuations, differences in current energy, and climatic changes.

Various structures observed within the sandstones include cross beds, laminations, tabular beds, joints, and gypsum-filled veins, highlighting the dynamic depositional environment. These sandstones possess qualities conducive to serving as reservoir rocks, with good sorting and less consolidation enhancing porosity and permeability, making them promising targets for hydrocarbon exploration.

Figure 15. Shows a sandstone outcrop with cross bedding.

3.2.2. Clay Sediments.

Different amounts of organic matter content preserved in anoxic depositional conditions were indicated by the clays found in the area, which ranged in color from brown and grey to dark grey. The thickness of the clay layers varied greatly; some beds were noticeably thin, spanning only a few centimeters, while others reached significant thicknesses of up to a few meters. Massive layers as well as those with laminations, gypsum-filled cracks, and veins were among the structural elements found in the clay beds. Gypsum is probably present because calcium sulfate-rich fluids that were initially deposited next to the clay deposits precipitated. These clays frequently appear cyclically with sandstone layers, indicating that they were deposited at times of river floods with comparatively low energy conditions. Given their substantial thicknesses, these clays have potential as suitable cap rocks.

Figure 16. Shows shale layers of different colours.

3.2.3. Silt.

These are fine-grained sediments that appeared grey to white, with some yellow due to iron (III) oxide coating. They were well sorted and fine-grained, with thin, continuous beds showing low scale cyclicity.

Figure 17. Silt and clay intercalations with Iron III oxide.

3.3. Well interpreted sedimentary-log for the group.

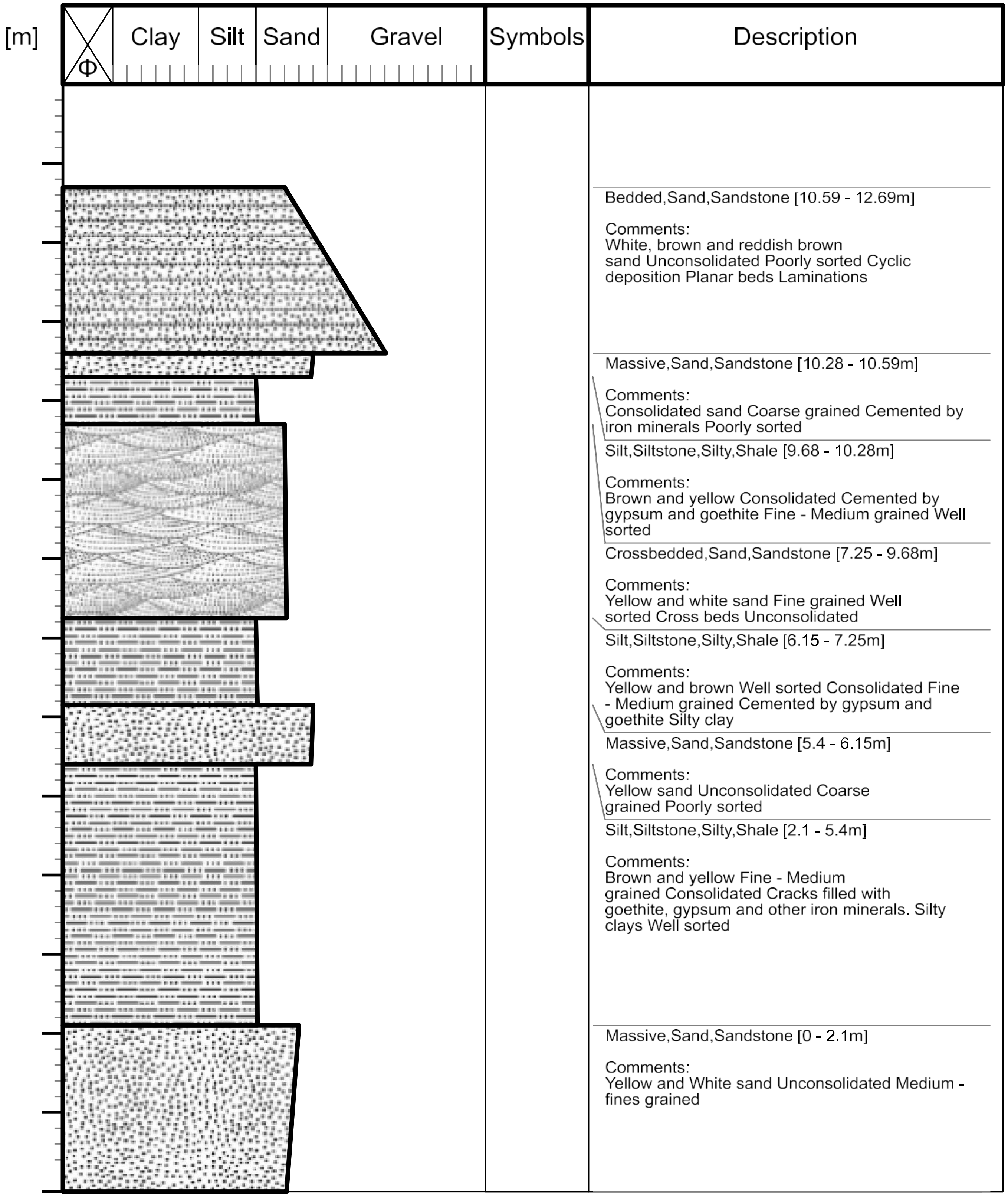


Figure 18. Shows lithostratigraphic log of the logged outcrop at (193006;101991).

3.3.1. Description of the Layers.

Layers from the Bottom	Thickness (m)	Minerology	Colour	Grain size	Consolidation
1	2.1	Quartz Iron minerals	Yellow and white sand.	Medium grained.	Unconsolidated.
2	3.3	Quartz Clay minerals. Gypsum	Brown and yellowish silty clay	Fine grained. Medium to fine	Consolidated.
3	0.75	Quartz, Clays, Iron minerals.	Yellowish brown sand	Coarse grained	Unconsolidated
4	1.1	Gypsum, Clays and Goethite.	Grey, yellowish brown	Medium to Fine grained	Consolidated
5	2.93	Quartz, Iron minerals	Yellow and white sand	Medium to fine grained.	Unconsolidated
6	0.6	Clays, Gypsum, Goethite	Brown and yellow	Fine grained	Consolidated
7	0.31	Quartz minerals Iron minerals, Clays	Brown, white sand	Medium to coarse grained	Consolidated
8	2.1	Quartz, Hematite,	White, reddish-brown sand	Coarse grained	Unconsolidated

Figure 19. Shows the description of the various layers from the log.

3.4. Stratigraphy of the Sediments.

The Semliki basin consists of basement rocks and sedimentary deposits. Basement rocks include high-grade metamorphic rocks, gneisses, reflecting intense tectonic and metamorphic activities. Over this basement are deposited Miocene to Recent sedimentary formations such as Kisegi, Kasande, Kakara, Oluka, Nyaburongo, Nyakabingo, and Nyabusosi formations.

- The Kisegi Formation, identified by Pickford et al. in the Semliki area along the Kisegi River, consists of basal conglomerates overlying the crystalline basement. These conglomerates transition into thick, channeled, and cross-bedded sandstones with thin interbeds of tuff, reflecting dynamic depositional processes.
- The Kasande Formation, which overlies the Kisegi Formation, is characterized by dark brown to yellow-brown mudstones interbedded with yellow sandstones. It also includes grey to dark grey claystones and mudstones, reflecting a varied sedimentary composition (Joshua Lukaye, 2016).
- The Kakara Formation, defined by Pickford et al., consists mainly of clays and silts with ironstones and is typically observed in road cuts, though often dominated by sand. The contact with the underlying Kasande Formation is not visible in outcrops but is believed to be marked by the initial appearance of ironstones or ferruginous sandstones in the sequence.
- The Oruka Formation, exposed between the Nyaburongo and Kisegi rivers, begins with dark shales overlying a widespread conglomeratic ironstone containing large rounded quartz pebbles. It serves as a secondary reservoir and includes interbedded claystone, shales, siltstone, and sandstone.
- The Nyaburogo Formation is best observed in new road cut exposures, where basal shales rest on a faulted and eroded surface of the upper Oruka Formation, forming a micro-graben structure. Outcrops reveal thick claystone sequences interbedded with rusty brown to yellow-brown siltstones, pisolitic ironstones, and paleosols.
- The Nyakabingo Formation begins with a lacustrine shale base and features light grey to greenish-grey claystone, iron-stained siltstone, pebbly and coarse sandstones, and carbonate nodules. The overlying Nyabusosi Formation, seen near the Makondo Fault Zone, lacks a clear boundary with Nyakabingo and consists of alternating clays and silts throughout its exposures.

Conglomerates, sandstones, clays, and fine-grained lacustrine material make up the majority of these sediments, suggesting a wide range of distinct depositional settings from fluvial to lacustrine. Excellent preservation of the fossil-bearing units in the sedimentary succession is another sign of active paleoenvironments and changing sedimentation conditions over time.

The basement rocks in the Rwenzori Mountains and the nearby escarpments are probably the main source of the sediments found in the Semliki Basin, based on the color and mineralogical features of the sediments found there as well as the basin's position. The sediments may have come from places like Lake Obweruka, which is now Lake Albert, as the uplift of the highlands happened more recently than the start of rifting. Rivers from the highlands most likely carried these sediments to the basin, where they were deposited. The sedimentary deposits, which cover the basement rocks and are representative of the basin's lacustrine and riverine habitats, comprise sandstones, clays, and silts.

CHAPTER 4. BASIN AND FACIES ANALYSIS

Basin analysis is a geological technique that focuses on analyzing sediment fill to determine the basin's history, including facies, sedimentation processes, and sediment origin. Different forms of sediment deposition are indicated by sedimentary facies, which are visibly distinct types of sedimentary deposits. The study of sedimentary deposits to understand the depositional settings and processes that created them is known as facies analysis. Geologists can deduce historical conditions, sedimentation processes, and basin evolution by analyzing the physical, chemical, and biological properties of sedimentary rocks, such as grain size, composition, and sedimentary formations. In order to comprehend reservoir potential in petroleum exploration, this approach aids in forecasting the distribution and geometry of sedimentary rock bodies.

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

Long-term subsidence areas that provide room for sediment infill are known as sedimentary basins. In essence, basin analysis entails examining sediment fill to uncover the basin's past (sediment provenance, sedimentation processes, and facies).

4.1.1. Formation of the Semliki Basin.

The Semliki sedimentary basin is a single stretch of the half-graben rift, a geological formation with a fault on one side. A depressed block of land surrounded by parallel faults is known as a complete graben. Intracontinental rifting, which is reliant on strong heat flow and results in expansion, upward arching, and extension, is what created the Semliki sedimentary basin (McConnell, 1972). Passive and active rifting are the two types of rifting. The continental lithosphere fails due to tensional forces during passive rifting, allowing heated mantle rocks to enter the lithosphere. Volcanic activity and crustal dooming are merely incidental phenomena. Hence the resulting basin geometry, rates of subsidence or uplift, sedimentation and erosion, magmatism, etc. are surface expressions of processes operating at crustal and mantle levels. On the other hand, active rifting is linked to a thermal plume or sheet impinging on the base of the lithosphere. The lithosphere may thin due to conventional heating, heat transfer from magma production, or conductive heating from the mantle plume. Isostatic uplift results from relatively quick thinning of the continental lithosphere if heat fluxes from the asthenosphere are significant enough. Rifting may then be encouraged by tensional strains brought on by the uplift. The thinning lithosphere is severely fractured by the upwelling of the hot asthenospheric material, which is indicative of the presence of geysers, fumaroles, and hotsprings, such as Sempaya hotsprings.

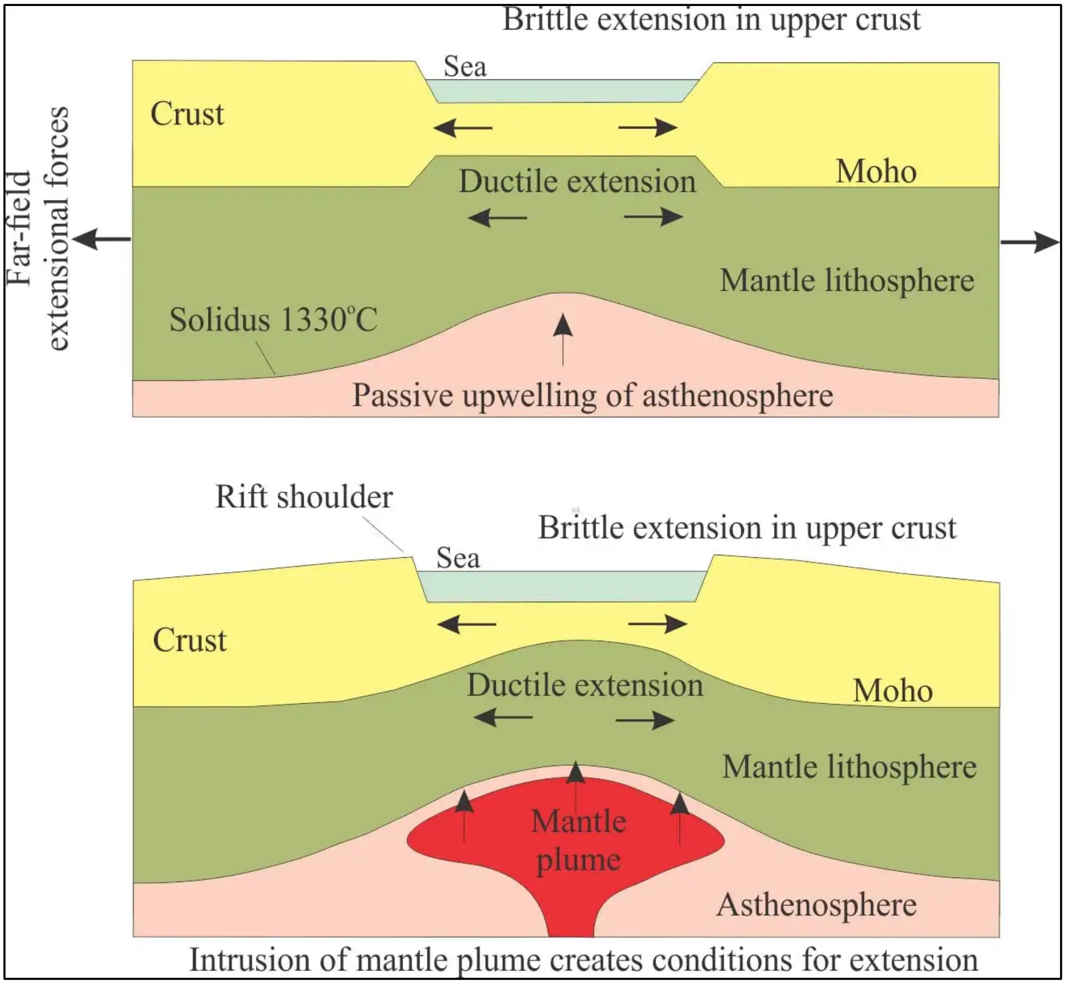


Figure 20. Shows how the semliki basin was formed.

Passive rifting where mantle passively upwells in (isostatic) response to crustal stretching and thinning; Active rifting where the stretching is a consequence of a rising mantle plume. Modified from Allen and Allen, 2005.

4.1.2. Basin Structure.

Structurally, the Semliki basin is a wedge-shaped (half graben) basin that is mostly composed of deposits from lacustrine, deltaic, and riverine sedimentary processes. Lithology and structures have been used to predict basin geometry. While reservoirs in shallow lacustrine and flexural sections as well as deep lacustrine zones formed sub-lacustrine sands or turbidites encased in mudstones or clays, source rocks primarily developed during the synrift in deeper portions. There may be deep sublacustrine "turbidite" sands among the fluvial-deltaic sediments directly on top of the basement. Numerous pinch outs into deltaic sandstone formation (later cut by faults on the right side) and partially into lacustrine mudstone/clays may be seen in alluvial fan deposits deposited up to about 6 km. The lower most sediments immediately above the nonconformity are fluvialdeltaic. The basin fill is dominated by lacustrine mudstones/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).

4.1.3. Basin Stratigraphy.

The Semliki Basin, part of the Albertine Graben in western Uganda, features a 3–6 km thick sequence of Cenozoic fluvial, deltaic, and lacustrine sediments. These rocks overlie Precambrian crystalline basement and are dominated by alternating sandstones, shales, silts, and clays. The basin contains seven major lithostratigraphic formations. The sedimentary fill of the Semliki Basin spans from the Paleogene or Early Miocene to the Pleistocene, generally divided into the following formations from oldest to youngest.

