MAKERERE UNIVERSITY

COLLEGE OF NATURAL SCIENCES (CONAS)

SCHOOL OF PHYSICAL SCIENCES

DEPARTMENT OF GEOLOGY AND PETROLEUM STUDIES

A FIELD STUDY PROJECT REPORT OF THE SEMLIKI BASIN IN THE ALBERTINE GRABEN OF WESTERN UGANDA.

COURSE CODE: PG4211

BY

MEEN JOHN MAPER

21/X/20151/PS

2100720151

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

SUBMITTED ON: 2nd June, 2025

DECLARATION

I, **MEEN JOHN MAPER,** hereby affirm that the information written in this document is entirely from my personal effort, to the best of my knowledge, under the guidance of my Lecturers and it has not been presented by anyone to Makerere University or any other Institution.

.... 02/06/2025 ....

Signature **Date**

APPROVAL

Signature.. **Date** 02/06/2025

DR. BETTY NAGUDI

PROJECT SUPERVISOR

DEDICATION

This report is dedicated to my beloved family, whose unceasing prayers, emotional support, and financial assistance have been fundamental to my upbringing and the completion of my Bachelor Degree.

ACKNOWLEGEMENT

I would love to express my deepest gratitude to the Almighty God for the gift of life and protection He has granted me throughout my life and academic journey.

I am thankful to my esteemed Lecturers for equipping me with the knowledge and skills that I have been able to apply in the field and further guidance during the compilation of this project's report. I also extend my heartfelt appreciation to the non-teaching staff at the Department of Geology and Petroleum Studies for their support during the field work.

With a heart full of gratitude, I extend my sincere recognitions to my friends and group-mates with whom I collaborated during and after our fieldwork. Your companionship and teamwork have been instrumental in the completion of this project.

Lastly, I am so grateful to my beloved parents and guardians for their unwavering support in my life, particularly in my education. Their encouragement has been a constant source of strength.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

This project report provides an in depth of the Field exercise (geologic and stratigraphic logging) carried out in the Semliki basin of the Albertine graben. The main objective was to obtain field training on how to collect and interpret stratigraphic, petrographic, sedimentologic and structural data; which are very important in hydrocarbon exploration. The other objective is to identify the facies and depositional environments. The materials that were used in the field include; grain size scale, tape measure, Jacob staff, compass, hand lens and a geological hammer. The basement lithologies identified include; granitic gneiss and migmatite while sediment lithologies observed include sands and clays. The Semliki basin is composed of both primary and secondary structures. The primary structures observed include; planar bedding, mudcracks and stratification while secondary structures were joints, folds, foliations, quartz veins and faults. The general trend of these structures was found to be in NE-SW direction that was consistent with tectonic forces that affected the Semliki Basin. The facies and basin analysis revealed three depositional environments; lacustrine, fluvial and deltaic that occurred in the Semliki basin basin. Sedlog software was employed to generate group Flog and a combined log for the different groups. Through geophysical studies Semliki basin, sedimentary basins were identified through analysis of magnetic and gravity the datasets using GeoSoft/Oasis Montaj software. Techlog software was also used to analyze well log data from Turaco-2 well which revealed gas filled sand formation. The findings from the field exercise reveal a good potential for hydrocarbons in the Semliki basin through presence of good quality reservoir sands, potential lacustrine clay source rocks, traps and migrating pathways formed by the structural and stratigraphic deformation of this basin.

CHAPTER 1: INTRODUCTION

1.1 Background

This project is a requirement for the final year petroleum students for the Award of a Bachelor’s Degree of Science in Petroleum Geoscience and Production (BBPG). The journey to the Albertine Graben, specifically the Karugutu area in Ntoroko District, Western Uganda, began on June 30^{th}, 2024. The six-hour journey concluded with the team setting up basecamp at Karugutu Secondary School. On the following day, a comprehensive briefing was conducted by team of Lecturers led by Dr. Betty Nagudi, alongside Dr. John Mary Kiberu, Dr. Simon Echegu, and Mr. Mugwano Patrick. The Semliki Basin field study involved detailed geological activities, which include structural identification, lithostratigraphic logging, facies and basin analysis. The different areas of study included Kichwamba, Itojo, Kisegi, Turaco site and the Sempaya Hot Springs.

1.2 Study area

1.2.1 Location

Karugutu is situated in Ntoroko District, western Uganda, approximately 23 km east of the town of Kibuku, where the district headquarters are located. The Semliki Basin, located in the western region of Uganda within the Albertine Graben, lies southwest of Lake Albert. It encompasses the Semliki Flats and the adjacent Toro Plain, bordered to the west by the Democratic Republic of Congo and to the southeast by a steep fault escarpment that rises nearly 1,000 m to the northernmost extension of the Rwenzori Mountains.

The Semliki Basin is one of Uganda's most promising areas for hydrocarbon exploration and falls within Exploration Area 3 (EA 3) of Uganda’s licensed exploration zones. It is a rift basin forming the northernmost segment of the western branch of the East African Rift System (EARS). The Toro Plain is geologically distinct from the Semliki Flats and floodplains on the eastern banks of the Semliki River, separated by prominent structural features such as the Kibuku and Makondo faults. The Semliki River serves as the natural boundary between Uganda and the Democratic Republic of Congo.

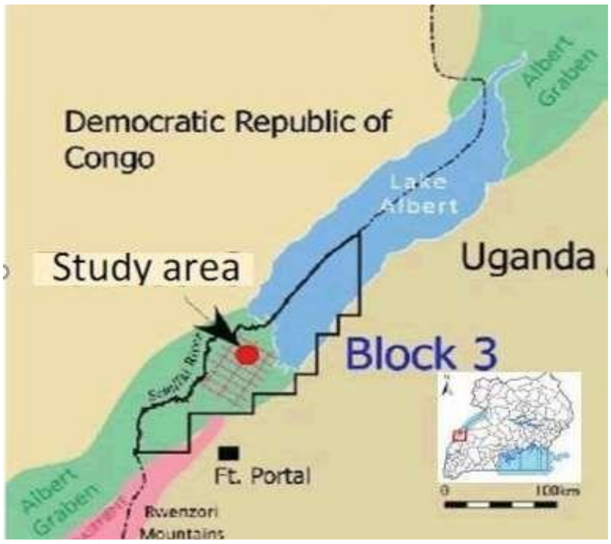


Figure 1. 1: Location map of the Semliki Basin (Mutebi et al., 2019)

1.2.2 Accessibility

The Ntoroko District is accessible via the Kampala-Mityana Road, which spans approximately 70 km and takes about 2 hrs to traverse. From there, continue along the same road to Mubende District, covering an additional 90 km in roughly 2 hrs. Upon reaching Mubende, take the Mubende-Fort Portal Road, a segment of about 150 km that takes about 3 hrs. Finally, proceed along the Fort Portal-Bundibugyo Road, which is around 60 km and takes about 1.5 hrs. In total, the journey covers roughly 370 km and takes around 7.5 hrs, depending on traffic and road conditions. The base camp was established at Karugutu Secondary School within Ntoroko District.

1.3 Objectives

1.3.1 Main objective

- To gain field training on how to collect and interpret stratigraphic, structural, petrographic and sedimentologic data

1.3.2 Specific objectives

- To identify facies and depositional environments
- To determine the presence of a petroleum system in the area.
- To identify lithologies and access the various elements of a petroleum system
- To identify and relate structures observed in the basement and in the sediments
- To identify lithologic types within the area

1.4 Geologic setting of the Albertine Graben

1.4.1 Formation and evolution of the Albertine rift system

The Albertine rift straddles over 500 km from Kivu in the south to Uganda/South Sudan border in the north, and is 45-50 km wide, defining the border between Uganda in the east and Congo to the west. This rift forms the northern section of the western branch of the East African Rift Valley (EARS). The rifting in the central part of the western rift commenced in the Miocene times, with rift propagation both to the north (12 Ma) and south (7 Ma). Therefore, the Semliki basin is a half Graben where the controlling fault/border fault is on the Congo side.

The sedimentary fill of the Lake Albert Basin reaches a maximum thickness of approximately 5 km (Karp et al., 2012). Sedimentary successions are accessible at only a few localities onshore around Lake Albert. The Kisegi-Nyabusosi area in the southern Lake Albert Sub-basin provides the most extensive record, extending down to the basal pre-rift infill at 12.5 Ma (Pickford et al., 1993; Roller et al., 2010). In the central Albertine Graben, the Nkondo-Kaiso area offers significant onshore exposures of synrift sediment.

The Rwenzori Mountains are a prominent feature within the Albertine Rift of the East African Rift System, composed of a dissected Precambrian metamorphic basement block reaching elevations exceeding 5 km. Through the application of low-temperature thermochronology, a complex exhumation history is revealed, with evidence of rock and surface uplift traced from the Paleozoic to the Neogene epochs. When the Rwenzori Mountains were uplifting, it affected the nearby areas and caused them to raise (uplift) and this explains why the basin is not exactly in the lowlands. The Rwenzori Mountains are younger and this is evidenced by the fact that the sediments are on top of the basement.

The provenance of late Miocene to early Pleistocene rift sediment in the northern Albertine Rift (Nkondo-Kaiso) area was determined using sediment modal compositions and the chemical compositions of detrital garnet and rutile. A significant shift in sediment composition occurred around 2.6 Ma, resulting in more mature sediments. However, potential source rocks exhibited only minor changes. Throughout the entire sedimentary succession, the chemistry of rutile and garnet remained largely unchanged.

Geologically, Semliki is both in Democratic Republic of Congo and Uganda. On the

DRC side, these are the Blue Moon Mountains which define the boundary while on the Uganda side; the rise doesn’t reach the mountain level. The fault on the DRC side is much stronger while the Kichwamba fault on the Uganda side keeps on changing. The Lake Albert Basin, traditionally considered an asymmetric half-graben dipping northwest, where the major bounding Bunia fault system likely contributed to the uplift of the 2100 m high Blue Mountains (Ebinger, 1989), is now understood differently.

The eastern boundary, defined by the westward-dipping antithetic Toro Bunyoro and Tonya fault systems, controlled the uplift of the 1200 m high topographic escarpment along the lake's eastern border. Recent seismic data and gravity reprocessing by Karp et al. (2012) reveal that the Lake Albert Basin is a full-graben that has symmetrically and continuously subsided during the Late Cenozoic along two extensive boundary fault systems.

The Albertine basin is located at the interface of the Archean Congo Craton and the Paleo- to Meso-Proterozoic Kibaran mobile belt, and it follows a roughly NE–SW trend. The timing of rifting initiation in the basin remains debated, with the earliest preserved Early Miocene sediments considered pre-rifting fluvial rather than syn-rift deposits. Based on available biostratigraphy, the initial syn-rift lacustrine sediments are dated to the Late Miocene, following a volcanic episode in the Virunga Province between 12.6 and 9.0 Ma (Kampunzu et al., 1998; Pouclet et al., 2016).

According to Abeinomugisha and Kasande (2012), petroleum exploration and biostratigraphical investigations suggest that rifting in the Albertine Graben initiated earlier, during the uppermost Early Miocene (approximately 17.0 Ma). This phase of rifting set the tectonic framework for the region. Later, as described by Pickford et al. (2012), a major rifting phase likely resulted in the formation of a paleo-lake, Lake Obweruka, which occupied the entire Albertine Rift area. The uplift of the Rwenzori Mountains around 2.5 Ma subsequently disrupted this paleo-lake. Micro-tectonic measurements and focal mechanism analyses further indicate that the tectonic setting of the Rwenzori Mountains is predominantly characterized by strike-slip movements, reflecting the complex structural evolution of the region.

Two primary mechanisms have been proposed to explain the extreme uplift of the Rwenzori Mountains:

- An isotactic response which is related to the removal of crustal material in the hanging wall of a normal fault (Koehn et al., 2016, 2010).

- ❖ Delamination of the lower crust and mantle lithosphere due to pre-existing weak zones (Wallner and Schmeling, 2010).

Simon et al. (2017), building on the work of Roller et al. (2010), outlined a four-stage evolutionary model for the Lake Albert Basin based on sedimentary studies of the Kisegi-Nyabusosi area outcrops. The stages are as follows:

- ❖ Sag Basin Phase (14.5–10 Ma)

During this initial stage, the basin was characterized by limited accommodation space, which was filled predominantly by fluvial sediments. This phase represents a pre-rift or early rift setting.

- ❖ Initial Rifting Phase (10.0–4.5 Ma)

The creation of limited accommodation space coincided with successive lake-level rises. This period marked the transition from a distal fluvial plain to a lacustrine environment, reflecting the onset of rifting activity.

- ❖ Classic Rift Phase (4.5–2 Ma)

This stage was dominated by sediment supply rather than accommodation space creation. It represents the active rifting phase, with significant sediment deposition in a tectonically active basin.

- ❖ Accelerated Subsidence Phase (2–1.5 Ma)

Increased subsidence and substantial sediment supply characterized this phase, accompanied by the accelerated uplift of the basin flanks. The sedimentary record during this period is marked by stacked transgressive cycles, transitioning from fluvial to lacustrine environments.

This chronological framework highlights the progressive tectonic and sedimentary evolution of the Lake Albert Basin, from its initial sag phase to the active rifting and subsequent subsidence stages.

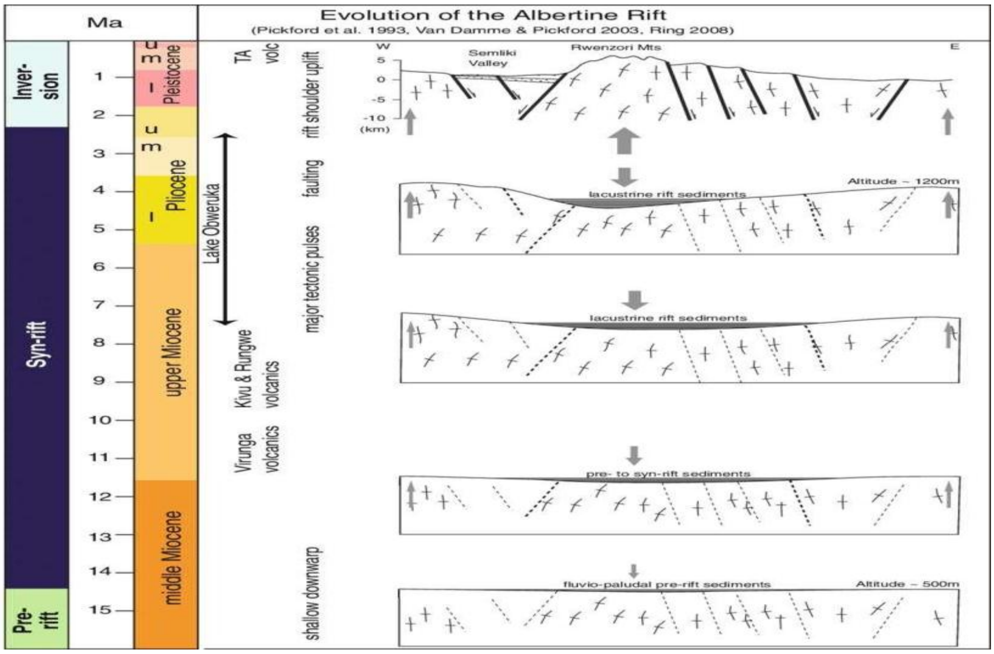


Figure 1.2: Stages of evolution of the Albertine Graben as of 2003 (Van Damme and Pickford

1.4.2 Structural setting

The Albertine Graben, located in the western part of Uganda, is a significant geological feature within the East African Rift System (EARS). It forms the northernmost part of the western arm of the East African Rift System (EARS) and stretches over 500 km from Rwanda in the south to South Sudan in the north, along Uganda's western boundary with the Democratic Republic of Congo.

The Albertine Graben can be divided into three structural domains based on structural geometry and trend. These are;

- ❖ Southern Domain.
- ❖ Central Domain.
- ❖ Northern Domain.

The fault system in the southern and northern domains trend in an almost N-S direction that changes to a SW-NE direction in the central domain. The central domain is almost full graben structure while the southern and northern domains are typically half grabens.

The Rwenzori and the Nile Delta accommodation zones separate these three structural domains.

The graben is characterized by highly segmented fault systems, separated by relay ramps and accommodation zones, which are sometimes basement highs. These fault systems have been active since the Miocene and have shaped the geometry of the basins within the graben.

The graben is part of the western branch of the East African rift system, which is a divergent plate boundary where the African plate is splitting into the Nubian plate (west) and the Somali plate (east). It is a result of extensional tectonics, where the earth's crust is being pulled apart forming the rift valley that is accompanied by faulting, subsidence and volcanic activity. The graben is bounded by major normal fault.

The Albertine Graben has experienced several tectonic episodes since the Miocene, resulting in a complex evolution history. Although it is primarily an extensional province, there is evidence of compressional tectonics. The observed structural styles from seismic data are due to a combination of pre-rift basement fabric and secondary modification from extensional and strike-slip tectonics.

The graben is characterized by lakes like Albert, Edward, which occupy the lowest parts of the rift valley. The surrounding highlands such as Rwenzori Mountains to the south and the Blue Mountains to the north, are uplifted blocks that form the margins of the graben.

The Albertine Graben is also associated with high seismicity, particularly around the Rwenzori Mountains. These are common along the boundary faults, as the crust continues to stretch and thin. The region experiences earthquakes with magnitudes ranging from 3.7 to 6.2 on the Richter scale. The depth of earthquakes varies from 4 to 40 km.

The Albertine Graben is a Tertiary rift system with a complex evolution history. Though it is essentially an extensional province, there is undeniable evidence of compressional tectonics. The Graben comprises a number of structural and topographic basins, lying in a general northeasterly (NE) trend in an echelon pattern. The basins have varying ages, "younging" both to the north and south. Therefore, correlation of the different stratigraphic units from one basin to the next has been a complex task. Since Miocene, when rifting was initiated in the Albertine Graben, there have been several tectonic episodes that have shaped the geometry of the basins. The observed structural styles from seismic data, is due to a combination of pre-rift basement fabric and secondary modification as a result of extensional and strike-slip tectonics that has been active since Miocene. The Albertine Graben forms the northernmost termination of the western arm of the East African Rift System. Since Miocene, thick sediments, up to 6 km in some basins, have accumulated. The fault systems that comprise this rift are highly segmented, separated by relay ramps and accommodation zones which sometimes are basement highs. Different stratigraphic schemes have been developed by oil companies and researchers that have operated in Uganda. These schemes have largely been uncoordinated and give varying ages to the same sedimentary packages.

