MAKERERE UNIVERSITY

COLLEGE OF NATURAL SCIENCES
SCHOOL OF PHYSICAL SCIENCES

A REPORT ON THE GEOLOGIC AND STRATIGRAPHIC LOGGING PROJECT OF THE SEMLIKI BASIN IN THE ALBERTINE GRABEN, NTOROKO DISTRICT, WESTERN UGANDA

COURSE CODE: PGP 4211

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

SUBMITTED ON:

APPROVAL

I KATO ENOCH certify that I carried out this field study under the supervision of my supervisor

.... 4th/June/2025

Signature Date

Dr. Nagudi Betty

(Project Coordinator)

DECLARATION

I, ***KATO ENOCH*** solemnly declare that this report is based on my own work and field observations carried out during the stratigraphic logging project in the Semliki Basin in the Albertine Graben Area, Western Uganda under the supervision of various lecturers at the Department of Geology and Petroleum Studies of Makerere University and has never been submitted in any institution for any award.

Signature:.............................. Date: 10/09/2025

DEDICATION

I dedicate this report to first GOD and then to my Watoto family that have worked tirelessly and made sure that my education is successful and all my family members.

I also dedicate this report to all my lecturers whose guidance has helped me accomplish this project, from the groundwork in the field and continuous follow up until the finishing of this report.

I also take this opportunity to appreciate the lecturers at the mighty Department of geology and Petroleum Studies especially those that we went with to the field in Karugutu. I thank them for their tireless efforts in making us understand the different concepts that will be very crucial and vital in my career. These lecturers include; Dr. Nagudi Betty, Mr. Mugwano Patrick, Dr. Echegu Simon and Dr. J.M Kiberu I thank the non-teaching team which was headed by Mr. Kasule for taking good care of us throughout the time in the field.

I also thank my classmates particularly my group members for the support, cooperation and making the field time memorable. To my group members namely; NALULE PAULINE JUSTINE, MBABAZI LEAKEY, NALUZZE PAMELA PRAISE, and ISIGA LAURA KAMBA, you were a great team thanks for your cooperation. God bless you all.

ACKNOWLEDGEMENT

I take this opportunity to thank Makerere University for allowing the students to go for a field trip for the fulfillment of the course. Thank you for providing financial support to us.

I express my sincere gratitude towards all the help and assistance from the team of lecturers Dr. Betty Nagudi, Dr. Simon Echegu, Dr. J.M Kiberu and Mr. Mugwano Patrick for accompanying us, providing moral support, guidance and expressing concern to us. The trip became successful and enjoyable because of your company.

I also want to thank the department of transport for their support by providing us with buses. The drivers did a wonderful job by ensuring that we reached all the places planned and we came back safely. My sincere appreciation to the non-teaching staff headed by Mr. Kasule who took care of us during the course of the field trip.

I extend my appreciation to my fellow students for their cooperation, discipline and adhering to all instructions. All this made the trip the most successful one. I want to thank the Almighty God for the safe journey, good health, protection and care that he gave us because we could not have made it by our own strength. Thank you very much.

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ABSTRACT

The Semliki Basin, located in the western branch of the East African Rift System, includes the Kibuku area and is part of Block 3 of Uganda’s Albertine Graben under a Petroleum Exploration License. This basin is shared by Uganda and the Democratic Republic of the Congo. The Ugandan portion lies in the southern part of Lake Albert and the adjacent land to the south.

The geological foundation beneath the rift (the pre-rift basement) is made up of both felsic and mafic rocks. After the rift formed, the overlying rock layers (post-rift lithology) included altered granites, granitic gneisses, and sedimentary rocks—mainly deposited by rivers and lakes. Both types of rocks are thought to have originated from the nearby Rwenzori Mountains.

Stratigraphically, the sediments are classified into five main formations. From oldest to youngest, these are the Kasande (bottom), Nyaburogo, Oluka, Karaka, and Katorogo (top) formations. Studies of the basin and sediment types suggest that the Kibuku area’s sediments, especially those exposed along road cuts, were deposited in environments such as rivers, lakes, and deltas. Pebbles found in the conglomerates that rest on the basement rocks closely match the mineral composition of the Rwenzori Mountains, indicating that the sediments likely came from there.