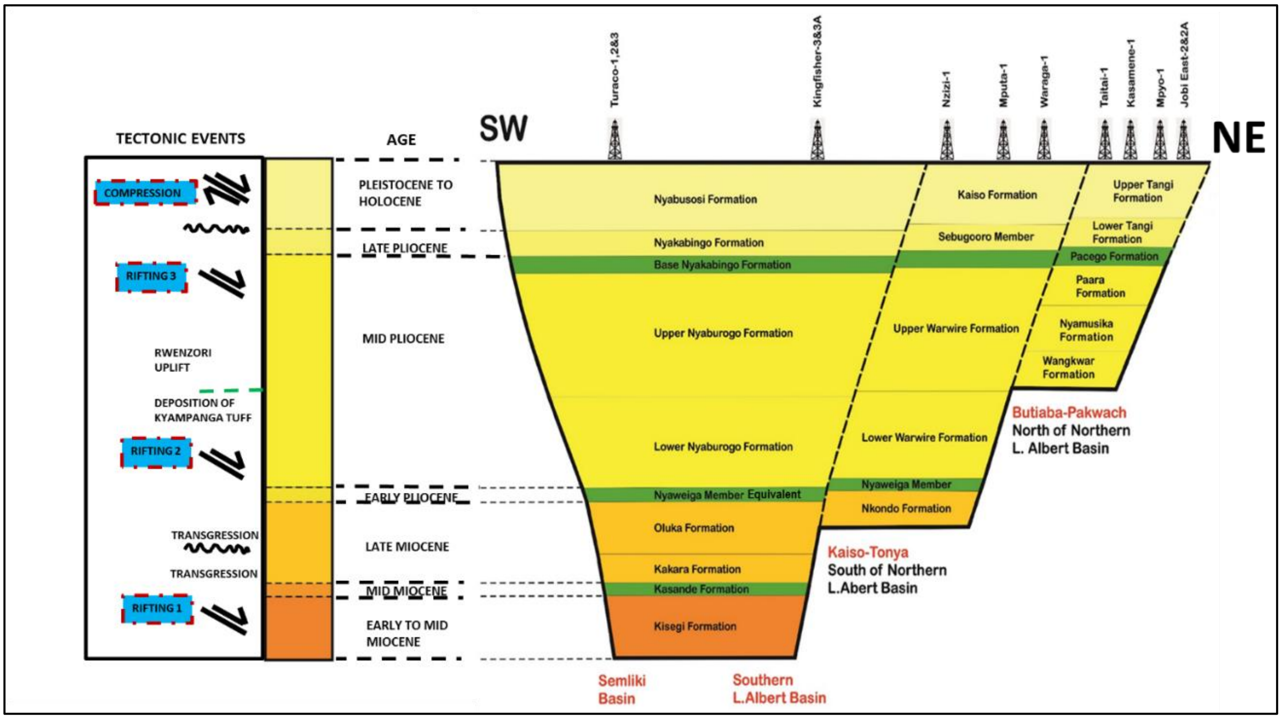


Figure 21. Illustrates Basin stratigraphy of the semliki basin and the formations.

Kisegi Formation.

The Kisegi Formation is considered the oldest formation in the Semliki Basin, lying directly on the basement complex of granite gneisses and Buganda-Toro metaquartzite. This contact is marked by a basal polymictic conglomerate. The basal conglomerates near the Kibuku seep transition into thick, friable, yellow, well-sorted, medium to fine-grained sandstone, comprising intercalations of conglomerates and low-angle cross-bedded sands. Gypsum veins and thin interbeds are common throughout the exposure. The upper part of this formation includes a cyclic sequence of sands and clays, suggesting formation in a combination of fluvial, deltaic, and lacustrine systems. The presence of gypsum and yellow sands indicates a semi-arid paleoenvironment with significant evaporation and oxidation. Hydrocarbon seeps in surface exposures of the basal stratotype at Kibuku show sandstones impregnated with waxy oil, likely due to a lacustrine source or biodegradation. The Kisegi Formation is estimated to be around 110m thick in its type section but much less than the 300m suggested by earlier studies.

Kasande Formation.

This formation, which serves as the source rock and seal and is situated above the Kisegi Formation, was given an informal name in 2002 by Heritage Oil & Gas plc in honor of Mr. Robert Kasande. It is distinguished by channelized sandstones that can be several meters thick and dark brown to yellowish-brown mudstones. The upper portion of the unit has thin black coaly shales. A transition from lacustrine to wet delta plain with fluvially produced marsh or swamp flora is indicated by the grey, dark grey, to reddish-brown claystones and mudstones found in these sections. The Formation has an estimated large lateral extension in the deeper western subsurface of Lake Albert and is 31 m thick in exposures and 115 m thick in the Turaco-3 well. The formation is characterized by thick clay and channelized sand sequences, which point to lacustrine conditions.

Kakara Formation.

Overlying the Kasande Formation is the Kakara Formation, which Pickford et al. (1993) examined and named. It is composed of sand-matrix conglomerates, brown to red pebbly and muddy sandstones interbedded with grey soft silty claystones, and intercalations of unconsolidated, yellowish-brown, poorly sorted, medium to coarse-grained sandstone. The formation was mostly deposited on a coastal plain, but neighboring channels' crevasse splay added coarse-ferruginous sandstones. The initial formation of ferruginous sandstones is thought to indicate interaction with the Kasande Formation. In Turaco-3, the Kakara Formation is 542 m thick, and irregular gamma-ray responses indicate shallowing upward sequences and coarsening. Exposures reveal a part that is primarily composed of sand, which is not typical of the formation in any other way.

Oluka Formation.

Named after Mr. John Oluka, this formation's base is exposed on the ridge between the Nyaburogo and Kisegi rivers. It consists of dark shales overlying well-developed widespread conglomeratic ironstone with large smooth, rounded quartz pebbles. The basal hypostratotype in the Turaco-3 well is defined by a thick shale unit marked by a rapid increase in gamma-ray and corresponding changes in SP, porosity, density, and sonic log responses. The formation comprises interbedded claystones, shales, siltstones, and sandstones. The formation is over 390 m thick in Turaco-3 and about 50 m thick in exposures, with a suggested age close to 7-8 Ma (Late Miocene).

Nyaburogo Formation.

Named after exposures in the Nyaburogo River valley, this formation consists of thick sequences of claystones with rusty brown to yellowish siltstones, pisolitic ironstones, paleosols, and fining upward sandstones at the top. The formation indicates deposition in regimes of humid tropical climates. It consists of a lower arenaceous sequence with stacked fluvial-channel sandstones that fine upwards into more clayey sequences. The Nyaburugo Formation's stratotype is proposed in the Turaco-1 well at an apparent log break at 1,492 m.

Nyakabingo Formation.

Named after exposures in the Nyakabingo river valley, this formation's type section is defined in the Turaco-1 well and is 207 m thick. It consists of repetitive coarsening-upward cycles, with exposures showing light grey to light greenish-grey claystones, iron-stained siltstones, pebbly and coarse sands/sandstones, and carbonate nodules. The formation indicates late Pliocene age in outcrops based on mollusc associations, suggesting flood plain and/or lagoonal deposition.

Nyabusosi Formation.

This formation, which was initially called by Pickford et al. (1993) after locations in the Nyabusosi river valley, is mostly composed of alternating silts and clays interspersed with characteristic ironstone horizons. It is composed of the ironstone-free Makondo member at the base, the ironstone-covered Behanga member on top, and the ironstone-free Kagusa member at the summit. With coastal to near-shore lacustrine deposition conditions and notable lake-level variations, the formation is thought to be late Pleistocene in age.

4.2. Elements of facies analysis and facies analysis interpretations from observed lithologic units.

In essence, facies are rock entities that can be distinguished from one another by certain observable traits, such as their general appearance and their textural, structural, and compositional qualities. These differences result from the various conditions that exist throughout the creation, transportation, and deposition of sediment. Fossil material (biofacies) or lithology (***lithofacies***) can be used to classify sedimentary facies. Whereas ***biofacies*** are distinguished by their fossil richness, lithofacies are defined by petrological features such grain size, mineralogy, and sedimentary architecture. By connecting historical rock formations to current depositional conditions, facies analysis enables geologists to create depositional models for ancient rocks. A particular area of the earth's surface where sediments build up under particular physical, chemical, and biological circumstances is known as a depositional habitat.

Both clastic and non-clastic sediments that were generated in a range of environments, such as lacustrine, deltaic, and fluvial settings, dominate the Semliki Basin's depositional framework. Situated in the western arm of the vast East African Rift System, the basin is an intricate geological formation. It is a rift basin with a half-graben structure, where a fault borders one side. Conglomerates, sandstones, siltstones, mudstones, and clay are among the several lithologies seen during the logging operation along the Kibuku roadcut. These differences in sediment types are a reflection of the basin's many habitats and depositional processes.

Lithofacies

Lithofacies classification is based on the lithology of the sediments. Four distinct lithofacies were identified in the field: sandstones, conglomerates, silts, and clays.

- **Sandstone;** The sandstones varry from poorly sorted to well sorted, with grain sizes ranging from fine to coarse. Their colours include white, grey, yellow, pink, and brown. The presence of gypsum indicates a semi-arid paleoenvironment, whereas the brown color indicates iron (III) oxide precipitation, indicating an oxidation environment. Paleocurrent flow direction may be inferred from the sands' angular and tangential strata, which are mostly dipping in the NW-SE direction.
- **Clays;** The clays range in color from dark green to brown and grey, and they are extremely fine-grained. While some clay deposits were discontinuous, others were durable and continuous. Beds range in thickness from a few centimeters to up to two meters. Blocky and massive clay beds suggest a low-energy lacustrine depositional environment, especially in the Kasande formation.
- **Silt;** These fine-grained sediments appear grey to white, with some yellow due to iron (III) oxide coating. They are well sorted and fine-grained, with thin, continuous beds showing low-scale cyclicity.
- **Conglomerates;** The conglomerates are poorly sorted, mostly brown due to iron-rich minerals, with a matrix-supported fabric of coarse sands and pebbles and cobbles. They form the contact between the basement and the sediments.

Biofacies.

A stratigraphic unit's biofacies are areas where the fossilized flora and animals are very different from those found elsewhere in the unit. Fossil assemblages are used to describe them. Biofacies in the Semliki Basin are remnants of preserved plants or animals. Fish bones, bivalves, and white oyster shells were discovered in Makondo, suggesting a freshwater lacustrine habitat. Plant roots, fossil wood, gastropods, and snail shells were among the other biofacies found in the Kisegi River channel.

4.3. Depositional Environments Summary.

Fossils provide critical clues about the depositional environment, as specific fossil occurrences are characteristic of particular environments and depth ranges. The Semliki Basin features clayey facies, fine to coarse sand facies, and conglomeratic facies.

Fluvial System; Fining-upwards sequences, point bar deposits at the Kisegi river channel, floodplain deposits of fine sediments, cross beds, meander channels in the coarse sands of the Kisegi formation, and water fossils like bivalves are used to explain these deposits. Local paleocurrent directions can be inferred from structures like as ripples and cross-beds. Sand and clay intercalations reveal shifts in the energy and environmental parameters of the depositional process. In floodplains, rivers deposit coarser materials during higher energy circumstances and clays and finer sands during low-energy or flood episodes.

Lacustrine Environment; A lacustrine depositional environment is indicated by thick clay layers and blocky sand layers. A delta may have served as a transitional zone during the change from fluvial to lacustrine. In certain areas of the Kibuku roadcut, coarsening ascending sequences suggest a deltaic environment.

Semi-arid Conditions; The presence of red sands and gypsum, associated with clays and sands, suggests semi-arid conditions. Gypsum results from high evaporation rates, and red sands result from iron oxide oxidation.

Therefore, the depositional environments in the Semliki Basin encompass fluvial, lacustrine, and deltaic systems.

CHAPTER 5. STRUCTURES.

5.1. Introduction.

Rock features known as geologic structures are created by a variety of mechanisms that impact sediments during deposition or by strong tectonic forces that occur within the earth after deposition and distort rocks. As rocks and sediments react to physical, chemical, and biological processes that tend to change, rotate, elevate, and internally twist them, structures are created. This can occur either during the development of the rock or during the deposition of the sediments, in which case it is referred to as primary structures, or it can occur after the formation of the rocks and the deposition of the sediments, in which case it is referred to as secondary structures. It can be stated that forces that tend to move and distort the rocks in a particular area of the earth will typically operate upon it (Bruce et al. 1976). The development of the structures is the outcome of the rock or sediments' reaction to these pressures.

This chapter focuses on the description of the various structures seen in both the basement rocks and the sediments in the area of study.

5.2. Structures in Basement Rocks.

5.2.1. Folds.

Figure 22. Shows an anticlinal fold, Plunge 39^{0}SW.

Figure 23. Shows a Synclinal fold, Plunge 28^{0}Sw.

Folds are most evident in the migmatites at Itojo (0191057,0094333; Elevation 1044m). They are primarily caused by intense geological processes such as high-grade metamorphism, extreme pressure, and partial melting. These rocks form in regions experiencing mountain-building events or tectonic activity, where deep crustal movements create complex deformation patterns. The outcrop is characterized by synclinal folds.

5.2.2. Joints.

Rock fractures, also known as joints, result from the brittle nature of rocks under stress. Due to both active tectonic processes and the rocks' natural brittleness, the basement rock in the research area is made of granite gneiss and has a high degree of jointing. There are two main types of these joints: non-systematic joints, which lack a uniform form, spacing, or orientation, and systematic joints, which exhibit a planar or parallel orientation and occur at regular intervals. By reducing stress and causing the rock to expand, exfoliation, caused by weathering and erosion of the overburden. These were found at the foot of mountain Rwenzori at the boundary between Fort Portal and Ntoroko District (0186953,0079664). Various joint sets exit in the rock and they preferentially break along foliation planes.

Figure 24. Shows are highly Jointed rock outcrop with various joint sets.

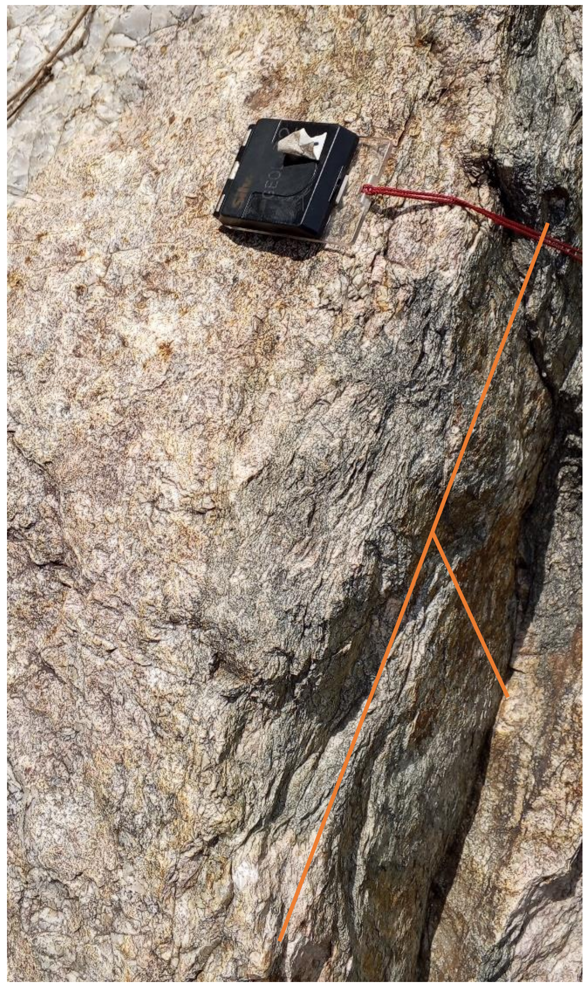


Figure 25. Shows a rock outcrop with exfoliated surface contributing to the jointing.

The dominant joint set trends in a northwest-to-southeast direction, dipping toward the northeast, while another set trends in a northeast-to-southwest direction, dipping toward the southeast. Notably, these joint surfaces align parallel to the foliation of the rock.

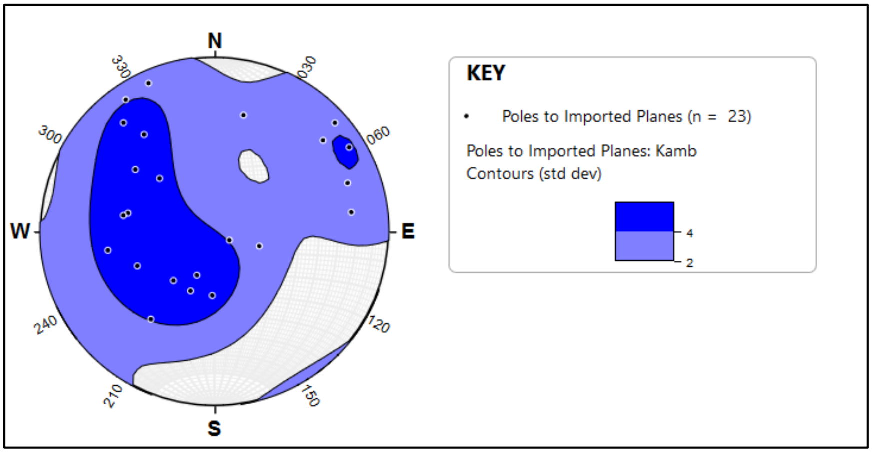


Figure 26. Shows the contour diagram for the joints.