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

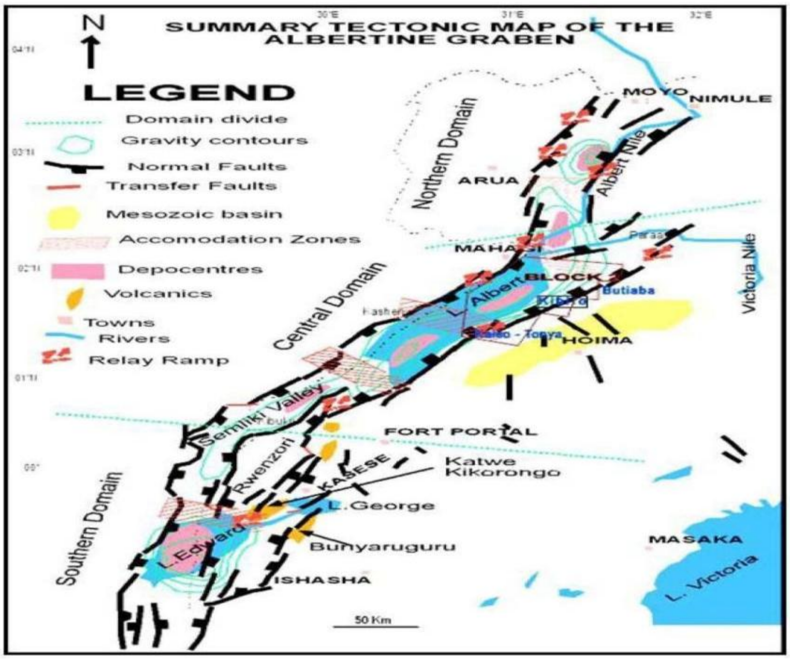


Figure 1. 3: Map of the Albertine Graben showing structural setting as of 2012, Dozith

1.4.3 Stratigraphy of the Albertine Graben

The Albertine Graben is one of the most petroliferous onshore rifts in Africa. It forms the northernmost termination of the western arm of the East African Rift System. Its surface exposures were first studied by Wayland (1925) and Pickford et al. (1993) among others. Pickford et al. especially developed the basic stratigraphic framework of the Graben which was later modified by the government geoscientists and international oil companies using subsurface data. However, the stratigraphic units were not fully and formally described, and have been used informally in different and often confusing ways. The current study therefore aims to solve this challenge by establishing a coherent stratigraphic scheme for the entire Graben through an integral study of surface and subsurface data.

Pickford reviewed in detail the molluscan and mammalian biostratigraphy of the successions and introduced most of the stratigraphic units described in the current study. His reviews made use of correlations to better-dated mammalian evolutionary lineages of the Kenyan and Ethiopian rift systems. He also tephrostratigraphically correlated the tuff horizons found in the Graben to the established sequences of Ethiopia and Kenya thereby providing age control for the Ugandan sequence and confirming the correlations previously established on the basis of fossil mammals.

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

Generally, the oldest units, the Proterozoic are well exposed on the rift flanks and shoulders of the Albertine Graben. It comprises mainly high-grade metamorphosed and igneous rocks of the Pre-Cambrian age. Seismic data points to a Pre-Cenozoic rift sedimentary section in some parts of the Graben, mainly restricted to the Lake Albert depocenters. The syn-rift section of the Albertine Graben was first recorded in the **Waki- 1B well,** which was drilled in 1938. This well penetrated both the Mid and Upper Cenozoic syn-rift sections which are characterized by conglomerates and sandstones. The well went through the Mesozoic pre-rift section before reaching basement. The Kisegi and Kaiso Formations of the Cenozoic are also quite well exposed in the Graben, consisting mainly of intercalation of conglomerates and sandstones deposited in fluvial and shallow lacustrine environments. The Kisegi Formation in some cases overlies the meta-quartzite Basement. Although the Lower Cenozoic may overlie the crystalline basement in many parts of the Graben, there is a possibility that it overlies a Mesozoic section (Karoo) in some parts of the Graben. The Lower Tertiary may overlap the crystalline basement in many parts of the Graben but there is a possibility that it overlies a Mesozoic section (Karoo) in most parts of the Graben (Heritage Oil and Gas, 2001).

Basing on age relationships of strata and bed successions, the stratigraphy of the Semliki Basin has been divided by Pickford et al. (1993) into seven Formations namely; Kisegi, Kasande, Kakara, Oluka, Nyaburongo, Nyakabingo, and Nyabusosi. These deposits show the most complete sedimentary succession in the entire Albertine Graben, spanning the period from the middle Miocene (15Ma) to recent, with a great thickness of fossiliferous sediment beneath the oldest fossil found, probably extending downward into the lower Miocene (Lukaye et al., 2016). These shall be discussed in detail under lithology and stratigraphy in Chapter 3.

1.4.4 Physiography of the Semliki Basin

The study area (Semliki basin) encompasses the Semliki Flats and the adjacent Toro Plain, located southwest of Lake Albert. The Semliki Flats are predominantly characterized by a flat to gently undulating surface, covered by savannah vegetation. The Toro Plain, with its undulating topography, is separated from the floodplains on the eastern banks of the Semliki River by the prominent Makondo Fault. The Semliki River, which meanders through the Semliki Flats, serves as the natural boundary between Uganda and the Democratic Republic of Congo (DRC).

The Semliki Basin, covering approximately 340 km², lies within the Northern Rwenzori Block. The Rwenzori Mountains plunge northward beneath the Semliki Flats, bounded by steep, fault-controlled escarpments on either side of the northernmost spur of the Rwenzori range. To the southeast, the basin is bordered by a steep fault escarpment that rises nearly 1,000 m to this spur. On its western margin, the basin is delineated by two major fault systems: the NNE-SSW trending Semliki Fault and the NE-SW trending Bunya Fault. These faults separate the Congo Escarpment from the basin, highlighting the region's complex structural framework shaped by tectonic activity.

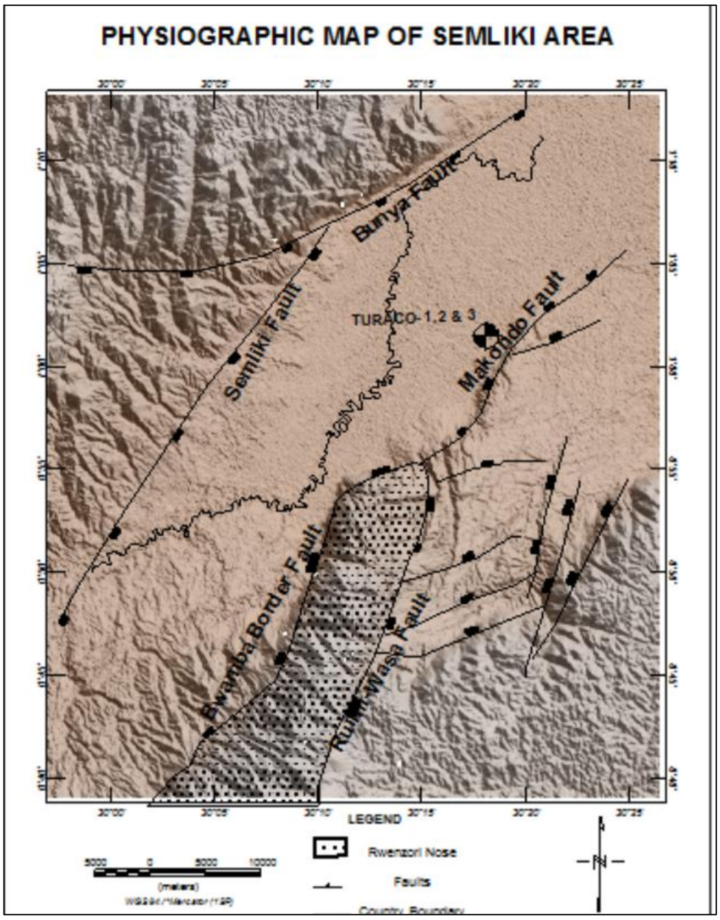


Figure 1.4: Main physiographic features of the Semliki Basin area

1.4.5 Topography

The Rift System is a unique physiographic region, comprising of the rift escarpments, the amorphous block of the Rwenzoris and an extensive Rift Valley or Graben that extends in a north-east direction from the districts of Kanungu and Rukungiri at the border with the Democratic Republic of Congo (DRC), to the districts of Moyo and Adjumani at the border with South Sudan. This Sensitivity Atlas covers an area of the Albertine defined by the boundary of oil exploration blocks which was established by Petroleum Exploration and

Production Department (PEPD). The area includes the Rift Valley floor and the largest parts of the escarpment except in some parts of the rift stretch in the northern most and southern most parts of Lake Albert. In this latter area, the boundary of the exploration blocks excludes the rift escarpment.

The Albertine Graben hosts several major lakes, including Lake Albert, Lake Edward, and Lake George, which formed as a result of intense rifting during the geological past. These rifting processes created depressions that were subsequently filled with water. The valley floor also features numerous crater lakes, adding to the diverse and dramatic landscape of the rift escarpments, the expansive rift valley, and the towering Rwenzori Mountains. The Albertine area is a landscape of great relief contrast, with both the lowest elevation in the country of about 620 m above mean sea level and the highest elevation in the country of about 5110 m above mean sea level on the Magherita peak of the Rwenzori Mountains. The Rift Valley extends for a total distance of over 500 km with variable widths of 45-80 km, including part of the Democratic Republic of Congo.

CHAPTER 2: MATERIALS AND METHODS

2.1 Materials

Table 2.1: Materials and their uses in the field

Tools	Purpose
Hand lens	It was used to determine the size of grains and also examine the rock clearly for fossils, minerals, textures and structures.
Grains size card	This was used to estimate the actual grain size of the rock sample by basing on the range of sizes on the card.
Tape Measure	It was used to measure the thickness of facies, thin beds and cross beds
Geological compass	It was used to measure orientation of geological structures; strike direction and dip angles for beds and joints.
Geological hammer	It was used to obtain fresh surface of a rock to determine its composition, nature, mineralogy, history, and field estimate of rock strength.
Jacob's Staff	It was used to measure accurately the thicknesses of steeply dipping beds.
Base maps	These were used for locating ourselves in the field. They also helped to show the type of geologic structural framework (such as faults like Makondo fault) to expect in a given location.
Geographic Positioning System (GPS)	This was used to locate ourselves in the field and on the map. A GPS was also used to determine elevations at different stops. Readings were taken after configuration of GPS to metric units, UTM - zone 36N coordinate system and the map datum of which case was "New (1960) Arc, WGS84".
Hoes	They were used to establish contacts between the basement and the sediments, and also cleaning sediment surfaces so as to clearly view beds to be logged.
Field notebook	It was used to record the raw data, sketches and observations that are collected from the field
Graph book/paper	It was used for plotting the stratigraphic logs during the logging exercise
Pens, pencils, rubbers	They were used for writing the observations that were made in the field.

2.2 Methods

2.2.1 Briefing

On the second day after camping at Karugutu Secondary school, there was thorough briefing by the Lecturers headed by Dr. Betty Nagudi. She gave cautions about the security threats in the area since it was near the Uganda-Congo boarder that was under risk of the rebels attack. There was an emphasis on the reporting time at the camp at the designated time and also reporting any cases of suspicions. Dr. Nagudi also encouraged maintenance of hygiene around the camp by damping rubbish and leftovers in the pits and she also highlighted that we had to collect as much data as possible from the field for the proper compilation of the report. The introduction to the Semliki Basin was done by Dr. Simon Echegu who presented the activities that were going to be carried out and these included; identification of lithologies and stratigraphy, basin and facies analysis. The aim of the Semliki exercise was to determine the presence of a petroleum system in the area. The introduction to the geophysics of the Semliki basin was handled by Dr. John Mary Kiberu.

2.2.2 Basement

Kichwamba area

We started by locating ourselves using GPS and the readings were (186918E, 079296N) at an elevation of 1614 m. The rock types and outcrops were described and structural measurements were taken. The rock types shall be disussed in details under Lithology and stratigraphy in chapter 3 while structures shall be explained in chapter 4. We were also introduced to digital mapping using Google maps and Strabospot software (strike and Dip)

Itojo

At Itoyo, a GPS was used to find the location at (191051E, 094332N) with an elevation of 1037 m. There was one stop in this area. The lithologies and outcrops were described, structures identified and structural readings taken. The detailed results are in chapter 3 and 4 respectively.

Kibuku

At Kibuku, location (192392E, 10180N) at an elevation of 668 m above sea level was measured using a GPS device. The outcrop was described and structures and their measurements were taken (chapter 4). Presentations were conducted by the various groups after each group was assigned a special location to get structural measurements. Discussions on the tectonic history, depositional environments and petroleum potential of the area were highly emphasized. More details are in chapter 7 under discussion of results.

The Basement-Sediment Contact

The location was established at (192596E, 02090N) with an elevation of 705 m. There was establishment of the Basement-Sediments Contact using hoes and spades to clear the top layers and identify the actual point of contact. The contact was a disconformity. Contacts between different lithologies were identified by use of grain size and thickness, color, cementing material, vegetation, structures and depositional environments.

2.2.3 Sediments

Kibuku Channel

We were also introduced to stratigraphic logging through identifying facies changes from bottom to top. Jacob's staff was used to measure the vertical thicknesses of rock layers. An exercise was given and a graph of thickness (depth) against the grain size was plotted.

Kisegi Channel

The Location was established at (192901E, 102917N) with an elevation of 670 m using GPS. We saw the younger sediments that were deposited by the Kisegi river (seasonal). During regression, the river cuts through its sediments and deposits coarse sediments.

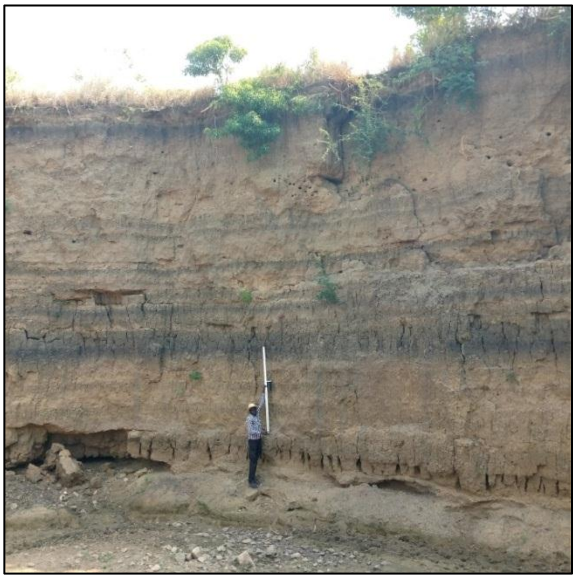


Figure 2.1: Deep cut by Kisegi river as younger sediments are deposited at (192901E, 0102917N, 670 m)

Logging

Sketching

There was sketching of the area of logging (Kibuku road cut) from the opposite side of the road. Several structures like planar beds, cross bedding and fractures were observed and sketched. The details are in chapter 4 of structures.

At the second stop, the logging exercise was carried out within the Kisegi formation of the Semliki basin. There was description of grain size, grain shape, mineralogy, fossils, sorting consolidations. Both primary and secondary structures were also identified and their measurements were taken. (Chapter 4). Paleocurrent direction was also established basing on dipping of beds. The group and combined logs for the facies were plotted. The different groups presented the findings of the areas that they were assigned to. There was a moment for question and answer after each group finished their presentation and supplementation from the Lecturers.

2.2.4 Makondo Fault

A GPS was used to find the location (201158E, 109998N) at an elevation of 702 m. Makondo fault was identified in this area using seismic data. The trend of this fault was was measured by geological compass. The Kibuku fault also meets the Makondo fault and the Turaco wells were drilled on the hanging side of the Makondo fault. The lithology in the area was also identified and fossils were also observed (Chapter 3 and 4).

2.2.5 Turaco Wells

The second stop on that day was at the Turaco Site, located at (199630E, 114153N). We were showed the area where the three Turaco Wells (Turaco-1, Turaco-2 and Turaco-3) were formerly drilled. There was use of 3D seismic data during the drilling of these wells, however after testing they were found to contain carbon-dioxide gas. This wasn't suitable for oil and gas and the Turaco area was relinquished to the government. More details are discussed in **chapter 6** under Geophysics of the Semliki basin.

2.2.6 Geophysics of Semliki basin

Dr. John Mary Kiberu introduced us to maps and data interpretation. The seismic data that was used was from the Gulf of Mexico. We started by using grid maps, and then shaded different layers with different colors and later matching the different sections on the maps. The direction of seismic lines to run survey depended on the geology and other geophysical methods. The seismic lines were also interpreted and thick patterns indicated high seismicity. Seismic-well tie was also performed manually. The results are discussed in details in **chapter 6.**

2.2.7 Sempaya Hotspring

This spot was the last one that was visited in the Semliki basin. It consisted of both the male and female hotspring. The Sempaya hotspring is an evidence of heat flow in the Semliki basin and the Albertine graben and it shows that hydrocarbons have been generated from the organic matter ($60 – 120^0$c, oil window). The age of the Albertine graben is of Miocene but this period is too short for the conversion of organic matter to hydrocarbons. However, for the geothermal gradient (high temperatures) the source rocks in the Graben and Semliki basin matured faster than they ought to be on normal circumstances. According to Time Temperature Index (TTI), both temperature and time are necessary for the maturation of source rocks. For the case of Semliki basin, the age is young (Miocene) but the temperatures are very high, thus this led to the maturation of source rocks within this region. The oil window in the Albertine graben is shallow because of the high temperatures (high geothermal gradient)

This area has potential for geothermal energy exploration (derived from the earth's internal heat, originating from radioactive decay in the core and residual heat from planetary formation).

Like a petroleum system, geothermal system also has elements.

Source rock; this is a rock that is hot enough and is near the mantle. The rock can also be hot if they contain some radioactive elements like uranium, potassium and thorium. Heat is also produced when radioactivity is taking place.

Reservoir; this is a rock that has high porosity and permeability (from secondary structures like faults) to allow fluids that transfer heat easily.

Fluids; these are transferring mechanisms for heat flow e.g water percolating. Meteoric water gets heat up from the reservoir, because beneath it, there is a source rock. The exploitation of hydrocarbons needs draining the energy from the hot fluids and using it to heat turbines and thus generate electricity. A network of faults provides the efficiency for the flow of hot fluids.

Seal; this is clay that prevents the heat energy from escaping out of the reservoir. However, salt cannot be a good seal for geothermal system because of its good conductivity and will allow heat to escape.

2.2.8 Laboratory work

The GeoSoft/Oasis Montaj Software was used to generate gravity and magnetic maps in order to identify the sedimentary basins. Techlog Software was also used to analyze data from Turaco-2 Well. Stereonets (Rose diagrams and Stereograms) were also generated for joints, foliations and bedding using Spheristat software.