The Semliki Basin is considered a potential petroleum system, showing essential features for oil accumulation: possible reservoirs, source rocks, seals, traps, and migration routes for hydrocarbons. It is a sub-basin within the broader Albertine Graben, which is Uganda’s most promising region for oil and gas exploration.

The basin holds sediments from the mid-Miocene to the present, lying over older layers that may date back to the Jurassic or Early Tertiary, and these rest unevenly on the basement rocks. The main types of sediment in the basin are sandstones, siltstones, and claystones, mostly deposited by rivers, lakes, and deltas. The basement consists of igneous and high-grade metamorphic rocks like granites and granite gneiss.

To evaluate the petroleum potential of the basin, detailed structural and stratigraphic data were collected and analyzed. Due to significant tectonic activity in the region, both the basement and sedimentary rocks display a variety of geological features, including folds, bedding planes, cross-bedding, unconformities, joints, veins, and faults.

The early development of oil-generating organic matter in these young sediments is supported by surface features like the Sempaya Hot Springs. Overall, the Semliki Basin has been confirmed as a potential petroleum play, with all the critical elements of a functioning petroleum system in place

1. CHAPTER 1: INTRODUCTION

The annual field study is designed for students enrolled in the Bachelor of Science in Petroleum Geosciences and Production program at the Department of Geology and Petroleum Studies, within the School of Physical Sciences, College of Natural Sciences, Makerere University. This degree program aims to build expertise and technical skills in petroleum geoscience and production through comprehensive training and research, which are crucial for the continued exploration and extraction of oil and gas resources. Fieldwork is one of the key approaches used to achieve this goal.

As part of this practical training, a geological and stratigraphic field study was conducted in the Semliki Basin, situated in the southern region of the Albertine Graben in Ntoroko District, Western Uganda. The study run from 1st July, 2024 to July 9th 2024.

1.1 Study Area

1.1.1 Location.

The study area is the Kibuku region, located in the Karugutu-Ntoroko District of southwestern Uganda. It lies within the southern part of the Albertine Graben (Figure 1.1) and forms part of the Semliki Basin, which is situated within the Ugandan section of the Albertine Graben.

The Semliki Basin spans approximately 1,200 km², with about 740 km² falling within Uganda's portion of the Albertine Graben, while the remainder extends into the Democratic Republic of the Congo (DRC). It is part of Block 3 of the Albertine Graben, which represents the northernmost extension of the East African Rift System (EARS).

The study area covers the northern Rwenzori Block, extending from the Kichwamba Fault into the Semliki flats, including the Sempaya Hot Springs. It is bounded to the east by the eastern escarpment and to the southwest by the Toro Plain, near Lake Albert. To the southeast, a steep fault escarpment rises nearly 1,000 meters to the northernmost spur of the Rwenzori Mountains.

This region is distinct from the surrounding areas of Uganda and the DRC due to its relatively low elevation of approximately 650 meters above mean sea level, compared to the adjacent rift shoulders, which range from 1,100 to 1,500 meters to the east and 1,500 to 1,800 meters to the west (Mutebi et al., 2018). Neogene sediments, estimated to be up to 700 meters thick, are believed to be exposed in tributary valleys of the Semliki River. However, previous estimates have varied, with Wayland (1925) and Pickford et al. (1993) suggesting a thickness of approximately 600 meters