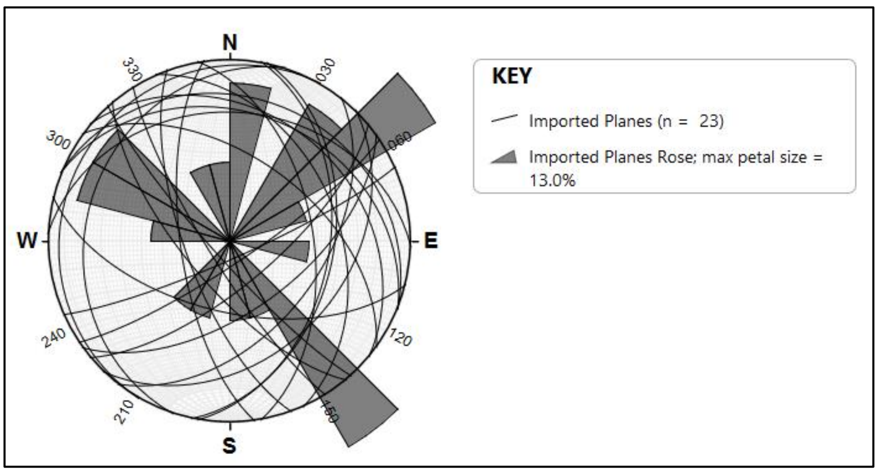


Figure 27. Shows the rose diagram for the joints with the major trend; NW-SE.

5.2.3. Foliation.

The granite gneisses of the Semliki basin exhibit foliation, which is defined by the parallel alignment of platy or elongated minerals in metamorphic rocks. Minerals align parallel to the direction of the shear force or perpendicular to the direction of high pressure as a result of directed pressure, shearing forces, or heat. Significantly, minor foliations trend in the NW-SE direction, reflecting the joint tendencies, while major foliations trend in the Northeast-South West direction. By taking advantage of weak points in the basement rock, a dolerite dyke may have intruded into the granite gneiss to generate the foliations that were seen.

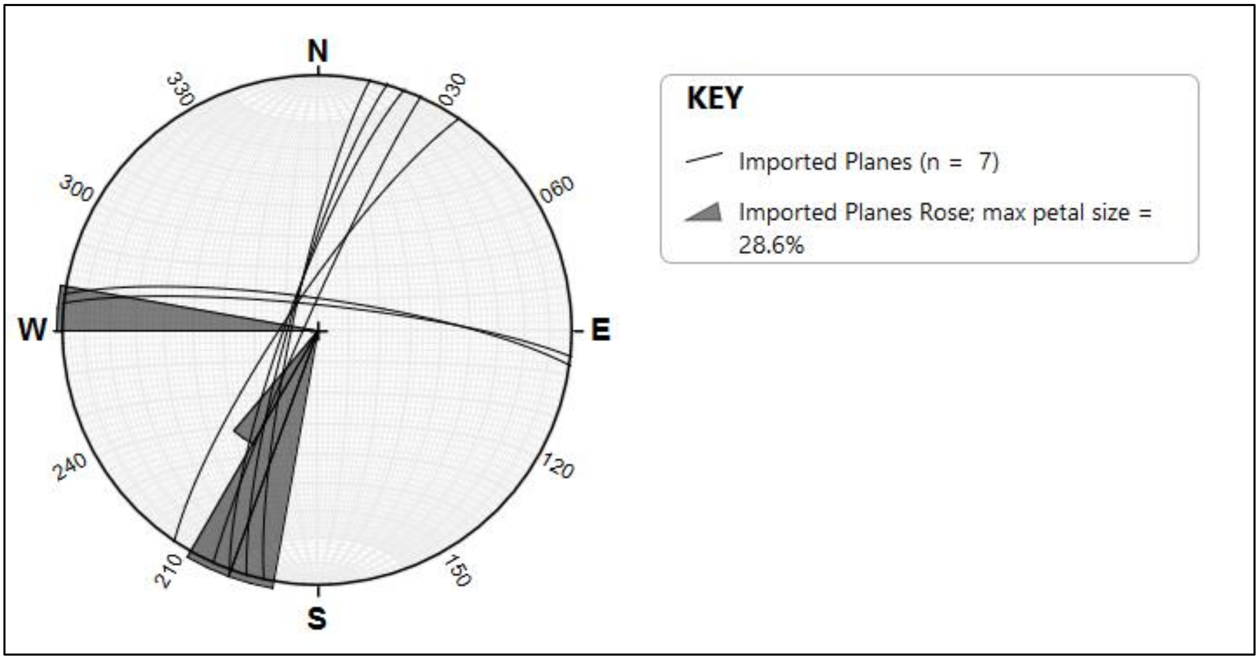


Figure 28. Shows the Rose diagram for foliation with major(NE-SW) and minor(NW-SE) trends.

Because of the tremendous heat carried by the igneous body, this intrusion caused shearing and differential mineral alignment in the granite. Quartz and the minerals mafic and felsic show clear elongation, creating a gneissic texture. Another event that contributes to the foliation within the dike is the intrusion itself, which exhibits foliation.

Figure 29. Shows a highly foliated rock outcrop with felsic minerals aligning in a certain direction.

Figure 30. Shows a fine grained originally dolerite dyke.

5.2.4. Faults.

Dip-slip normal faults, which are created by tensional forces impacting the area, are the most common type of fault in the Semliki basin. These faults, which include both large-scale and minor faults, are oriented mostly in the NE-SW direction. Their pattern is consistent with the larger fault pattern found in the Albertine rift. The Makondo fault, which lies between the Semliki flats and the Toro plains, and the steep fault escarpment to the southeast, which rises towards the northernmost point of the Rwenzori Mountains, are two of the main faults in the Semliki basin. Furthermore, two major normal faults that separate the Congo escarpment from the basin are the Semliki fault, which trends NNE-SSW, and the Bunya fault, which trends NE-SW.

The graben architecture seen in the basin was formed in part by these conjugate normal faults, which have identical dip magnitudes but opposing directions. The Kichwamba normal fault, which trends NE-SW with a Western dip, is particularly important in regulating the escarpment and affecting the drainage patterns in the region. It's important to note that these large faults frequently appear as shorter, discontinuous faults that somewhat deviate from the overall fault orientation. Their presence has a major effect on drainage patterns because water can erode the weathered and brecciated rocks along fault lines, creating seasonal streams and gullies.

5.3. Structures in Sediments.

In the sedimentary layers overlaying the basement rocks, a variety of primary and secondary structures were identified. Primary structures, reflecting the original depositional environment, comprised beds with various types such as cross-beds, tangential beds, tabular beds, and angular beds, along with laminations, unconformities, ripple marks, and mud cracks. These features provide insights into the sedimentary processes and conditions at the time of deposition. Additionally, secondary structures were present, including faults, veins, and joints, indicating subsequent tectonic activity and deformation in the sedimentary sequence. These structures collectively contribute to understanding the geological history and processes shaping the sedimentary basin over time.

5.3.1. Bedding.

Bedding refers to the layering observed within sedimentary deposits, resulting from variations in sedimentation patterns. These layers are characterized by differences in grain size, colour, texture, mineralogy, and thickness, reflecting changing environmental conditions during deposition. The types of beds formed are influenced by factors such as water depth, grain size, and current energy. Several types of beds were identified, including planar beds, cross-beds, and graded beds. In the study area, the predominant trend of bedding is oriented in a North East – South West direction, with a dip towards the South East direction from the rose diagram below.

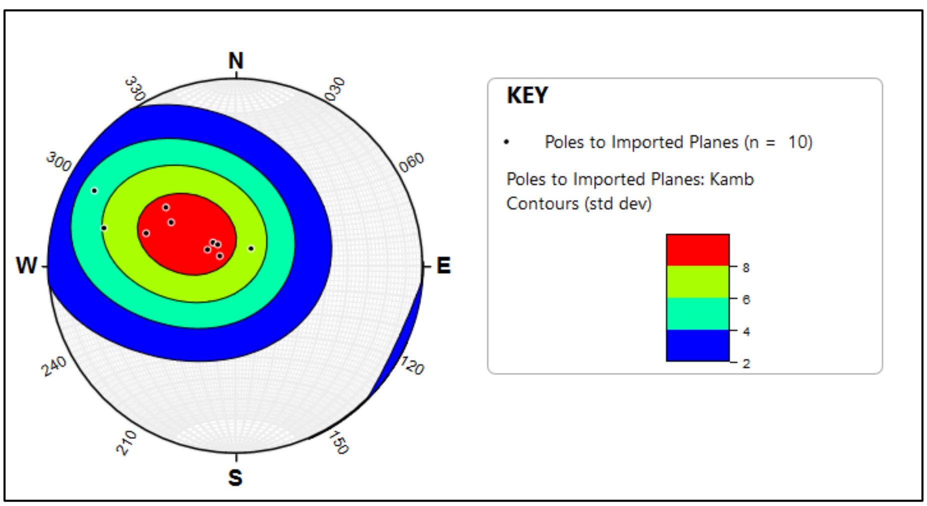


Figure 31. Shows a contour plot of the bedding measurements.

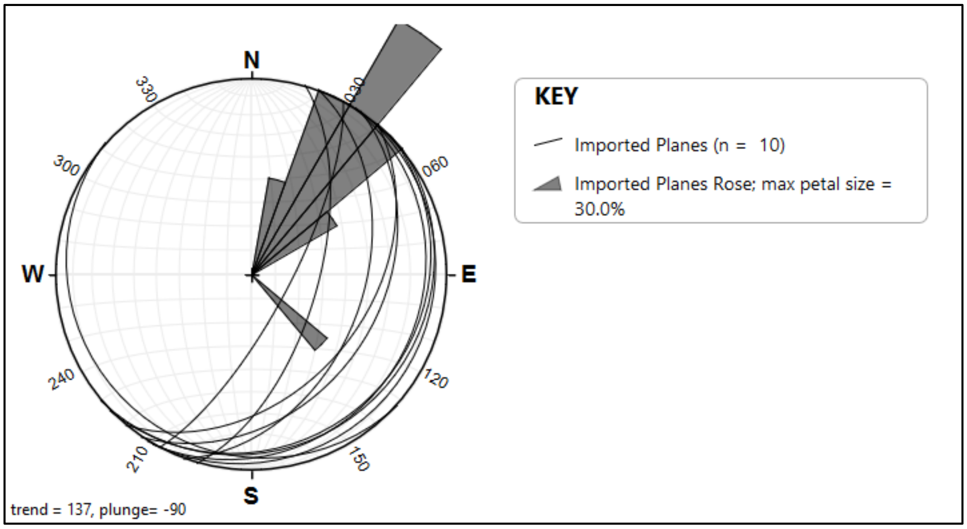


Figure 32. Shows a Rose diagram of the beds with the major trend; NE-SW.

Types of Beds Observed in the Field.

a) Planar bedding.

Planar beds were sedimentary layers that were usually deposited almost horizontally and had flat, parallel bedding planes. They developed when weak currents that were unable to move the incoming silt caused sediment to settle on a level surface. These beds had laminae of different thicknesses, which could be identified by variations in grain size and color.

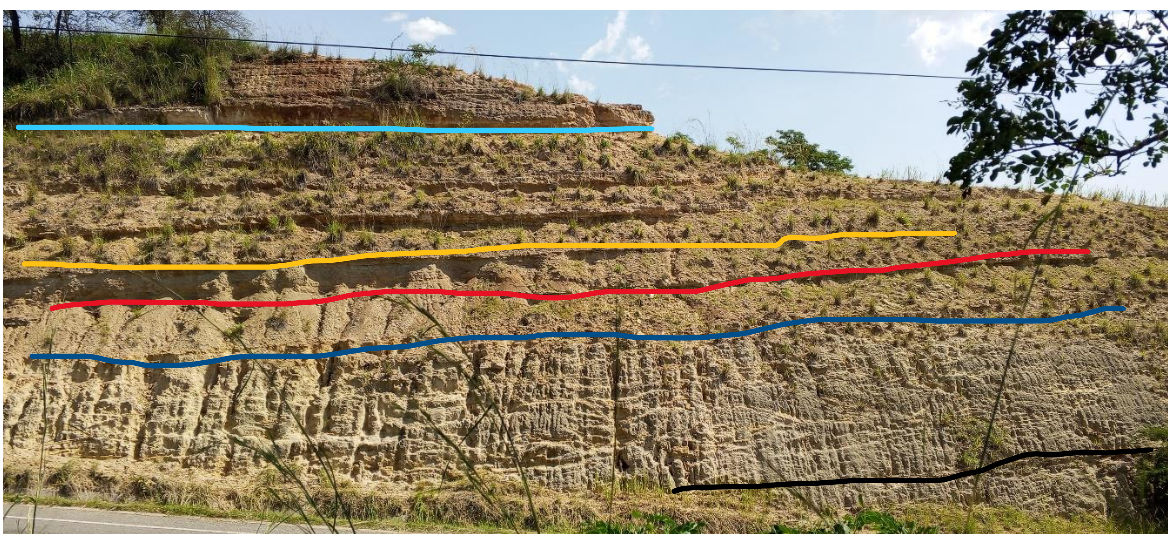


Figure 33. Shows planar bedding.

b) Cross bedding.

In geology, layering within a stratum that takes place at an angle to the main bedding plane is referred to as cross-bedding, also called cross-stratification. As a result, units made up of inclined layers are roughly horizontal. When bedforms like ripples or dunes move downstream in a flowing fluid, such water or wind, cross-bedding occurs. Sand grains gradually slide down the downstream side of the bedform due to gravity as they travel up the upstream side and gather at its apex. The layers dip in the direction of the paleocurrent flow when this process is repeated, resulting in cross-bedding.

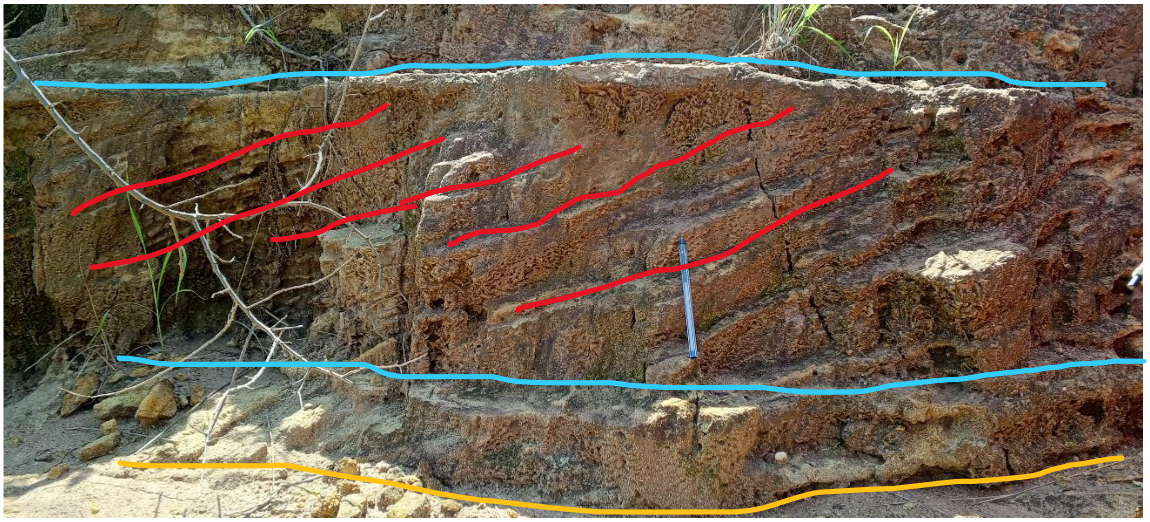


Figure 34. Shows cross bedding in a sandstone.

5.3.2. Laminations.

Laminations are thin sedimentary layers that are frequently seen in fine sand deposits. They are usually less than 10 millimeters thick. They arise when fine-grained particles settle from suspension in calm water conditions, including deep lacustrine settings, and are caused by cyclical changes in the supply of sediment. These layers are distinguished by their parallel or angled features and have a finer scale than bedding layers. Grain size variations, size grading within layers, and compositional changes between neighboring layers can all result in laminations. Laminations, which depict the minute internal structures within sedimentary strata, were mostly found in clays and silts in the field.