2.2.9 Report Write up

A field report on geologic and stratigrahic logging of the Semliki Basin in the Albertine Graben was then compiled and submitted to the Department of Geology and Petroleum Studies (DGPS). The report is arranged in chapters starting from Introduction, Materials and Methods, Lithology and Stratigraphy, Structures, Basin and Facies Analysis, Geophysics of the Semliki Sedimentary Basin, Discussion, Conclusion and Recommendations. These chapters also contained several sub-headings under each of them.

CHAPTER 3: LITHOLOGY AND STRATIGRAPHY

3.1 Lithology

3.1.1 Basement Lithology

The basement rocks were encountered in Kichwamba at the foothill of the Rwenzori Mountain, Itoyo area and Kibuku quarry. The high-grade metamorphic rocks such as granitic gneiss and migmatite were observed in the study area.

Granitic gneiss

The granitic gneisses in the study area are part of the Pre-Cambrian rocks that form the basement onto which sediments were deposited. At Kibuku quarry (192392E, 101800N), the outcrop was large, artificially exposed by quarrying and heavily weathered. The rock was grey in color with moderate grain size and the minerals present include quartz, feldspar and plagioclase.

Figure 3.1: Large and highly fractured granitic gneiss outcrop at Kibuku quarry (192392E, 101800N, 668 m)

Migmatite

This is a partially igneous and partially metamorphic rock formed by partial melting and recrystallization from granitic gneisses. The migmatite outcrop was artificially exposed by the rock construction at Itojo. These rocks have undergone high grade metamorphism evidenced by foliations and schistose. The outcrop was large and highly weathered. The rock was white in color with medium to coarse grains. The minerals that were observed from the field include biotite and quartz. Biotite is part of the discontinuous reaction according to Bowen's reaction series while quartz also crystallizes at relatively low temperatures.

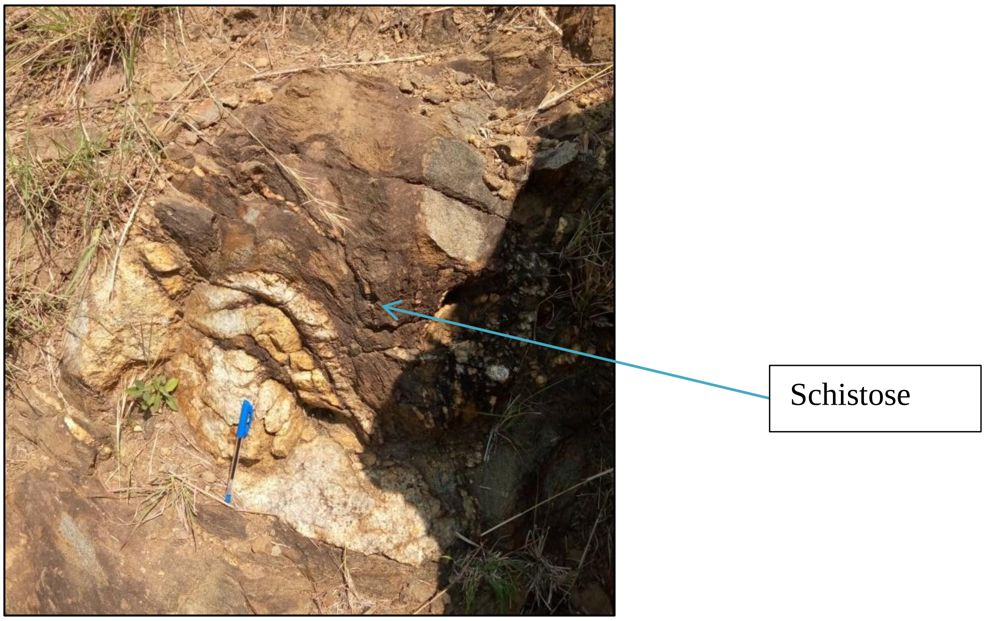


Figure 3.2: Highly weathered and folded migmatite outcrop at Itojo road cut (191051E, 094332, 1037 m)

3.1.2 Sediments

The Semliki Basin sediments are primarily clastics (fluvial deposits) and non-clastic (lacustrine deposits). The sediments are on top of the Basement and the basement-sediment contact was established at (192596E, 02090N). The sedimentary that were observed in the study area include sandstones and clays.

Sandstones

Sandstones are predominated by quartz and feldspars and they exhibit a wide range of colors including brown, yellow, red and grey, depending on the source, mineral composition and the presence of iron oxides.

At the basement-sediment contact (192596E, 102090N) with an elevation of 705 m, some sands were medium to coarse grains and poorly sorted. The sand grains were cemented by gypsum and iron oxides. The consolidated sands at location (192960E, 101767N) were massive with medium to coarse grain size and they were moderately sorted while the unconsolidated sands displayed a very large thickness with gypsum mineral filling the fractures that cut the beds vertically.

Figure 3. 3: Poorly sorted sands at (192596E, 102090N, 705 m)

Clays

At Kibuku road cut (192960E, 101767N), there were intercalations of clays with varying colors ranging from brown, pink and yellow. The grains were fine, well sorted and massive with different layers of gypsum cementing them together. Most of the clay layers in study area F, were intercalated with sand beds. This is due to cyclic deposition, owing to changes in climate patterns. Clays could have been deposited during periods of transgression when the waters were calm, whereas sands could have been deposited during periods of regression by high energy and dynamic waters.

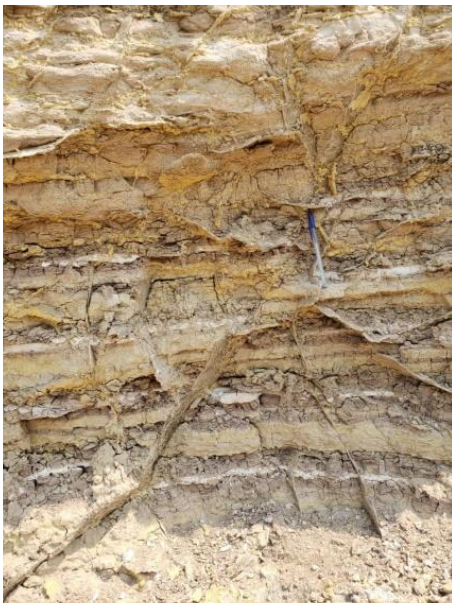


Figure 3. 4: Clay layers cemented by gypsum at the Kibuku road cut (192960E, 101767N, 746 m)

3.2 Stratigraphy

Basing on age relationships of strata and bed successions, the stratigraphy of the Semliki Basin has been divided by Pickford et al. (1993) into seven Formations.

The Kisegi Formation, the oldest, is composed of thick cross-bedded sandstones interbedded with tuff, bleached silts, and clays, with abundant gypsum veins. This formation is underlain by the Pre-Cambrian basement rocks. Kisegi is overlain by the Kasande Formation which is marked by dark brown to yellowish mudstones with channelized sandstones and thin coaly shale beds at the top. The Kakara Formation consists of poorly sorted sandstones, conglomerates, and muddy sandstones interbedded with soft silty claystones. The Oluka Formation overlies Kakara Formation and it features dark shales overlying conglomeratic ironstone with smooth quartz pebbles, interbedded with claystones, shales, and sandstones. The Nyaburugo Formation displays thick sequences of claystones, siltstones, pisolitic ironstones, paleosols, and fining-upward fluvial-channel sandstones. The Nyakabingo Formation exhibits repetitive coarsening-upward cycles with light grey-green claystones, iron-stained siltstones, pebbly sandstones, and carbonate nodules. At the top of the stratigraphy is the Nyabusosi Formation that is characterized by alternating clays and silts with distinct ironstone horizons, divided into the Makondo, Behanga, and Kagusa members.

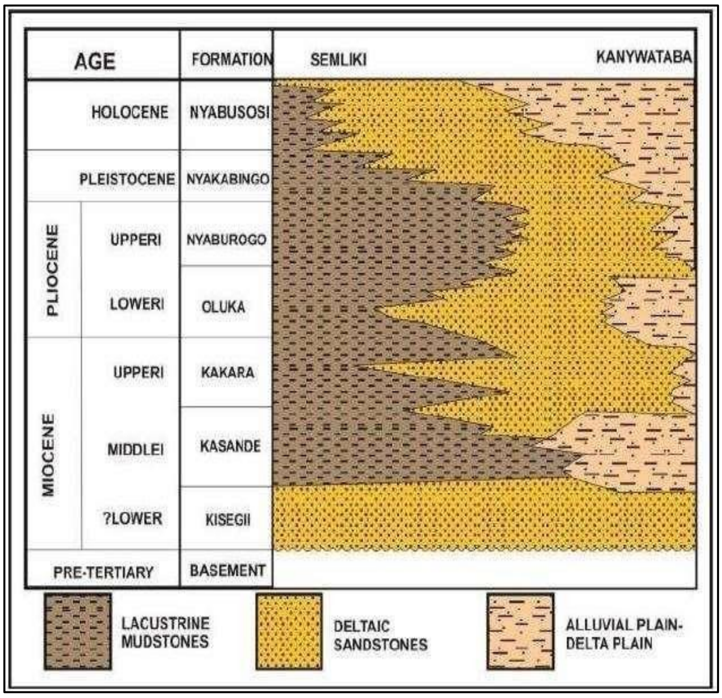


Figure 3.5: Formations of the Semliki Basin and their Ages (PEPD, 2013).

CHAPTER 4: STRUCTURES

4.1 Structural Evolution of the Semliki Basin

The Albertine Graben is a Tertiary rift system with a complex evolution history. Though it is essentially an extensional province, there is undeniable evidence of compressional tectonics. The Graben comprises a number of structural and topographic basins, lying in a general northeasterly (NE) trend in an echelon pattern. The basins have varying ages, "younging" both to the north and south. Therefore, correlation of the different stratigraphic units from one basin to the next has been a complex task. Since Miocene, when rifting was initiated in the Albertine Graben, there have been several tectonic episodes that have shaped the geometry of the basins. The observed structural styles from seismic data, is due to a combination of pre-rift basement fabric and secondary modification as a result of extensional and strike-slip tectonics that has been active since Miocene. Pickford et al. (1993)

4.2 Primary structures

Planar bedding

Some clay beds were identified as sub-horizontal to horizontal especially along the Kibuku road cut at (192960E, 101767N). The thickness of these beds ranged from 0.3m to 1.28m. These beds were mainly dipping in SE direction. (Refer to **Figure 3.4**)

Angular Cross bedding/stratification

In the study area, the angular stratifications were observed in the sands sediments. Despite being highly weathered, these cross beds were still preserved on these sediments. The cross stratification is a result of ripples that formed during the flow of a river.

Figure 4. 1: Angular stratifications in weathered sands sediments at (192596E, 102090N, 705 m)

Trough cross bedding

These curved, concave-upward erosional surfaces were observed in the unconsolidated sands at the Kibuku road cut. Therefore this implies that the flowing water deposited these coarse sediments in migrating dunes or ripples with a three dimensional shape.

Figure 4. 2: Trough stratification in unconsolidated sand layers at Kibuku road cut (192960E, 101767N, 746 m).

Mudcracks

These polygonal patterns in the clay-rich mud were located in the Makondo fault area (201158E, 10998N). This implies there was a water body particularly a lake (Obweruka) that existed in this area and it dried up due to dry conditions. These cracks trapped and preserved fossils which further indicates there was a lake in the area.

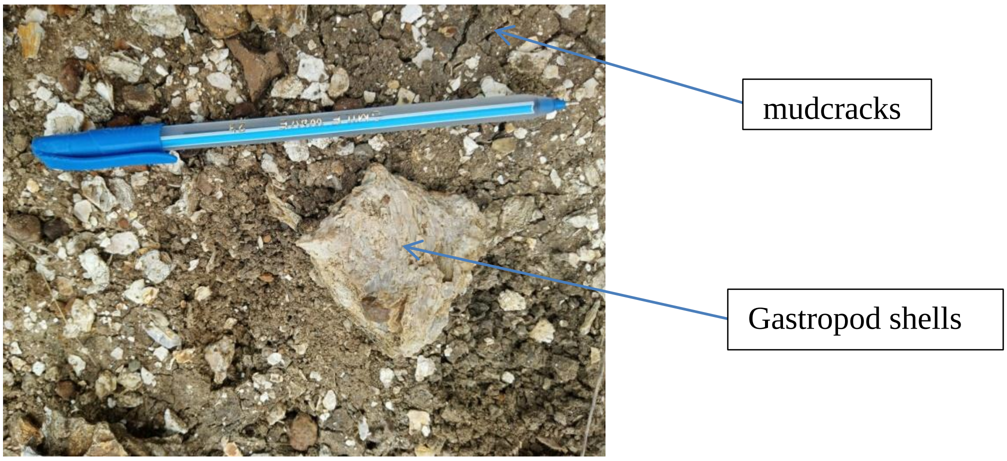


Figure 4. 3: Mudcracks in clay-rich mud with fossils in Makondo fault area (201158E, 10998N, 637 m)

4.3 Secondary structures

Joints

Joints were widely distributed in the area of study. In the basement rocks, two joint sets were observed with the Major joint set trending in the NE-SW and the minor set trended in the NW-SE. These joint fractures resulted from tectonic forces that led to the formation of Mountain Rwenzori. These joints were observed on granitic gneiss outcrop at the Kichwamba road cut (186918E, 079296N). In the sediments, the joints were also observed but they were filled with gypsum and iron minerals. In the clay beds, gypsum exhibited intercalations of colors while in the sands, it filled the fractures (joints) that vertically cut through the sand beds. The gypsum may act as barrier to flow of hydrocarbons thus reducing the quality of reservoirs in these sediments.

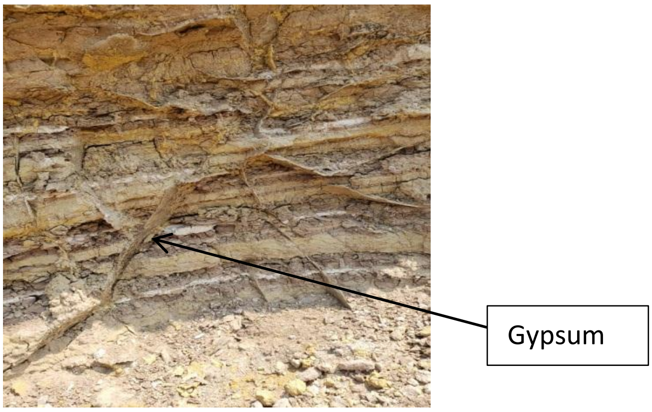


Figure 4.4: Joint plane on granitic gneiss at Kichwamba. **Figure 4.5:** Joints filled with gypsum at Kibuku

Foliation

In the study area, foliation was observed at Kichwamba on an outcrop of granitic gneiss (186918E, 079296N). These foliations could have been formed by the intrusion of dolerite dyke into the granitic gneiss. This intrusion of an igneous body via lines of weakness in the basement rock resulted into shearing and together with the excessive heat carried by the body caused the differential alignment of the minerals in the granitic gneiss. The trend of the foliations in the study area was in NE-SW, similar to that of the joints in the same area.

Figure 4.6: Foliation plane on granitic gneiss along a road cut at Kichwamba (186918E, 079296N, 1614 m).

Folds

Folding was observed in the basement high grade metamorphic rocks at a road cut in Itoyo area (191051E, 0094332N). The folds trended in NE-SW direction with plunge amount of 54^0 SW. This trend is similar to that of joints that were observed in the area. The folding could have resulted from the high temperature and pressure conditions that partially melted granitic gneiss to migmatite rock.

Figure 4.7: Anticlinal fold in migmatite outcrop along road cut at Itojo (191051E, 094332N)

Faults

In sedimentary sequences, the presence of faults can be quite obvious because of abrupt truncation and offset of bedding. In the Semliki Basin, the fault keeps on changing from Kichwamba fault to Toro fault and then Kibuku fault. The NE-SW trending Kichwamba normal fault with a Western dip, controlled the escarpment (exposed by road cut) along which several measurements of structures in basement rocks were taken. The Kibuku fault meets the Makondo fault at around (0201158, 0109998). The Major fault is the Makondo fault which trends in the NE-SW direction and it is a dip-slip normal fault and the Turaco Wells were drilled on its hanging wall. In the study area F, a minor fault was observed, indicated by vertical displacement of the white gypsum layers. The displacement of this fault was approximately 4.5 cm and it trended in the NE-SW direction that is related to the direction of the tectonic forces that affected the Semliki Basin.

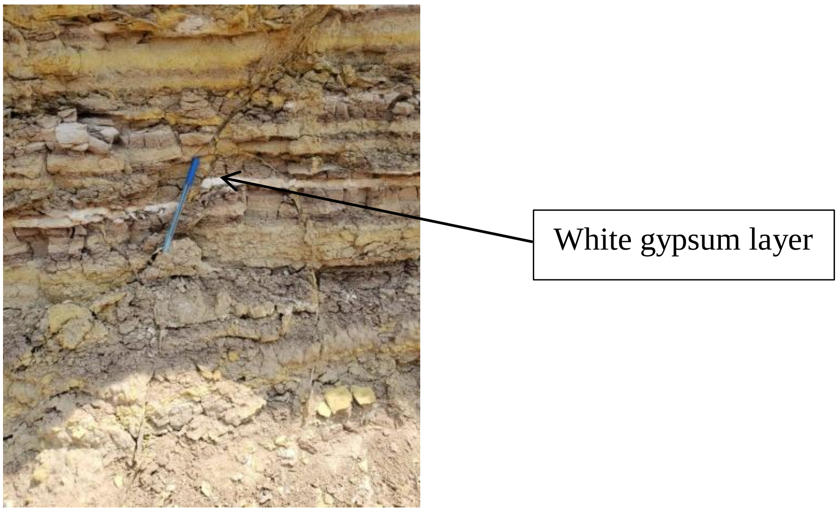


Figure 4.8: Minor normal fault observed at the Kibuku road cut at (192960E, 101767N)

Veins

In the basement rocks, quartz veins were observed at Itoyo road cut, and the trend was NE-SW direction similar to that of joints. There was high grade metamorphism in the area and during precipitation; quartz mineral filled the fractures that were created.