Figure 35. Shows Laminated silt and clay layers.

Figure 36. Shows laminated sandstone with micro faults.

5.3.3. Mud Cracks.

When water-rich sediments dry out from extreme heat, the mud cracks forming polygonal forms with concave upward surfaces. The Kisegi seasonal river flood basins exhibited these characteristics. Mud cracks are important for figuring out the stratigraphic up-direction because the tapering end represents the direction of rock maturity, while the concave side shows the direction of younging. Mud that has been dewatered and exposed to air develops these polygon-shaped fissures. Mud fissures are helpful as geopetal constructions because they curve upward. Mud cracks in the clays in the research region indicate that the lake that deposited the clays dried up, exposing the sediments to the atmosphere.

And also they were attributed to the lacustrine environment which was discussed at the location (201131, 110298; Elevation 681m) found associated with fossils like mollusks and bivalves where the formally lake Obweruka was and currently part of lake Albert.

Figure 37. Shows mud cracks found with in fine grained clay sediments.

5.3.4. Ripples

On the surfaces of sediments, ripple marks are tiny, wavy ridges and troughs created by wind or water flow. Geologists employ these bedforms, which function as nature's tape recorders, to map the Earth's paleogeography, reconstruct ancient ecosystems, and ascertain the direction of prehistoric currents. These were observed at the River Semliki Channel and they are used to depict the direction of flow of the river.

Figure 38. Shows ripple marks formed at river semliki.

6.0. Geophysics And Geothermal Exploration of The Semliki Sedimentary Basin.

6.1. Introduction.

By examining changes in the physical characteristics of rocks, geophysics uses the concepts of classical physics to investigate the Earth's interior. Certain rock qualities are correlated with different geophysical methods: resistivity or electromagnetic (EM) methods to electrical conductivity, gravity methods to density, magnetic methods to magnetic susceptibility, and seismic methods to velocity and density. These techniques can be passive (such as gravity, magnetic, and radiometric) or active (such as seismic and electrical), with the latter producing more intricate subsurface images at a higher cost.

With an emphasis on the assessment of the petroleum system in the Albertine Graben, a number of geophysical studies have been carried out in the Semliki Basin with the goal of deciphering its structure and geological configuration. Using the Oasis Montaj software, maps of Bouguer anomaly and magnetization intensity were created using gravity and aeromagnetic surveys carried out over a 9578 km^2 area between 1999 and 2002. The Makondo Fault was first identified in 1983 by Kenting Earth Sciences' airborne magnetic surveys. This identification was further supported by 1998 seismic data showing a NE-SW strike and a folded hanging wall with a positive flower structure.

The focus was on evaluating and connecting previous data of the Semliki Basin and Gulf of Mexico, including seismic sections, gravity and magnetic maps, and petrophysical data from the Turaco well, even though no new data acquisition took place during recent fieldwork due to equipment limitations. These datasets aided in formation appraisal and facies correlation, which are crucial for comprehending subsurface structures and hydrocarbon potential.

6.2. Potential Field Survey Methods.

Gravity and magnetic techniques used in geophysical research in the Semliki Basin are collectively referred to as potential field surveying techniques because they make use of the earth's naturally existent gravitational and magnetic fields.

The Earth's gravitational field's spatial and temporal variations are determined by gravimetry, whereas the magnetic field's equivalent variations are determined by magnetometry. Geophysicists can understand the geometry of subsurface rocks by using these methods to define single field elements or total field values. In order to facilitate structural and resource mapping of the basin, the data is used for the identification and mapping of geological anomalies, depth, size, and coverage of subsurface structures, qualitative description, and quantitative estimation of anomaly sources, such as density and geometry.

6.2.1. Gravity data interpretation for Semliki Basin.

Understanding underlying geological features is greatly aided by gravity survey techniques that make use of the Bouguer anomaly. The Bouguer anomaly is computed by adjusting the measured gravity values for the survey area's topographic relief, elevation, and latitude. This adjustment makes it possible to read the gravity data more clearly by eliminating the gravitational effects brought on by variables other than underlying geology. Negative Bouguer anomalies point to regions of lesser density, such as sedimentary basins or empty spaces, whereas positive anomalies show regions of higher-density rocks, such as igneous intrusions or mineral deposits. Geophysicists can better comprehend the geological history of the examined area, discover possible mineral or hydrocarbon reserves, and delineate subsurface structures by examining these anomalies.

A Bouguer anomaly map of the gravity data of the Semliki basin was generated using Geosoft Montaj software.

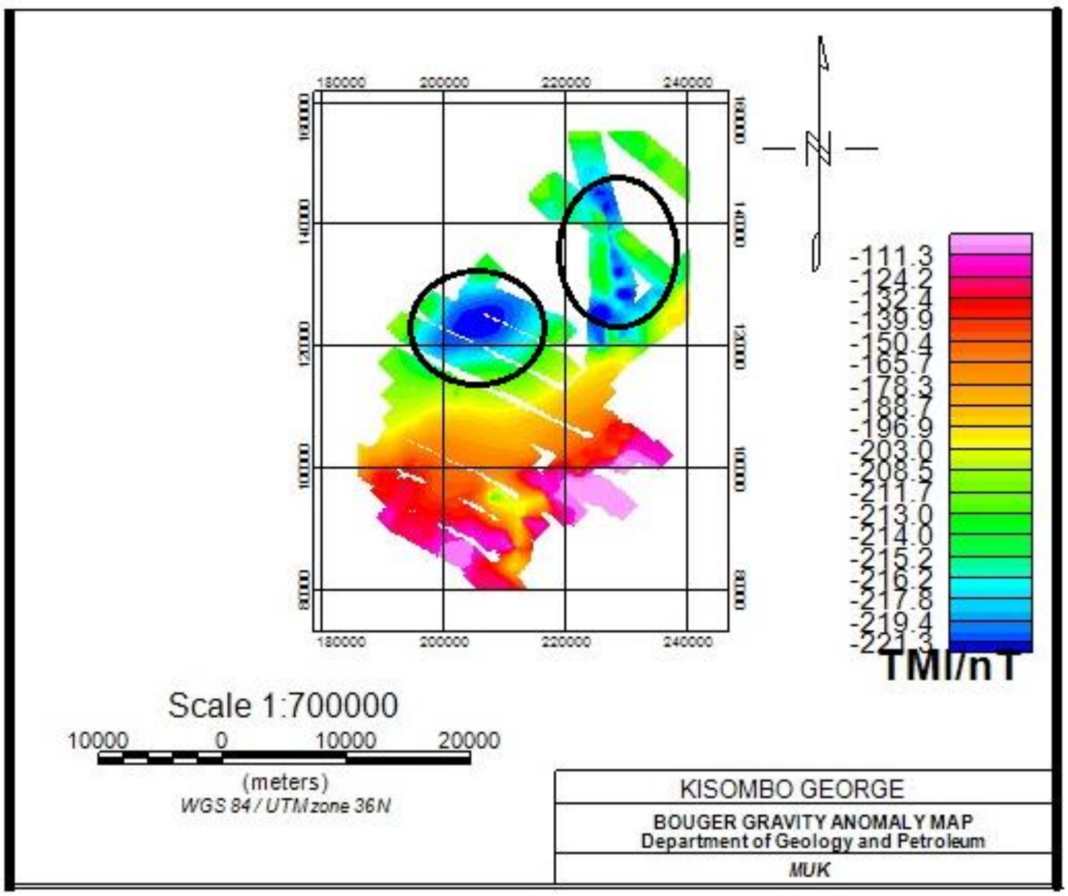


Figure 39. Shows the Bouguer Gravity anomaly map of semliki basin.

As a result, Semliki's northeastern (usually northern) portion is deeper than the basin's southern portion. This indicates that the deeper areas had more sediment accumulation than the shallower areas. As a result, the Semliki basin is asymmetrical, with the deeper portions located on the northern portion—more precisely, the northeastern portion, which is on the DRC side. Because the side with the principal controlling fault is usually deeper than the opposing side, this layout is typical of half grabens. The typical gravity anomaly values in the center of the Semliki basin suggest that the sediment thickness is likewise average. The gravity anomaly exhibits smaller negative values (-111 mgals to -203 mgal) in the southern portion of the basin. In comparison to other areas of the Semliki basin, this section is the shallowest.

Because different areas of the Semliki basin have varying silt deposit thicknesses, the gravity anomaly varies throughout the basin. In contrast to the deeper portions of the basin, where the basement rocks that would yield high values are deeply buried by the thick sediment accumulation, the areas with less negative values have the thinnest sediments, making the basement rocks that produce high gravity anomaly values relatively close. Low gravity anomaly findings indicate low density rocks, which are undoubtedly sediments with potential hydrocarbon accumulations or entrapments. The variety in depths (accommodation space) in the various basin sections caused the variability in sediment accumulation thickness.

6.2.2. Magnetic Data Interpretation of the Semliki Basin

Geophysical techniques called magnetic surveys are used to find differences in the magnetic susceptibility of underlying rocks that result in anomalies in the Earth's magnetic field. These surveys provide vital information about the composition and structure of the Earth's crust by assisting in the determination of the geometry, depth, and magnetic characteristics of rock formations. On maps, magnetic anomalies deviations from the local magnetic field are usually displayed to draw attention to subsurface features.

The quantity of magnetic material and its distance from the sensor both affect how strong the observed magnetic signal is. The strongest magnetic responses are produced by basic igneous rocks, weak signals are produced by sedimentary rocks, and intermediate readings are produced by acidic gneisses and metamorphic rocks. Geosoft Oasis Montaj software was used to evaluate magnetic data for the research region, facilitating geological and resource exploration and helping to identify underlying structures.

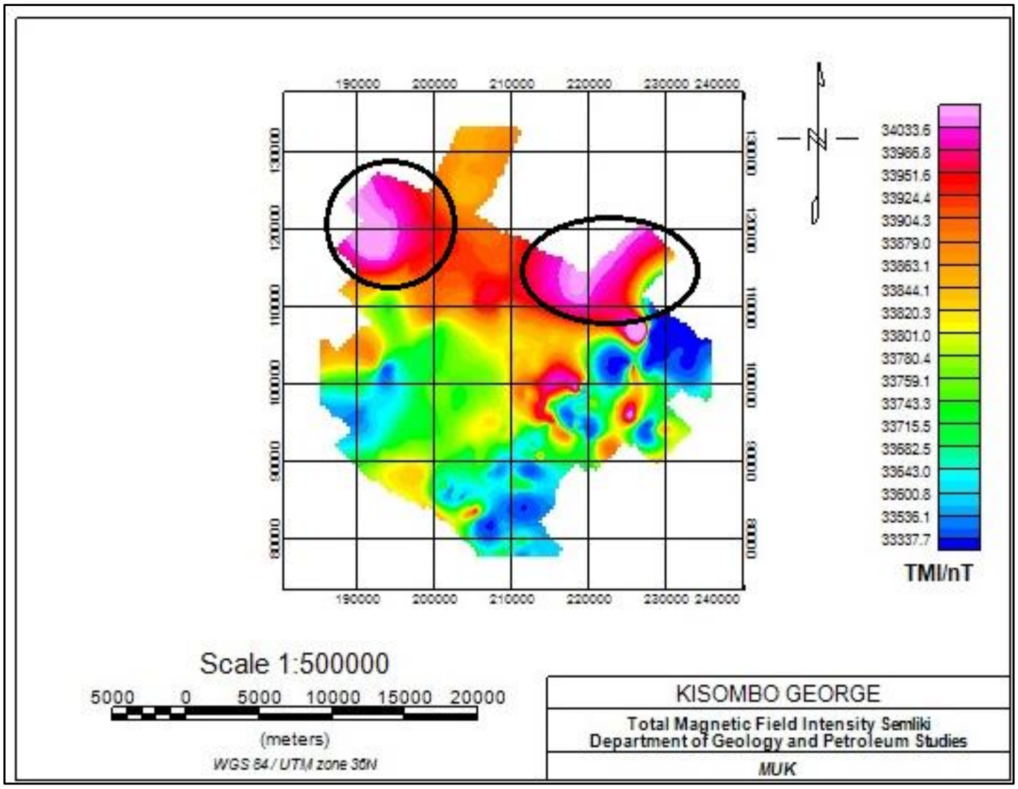


Figure 40. Map Shows the Total Magnetic Intensity of Semliki basin.

The northern portion of the Semliki Basin exhibits strong magnetic field intensities (pink to yellow) on the magnetic anomaly map, with values ranging from 33844.1 to 34033.6 nT, suggesting the existence of igneous basement rocks with high magnetic susceptibility. The high gradients that surround these regions indicate that the magnetic sources are close to the surface, most likely indicating the basin's edge. On the other hand, the southern region has low magnetic intensities (green to blue, ranging from 33643.0 to 33337.7 nT), which correspond to sedimentary rocks with low remnant magnetization. The sudden change in magnetic susceptibility or magnetite content required to produce the observed magnetic anomalies may be caused by the enormous transition from sedimentary to igneous rocks.

The magnetic interpretation is predicated on the following presumptions:

- Rocks that produce anomalies are magnetized in the earth's field and are magnetically homogenous.
- The rock masses that cause anomalies have an unlimited deep extension, a level surface, and vertical sides
- Contrasts in magnetic susceptibility cause anomalies of considerable amplitude and wide areal extent (topographic relief of a magnetic rock unit typically creates relatively small amplitudes of anomalies).
- There is very little remnant magnetization in the direction of the earth's field.

6.3. Seismic Surveys.

According to Mondol and Bjørlykke (2010), seismic investigation is unquestionably the most significant of all geophysical exploration techniques, mainly due to its ability to identify both large-scale and small-scale subsurface structures. By examining the return of sound waves that have passed through the earth, seismic techniques aid in predicting the forms and physical characteristics of the Earth's underlying layers. In order to obtain important information about the composition and structure beneath the surface, a seismic pulse is created from a source at or close to the Earth's surface. The amplitudes and travel times of the waves are then recorded as they reflect or refract off various subsurface layers.

Numerous variables, including sedimentary facies and structural traits, can be identified by interpreting the acquired seismic data. Seismic data interpretation in the Semliki Basin study depended on information obtained by ExxonMobil from the Gulf of Mexico and the basin in the Albertine Graben. Analyzing the sedimentary facies found in these two locations' subsurface was the main goal.

6.3.1. Results of seismic interpretation of structures for the Semliki Basin.

Random Line 1

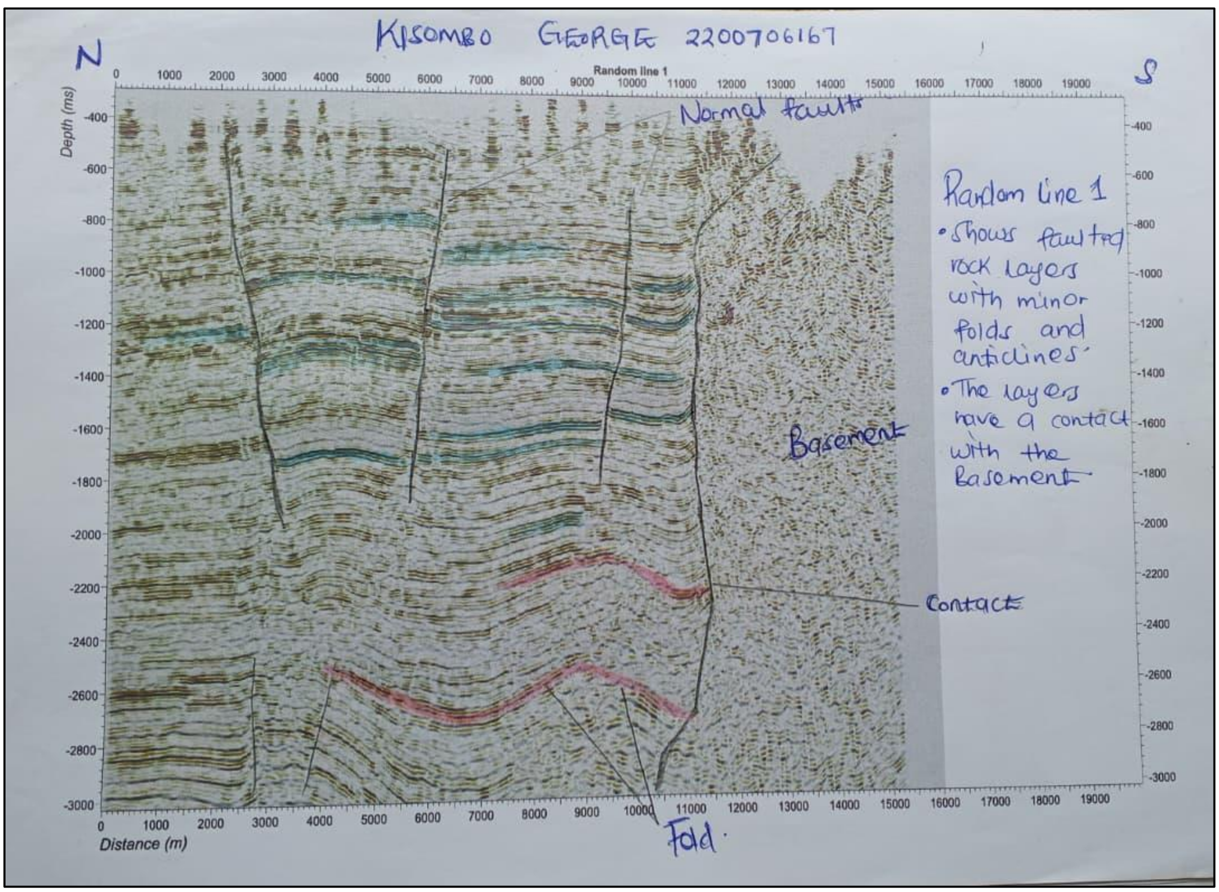


Figure 41. Seismic section of Random line 1.

Random Line 2

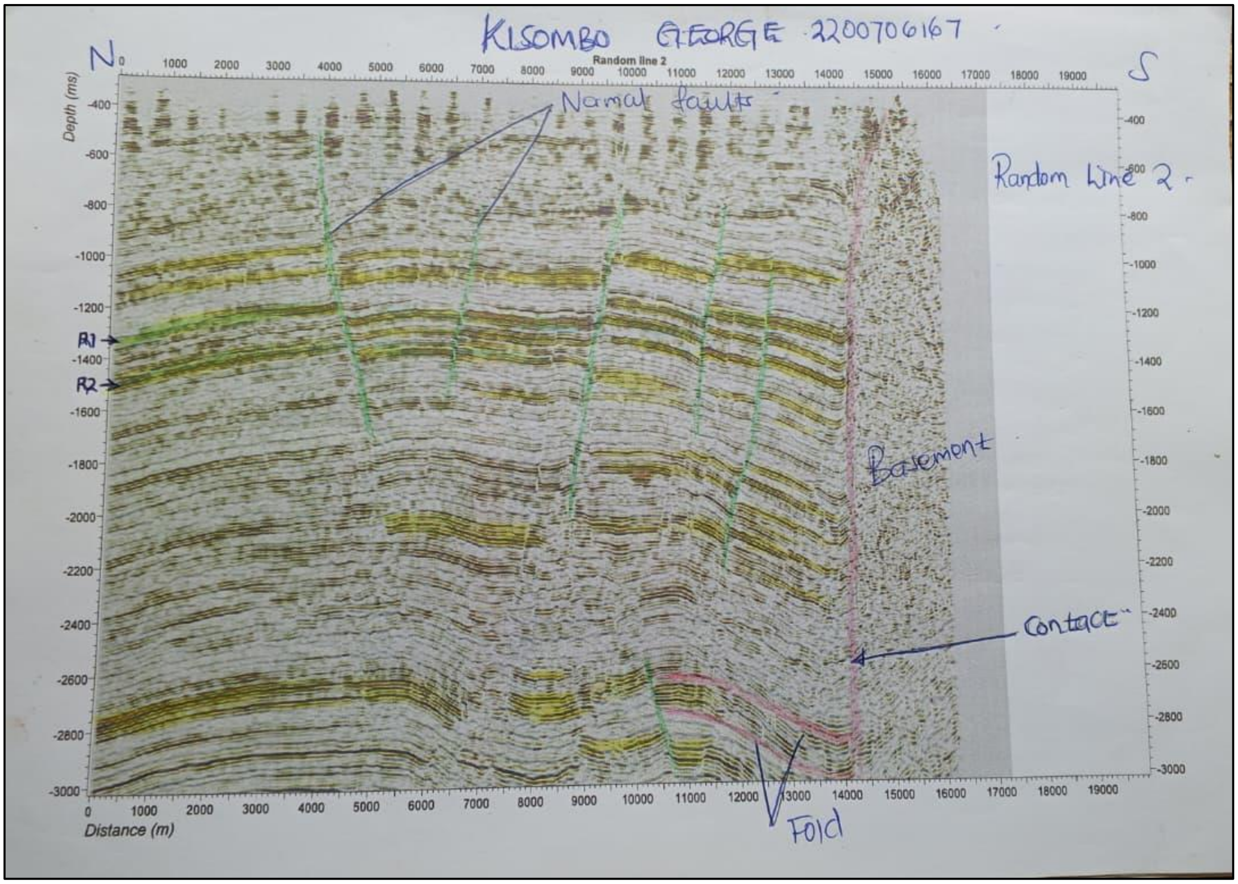


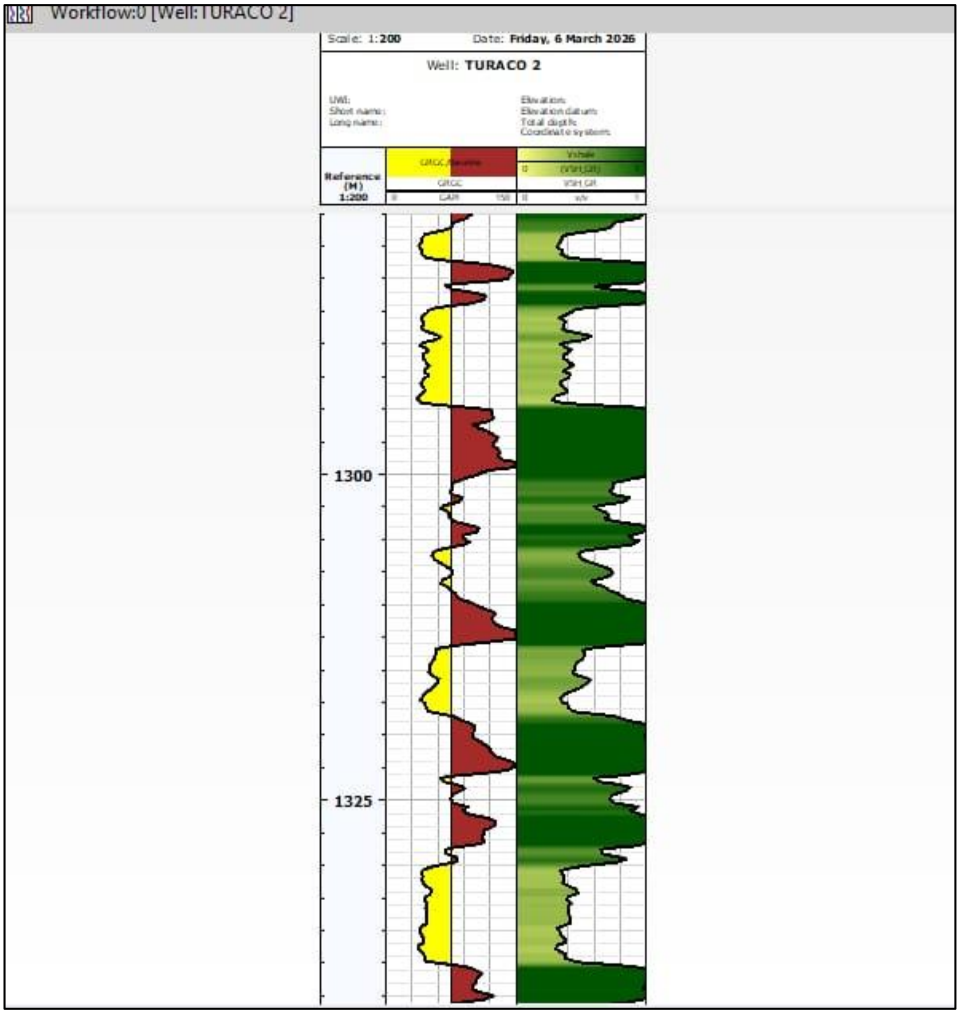
Figure 42. Shows seismic section for random line 2.

Two different sedimentary facies were determined by analyzing the available seismic pictures. Green is the distinguishing feature of the first facies, whereas yellow is the characteristic of the second. Thick, high-amplitude seismic reflections define the first facies, which are probably a sign of a lithology of sandstone. On the other hand, clay or shale deposits may be represented by the second facies, which is characterized by thinner low-amplitude reflections and a yellow hue. A unique depositional framework is also suggested by the first facies' uninterrupted seismic reflections that end against an overlapping surface. Different depositional settings may be indicated by variations in the facies. Sands were deposited during sea level decrease (regression), whereas fine grain facies (shales and clays) were deposited during sea level rise (transgression).

6.4. Petrophysics for Formation evaluation.

The study of rocks' chemical and physical characteristics as well as how they interact with the liquids they contain is known as petrophysics. Converting well log data into important reservoir characteristics like porosity, permeability, and hydrocarbon saturation is the main objective of petrophysical well log analysis. Density, neutron, and gamma ray logs were used in this study's formation evaluation. To estimate the amount of shale in the formations, the volume of shale (V-shale) was also computed.

6.4.1. Results of Wireline logging study for Turaco 1, 2 & 3.



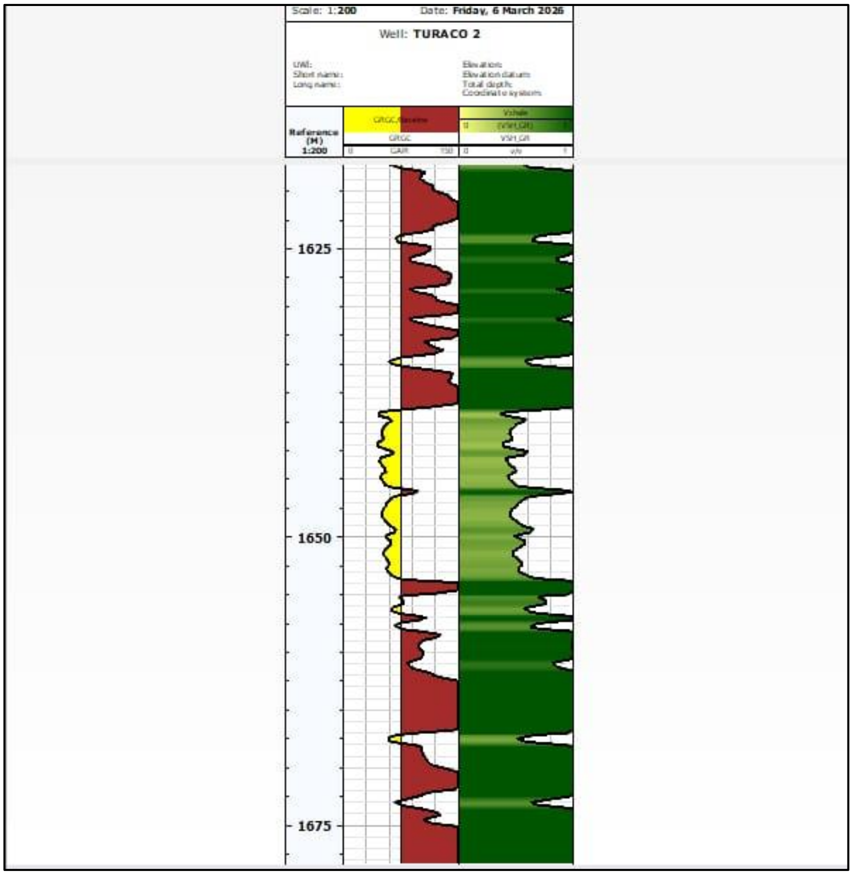


Figure 43 Turaco 2 well logs for shale volume computation.

- **Gamma Ray Log.**

Shales, which contain a variety of radioactive minerals, including potassium, are indicated by high gamma ray readings. On the logs, these high readings are indicated by brown color zones. On the other hand, clean sands and carbonates are indicated by low gamma values, which are indicated by yellow color zones. For instance, low gamma measurements between 1640 and 1655 feet indicate the existence of clean sands.

Because they include radioactive minerals, shales have high gamma ray readings, whereas sands have low gamma readings because they don't contain radioactive materials. A negative reading or mud cakes that develop as a result of the interaction of drilling and reservoir fluids are common indicators of the existence of a reservoir.

The high gamma values from the gamma-ray log clearly show that the Turaco well encountered mostly shaly strata. This implies that the well probably reached the Kasande, Oluka, and Nyakabingo formations, which are known to have substantial shale and clay contents in the Semliki Basin.

- **V-Shale.**

The volume of shale in a formation can be determined using the gamma-ray log. Low volumes suggest that there is less shale in the formation, making it more porous and conducive to the presence of hydrocarbons, particularly water and oil. The V-shale log is obtained from the Techlog software using the in-built calibration and can also be calculated manually from the equation;

$$V_{shale} = \frac{GR_{log} - GR_{min}}{GR_{max} - GR_{min}}$$

Where;

GR_{log}; is the gamma-ray log reading at the point of interest,

GR_{max}; is the gamma-ray reading for shale (maximum gamma-ray value),

GR_{min}; is the gamma-ray reading for clean sand (minimum gamma-ray value).

In summary, low Vshale values suggest higher porosity and potential hydrocarbon zones within the formation and high Vshale values are indicative of an organic matter rich source rock from which hydrocarbons can be generated.

- **Neutron-density Logs.**

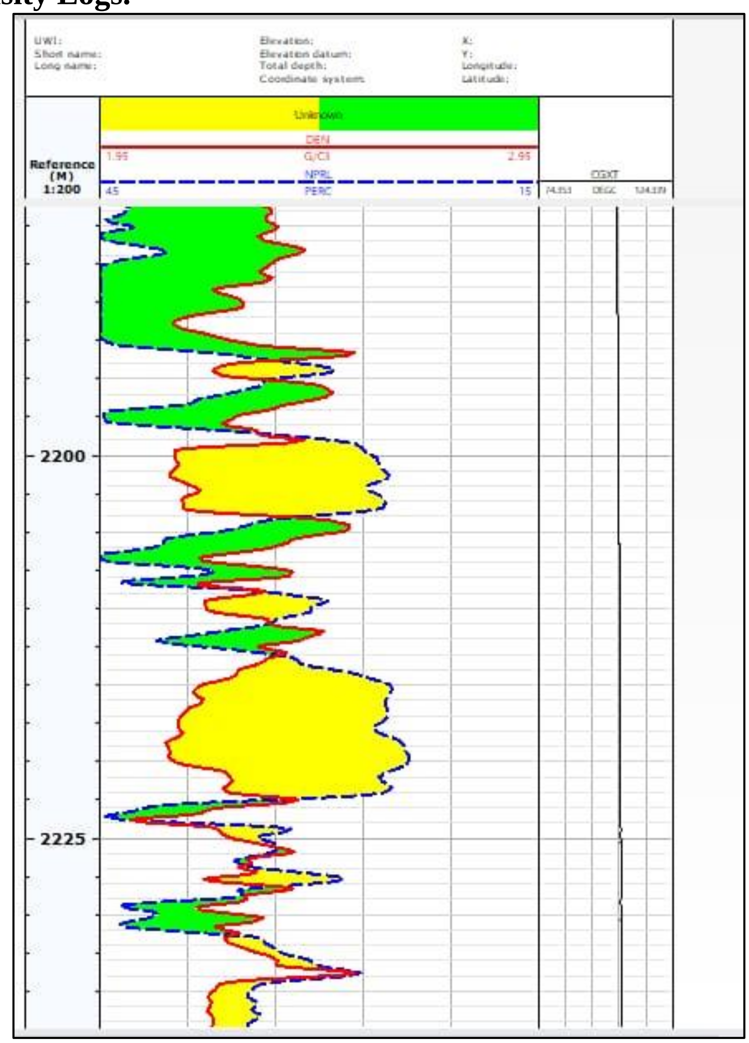


Figure 44. Turaco well 2 Neutron and density log with a hydrocarbon interval; 2200-2225m.

The logs are used to measure the porosity of the formation, with the density log (red line) measuring the electron density of the formation, and the neutron porosity log (blue dashed line) measuring the hydrogen concentration. When the density log is to the right and the neutron log to the left, the formation is shale.

If the logs cross over with the density log on the left and the neutron log on the right, this indicates an oil and gas-filled sand. When the two logs track each other, the formation is either a wet sand or oil sand. The observed log section suggests that the formation contains more gas than oil. Low neutron log readings indicate the presence of gas due to its low hydrogen concentration compared to oil or water. Thus, a wide separation of the two logs signifies gas presence, while superimposed logs indicate oil or water. The Turaco 2 well data shows more gas than oil, which may not be economical for companies primarily interested in oil extraction. The high amounts of gas present can be attributed to type of organic matter origin and thermal cracking attribute to increased temperatures.