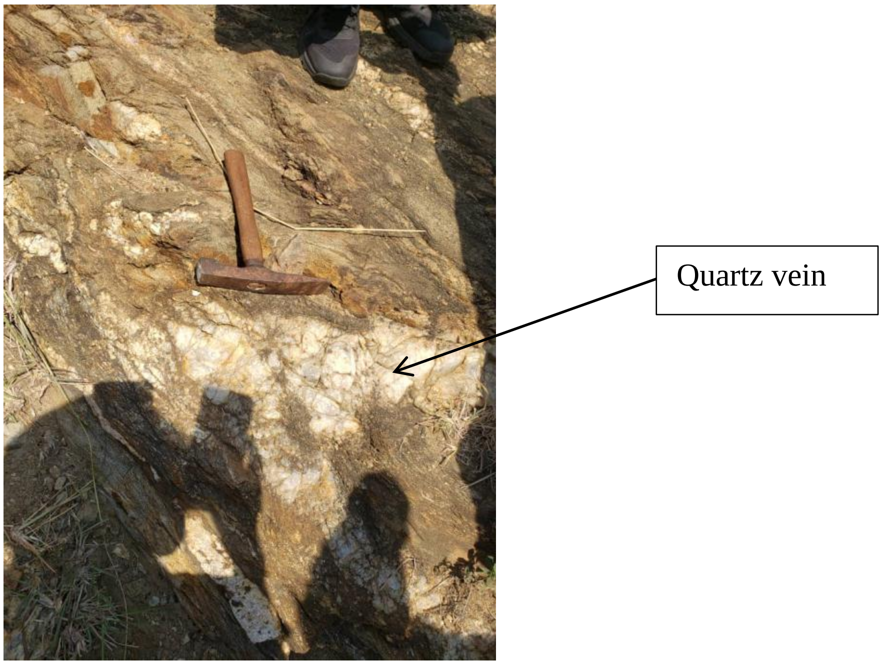


Figure 4.9: Quartz vein in a migmatite outcrop along Itojo rock cut (191051E, 094332N)

<u>**Stereographic projection of bedding measurements.**</u>

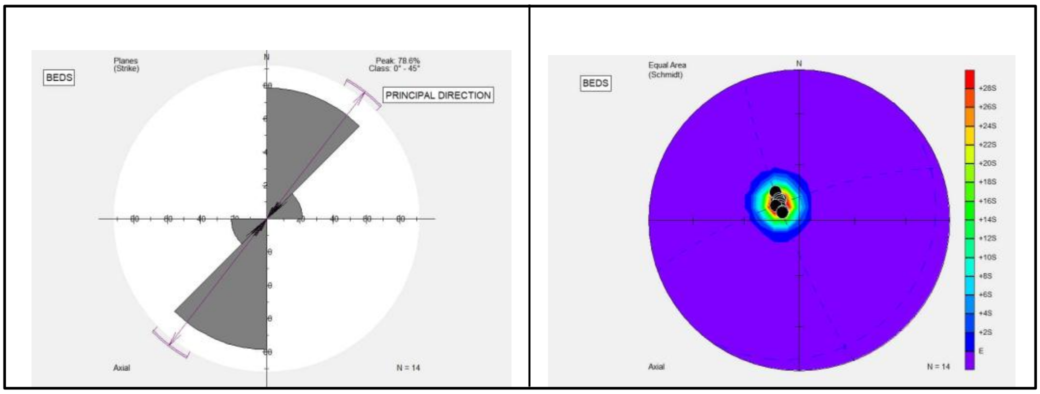


Figure 4.10: Rose diagram (left) and contour diagram (right) for bedding planes

The rose diagram dominantly trends in the NE-SW direction based on the prominent peaks in this direction. Bedding contour diagram reveals dominant SE gently dipping of the beds (paleocurrent direction). This is consistent with the NE-SW trend of the Semliki basin and Albertine graben.

Stereographic analysis of Joint measurements.

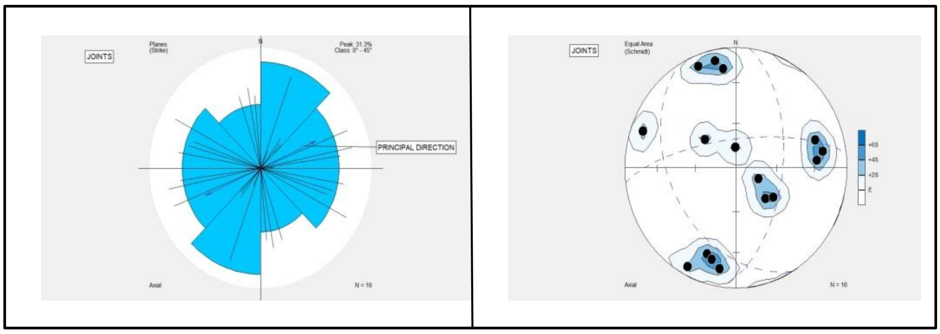


Figure 4.11: Rose diagram (left) and contour diagram (right) for joint planes

From the rose diagram (left), the major trend of the joint is NE-SW while the minor joint is NW-SE direction. The area was affected by dominant forces that acted in the principal direction as indicated on the rose diagram above. The Rwenzori uplift is linked to the regional forces that resulting to joint in the rocks. The joints are steeply dipping indicated by the points that plot at the edges of the contour diagram.

Stereographic projection of Foliation measurement

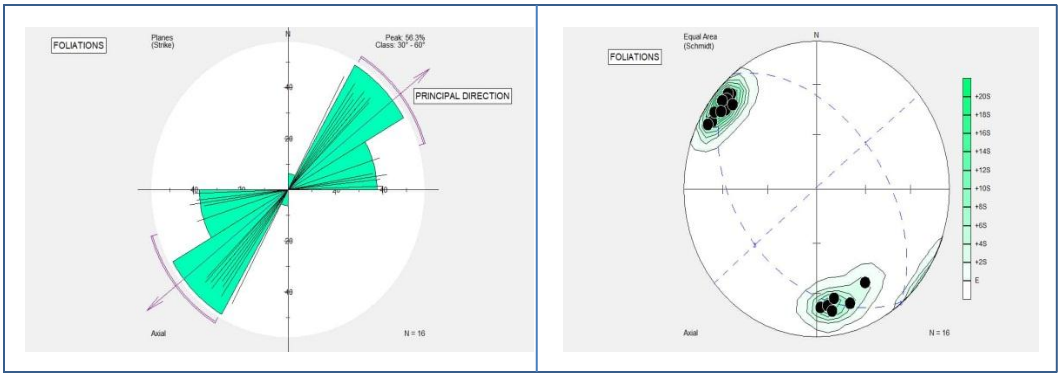


Figure 4.12: Rose diagram (left) and contour diagram (right) for foliations planes

The principal direction is in the NE-SW direction, therefore the foliation in the study area trend in this direction. The joints are steeply dipping in SE direction, the points plot on the extreme edges of the contour diagram (right).

CHAPTER 5: BASIN AND FACIES ANALYSIS

5.1 Facies Analysis

In the geologic context, facies analysis involved the study of rock units characterized by distinct, physical, chemical and biological features to reflect their formation environment. This enables the reconstruction of past environments, interpretation of the earth's history, including paleogeography and climatic conditions. However, basing on petroleum geology, facies analysis helps in identification of a petroleum system (source rocks, reservoirs seals and migrating pathways) and also in mapping reservoir geometry and connectivity for efficient exploration and production.

In the study area, lithofacies were greatly considered and the facies that were encountered included mainly sandstones and clays. Facies were studied in association instead of isolation in order to determine the depositional environment and petroleum potential.

From the group Log of area, F two fining upward sequences are witnessed (layer 1 & 2). This is indicative of fluvial environment. There is a large coarsening upward sequence from layer 2 to the top indicative of deltaic environment. The thickness of the top sand layer suggests prolonged and stable depositional conditions, while the presence of clays and gypsum points to a mixed fluvial-lacustrine sedimentary environment. Iron oxides and gypsum cemented the particles together which indicates periods of semi-arid or arid conditions

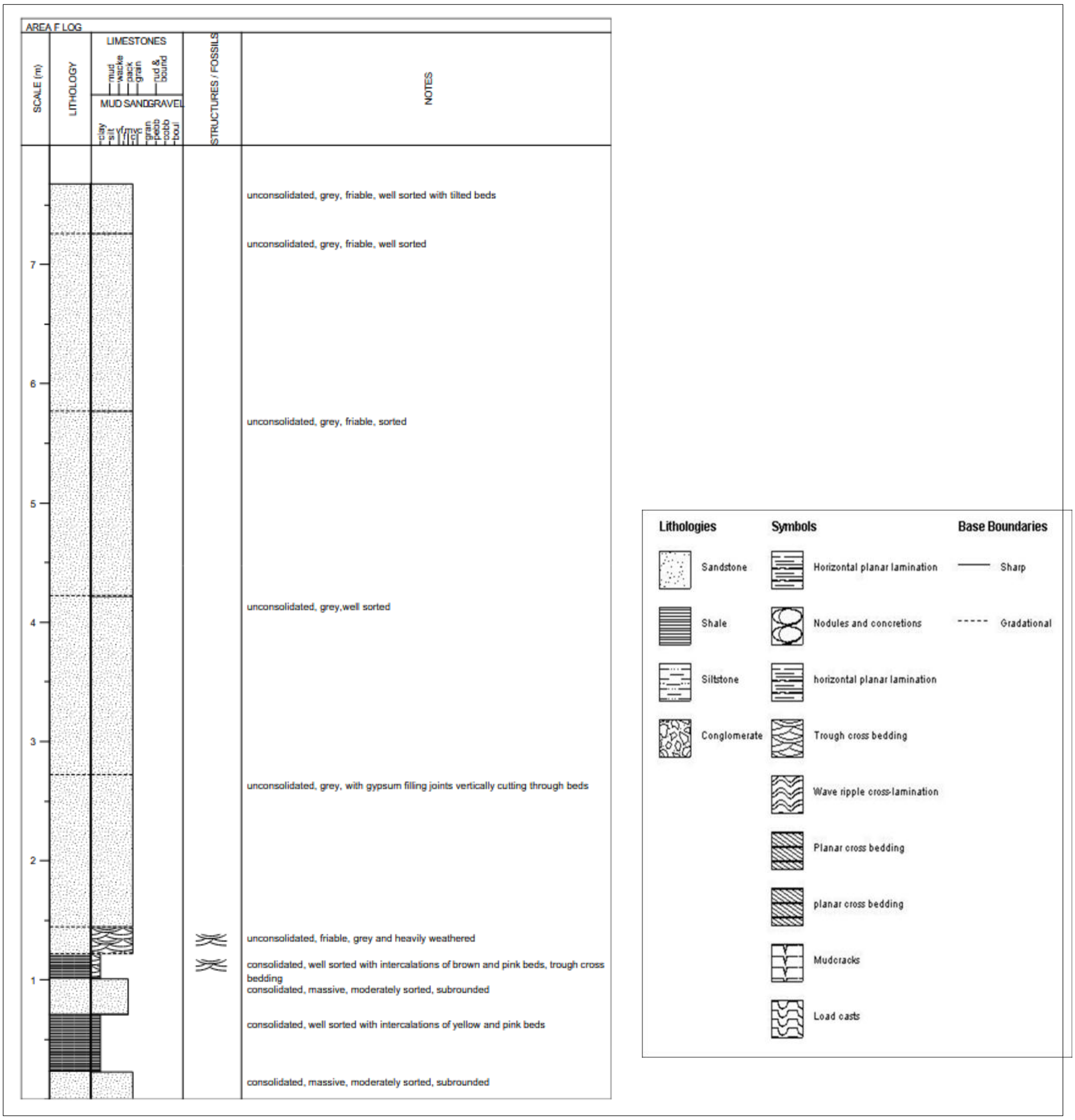


Figure 5.1: Lithostratigraphic log of area F, in the Kisegi formation of the Semliki Basin at (192960E, 101767N)

Depositional environments

Fluvial environment; the presence of fining upward sequence and cross stratification indicates the system of deposition was a river. During transgression, the river deposits fine sediments on top of the coarse sediments.

Lacustrine environment; the presence of clay beds that are sub-horizontal indicates that they might have been deposited by a low energy system (lacustrine environment).

Deltaic environment; during sea level rise (transgression), fine sediments were deposited on the shore. The wide spread of gypsum across the area of study, also indicates semi-arid conditions. The sediments in the study area were exposed to chemical weathering (oxidation), due to the red/brown sand layers

5.2 Basin analysis

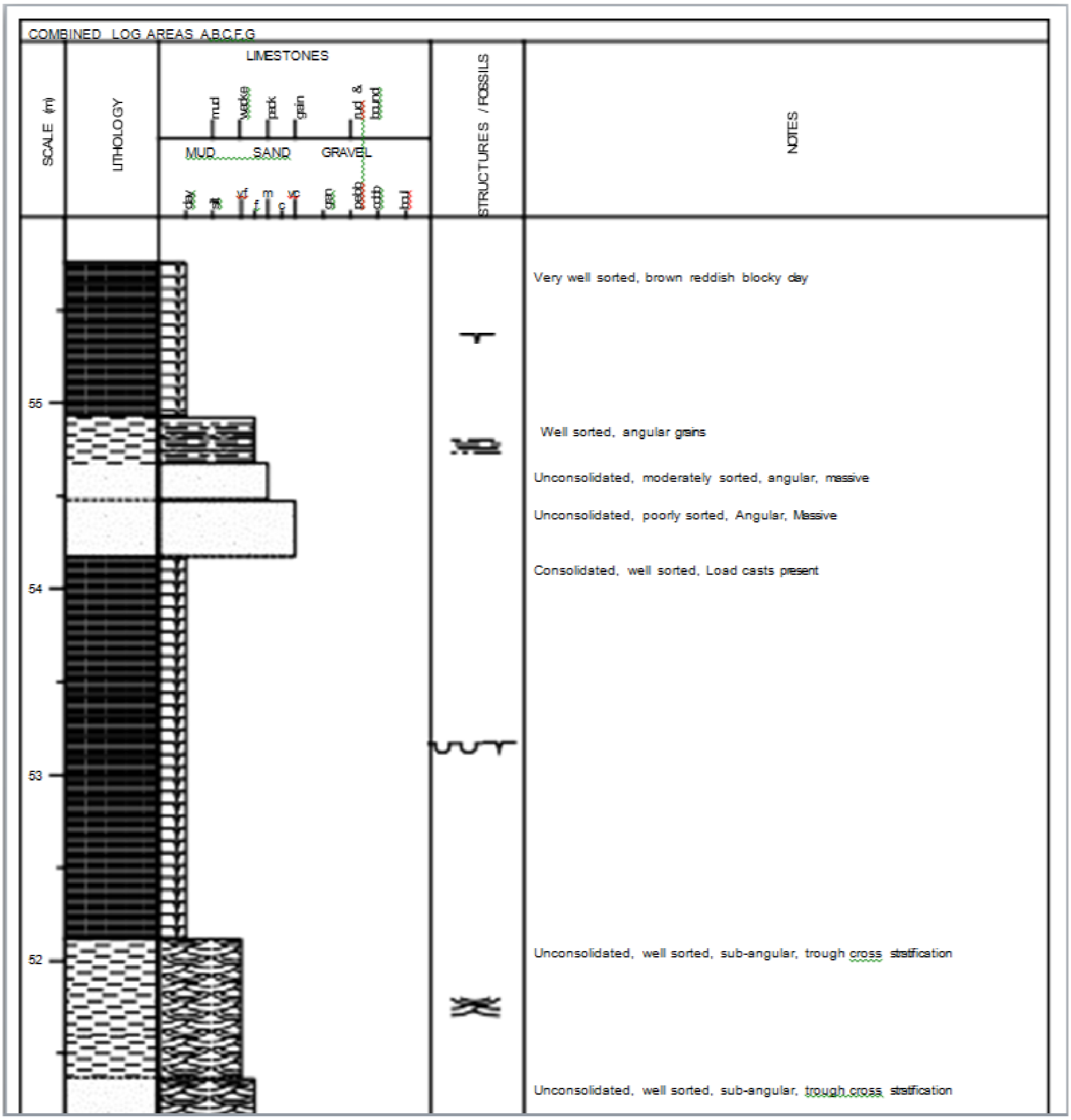
Evolution of the Semliki Basin

The geometry of the Semliki basin was shaped by rift tectonics, sediment deposition and structural evolution. The formation of the Semliki Basin resulted from interactions between the asthenosphere and the crust. The upward movement of the asthenosphere, through both active and passive mechanisms, induced partial melting of the upper mantle, leading to the emplacement of magma bodies within the crust. Initial crustal rifting commenced with the formation of deep-penetrating, high-angle normal faults, which facilitated the development of large half grabens. As rifting advanced, the brittle-ductile transition zone rose, contributing to the elevation of earthquake epicenters in the region. Subsequently, lower-angle boundary faults emerged, further shaping the basin's structural framework. Continued crustal extension, accompanied by igneous intrusions, resulted in the formation of dike swarms and minor fault systems. The Basin is dominated by sediments of fluvial, lacustrine and deltaic environments. Extensive alluvial fan sediments, stretching nearly 6 km, display numerous pinch-outs into deltaic sandstone formations, later disrupted by faulting. The lowest sediments above the nonconformity consist of fluvial-deltaic deposits, while the overall basin fill is dominated by lacustrine mudstones and clays interbedded with fluvial-deltaic sequences. The sedimentary facies exhibit lateral discontinuities and strong facies contrasts, characteristic of freshwater sedimentation where precipitation exceeds evaporation, resulting in a fluvial-lacustrine facies association (Carroll & Bohacs, 2001).