From the figure above, the depth interval 2200 to 2225m, is generally a gas zone from the large size of the crossover and the sharp decrease in the density values and the decrease in the neutron values while from the figure below an oil zone is observed at the interval 2800 to 2825m due to the small crossover.

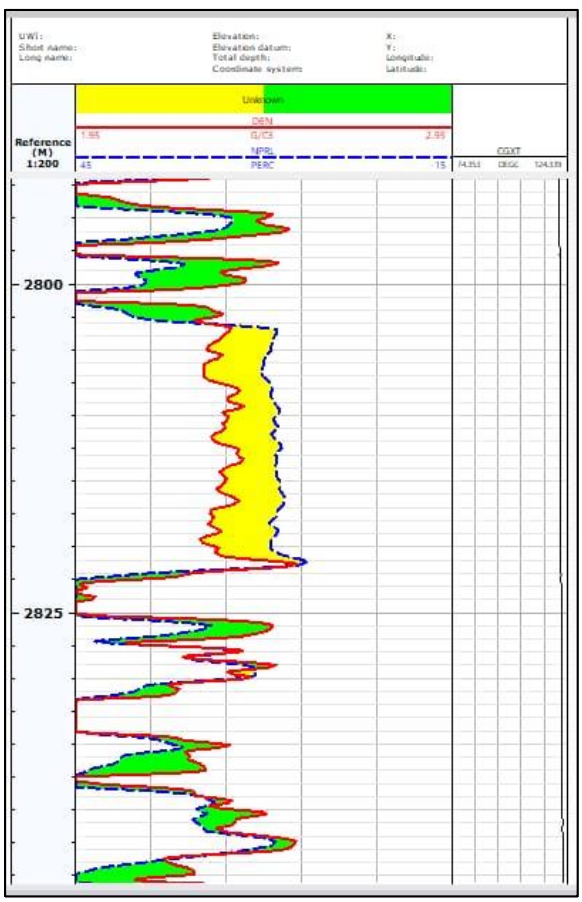


Figure 45. Turaco well 2 Neutron and density log with a hydrocarbon interval; 2800-2825m.

6.5. Results from the field visit to Turaco drilling Site.

Over the years, numerous drilling attempts have been made at the Turaco well site, which is situated on the Makondo fault's hanging wall. According to earlier research, the three Turacos (Turaco 1, 2, and 3) were the second group of wells dug in the Albertine Graben following the Butiaba-Waki well. Driven by surface oil seeps, the Butiaba-Waky well in 1937 marked the beginning of drilling in the Albertine Graben. After seismic investigations, Turaco wells were later drilled.

- Turaco 1 (199706,113822); started September 2002 to January 2003, while in march 2003, drilling was suspended due to loss of drilling pipes probably caused by differential pipe sticking in shales. Depths upto 2.5km were drilled to a target of a Kisegi sandstone which was expected to be a potential reservoir.
- Turaco 2 (199740,113753); This was drilled about 10 metres from Turaco 1 to a depth of about 2.962km. This well was started in 2002 with oil shales but was not tested, and it was found that the oil was mixed with carbon dioxide.
- Turaco 3 (199763,113762); Drilled 200 metres apart from Traco 2 and was found to contain hydrocarbons which were contaminated by carbon dioxide probably generate due to thermal cracking of the hydrocarbons in the presence of oxygen to generate high amount of carbon dioxide.

6.6. Results from the study of methods for geothermal exploration.

Situated in the Albertine Graben's Semliki National Park, the Sempaya hot springs are an amazing natural occurrence. These hot springs are an interesting aspect of the terrain, located about 40 kilometers from the Democratic Republic of the Congo (DRC) border. The East African Rift System, where the Earth's crust is being torn apart to allow geothermal energy to reach the surface, is the source of the hot springs. This subterranean heat, which can also affect the maturation of hydrocarbons, is demonstrated by the bubbling springs and mud pots.

The Geothermal System consists of a heat source, reservoir (where water/steam collects), and fluid pathways. The indicators of a geothermal system include; fumaroles, geysers, travertine deposits and hotsprings which were observed in the study area (male and female Hotspring).

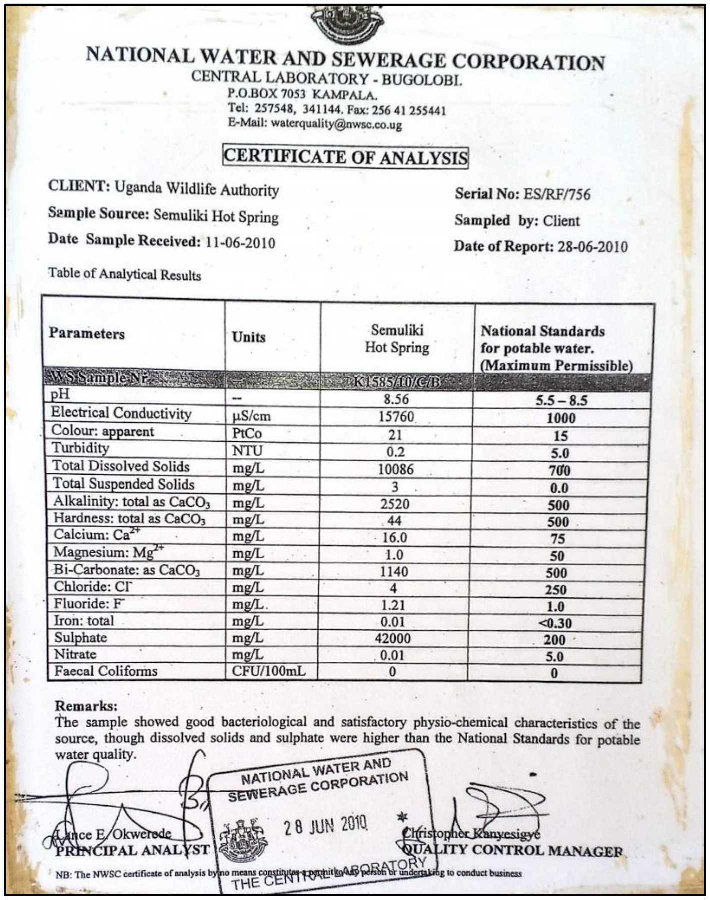
Figure 46. Shows the male hot spring.

Figure 47. Shows the female hot spring.

Geothermal exploration in the Semliki Basin relies on an integrated, phased approach combining surface studies, geophysical surveys, and exploratory drilling to map the region's fault-controlled geothermal systems. Sempaya Hot Springs (with temperatures >100^0C) act as the primary guide for identifying subsurface heat sources and structural conduits.

The main exploration methods used in the basin include:

- **Geological & Structural Mapping:** Field geologists map stratigraphy, fault lines, and fracture zones, focusing on the boundary faults of the East African Rift System that allow deep meteoric water to circulate and get superheated. And during field mapping exercise, important geothermal features can be identified for example; alteration zones that include, Argillic, illitic, propylitic, and thermometamorphile zones.
- **Geochemical Analysis:** Scientists sample fluid and gas emissions (such as the sulfur-rich waters at Sempaya) to determine the chemical composition through geochemistry studies and estimate deep reservoir temperatures through geothermometry. The source of ions in the hotsprings were attributed to, WRI (water rock interactions), Calcium carbonate, Carbon dioxide of magmatic origin and H_2S also from magma. Some geochemical analysis has been carried out by the National Water and Sewerage Corporation as shown below.



NATIONAL WATER AND SEWERAGE CORPORATION
CENTRAL LABORATORY - BUGOLOBI.
P.O.BOX 7053 KAMPALA.
Tel: 257548, 341144. Fax: 256 41 255441
E-Mail: waterquality@nwsc.co.ug

CERTIFICATE OF ANALYSIS

CLIENT: Uganda Wildlife Authority
Sample Source: Semuliki Hot Spring
Date Sample Received: 11-06-2010

Serial No: ES/RF/756
Sampled by: Client
Date of Report: 28-06-2010

Table of Analytical Results

Parameters	Units	Semuliki Hot Spring	National Standards for potable water. (Maximum Permissible)
WS Sample Nr.	--	K1585/10/C/B	
pH	--	8.56	5.5 – 8.5
Electrical Conductivity	µS/cm	15760	1000
Colour: apparent	PtCo	21	15
Turbidity	NTU	0.2	5.0
Total Dissolved Solids	mg/L	10086	700
Total Suspended Solids	mg/L	3	0.0
Alkalinity: total as $CaCO_3$	mg/L	2520	500
Hardness: total as $CaCO_3$	mg/L	44	500
Calcium: Ca^{2+}	mg/L	16.0	75
Magnesium: Mg^{2+}	mg/L	1.0	50
Bi-Carbonate: as $CaCO_3$	mg/L	1140	500
Chloride: Cl^-	mg/L	4	250
Fluoride: F^-	mg/L	1.21	1.0
Iron: total	mg/L	0.01	<0.30
Sulphate	mg/L	42000	200
Nitrate	mg/L	0.01	5.0
Faecal Coliforms	CFU/100mL	0	0

Remarks:
The sample showed good bacteriological and satisfactory physio-chemical characteristics of the source, though dissolved solids and sulphate were higher than the National Standards for potable water quality.

NATIONAL WATER AND SEWERAGE CORPORATION
28 JUN 2010
THE CENTRAL LABORATORY

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NB: The NWSC certificate of analysis by no means constitutes a permit to any person or undertaking to conduct business

Figure 48. Shows some of the results obtained from the geochemical analysis of the water by NWC.

- **Geophysical Surveys:** Magnetotelluric (MT) and transient electromagnetism (TDEM) methods measure electrical conductivity to map deep, sub-vertical fault networks and potential clay caps. Additionally, gravity and magnetic surveys identify basin depocenters and basement structures.

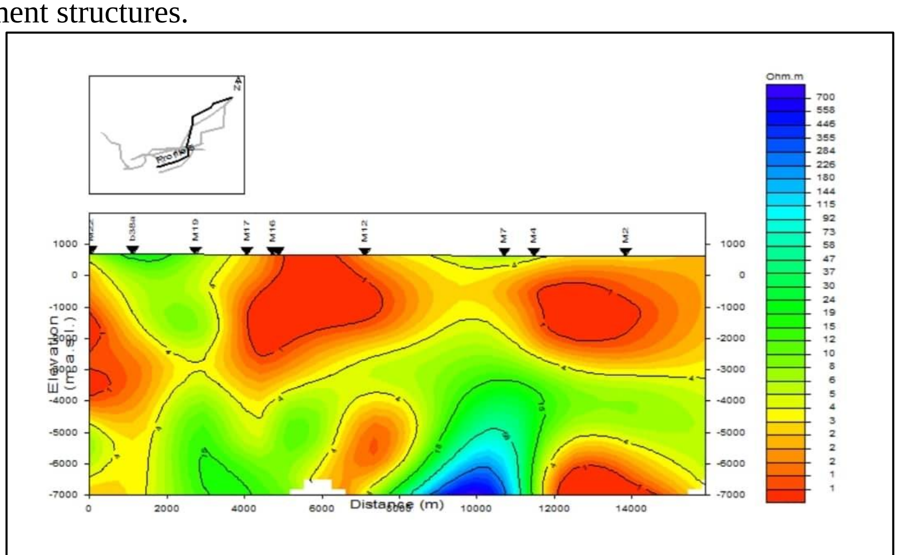

Figure 3.2: MT Resistivity cross-section SW-NE

Figure 49. Shows MT Resistivity Cross-section.

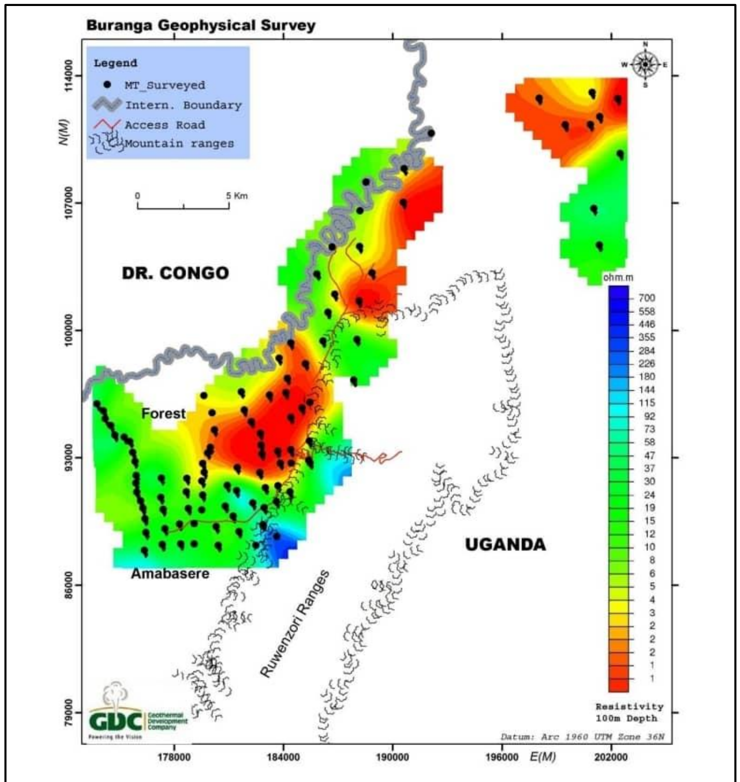

Figure 3.3: Resistivity map at 100 m depth.

Figure 50. Shows the Buranga Resistivity map

- **Temperature Gradient Drilling:** Shallow temperature gradient holes (TGH) are drilled to measure the local thermal gradient (which can exceed (67^0C/km) in the basin) and confirm shallow heat flow before committing to expensive deep drilling. Some geothermal exploration wells drilled in the past were present these could have been drilled to establish the temperature gradients.

Figure 51. Shows the geothermal exploration wells drilled in the past.

CHAPTER 7. DISCUSSION

7.1. Facies and Depositional Environments.

Both clastic and non-clastic materials produced in lacustrine, deltaic, and fluvial environments make up the sediment deposition in the Semliki Basin. The basin, which is part of the East African Rift System's western branch, has a complicated geological structure. Faulting on one side defines the half-graben configuration of this rift basin. A range of rock types, including sandstones, siltstones, mudstones, and clay, are revealed by lithological observations from the Kibuku roadcut. These observations show the impact of the various depositional processes and environmental conditions within the basin.

The Semliki Basin is covered in lacustrine sediments, which are primarily composed of sandstones interbedded with claystones and siltstones. Evaporites like gypsum and invertebrate fossils like freshwater mollusks support the idea of a lacustrine environment. Calm water conditions that permit fine sediments to settle and collect are characteristic of lacustrine environments. Gypsum, an evaporite mineral, is found in semi-arid environments with significant evaporation rates, indicating times when rivers or lakes were drying up. Deltaic deposition, which serves as a transitional area where river silt is deposited before it reaches the lake, frequently occurs during the transition from fluvial to lacustrine ecosystems.

The occurrence of fine sediment loads, such as mud diapirs, fine sand, and silts, which frequently show a coarsening upward sequence in sandstones, suggests deltaic conditions in the Semliki Basin. These sequences show how the energy and sediment supplies have changed throughout time. The sandstone strata exhibit both coarsening and fining upward patterns, which indicate periods of retreat and transgression, respectively. A fining upward sequence results from fine sediments being deposited atop coarser ones during transgressions as sea levels rise. On the other hand, a coarsening upward sequence occurs during regressions when sea levels drop and coarse sediments are deposited over finer ones.

The Semliki Basin had a tectonically active environment during sediment deposition, as evidenced by the existence of deformational structures like joints and faults within the sedimentary layers. By altering sediment movement and deposition patterns as well as providing room for sediments to collect, tectonic activity can have an impact on sedimentation. The formation of the Rwenzori Mountains and the related faulting and fracturing seen in the basin are proof of the tectonic activity in the region.

In conclusion, the Semliki Basin has a complicated depositional history with lacustrine, deltaic, and riverine habitats. The varied conditions of sediment transport and deposition over time are reflected in the basin's varied lithologies and sedimentary formations. Predicting the distribution of sedimentary rocks and identifying possible petroleum plays are made possible by facies study of these sediments, which offers important insights into the paleoenvironmental conditions and depositional processes that produced the basin. The Semliki Basin's sedimentary sequences show signs of mature source rocks, seals, traps, and hydrocarbon migration paths, as well as a feasible petroleum system with great potential for reservoirs and top seals.