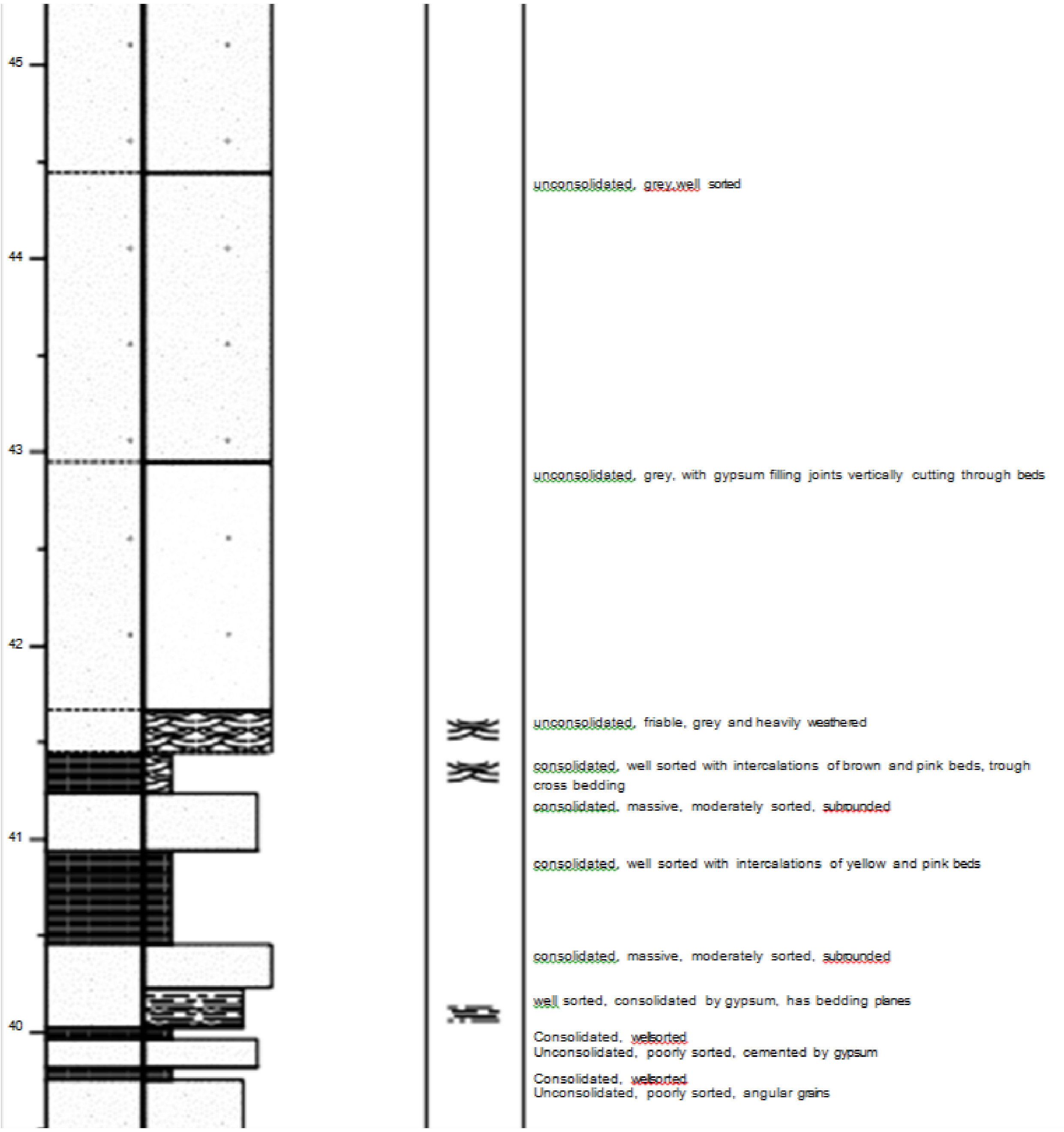
Interpretation of the combined Log of groups A, B, C, F and G

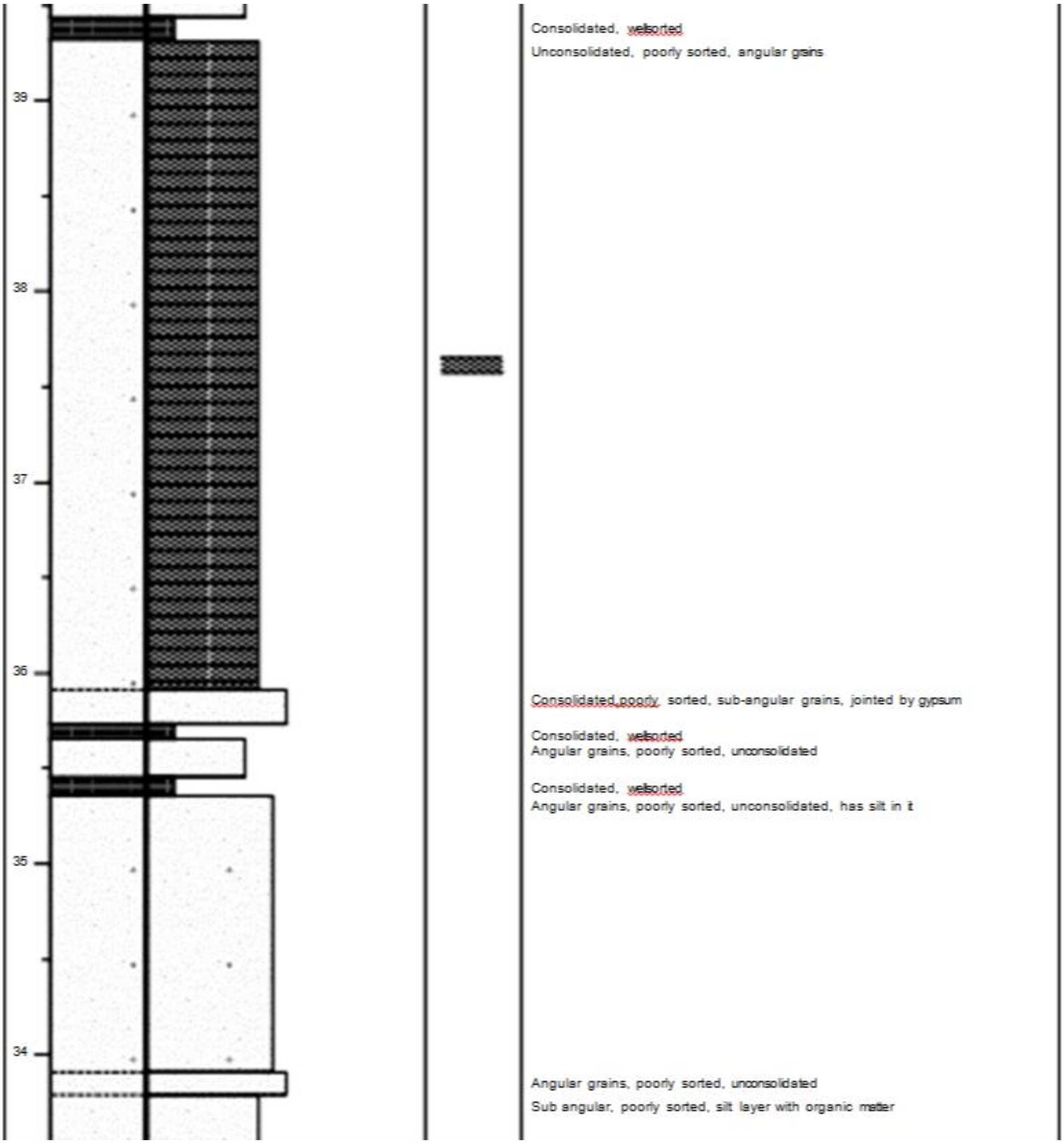
The sedimentary sequence within the Kisegi Formation, as explained in the lithostratigraphic log of groups A, B, C, F, and G, primarily consists of sandstones, silts and clays. There are 18 depositional episodes, with 9 fining upwards sequences, 6 coarsening upwards sequences and 3 blocky sequences. The lower section (0-10 m) is dominated by fining upward sequence. From (10 – 30 m) the deposition alternates between coarsening upwards and fining upwards. From (30 – 50 m), more heterogeneous facies are present. This further confirms that there is an alteration between the fluvial, deltaic and lacustrine environments. The fining upwards sequences indicates a fluvial environment where there is a decrease in depositional energy with flow resulting into deposition of finer material as flow progresses. The substantial thickness of the sandstone beds suggests prolonged and stable depositional conditions, while the presence of clays and gypsum points to a mixed fluvial-lacustrine sedimentary environment. These facies relationships show promising petroleum potential within the Semliki Basin. The coarsening upwards sequence indicates a deltaic environment where there is an increase in depositional energy as the flow enters a standing water body. This results into deposition of sediments of increasing grain size. The blocky sequences are representative of a lacustrine environment where the conditions are calm resulting into deposition of material of equal grain sizes which is usually clays.

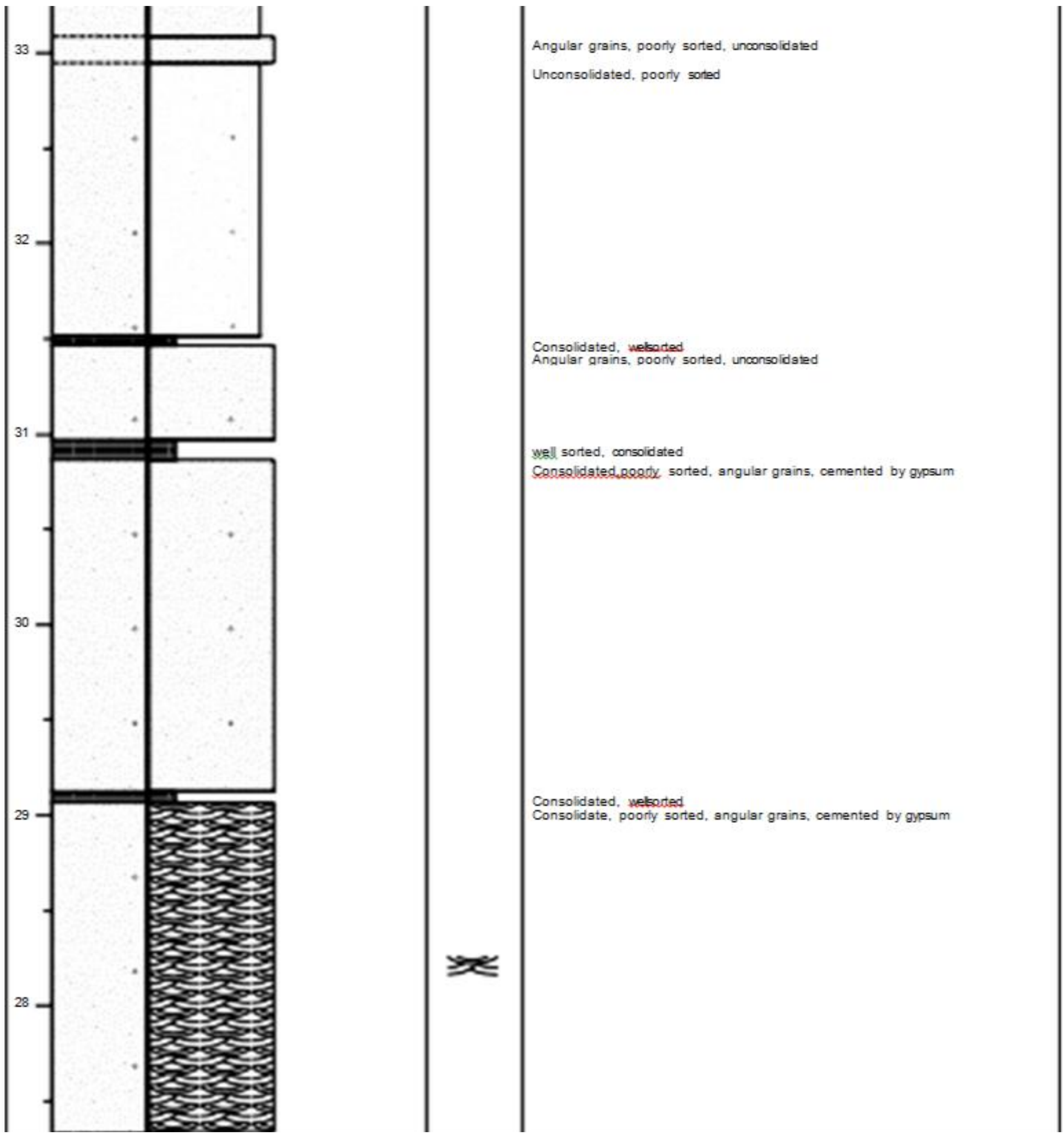
The consistent NE-SW trend in the structures shows the direction of paleocurrents. As the sediments were deposited, they were tilted towards the rifts' depocenters.

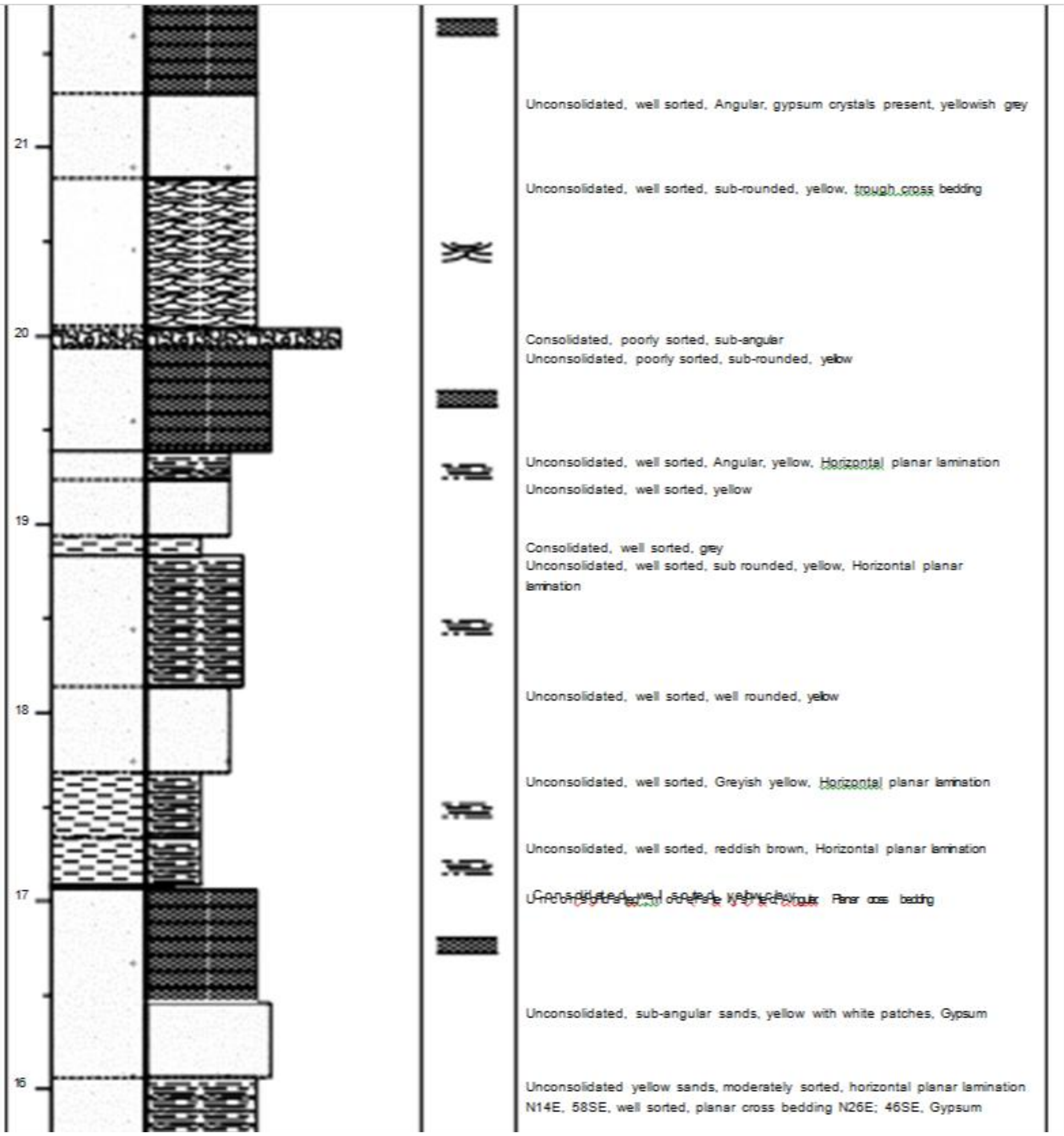

COMBINED LOG AREAS A,B,C,F,G
SCALE (m)
LITHOLOGY
LIMESTONES
mud
wacke
pack
grain
rud &
bound
MUD
SAND
GRAVEL
clay
silt
vf
f
m
c
vc
gran
pebb
cobb
boul
STRUCTURES / FOSSILS
NOTES
55
54
53
52
Very well sorted, brown reddish blocky clay
Well sorted, angular grains
Unconsolidated, moderately sorted, angular, massive
Unconsolidated, poorly sorted, Angular, Massive
Consolidated, well sorted, Load casts present
Unconsolidated, well sorted, sub-angular, trough cross stratification
Unconsolidated, well sorted, sub-angular, trough cross stratification

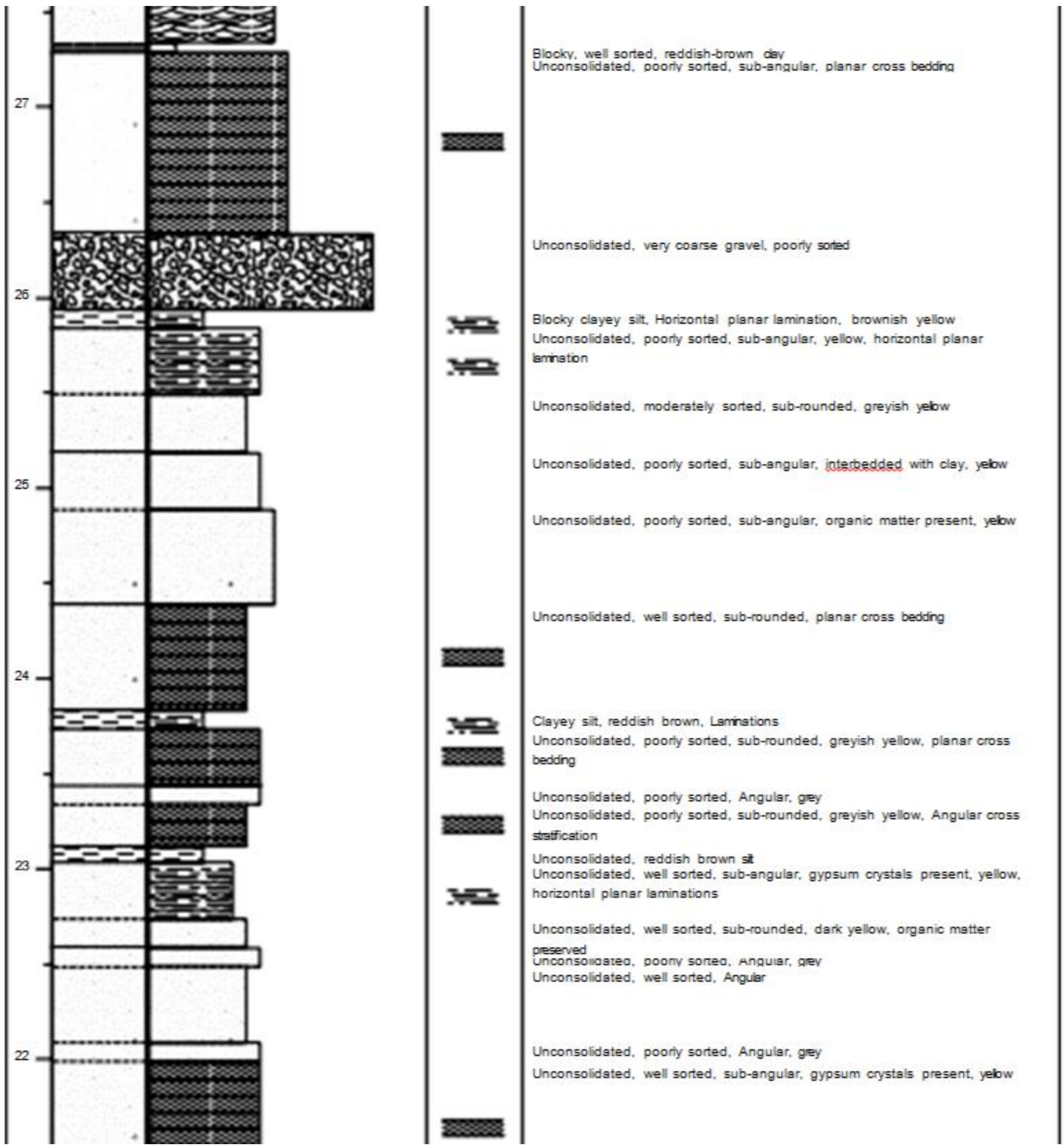

51
50
49
48
47
46
Unconsolidated, moderately sorted, sub-angular, massive
Unconsolidated, poorly sorted, sub-angular, banding
Unconsolidated, poorly sorted, Angular, Massive
unconsolidated, grey, friable, well sorted with tilted beds
unconsolidated, grey, friable, well sorted
unconsolidated, grey, friable, sorted

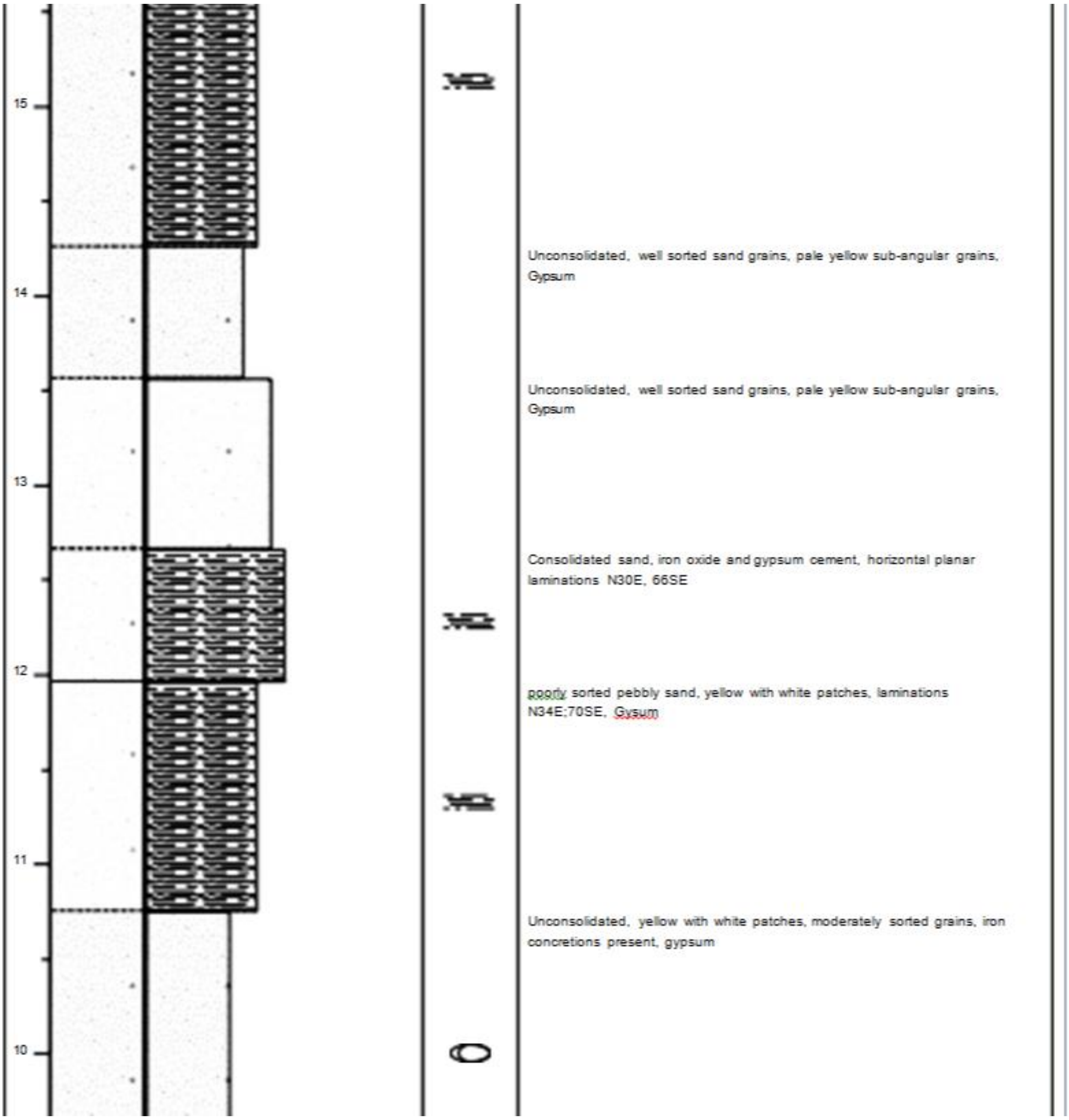

45
44
43
42
41
40
unconsolidated, grey,well sorted
unconsolidated, grey, with gypsum filling joints vertically cutting through beds
unconsolidated, friable, grey and heavily weathered
consolidated, well sorted with intercalations of brown and pink beds, trough cross bedding
consolidated, massive, moderately sorted, subrounded
consolidated, well sorted with intercalations of yellow and pink beds
consolidated, massive, moderately sorted, subrounded
well sorted, consolidated by gypsum, has bedding planes
Consolidated, wellsorted
Unconsolidated, poorly sorted, cemented by gypsum
Consolidated, wellsorted
Unconsolidated, poorly sorted, angular grains

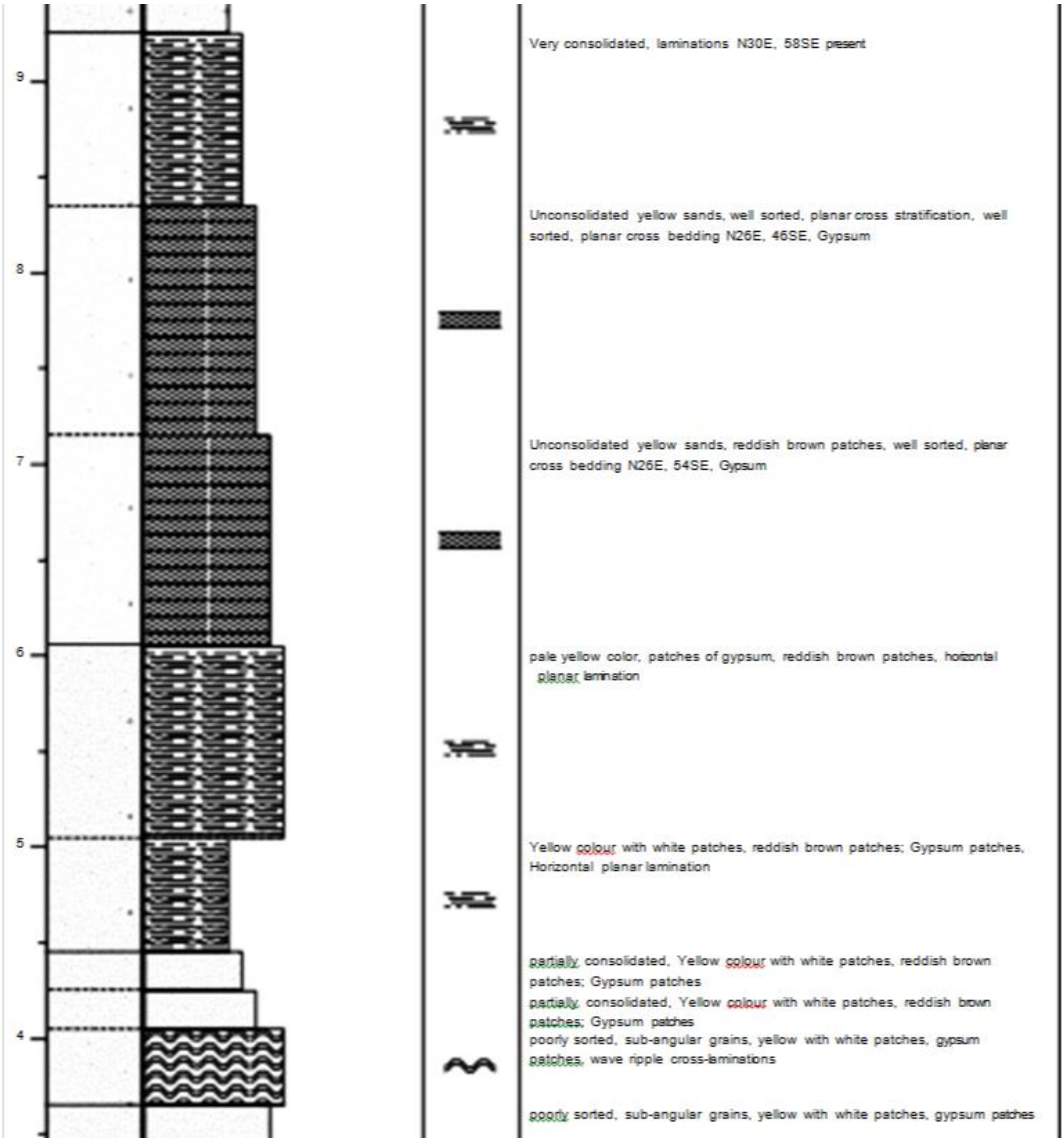

39
38
37
36
35
34
Consolidated, wellsorted
Unconsolidated, poorly sorted, angular grains
Consolidated,poorly sorted, sub-angular grains, jointed by gypsum
Consolidated, wellsorted
Angular grains, poorly sorted, unconsolidated
Consolidated, wellsorted
Angular grains, poorly sorted, unconsolidated, has silt in it
Angular grains, poorly sorted, unconsolidated
Sub angular, poorly sorted, silt layer with organic matter


33
32
31
30
29
28
Angular grains, poorly sorted, unconsolidated
Unconsolidated, poorly sorted
Consolidated, welsorted
Angular grains, poorly sorted, unconsolidated
well sorted, consolidated
Consolidated,poorly sorted, angular grains, cemented by gypsum
Consolidated, welsorted
Consolidate, poorly sorted, angular grains, cemented by gypsum


21
20
19
18
17
16
Unconsolidated, well sorted, Angular, gypsum crystals present, yellowish grey
Unconsolidated, well sorted, sub-rounded, yellow, trough cross bedding
Consolidated, poorly sorted, sub-angular
Unconsolidated, poorly sorted, sub-rounded, yellow
Unconsolidated, well sorted, Angular, yellow, Horizontal planar lamination
Unconsolidated, well sorted, yellow
Consolidated, well sorted, grey
Unconsolidated, well sorted, sub rounded, yellow, Horizontal planar lamination
Unconsolidated, well sorted, well rounded, yellow
Unconsolidated, well sorted, Greyish yellow, Horizontal planar lamination
Unconsolidated, well sorted, reddish brown, Horizontal planar lamination
Consolidated, well sorted, yellow clay
Planar cross bedding
Unconsolidated, sub-angular sands, yellow with white patches, Gypsum
Unconsolidated yellow sands, moderately sorted, horizontal planar lamination N14E, 58SE, well sorted, planar cross bedding N26E; 46SE, Gypsum


27
26
25
24
23
22
Blocky, well sorted, reddish-brown clay
Unconsolidated, poorly sorted, sub-angular, planar cross bedding
Unconsolidated, very coarse gravel, poorly sorted
Blocky clayey silt, Horizontal planar lamination, brownish yellow
Unconsolidated, poorly sorted, sub-angular, yellow, horizontal planar lamination
Unconsolidated, moderately sorted, sub-rounded, greyish yellow
Unconsolidated, poorly sorted, sub-angular, interbedded with clay, yellow
Unconsolidated, poorly sorted, sub-angular, organic matter present, yellow
Unconsolidated, well sorted, sub-rounded, planar cross bedding
Clayey silt, reddish brown, Laminations
Unconsolidated, poorly sorted, sub-rounded, greyish yellow, planar cross bedding
Unconsolidated, poorly sorted, Angular, grey
Unconsolidated, poorly sorted, sub-rounded, greyish yellow, Angular cross stratification
Unconsolidated, reddish brown silt
Unconsolidated, well sorted, sub-angular, gypsum crystals present, yellow, horizontal planar laminations
Unconsolidated, well sorted, sub-rounded, dark yellow, organic matter preserved
Unconsolidated, poorly sorted, Angular, grey
Unconsolidated, well sorted, Angular
Unconsolidated, poorly sorted, Angular, grey
Unconsolidated, well sorted, sub-angular, gypsum crystals present, yellow


15
14
13
12
11
10
Unconsolidated, well sorted sand grains, pale yellow sub-angular grains, Gypsum
Unconsolidated, well sorted sand grains, pale yellow sub-angular grains, Gypsum
Consolidated sand, iron oxide and gypsum cement, horizontal planar laminations N30E, 66SE
poorly sorted pebbly sand, yellow with white patches, laminations N34E;70SE, Gysum
Unconsolidated, yellow with white patches, moderately sorted grains, iron concretions present, gypsum


9
8
7
6
5
4
Very consolidated, laminations N30E, 58SE present
Unconsolidated yellow sands, well sorted, planar cross stratification, well sorted, planar cross bedding N26E, 46SE, Gypsum
Unconsolidated yellow sands, reddish brown patches, well sorted, planar cross bedding N26E, 54SE, Gypsum
pale yellow color, patches of gypsum, reddish brown patches, horizontal planar lamination
Yellow colour with white patches, reddish brown patches; Gypsum patches, Horizontal planar lamination
partially consolidated, Yellow colour with white patches, reddish brown patches; Gypsum patches
partially consolidated, Yellow colour with white patches, reddish brown patches; Gypsum patches
poorly sorted, sub-angular grains, yellow with white patches, gypsum patches, wave ripple cross-laminations
poorly sorted, sub-angular grains, yellow with white patches, gypsum patches

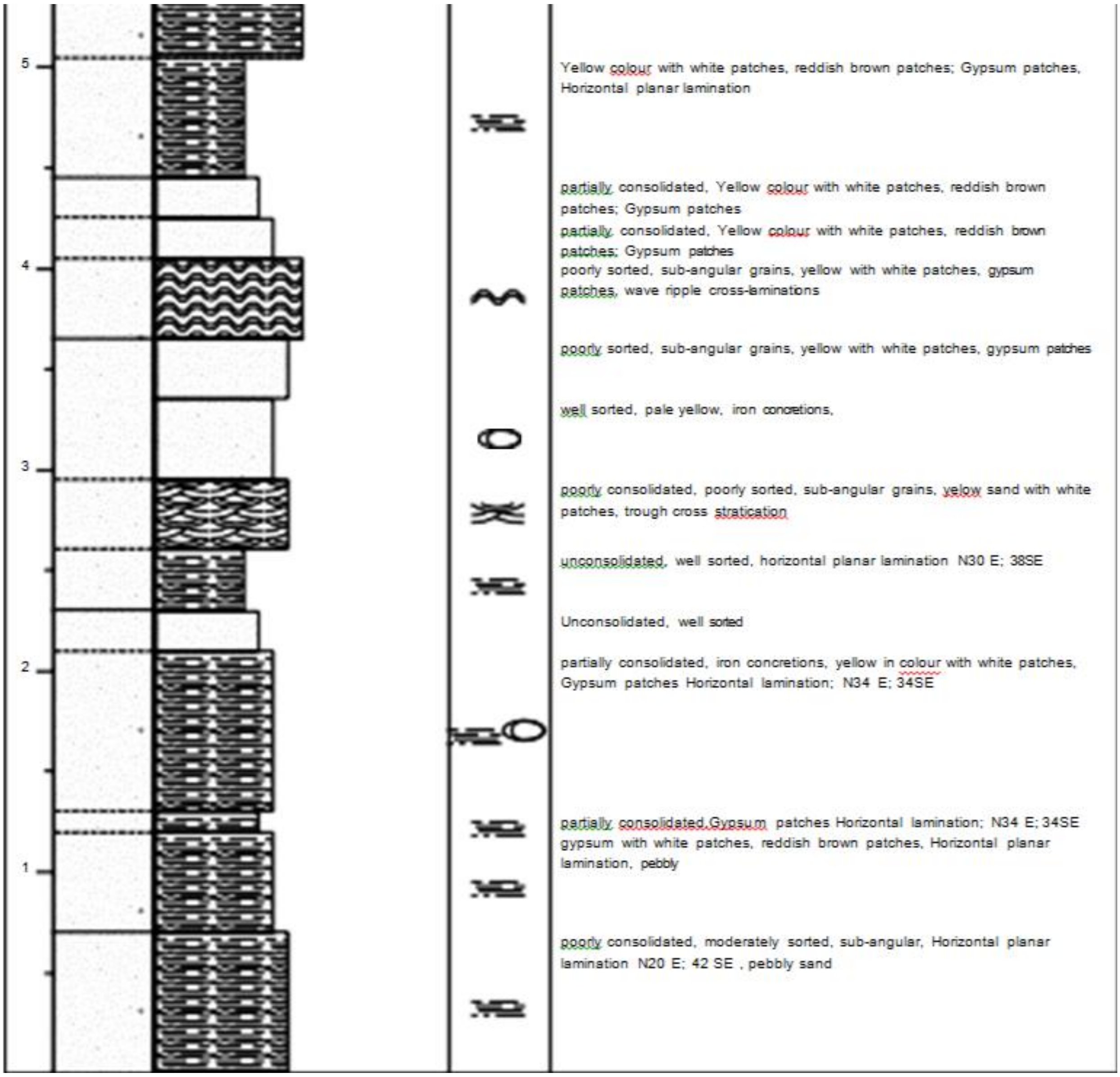


Figure 5.2: Combined lithostratigraphic log of groups A, B, C, F and G

CHAPTER 6: GEOPHYSICS OF THE SEMLIKI SEDIMENTARY BASIN

6.1 Introduction

Geophysics is tool used to provide information about the subsurface. It helps to identify subsurface structures and rock composition. This concept uses the principles of physics to measure variations in physical properties like density, magnetism and conductivity to infer geological information.