7.2. Summary of the Geological History of the Semliki Basin.

Significant tectonic and sedimentary processes connected to the East African Rift Valley system have sculpted the Semliki Basin, which is a portion of the Albertine Graben. This basin, which is home to high-grade Pre-Cambrian igneous and metamorphic rocks, saw several tectonic processes that produced favorable circumstances for significant sediment buildup. Rapid sedimentation brought about by the main rift shoulders' creation and increasing subsidence filled the half-graben with lacustrine and continental sediments in a more tectonically relaxed setting.

The neighboring mountains, escarpments, and the region surrounding modern-day Lake Albert are the main sources of sediments in the Semliki Basin. Because of seasonal and climatic fluctuations, these sediments—which include sands, clays, silts, and conglomerates—were deposited in cyclic sequences. Fluvial systems had a major role in the sediment buildup as the depositional systems in the basin changed from fluvial to lacustrine settings. The stratigraphy of the basin reveals a sequence starting with a basal conglomerate, overlain by sand-prone layers, and topped by clay-prone layers. Later tectonic events led to mineral remobilization, resulting in the formation of quartz veins within the basement rocks.

The oldest formation in the basin, the Kisegi Formation, has a base conglomerate that gives way to yellow sandstone with gypsum veins, suggesting lacustrine, deltaic, and fluvial deposition in a semi-arid climate. The black mudstones and coaly shales of the Kasande Formation indicate a change from lacustrine to wet delta plain environments. With inputs from neighboring channels, the Kakara Formation was deposited on a coastal plain with ferruginous strata and poorly sorted sandstones. The black shales and conglomeratic ironstone found in the Oluka Formation are typical of lacustrine and nearshore mudflat habitats.

Further, the Nyaburugo Formation comprises claystones with ironstone concretions and fining upward sandstones, reflecting fluvial channel deposition in humid tropical climates. The Nyakabingo Formation exhibits coarsening-upward cycles with light grey claystones and iron-stained siltstones, typical of floodplain and lagoonal environments. Lastly, the Nyabusosi Formation, with alternating clays and silts and distinctive ironstone horizons, suggests coastal to near-shore lacustrine environments with significant lake-level fluctuations.

Overall, the geology of the Semliki Basin is a complex interplay of tectonic and sedimentary processes, resulting in diverse sedimentary sequences that provide valuable insights into the past environmental conditions and geological history of the region.

7.3. Petroleum Potential of the Basin.

Analyzing the quality, thickness, and lateral extent of several facies that represent source, reservoir, and cap rocks is necessary to assess the Semliki Basin's hydrocarbon potential. These components are essential for the production, storage, and accumulation of hydrocarbons. It is clear from surface geology mapping, seismic, and well data that the Semliki Basin has all the necessary elements for a successful hydrocarbon system.

- **Source Rocks.**
  Evidence of oil generation in the Semliki Basin is supported by the Kibuku oil seep, characterized by dark, paraffin-smelling sands observed at the base of the Kisegi Formation at the sediment-basement contact. This oil seep indicates the presence of a regionally mature source rock. The extensive lacustrine clays in the area, which are potential source rocks, could become prolific given sufficient time for burial and increased temperatures. The dark grey colour of some clays suggests a high organic matter content, which is essential for petroleum formation. Additionally, the basin's sedimentary section, varying from 4 to 6 kilometres in thickness, provides adequate temperature and pressure for organic matter to reach maturity and generate hydrocarbons.
- **Reservoir Rocks.**
  Sandstones with medium to extremely coarse grain sizes can be found in the Semliki Basin. These sandstones have high porosity and permeability, which are crucial characteristics for effective hydrocarbon reservoirs. They are moderately to well sorted. The sediments provide possible petroleum migration channels and improve reservoir quality by covering heavily fractured and jointed basement rocks. However, by restricting communication between various reservoir compartments, the intercalation of sand and clay layers inside the sediments may cause reservoir compartmentalization, which would lower reservoir quality.
- **Traps and Seal rocks.**
  Impermeable lacustrine claystones interbedded with sandstones and fine-grained lacustrine sequences covering sandstones provide prospective top seals in the Semliki Basin. Petroleum could be kept from escaping the reservoir by the presence of 20-meter-thick clay strata that function as regional seals. Oil leaks, however, are a sign of poorly sealed intervals. Hydrocarbons may be trapped in a number of geological features found in the region, including rollover anticlines, unconformities (both plotted and recognized on seismic data), tilted faults, and joints and fractures filled with gypsum and these fractures also act as migration pathways.
- **Maturation.**
  High temperatures in the Semliki Basin, as evidenced by hot springs, can facilitate the conversion of organic matter to hydrocarbons and promote their maturation. The geothermal gradient in the basin is sufficient to drive the maturation process, ensuring that organic matter reaches the oil window and generates hydrocarbons.

Because the Semliki Basin has all the necessary components for a hydrocarbon system—mature source rocks, superior reservoir rocks, efficient traps, and seals—it has substantial hydrocarbon potential. A viable petroleum system with the capacity to produce, accumulate, and preserve hydrocarbons is indicated by the geological and geophysical data. To completely grasp the hydrocarbon potential of the basin and deal with issues such reservoir compartmentalization and seal integrity, more investigation and thorough study are necessary.

7.4. Effect of High Temperature on Hydrocarbons.

High temperatures in the Semliki Basin, exemplified by the Sempaya hot springs in the Buranga geothermal field, can significantly influence the maturation of hydrocarbons through hydrothermal heating. The temperatures at the Sempaya hot springs range from 95°C to 100°C. If low-conductivity rocks are present, they can retain enough heat to facilitate the maturation process.

However, if temperatures rise above the oil window range (60°C-120°C), thermal cracking can occur, transforming oil into gaseous hydrocarbons such as carbon dioxide and methane, which results in high API gravity oils. Intense heat can also cause hydrocarbons to undergo coking, producing carbon or coke.

7.5. How Structures Influence Hydrocarbon accumulation.

The migration and concentration of hydrocarbons are greatly influenced by a number of important geological structures found in the Semliki Basin, such as faults, beddings, and joints. High tectonic activity created faults and joints, which are secondary structures affecting the sediments in the basin. The migration of hydrocarbons from source rocks to reservoirs can be facilitated by faults, which may result in surface oil leaks. When compared to sealing materials, they can also serve as structural traps for hydrocarbons. Similarly, hydrocarbons can migrate through joints in sediments and basement rocks. These joints may function as traps that stop hydrocarbons from moving if they are filled with impermeable materials like quartz or gypsum. Hydrocarbon accumulation can also be aided by stratigraphic traps created by unconformities in the sediments.

CHAPTER 8. COCLUSION AND RECOMMENDATIONS.

8.1. Conclusions.

This field study successfully achieved its main and specific objectives through systematic geological, sedimentological, structural, and geophysical investigations in the Semliki Basin, Ntoroko District. The following conclusions are drawn in alignment with those objectives:

- A wide range of lithologies were identified in the study area. The basement is dominated by high-grade metamorphic rocks, principally granite gneisses, migmatites, and quartzites belonging to the Buganda-Toro system. The overlying sedimentary succession includes sandstones ranging from fine to very coarse grained, clay and shale sequences of varying organic content, silts, and basal conglomerates. These units collectively represent seven distinct formations from the Kisegi (oldest) to the Nyabusosi (youngest).
- Contacts between lithological units were clearly delineated using changes in grain size, colour, mineralogy, and sedimentary structure. The basement–sediment contact is marked by a basal polymictic conglomerate overlying the crystalline basement unconformably. Primary sedimentary structures — cross-bedding, laminations, ripple marks, and mud cracks — were documented throughout the sedimentary section. Secondary structures in the basement include NE-SW-trending joints, foliations, and anticlinal and synclinal folds at Itojo. Major faults such as the Makondo, Semliki, Bunya, and Kichwamba faults control basin geometry and sediment distribution. All structural orientations are consistent with the extensional regime of the Albertine Graben.
- The NE-SW foliation and joint trends in the basement rocks are mirrored in the orientation of bedding and faulting in the overlying sediments, demonstrating that pre-existing basement fabric exerted a strong structural control on the geometry of the rift basin and the deposition of syn-rift sediments. Joints and fractures in the basement gneisses also act as potential hydrocarbon migration conduits into reservoir units.
- Textural and structural analysis revealed three principal depositional environments in the Semliki Basin:
  Fluvial environment: evidenced by fining-upward and coarsening-upward sand sequences, cross-bedding, point bar deposits, ripple marks at the Kisegi river channel, and freshwater fossils (bivalves, gastropods).

  Lacustrine environment: characterised by thick, massive clay layers, fine laminated silts, mud cracks, and fish bone/oyster shell biofacies at Makondo, indicating the former presence of palaeolake Obweruka.

  Semi-arid/evaporitic conditions: indicated by red-brown iron oxide-stained sands, gypsum-filled joints and veins in clays and sandstones, pointing to periods of elevated evaporation and shallow water tables.

- Four lithofacies were identified — sandstone, clay, silt, and conglomerate — along with corresponding biofacies. The sandstone lithofacies, ranging from poorly to well-sorted with variable grain sizes and colours, constitutes the primary reservoir facies. Clay lithofacies, with dark colours reflecting organic richness, represent potential source and seal rocks. Conglomerate lithofacies mark the basement-sediment unconformity and the base of the Kisegi Formation. Biofacies including fish bones, bivalves, and gastropods confirm freshwater lacustrine conditions, consistent with the transition from Lake Obweruka to modern Lake Albert.

In summary, the Semliki Basin is a geologically complex and petroleum-prospective rift basin. The integration of field observations, lithological descriptions, structural measurements, and geophysical data confirms the presence of a viable, potentially productive hydrocarbon system.

8.2. Recommendations.

Based on the findings of this field study, the following recommendations are made for future research and exploration activities in the Semliki Basin:

- Further geophysical acquisition: New 2D and 3D seismic surveys should be acquired over the Semliki Basin to better constrain subsurface fault geometry, basin depth, and the lateral continuity of reservoir and seal units beyond what existing data from the Turaco wells can resolve.
- Additional drilling and well testing: The hydrocarbon shows at the Kibuku seep and in the Turaco wells should be followed up with dedicated exploration wells equipped with modern logging suites, formation testing tools, and fluid sampling programs to determine flow rates and commerciality.
- Organic geochemical analysis: Systematic Total Organic Carbon (TOC) measurements and Rock-Eval pyrolysis on core and outcrop samples from the Kasande and Oluka formations are recommended to quantify source rock richness, type, and maturity across the basin.
- Reservoir characterisation: Petrographic and petrophysical studies (thin section analysis, SEM, porosity, and permeability measurements) on sandstone samples from the Kisegi and Kakara formations should be conducted to better characterise reservoir quality and assess the impact of diagenesis on porosity.
- Structural modelling: Detailed 3D structural modelling of the Makondo and Semliki fault systems is needed to evaluate trap integrity, identify potential breach pathways, and de-risk prospects ahead of drilling.
- Geothermal resource assessment: Given the strong geothermal indicators at Sempaya, a dedicated geothermal resource assessment including temperature gradient drilling, magnetotelluric surveys, and geochemical thermometry is recommended to evaluate the Buranga Geothermal Field for potential power generation.

Environmental and baseline studies: Prior to any intensification of exploration and production activities, comprehensive environmental baseline surveys and Environmental Impact Assessments (EIAs) should be carried out, given the ecological sensitivity of the Semliki National Park and its surroundings.

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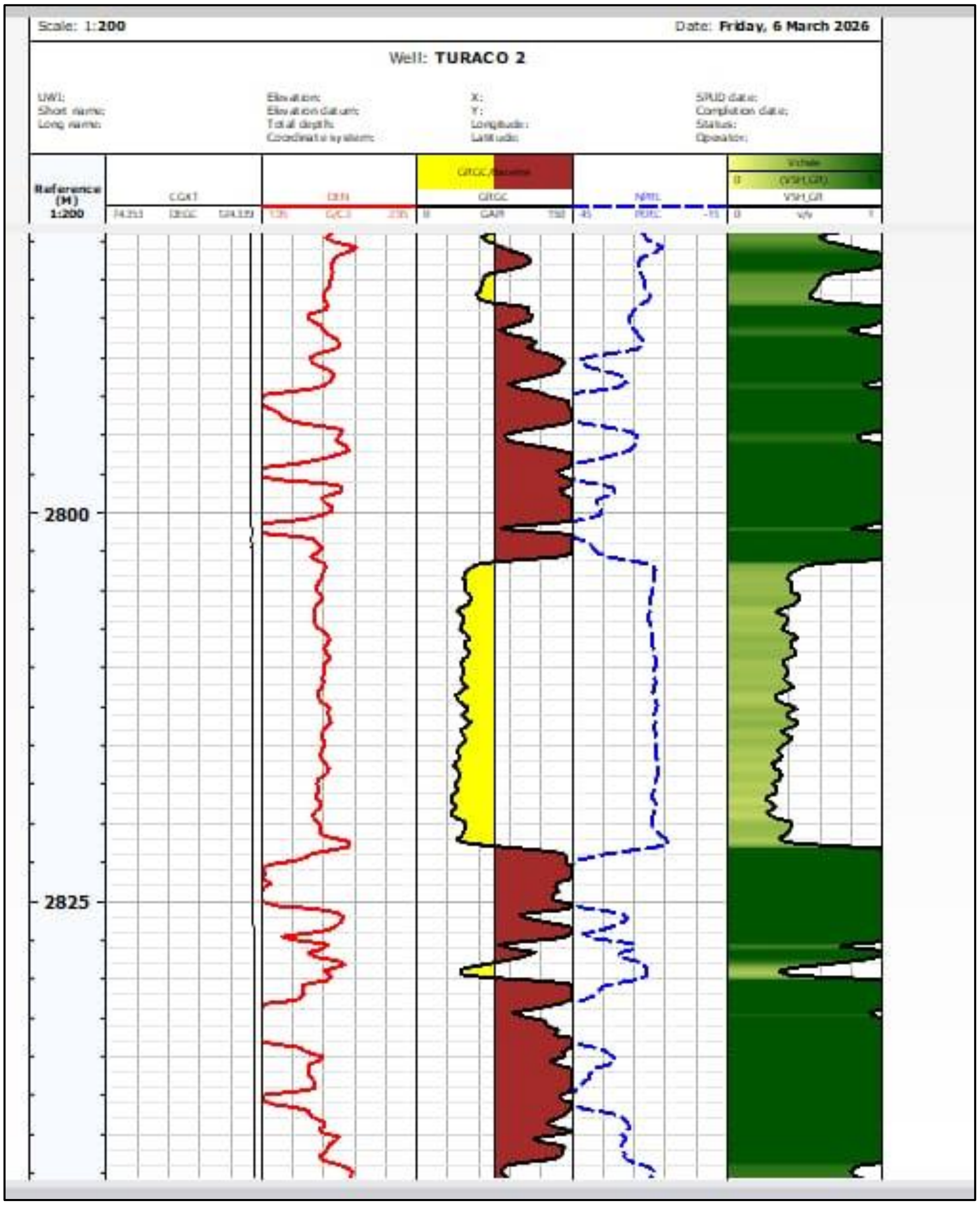
Appendices.