The Albertine Graben is a frontier graben where gravity and magnetic data, together with 2D and 3D seismic data have been acquired. The interpretation of this data revealed the major tectonic regimes that have shaped the graben and the sediment facies that fill up to 6 km deep basins. Contrary to the long held view, that the Albertine graben is purely controlled by extensional tectonics, seismic data interpretation shows a late compression episode in the graben generating an inversion tectonic regime and creating major hydrocarbon traps. (AAPG Search and Discovery)

Seismic data

This is collected from seismic surveys where seismic waves are generated using controlled sources and then recorded using geophones or seismometers. Seismic waves are directed into the ground and bounce off subsurface interfaces (rock layers or faults). By recording the time it takes for these reflections to return and their amplitudes, geophysicists can create detailed images of the subsurface, revealing the layering and geometry of geological formations.

Magnetic surveys

These measure variations in Earth's Magnetic field, which can be used to map geological structures like faults and igneous intrusions. It uses highly sensitive magnetometers to detect changes in the magnetic properties of subsurface rocks and features. These variations in magnetic intensity can be caused by different rock types and mineral deposits.

Gravity surveys

These measure subtle variations in the Earth's gravitational field, which can reveal the presence of dense ore bodies or other geological anomalies. Gravity measurements define anomalous density within the earth; in most cases, ground-based gravimeters are used to precisely measure the variation in gravity field at different points. Gravity anomalies are computed by subtracting a regional field from the measured field, which results in gravitational anomalies that correlate with source body density variations. Positive gravity anomalies are associated with shallow high-density bodies, whereas gravity lows are associated with shallow low-density bodies

6.2 Gravity data interpretation

Gravity data is interpreted by identifying the gravity anomalies that correlate with the source body density variations. Through the application of the Geosoft (Oasis Montaj) software, geophysical gravity anomaly map of the Semliki Basin was produced.

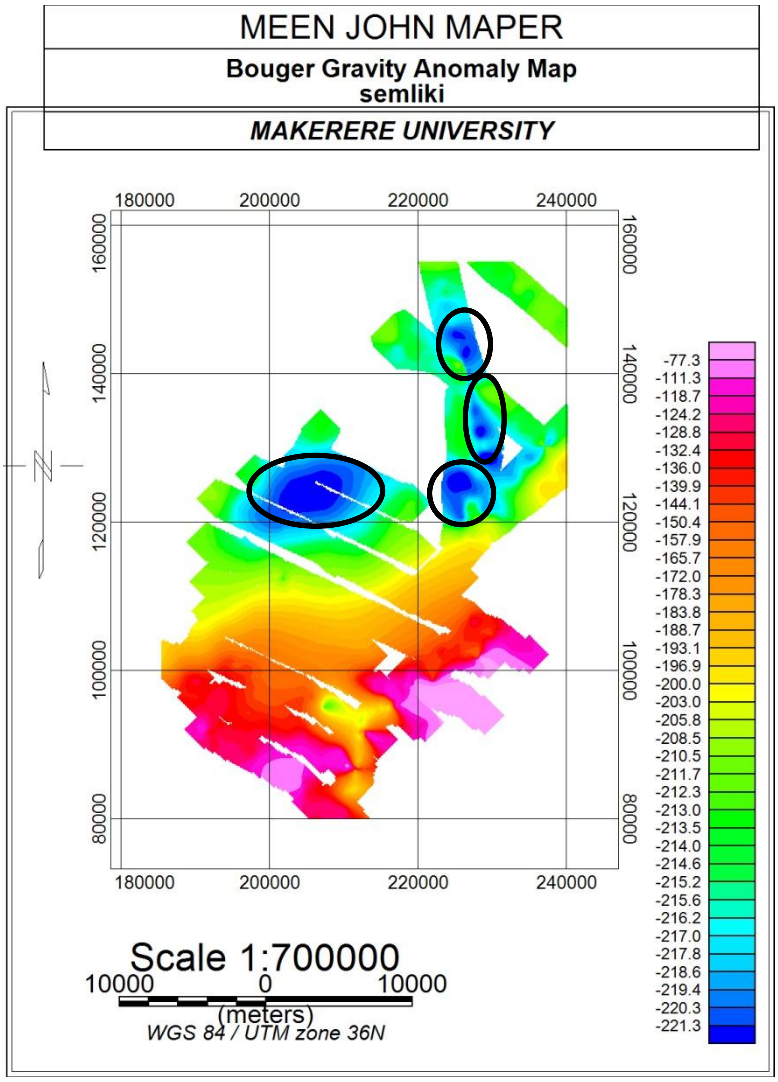


Figure 6.1: Bouger Gravity Anomaly map of the Semliki Basin showing sedimentary Basins

On the gravity anomaly map above, the values of the gravity anomaly range from -221.3 mgal to 77.3mgal basing on the Color Legend bar. These values are all negative and it may imply very low rock densities possibly of the sediments within the Semliki Basin. The strongest gravity lows (-221.3 mGal) represent the deepest part of the sedimentary basin due to large sediment thickness with low density. The moderate gravity lows (-196.9 mGal) may represent basin edges with moderate sediment thickness or fault bound depressions.

Therefore, the circled blue areas on the Bouger gravity anomaly map above represent the deepest parts of the basin (depocenters) of the Semliki. The difference in thicknesses of sediment accumulation is due to difference in accommodation space in the different parts of the basin. Therefore, the northern parts of the Semliki basin with the green and blue colors are the deepest while the southern region is shallower represented by the pink and red colors on the map.

6.3 Magnetic Data Interpretation

The Geosoft (Oasis Montaj) software was used to generate a geophysical magnetic map from the potential field (magnetic) data that was provided. The Total Magnetic Intensity in the Semliki Basin and direction are altered by variations in the magnetic susceptibility of rocks as indicated on the map below.

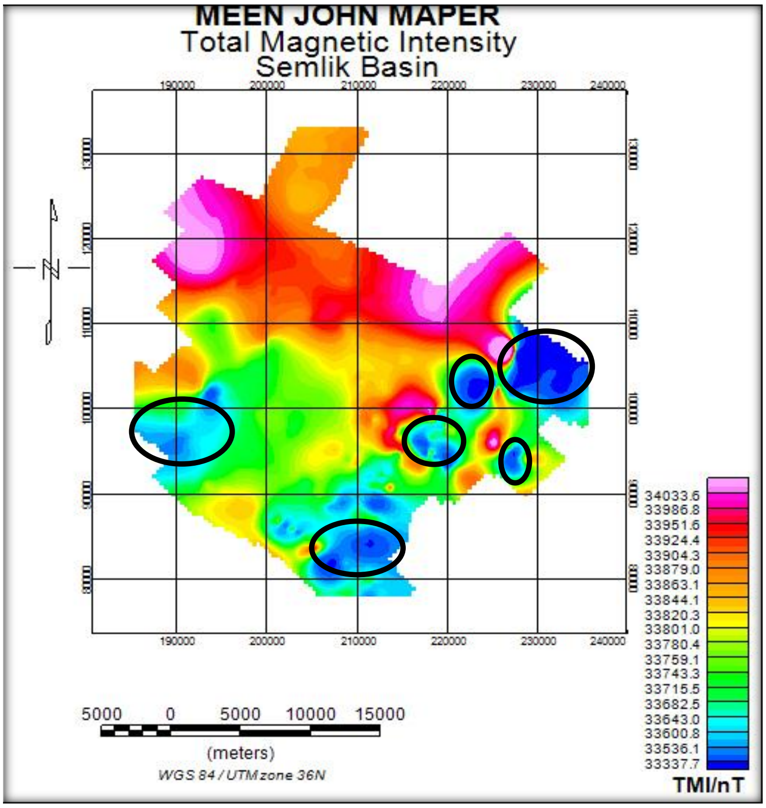


Figure 6.2: Map of Total Magnetic Intensity of the Semliki basin showing sedimentary basins

The map of total magnetic intensity above has highest magnetic intensity (highs) of 34033.6 nT that is indicated by the pink colors and lowest magnetic intensity (lows) of 33337.7 nT indicated by the blue colors on the Color legend bar. The intermediate magnetic intensity is approximately 33820.3 nT as represented by the yellow color on the Color legend bar. The highs in the north of Semliki basin indicate existence of igneous or metamorphic rocks in that area.

However, the points that have been circled on the map indicate sedimentary basins. This is indicated by the lowest magnetic intensity (blue color) according to the color legend bar on the lower left corner. According to the compass direction indicated by the north arrow, the southern part of Semliki basin is generally contain rocks with low remnant magnetization and these could be sediments. This could result from sedimentary rocks like sandstones, shales that contain few magnetic materials, thus they have inherently low magnetic susceptibility.

6.4 Seismic Data Interpretation

The seismic method can be used inland, offshore, and in transition zones. Though details of the seismic method are complex, the principle is relatively simple. Seismic sources at or just below the surface generate elastic waves that propagate in different directions through the subsurface. Variations in the physical properties of the geological layers cause the seismic signals to reflect, refract at the boundaries of these layers. The reflected waves head back towards the surface where detectors have been placed to record these waves. The recorded signals are subsequently processed to generate images of the subsurface, and to estimate physical properties such as wave velocity. (International Journal of Scientific Engineering and Research (IJSER)

In the Semliki Basin, seismic activity has been carried out to produce images of the subsurface structures. Seismic line on the Random line 2 was analyzed to identify different structures of faults and folds were identified and marked as indicated. Reflectors R1 and R2 on Random line 2 are initially continuous with relatively high amplitude reflection, most likely a strong impedance contrast. These reflections become terminated abruptly and this indicates the presence of faults. The terminations are recurring across the sediments until the basement sediment contact. The faults are identified as normal faults with displacements approximated as (R1=0.3cm & R2=0.3cm). The abrupt termination of the reflectors may also indicate an erosional truncation. Tracking the horizons involved locating intersection points where Random Line 2 crossed in-lines and X-lines.

From the Random line 2, normal faults (indicated by pink lines) were observed. This was based on the discontinuities that were observed on the seismic section. This shows there was intense faulting that occurred in the Semliki basin. However, these faults are not visible in the basement rocks rather they were evident in the sediments. The black line indicates the basement sediment contact on the seismic section. The Semliki basin is characterized by faulting and folding due to tectonic activity that took place within the Albertine Graben. Normal faults that cut across anticlinal folds are identified on seismic section. These faults could act as migration pathways for hydrocarbons, and on the other hand may also be useful traps for oil and gas in case of clay smear. The anticlinal folds indicated by the orange lines on the seismic section may form potential structural traps for hydrocarbons.

Seismic Facies Analysis for the Gulf of Mexico

The data used was from the Gulf of Mexico and we carried out seismic data interpretation on a High- Resolution Seismic Stratigraphy of Intraslope Fans from the East Breaks Basin of the Gulf of Mexico. This exercise involved identifying and marking reflection terminations, including truncations, onlaps, and downlaps, on seismic line D1. These features were then correlated with seismic lines S1, S2, S3…… S7. Thick patterns of seismic lines show high seismicity.

Summary of procedures

- ❖ Seismic line D1 was examined to identify and mark all reflection terminations like downlaps, onlaps and truncations.
- ❖ These reflections were then correlated and tied across the seismic lines (S1,S2,S3……S7)
- ❖ Major sequence boundaries were mapped based on the identified reflection terminations.
- ❖ Facies units were delineated, color-coded and recorded directly onto the seismic sections

Through the analysis of the provided seismic images, I identified two distinct sedimentary facies. The first facies is characterized by a pink color, while the second is distinguished by a green color. The first facies, characterized by thick, high-amplitude seismic reflections, is likely indicative of a sandstone lithology. However, the second facies, marked by thinner, low-amplitude reflections and represented by a green color, may correspond to clay or shale deposits. Additionally, the first facies exhibits continuous seismic reflections that terminate against an onlapping surface, suggesting a distinct depositional framework. The difference in the facies may indicate different depositional environments. During sea level rise (transgression), the fine grain facies (shales/clays) were deposited while sands were deposited during sea level fall (regression).

6.5 Petrophysics for formation evaluation

Rock physics provides a physical understanding of how changes in the rock and fluid properties may affect seismic parameters, such as P-wave and S-wave velocities, P-to-S wave velocity ratio, elastic moduli, density and acoustic and elastic impedances. As such this opens a link between geologic reservoir parameters (porosity, clay content, sorting, lithology, saturation) and the seismic properties as described above (Avseth et al., 2010a, Avseth et al., 2010b).

In our study, the data provided was for the Tura-2 Well and it was used in formation evaluation using Density, Neutron, and Gamma Ray Logs. In addition to that, the V-shale parameter was computed to assess the shale content within the formations.

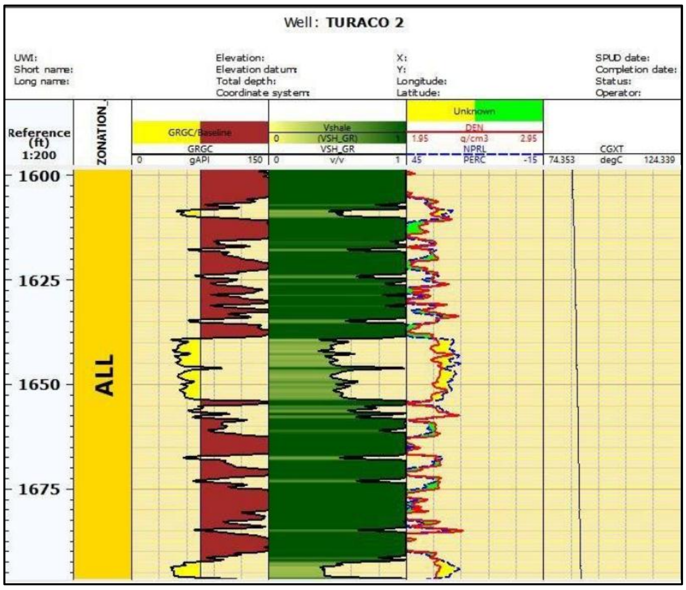


Figure 6.3: Section of interest on Wireline log for Turaco-2 well

Using Gamma Ray log

The deflection of the gamma ray to the right of shale baseline indicates high gamma ray readings marked by brown color zones. This shows that these zones are occupied by shale lithologies (1600 – 1640 ft) and (1647.5- 167 ft) due to their high radioactive element content.. On the other hand, low gamma ray readings, indicated by yellow color zones indicate sand lithologies.

Basing on V-shale Log

The gamma ray log was used in Techlog software to derive the V-shale log. This log is used to estimate the fraction of shale present in a rock formation. The V-shale also shows very high values in the zones with shales.

$$\text{V-shale} = \frac{GRlog - GRmin}{GRmax - GRmin}$$

Where:

Vshale - the fraction of shale volume in the rock

GRlog - the gamma ray reading at specific depth

GRmin – the minimum gamma ray value from a clean sand interval

GRmax – the gamma ray reading from a pure shale interval.

Basing on Neutron-density logs

From the log section above, the formation contains more gas than oil because of the low neutron log readings (blue dashed line). Gas has the lowest hydrogen concentration compared to oil and water. The density log (red line) shows higher readings also shows gas. The wide separation of the neutron and density logs at (1640 - 1647.5 ft) confirms the presence of gas in sand lithology. Therefore Turaco-2 well contains gas.

Porosity can be calculated from the Neutron-density logs using;

$\boldsymbol{\Phi = \rho matrix - \rho density\ log}$

$\boldsymbol{\rho matrix - \rho fluid}$

Where:

Φ = porosity

P matrix = the density of the matrix (g/cc)

P density log = the density read from the density log (g/cc)

P fluid = the density of the fluids (g/cc)

6.6 Turaco Drilling Site

The Turaco Drilling Site is located in the Semliki Basin in the Albertine Graben. The site contains a set of three wells (Turaco-1, Turaco-2 and Turaco-3) that were drilled by Heritage Oil and Gas Corporation and Energy Africa. These wells are located on the hanging wall of the Makondo fault. There was use of 3D seismic data in exploration.

Turaco-1 Well was located at (199706E, 113822N) and it was the first well drilled in 2002 by Heritage Oil and Gas, however, it did not reach total depth as a result of technical issues. Turaco-2 well located at (199819E, 113453N) was then drilled over 10 m away from Turaco-1 in 2004. There were oil shows though they were stained with material. Turaco-3 well (199763E, 11376N) was drilled over 200 m from Turaco-2. The natural gas tested in Turaco-3 was heavily contaminated with carbon dioxide, which posed challenges for commercial viability (**Petroleum Authority of Uganda).** This carbon dioxide could have resulted from igneous activity (magmatism) or combustion of hydrocarbons due to very high temperatures. Therefore, the project was abandoned and Turaco Site was relinquished to the government after Heritage Oil and Gas Limited realized there was no economic value in producing the hydrocarbons.

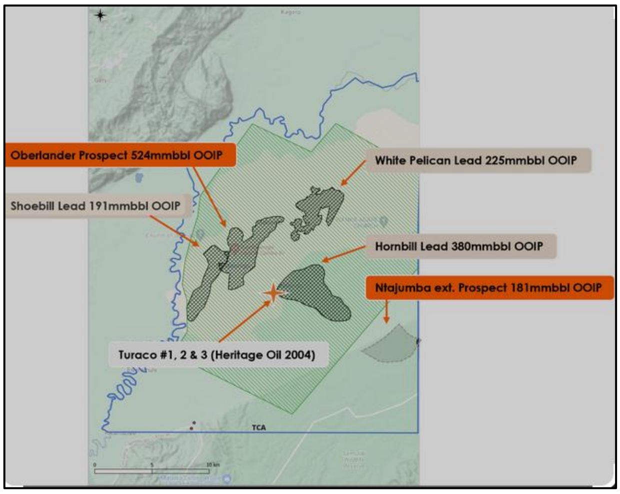


Figure 6.4: Map showing Turaco- well site (source: Conjugate Energy)

Figure 6.5: Abandoned Turaco Site located at (199630E, 114153N , 637 m)

6.7 Geothermal Exploration in the Sempaya Hotspring

A hotspring is a spring of water that is produced by emergence of geothermally heated ground water from the Earth's crust. It is a common surface expression of geothermal energy. The Sempaya hotspring lies in the western arm of the East African Rift System (EARS). It is bordered by Semliki flats or Lake Albert in the north, escapements of mountain Rwenzori in the South east and river Semliki in the west. The Bwamba fault is in close proximity with the Semliki forest where the hotspring is located. The Sempaya consists of the male and the female hotsprings. The female hotspring is over 100^0c and this is an evidence of strong geothermal gradient or high heat flow in the Semliki basin and the Albertine graben. This is also an indicator of the maturation of source rocks in the basin. The age of the Albertine graben is Miocene and it is too young for the conversion of organic matter to hydrocarbons. However, as a result of the high geothermal gradient, the source rocks have matured faster in the Albertine graben than they ought to be on normal circumstances.