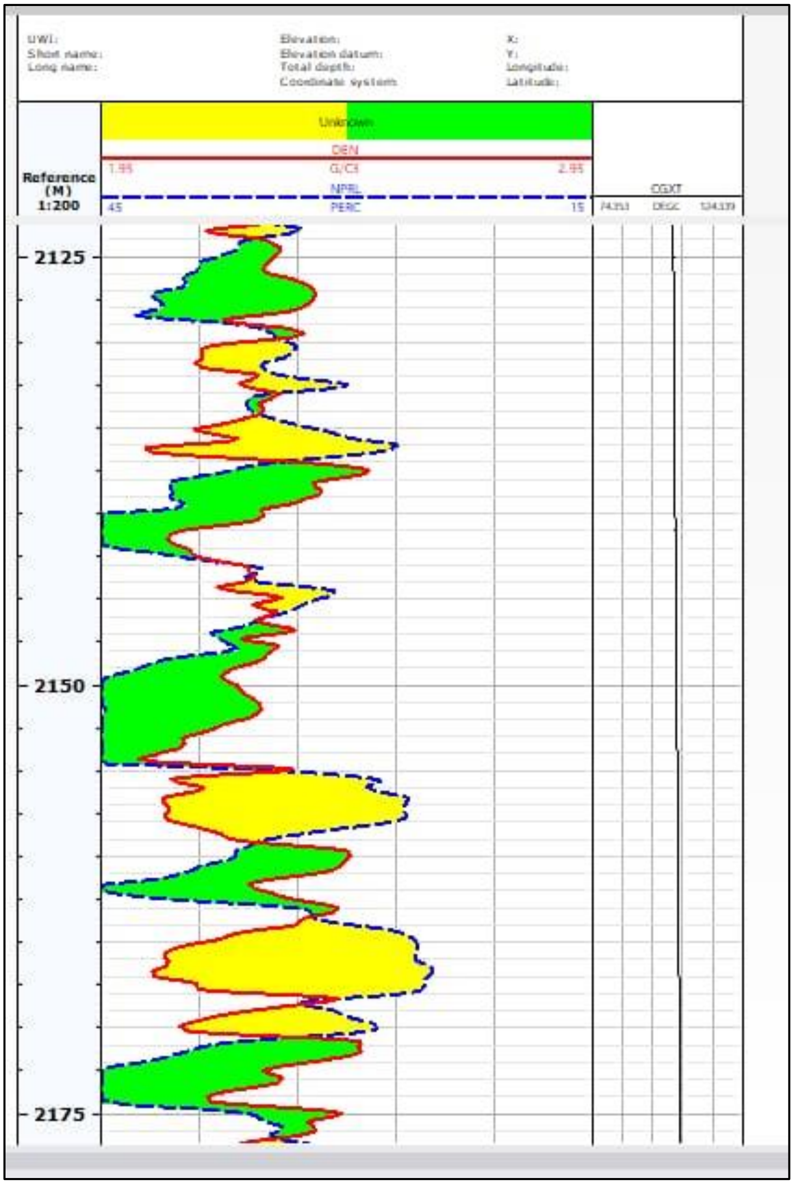
Location & Elevation	Joints Strike (Azimuth)	 Dip	Foliation	Folding
36N 0186953 0079664 1604m	198 056 066 038	22 80 82 48	278;80^{0}NE	
36N 0187017 0079770 1614m	336 054	40 58	276;82^{0}NE	
36N 0187080 0079770 1601m	210	8		
36N 0187106 0079831 1598m	272	30		
36N 0191057 0094333 1044m	104 050 310 350	58 70 30 52		N70^{0}E-SW Plunge; 16^{0}SW N84^{0}E Plunge390SW N60^{0}E Plunge 28^{0}SW Syncline
36N 0192414 101902 670m	148 160 172 140 012 010 044 306 292 138 292	80 70 68 70 42 44 36 52 30 82 22	214;80^{0}NW 204;86^{0}NW 200;80^{0}NW 192;82^{0}NW 196; 81^{0}NW	

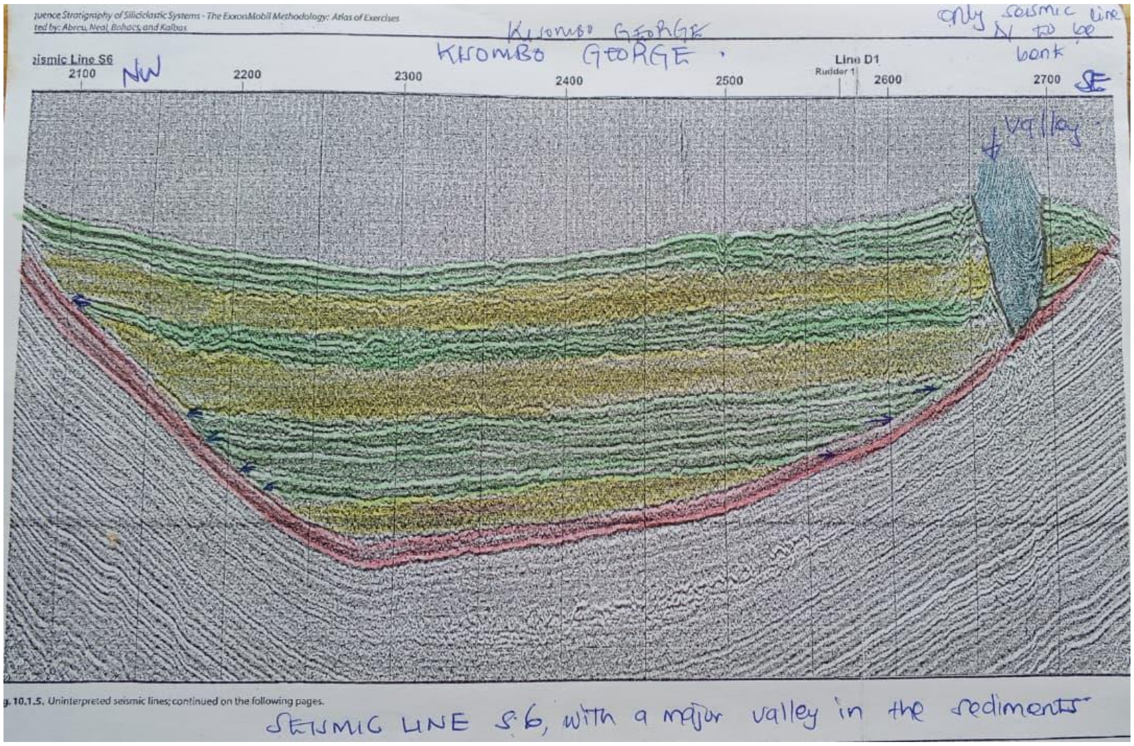
Bedding measurements Logged area, (193058;101991), 762m.

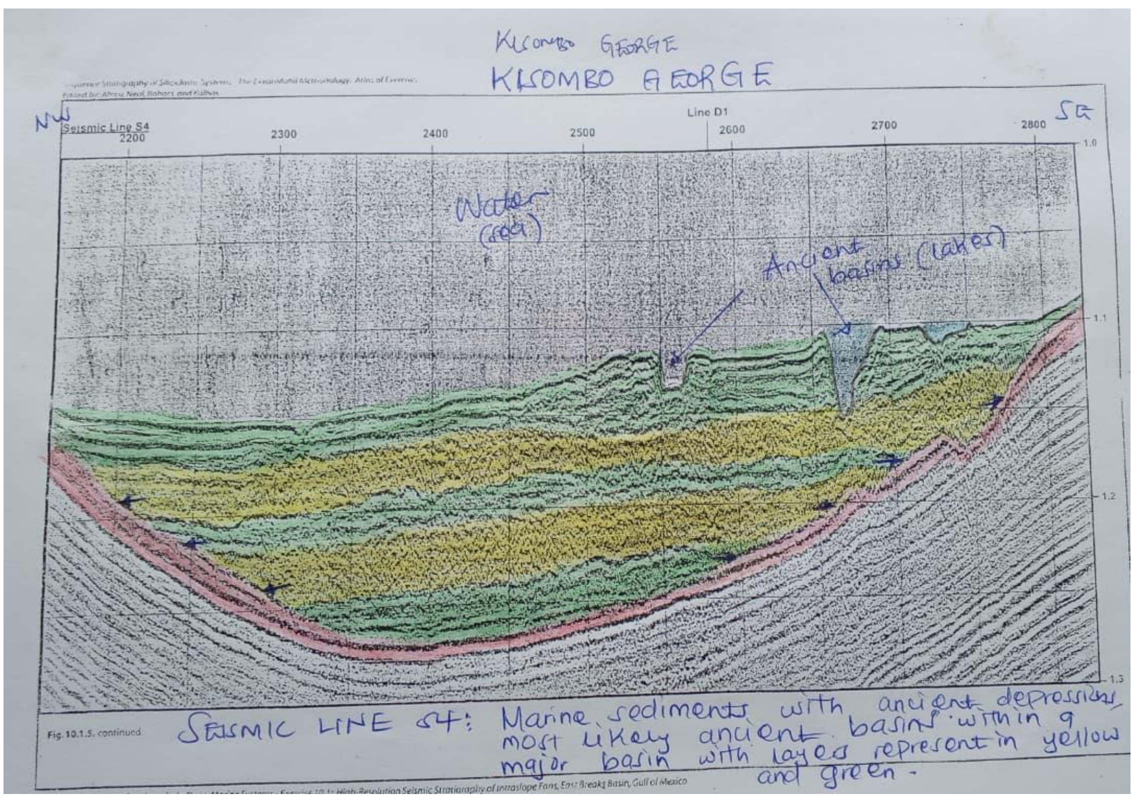
Strike	Dip
46	14
132	10
30	14
50	12
32	8
20	42
34	34
16	62
28	74
40	40

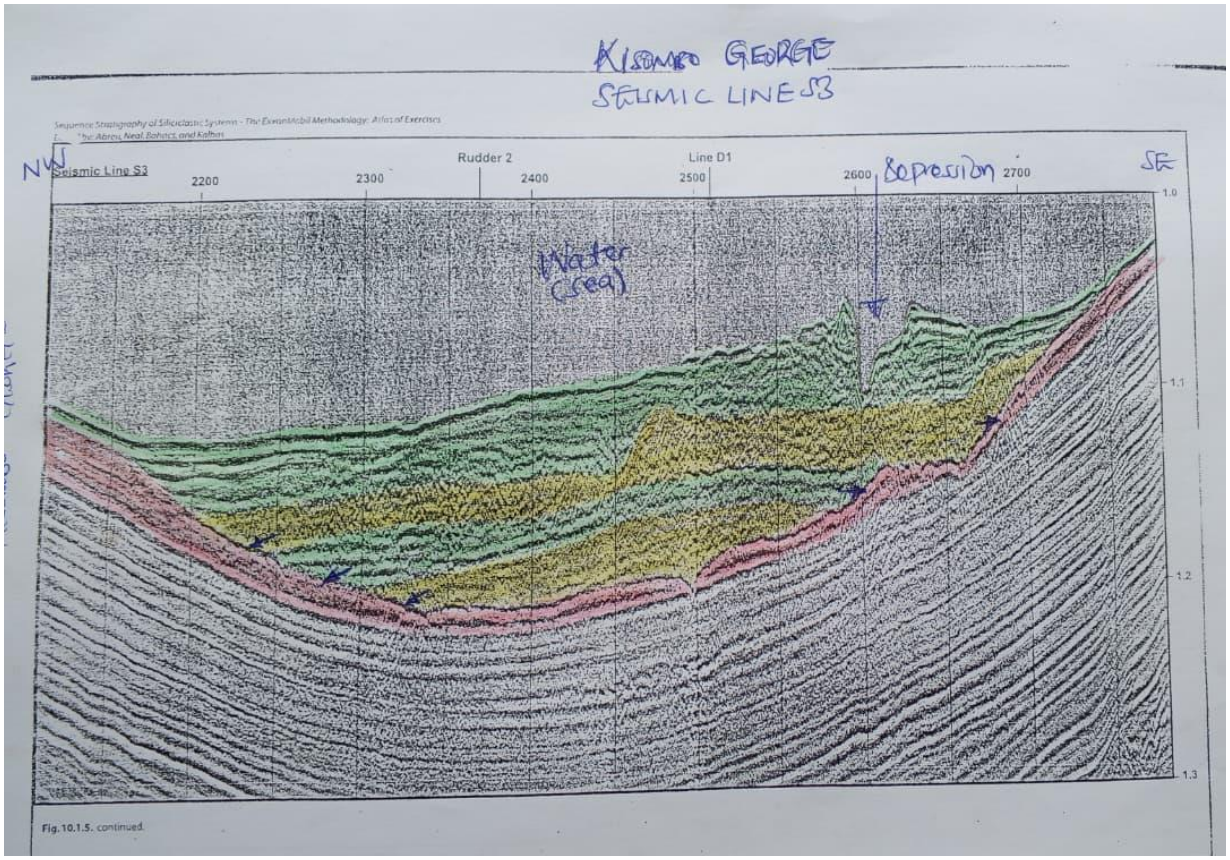
Turaco 2 well; Logs.



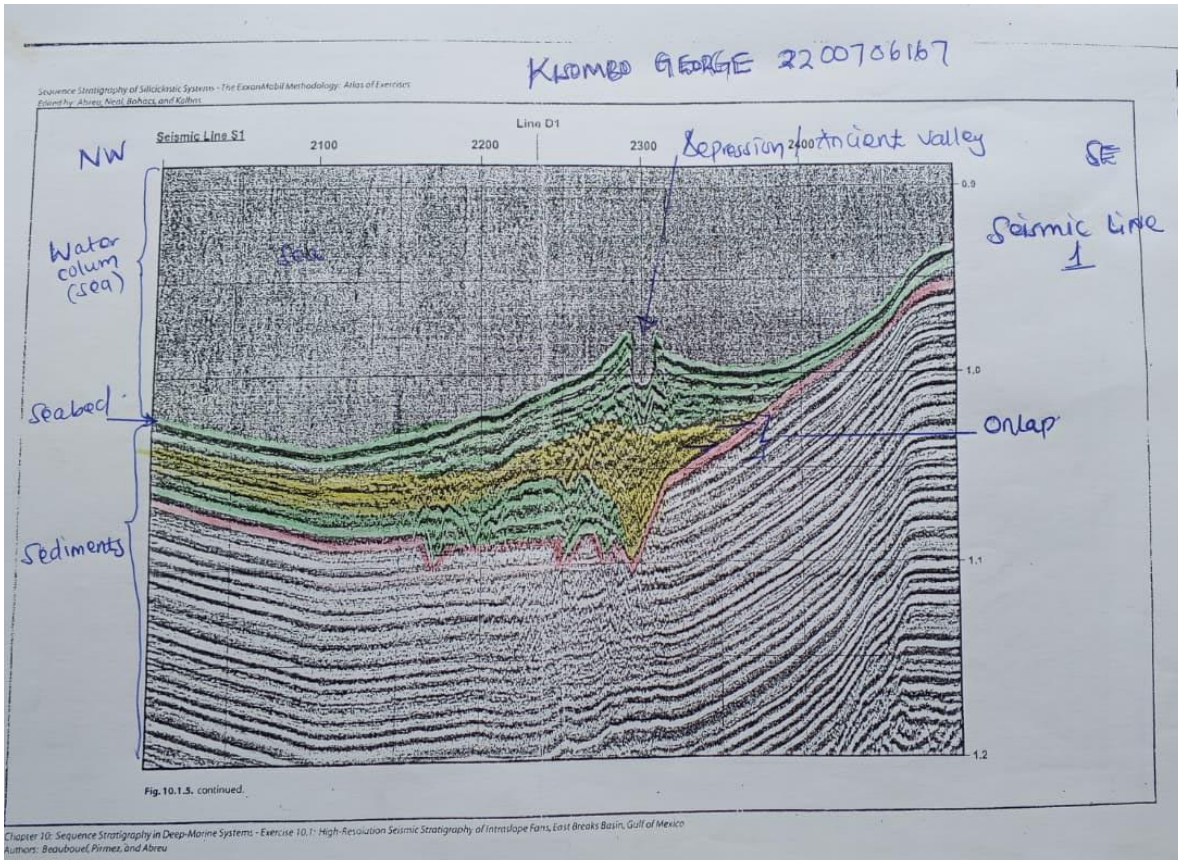

UWI:
Short name:
Long name:
Elevation:
Elevation datum:
Total depth:
Coordinate system
X:
Y:
Longitude:
Latitude:
Unknown
DEN
1.95
G/C3
2.95
Reference (M) 1:200
NPHI
45
PERC
15
CGXT
DEGC
2125
2150
2175


Seismic Line S6
NW
2100
2200
2300
KISOMBO GEORGE
2400
2500
Line D1
Rudder 1
2600
2700
SE
Valley
g. 10.1.5. Uninterpreted seismic lines; continued on the following pages.
SEISMIC LINE S6, with a major valley in the sediments


KISOMBO GEORGE
NW
Seismic Line S4
2200
2300
2400
2500
Line D1
2600
2700
2800
SE
1.0
1.1
1.2
1.3
Water (sea)
Ancient basins (lakes)
Fig. 10.1.5. continued
SEISMIC LINE S4: Marine sediments with ancient depressions most likely ancient basins within a major basin with layers represent in yellow and green.



KISOMBO GEORGE
SEISMIC LINE S3
Sequence Stratigraphy of Siliciclastic Systems - The ExxonMobil Methodology: Atlas of Exercises
Abreu, Neal, Bohacs, and Kalbas
NW
Seismic Line S3
Rudder 2
Line D1
2200
2300
2400
2500
2600
Depression
2700
SE
1.0
1.1
1.2
1.3
Water (sea)
Fig. 10.1.5. continued.


Sequence Stratigraphy of Siliciclastic Systems - The ExxonMobil Methodology: Atlas of Exercises
KASOMBO GEORGE 2200706167
Line D1
Seismic Line S1
2100
2200
2300
2400
Depression/Ancient valley
NW
SE
Water colum (sea)
Seismic Line 1
Seabed
Onlap
Sediments
1.0
1.1
1.2
Fig. 10.1.5. continued.
Chapter 10: Sequence Stratigraphy in Deep-Marine Systems - Exercise 10.1: High-Resolution Seismic Stratigraphy of Intraslope Fans, East Breaks Basin, Gulf of Mexico
Authors: Beaubouef, Pirmez, and Abreu