Uganda currently hosts ~25 geothermal sites with an estimated 1500 MW of capacity. With a stark contrast between the geothermal resources in the two arms of the East African System, it has been imperative that favourable techniques be perfected for the integrated geological, geophysical, geochemical, and hydrological investigations of the major geothermal (Jacinta Achieng, Geothermal Resources Department, Ministry of Energy and Mineral Development)

In the Sempaya locality, various geophysical methods have been applied for geothermal exploration and these exploration methods can be classified into several groups like seismic, electrical resistivity, potential methods (gravity and magnetics), heat flow measurements, and surface deformation measurements. Thermal gradient holes (TGH), exploration wells (slim holes), and full-scale production wells (wildcats) provide the most reliable information on the subsurface. Temperature gradients, thermal pockets and other geothermal characteristics can be measured directly after drilling, providing valuable information.

Seismic methods; measure sound velocity distribution and anomalies in the earth as well as attenuation of the sound waves. They are divided into two groups, active methods where an external source is used to create sound waves, such as explosions or hammer devices, while passive methods detect the seismic activity in the earth and use that to get information on parameters that may be influential for the geothermal system. Seismic methods rely on elastic waves which have different velocities when travelling through different rock types, and are refracted or reflected at discontinuities in or between formations. There are two types of elastic body waves: P-waves, or pressure waves, where the wave movement is in the travel direction; and S-waves, where the material movement is perpendicular to the wave direction; due to the wave movement, S-waves do not penetrate through fluids, but only solid rocks. Active measurements give information on the density of the formations, the porosity and texture, boundaries and discontinuities and fluid-filled zones and thus even temperature. The measurements are quite expensive, especially good reflection measurements. And despite being the most used of all geophysical methods as a key method in oil exploration, active seismic measurements, and especially reflection measurements, are not used routinely in geothermal exploration. High-temperature geothermal activity is mainly found within or at least associated with active central volcanoes, which are usually dominated by complicated bodies of crystalline rocks. The information can therefore be quite difficult to interpret and depth penetration not high, and the method thus not cost-effective. The strength of the active methods is in sedimentary surroundings as is to be expected for the basic methods used for oil carrying formations.

Gravity measurements; are used to detect geological formations with different densities. The density contrast leads to a different gravitational force which is measured, and usually presented in mgal or 10 -3 cm/s2. The density of the rocks depends mainly on the rock composition and its porosity, but partial saturation of the rocks may also influence the values. Normally the density is between ~2 and 3 g/cm3. Generally, sedimentary rocks are lighter than crystalline rocks. The raw data needs to be corrected for several factors. The results are usually presented or shown in Bouger maps based on the Bouger anomaly Δg B, where corrections have been done on the measured value g for tidal effects, elevation, local topography, latitude and drift in the gravimeter. Applications in geothermal exploration include mapping of: basement depth variations in sedimentary areas, intrusive rocks sometimes associated with a possible heat source, fault or dyke systems, and alteration/cementation due to thermal effects.

Magnetic measurements; in geothermal exploration these measurements generally aim mainly at locating hidden intrusives and possibly estimating their depth, or at tracing individual buried dykes and faults. They may also aim at finding areas of reduced magnetization due to thermal activity. The measurements for local structures such as individual faults or dykes are done on the ground by regular measurements along parallel profiles or in a grid. Measurements aimed at larger anomalies such as mapping of deeper intrusions or outlining sedimentary basins are done through aeromagnetic surveys, where the height and spacing of the profiles relies on the preferred data density. In geothermal exploration an elevation of about 100 m above ground and 100 m spacing between profile lines is often used, but this is also influenced by the topography below. Data presentation is through contour maps or profile maps, and quite advanced filtering techniques can be used to distinguish anomalies in the data.

MT or natural-source electromagnetic: uses the earth's natural electromagnetic field as its power source. The variable natural magnetic field induces electrical currents in the conductive earth. By measuring the signal of the fluctuating magnetic field and the electrical currents (i.e. the electrical field) on the surface of the earth, it is possible to correlate this to the resistivity of the earth below the measuring site. The frequency of the signal relates to its probing depth, with low frequencies reaching deeper levels. Thus, frequencies of 0.00001 - 10 Hz are used for deep crustal investigations, while higher frequencies, like 10 - 1000 Hz, for the upper crust. The MT equipment is fairly simple and portable with the electromagnetic field monitored through magnetic coils and electric dipoles, through a data acquisition system, usually connected to remote-reference station for electro-magnetic noise. MT is a powerful method to probe deep resistivity structures, which gives it an advantage compared to the other main electrical methods. The equipment is portable and the data collection is simple, involving measurement magnetic field components B and the induced electrical field E, both as a function of time for several hours, at each site.

Figure 6.6: Female hotspring at Sempaya

Figure 6.7: A male hotspring at Sempaya.

CHAPTER 7: DISCUSSION

7.1 Discussion of Facies and Depositional Environments

In the study area, facies were studied in association (in groups) instead of isolation. According to Walter's law of facies, a vertical sequence of facies will be the product of series of depositional environments which lay laterally adjacent to each other. Facies were identified basing on observable characteristics like color, texture, thickness, mineralogy and observed structures. The Semliki Basin consists mainly of the clastic and non-clastic sediments that include clays, siltstones, consolidated and unconsolidated sands.

Sedimentation in the Semiliki basin was basically influenced by three depositional environments that include fluvial, lacustrine and deltaic environments. The study area exhibited a fining upward sequence which indicates fluvial environment. During sea level rise (transgression), the fine sediments were deposited on top of the coarse sediments forming a fining upward sequence. The point bars along the Kisegi channel also indicates of a fluvial system of deposition in the area. The cross stratification is a result of ripples that resulted during the flow of this river. The large thickness of the unconsolidated sand layers in our sandy area, F and across other neighboring areas may deduce that there was a high magnitude of climate stability and sedimentation took quite a longer period. The presence of massive clay beds that were nearly horizontal indicates that there was deposition by a low energy system (lacustrine environment). There could have been an ox-bow lake that deposited these sediments. This lake could have formed when the Kisegi river meandered, creating sinuous path. As it eroded from the outside, it deposited sediments on the inner bends. Over time, the meander loop tightens and during high water event, the river breaches the meander neck, creating a more efficient channel. The presence of invertebrate fossils, such as gastropods shells around the Makondo area (201158E, 109998N) in the clay lithology indicates a lacustrine environment. There was a water body that supplied these sediments and because of tectonism, inversion of the topography occurred which forced Lake Obweruka to change its course. The Semliki basin might have experienced some aridity conditions due to the wide spread of the evaporites (gypsum) across the study area. This mineral is precipitated due to high rates of evaporation. There was also ample time for which the sediments were exposed to chemical weathering (oxidation) due to the presence of iron oxides in the red sands.

The fine sediment loads like muds, fine sands and silts indicates a deltaic environment. The coarsening upward sequence evidently in area H, is another indication of a deltaic deposition especially during regression where coarse sediments were deposited onto the finer sediments. The presence of clay balls in the Kibuku stream shows that some depositional episodes sparked off with very high energy thus eroded the fine clays on top of the previous episodes/sequences

7.2 Summary of the geological history of the Area

The area of study has experienced intense tectonic events primarily rifting, which resulted to the formation of different structures observed like the faulting, severe jointing in granitic gneisses and of the Pre-Cambrian Basement rocks. In the sediments, minor fault was observed in our study area, F. **(refer to Figure 4.9).** The area has also suffered high grade metamorphism as evidenced by folding in the migmatites exposed at Itojo road cut. The sediments are deposited on top of the basement rocks evidenced by a disconformity at the basement-sediment contact (192596E, 02090N, 705 m). Since this area is part of the bigger western arm of the East African Rift System, rifting has also affected it that led to the formation of normal faults and the Semliki basin. Geologically, the Semliki basin is both in Democratic Republic of Congo and Uganda, but the fault on the DRC side is stronger evidenced by the Blue Moon Mountains, however the fault on the Uganda side keeps on changing from Kichwamba, Toro and Kibuku fault.

The process of rifting also provided accommodation space for sedimentation due to subsidence and formation of the Semliki basin that was later filled with sediments. However, the study area wasn't flat as it was expected to be on normal circumstances. This could be as a result of inversion/tectonic uplift that led to the formation of the Rwenzori Mountain and these forces also affected the nearby areas. The sediments that filled the created graben could have been from the basement rocks or transported by rivers from the highland areas. The Rwenzori Mountain is younger than rifting; therefore it is not possible to have supplied these sediments.

In the Semliki basin, the bedding were the first to be formed during sedimentation, these beds were exposed to tectonic forces which rested to their tilting. Folds resulted from ductile deformation of rocks while faults and joints resulted from brittle rock deformation. The quartz veins in the area occurred after the brittle deformation hence filling the fractures created. These veins are younger since they crosscut the folds. The major trend of the joints

(NE-SW) is similar to that of the major faults, and beds thus they were affected by similar tectonic events.

7.3 Petroleum Potential in the area

The main aim of the Semliki basin exercise was to determine the presence of a petroleum system.

The facies relationships show promising petroleum potential within the Semliki Basin; reservoir potential, top seals, and evidence of mature source rocks. The coarse grain, moderately sorted and friable sands within the Kisegi formation of the Semliki Basin indicate good porosity and permeability which are the main necessities for high quality reservoir. Therefore, the area has potential for reservoir rocks. However, the reservoir quality may be reduced because of the presence of gypsum mineral which occupies the fractures that cut these sediments vertically. This mineral may clog the pore throats in the reservoir reducing its permeability.

The massive lacustrine clays of area H in Kasande Formation may also act as potential source beds upon maturation, and can be seals/cap rocks due to their low permeability. However, the clays in most areas in the Kisegi Formation were not thick enough to reach over 6 km that has sufficient temperatures for conversion of organic matter to petroleum. An oil seep was also observed at Kibuku area which is an indicator of source rock maturation and the presence of the Sempaya hotsprings within the Semliki basin also reflects a potential geothermal gradient for the hydrocarbon's maturation. The identified structural and stratigraphic features also act as hydrocarbon migration pathways. The high jointing in the granite gneisses that underlie the sediments is a good potential for migrating routes for hydrocarbons. The faults may also act as a good trap when they juxtapose reservoir rock against fine grain clays. The folds encountered in the field could also act as potential structural traps for hydrocarbons.

However, at extremely high temperatures as evidenced by presence of Sempaya hotspring, hydrocarbons become unstable and may decompose into methane and to graphite (carbon) after passing the gas window. It may lead to metamorphic alteration, converting organic matter into inert carbon or mineralized deposits. The shear zones (weathered part) on the granitic gneiss outcrop could also lead to biodegradation of hydrocarbons and water washing.

CHAPTER 8: CONCLUSION AND RECOMMENDATION

8.1 Conclusion

The study area, located within the Albertine Graben was affected by tectonic events with rifting dominating the area. This has caused structural deformations that resulted to faulting, folding and jointing in the basement rocks and sediments within the area. The basement rocks revealed high-grade regional metamorphism, indicated by presence of migmatites, shearing, foliation, and mineral banding in the granitic gneisses. There is an active tectonism in the Semliki Basin with the high geothermal gradient evidenced by the presence of the Sempaya hotspring. The hotspring is also an indicator of source rock maturation in spite of the fact that the Semliki Basin is of Miocene age. Structural studies revealed that the dominant orientation was in the NE-SW direction which is similar across the entire Albertine graben. Structural features are significant in hydrocarbon potential in that joints and faults act as migrating pathways for hydrocarbons, while folds may be useful structural trapping mechanisms. This shows that the tectonic forces that affected this area acted in this same direction. Through analysis of the facies, both clastic (sands) and non-clastic (clays) sediments, three depositional environments were identified; fluvial, lacustrine and the deltaic environments. Through logging of the sediments, thick layers of coarse grain, friable sands indicate good porosity and permeability, thus can act as reservoir rocks. The thick, fine grain consolidated lacustrine clays may act as source beds or seals/cap rocks. Tectonism has also resulted into the formation of structural and stratigraphic features that act as migrating pathways and trapping mechanisms for hydrocarbons.

Therefore the Semliki basin exhibits promising hydrocarbon potential and may require more studies in order to determine the magnitude of this prospect.

8.2 Recommendations

Based on the field study carried out in the Semliki Basin, most of the intended objectives were achieved; however the following recommendations may be put in consideration in order to improve efficiency in data acquisition.

The Department should increase the duration in which students take in the field to at least a period of one month in order to enable them familiarize with the lithostratigraphic logging exercise and basin analysis.

Students training; there should be more collaborations among the Department of Geology and Petroleum Studies, the oil companies and the government agencies like Petroleum Authority of Uganda (PAU) to have joint research initiatives for the integrated basin studies. The students should be given internship training opportunities by the oil companies to gain hands-on experience in basin analysis and petroleum systems modeling studies.

There is need for more high resolution 3D seismic data to improve subsurface imaging, especially near the fault zones where hydrocarbon traps may exist.

Geochemical analysis should like Total Organic Carbon Content (TOC) and Rock Pyrolysis should be made more available to students in order to assess the hydrocarbon generation potential of the study area.

REFERENCES

Abeinomugisha, D and Kasande, R. (2008). "Tectonic control on hydrocarbon accumulation in the intra continental Albertine Graben of the East African rift system". AAPG international conference and exhibition, Cape Town, South Africa.

Bishop, W. W. (1965). "Quaternary Geology and Geomorphology in the Albertine Rift Valley, Uganda." *Geol. Soc. America Special Paper* 84: 293-321.

Bruce E. Hobbs/Winthrop D. Means/Paul F. Williams, (1976). "An outline of Structural Geology". p. 149, 153-154.

Ebinger, C.J., (1989). Tectonic development of the western branch of the East African Rift System. *Geological Society of America Bulletin* **101**, 885-903.

Ernest N.T. Rubondo., (2001). Petroleum potential of East African Rift System with special reference to the Albertine Graben. *A key note address for regional conference of the Geological Society of Uganda and Geological Society of Africa,* 16-20.

Godfrey, B. (2003). "Geothermal energy in Uganda, country update, Department of Geological Survey and Mines".

Harris, N., Pallister, J. W., and Brown, J. M. (1956). "Oil in Uganda." *Mem. Geol. Survey Uganda* 9: 33.

Karp, T., Scholz, C. A., and McGlue, M. M. (2012). "Structure and Stratigraphy of the Lake Albert Rift, East Africa: Observations from Seismic Reflection and Gravity Data." In *Lacustrine Sandstone Reservoirs and Hydrocarbon Systems*, edited by Baganz, O. W., Bartov, Y., Bohacs, K., and Nummendal, D. AAPB Memoir 95: 299-318.

Kiconco, L. (2005). "The Semliki basin Uganda: Its sedimentation history and stratigraphy in relation to petroleum accumulation". MSc. thesis, University of Cape Town, South Africa.

Lukaye, J. M. (2009) "Biostratigraphy and Palynofacies of Four Exploration Wells from the Albertine Graben, Uganda

Maurice, E. Tucker (1991). "Sedimentary Petrology, an introduction to the origin of sedimentary rocks". 2nd edition, P. 40-67.

Morley, C., Harper, R. M., and Wigger, S.T. (1999). "Tectonic inversion on East African in geosciences of rift system". pp 193-210, AAPG studies in geology NO.44.

Mutebi S, Ozumba BM, Adeigbe OC (2018) An Aspect of Palyno Stratigraphy of "XM" Field Located in Semliki Basin South Western Uganda.J Pet Environ Biotechnol 9:

388. doi: 10.35248/2157-7463.19.10.388

Pickford, M., Senut, B., and Hadoto, D. (1993). "Geology and Palaeobiology of the Albertine Rift Valley, Uganda-Zaire." *CIFEG. Publ Occas*. 1993 (24): 190.

Robert Kasande and E.N.T. Rubondo, Principle Geologist, March, 1996, *A report on the geological mapping of the Semliki Basin, Western Uganda* (published).

Roller, S., Hornung, J., Hinderer, M., and Ssemmanda, I. (2010). "The Middle Miocene to Pleistocene Sedimentary Rift Sequence of the Southern Albertine Graben (Uganda)." *International Journal of Earth Sciences* 99: 1643-61.

RPS Energy. (2008). Palynological Analysis of the Turaco-3 and Turaco-2 Wells, Block 3A, Albert Basin, Uganda. 32 p + 4 encl. Confidential Report.

Rubondo, E.N.T., (2001). "Petroleum potential of East African Rift System with special reference to the Albertine Graben". A key note address for regional conference of the Geological Society of Uganda and Geological Society of Africa.

Sam Boggs, Jr., (2006). Principles of Sedimentology and Stratigraphy. *Prentice Hall*, 579-580.

Selley, R., (1978), Concepts and methods of subsurface facies analysis, Cornell University Press, New York.

Twinomujuni, L. (2010). "Facies Analysis and Sequence Stratigraphy of the South East Lake Edward Basin, Southwestern Uganda". Unpublished Msc. thesis, Makerere University, Uganda.

Wayland, E. J. (1925). "Petroleum in Uganda." *Mem. Geol. Survey Uganda* 1: 61

APPENDICES

Appendix 1: Joint Measurements in Basement Lithologies

Set 1		**Set 2**	
Strike	**Dip**	**Strike**	**Dip**
S40W	34NW	S85E	62SW
N20E	78SE	N62W	82NE
N82E	72SE	N70W	65NE
N88E	14SE	S80E	68SW
N40E	30SE	N74W	68NE
N68E	80SE	N80W	74NE
S24W	18NW	S72E	64SW
S44W	30NW		
S36W	34NW		
N78E	80SE		

Appendix 2: Foliation measurements

Strike	**Dip**
S86^{0}W	70^{0}NW
S88^{0}W	69^{0}NW
S84^{0}W	68^{0}NW
S72^{0}W	70^{0}NW
S82^{0}W	72^{0}NW
N45E	80SE
N44E	82SE
N42E	80SE
N38E	76SE
N30E	80SE
N34E	82SE
N40^{0}E	82^{0}SE
N28^{0}E	82^{0}SE
N42^{0}E	74^{0}SE
N36^{0}E	78^{0}SE
S80^{0}W	64^{0}NW
S60^{0}W	62^{0}NW

Appendix: 3 Bedding Measurements

Strike	**Dip**
$N40^0E$	18^0SE
$N36^0E$	15^0SE
$N30^0E$	10^0SE
$N35^0E$	15^0SE
$N48^0E$	15^0SE
N40E	26SE
N50E	20SE
N46E	16SE
N44E	15SE
N42E	14SE
N38E	13SE
N34E	12SE
N32E	15SE
N28E	10SE
N25E	10SE