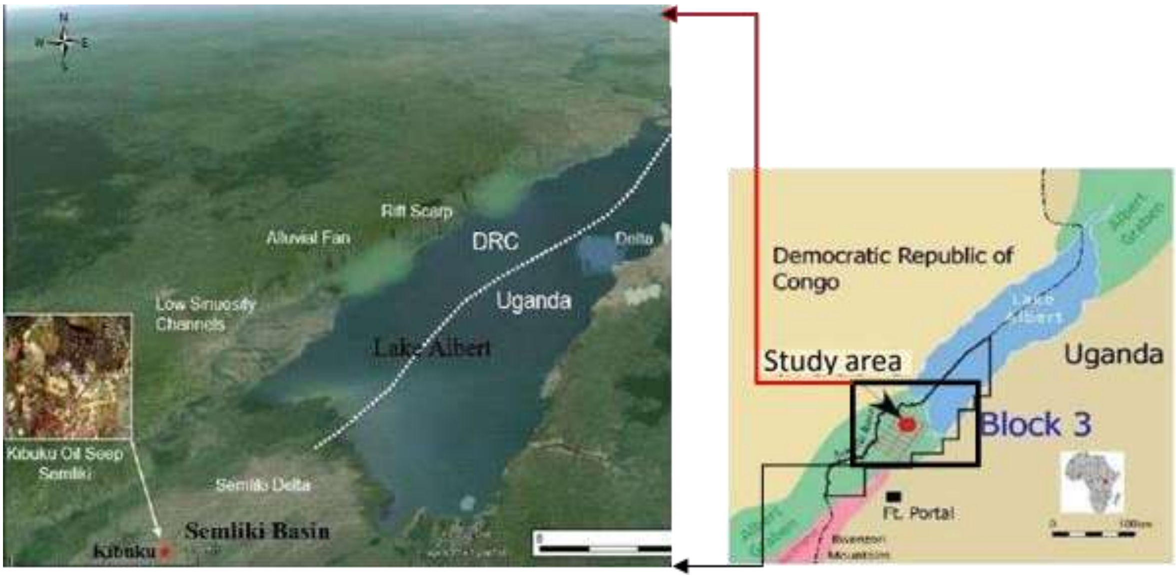

FIGURE 1:MAP SHOWING LOCATION OF THE KIBUKU STYDY AREA AND ITS LOCATION IN THE SOUTHERN PART OF THE ALBERTINE GRABEN(MUTEBI ET AL, 2018

1.1.2 Accessibility

The region can be reached by land travel from Kampala, passing through Mubende, Kyenjojo, and Fort Portal before arriving in Ntoroko. The highway from Fort Portal to Bundibugyo runs through Mubende and Kyenjojo, covering approximately 290 km to Fort Portal, followed by an additional 25.6 km from Fort Portal to Karugutu Town in Ntoroko District (Figure 1.2).

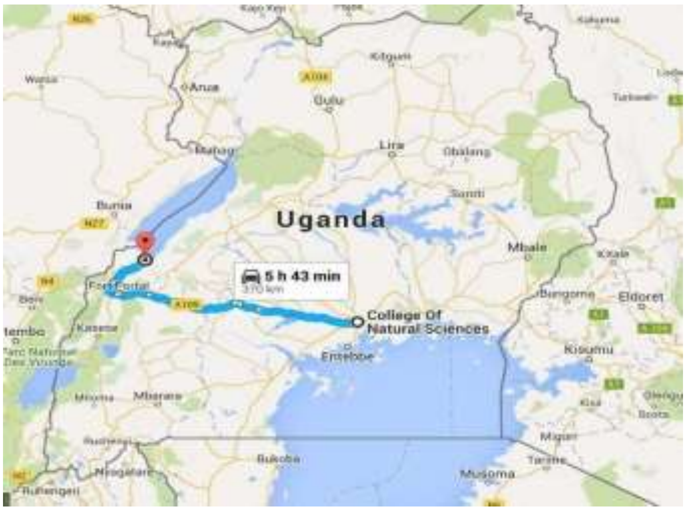

FIGURE 2: A MAP SHOWING THE ACCESSIBILITY OF THE STUDY AREA(ACCESS ROUTE IN BLUE)

1.2 OBJECTIVE OF FIELD STUDY

1.2.1 Main objective/Study Aim.

- To gain field training in the collection and interpretation of stratigraphic, petrographic, sedimentologic, and structural data, which are essential for hydrocarbon exploration.

1.2.2 The Specific objectives.

- To identify the various lithology types present in the study area.
- To observe and analyze the structural features found in both the basement rocks and sedimentary formations.
- To determine the facies and associated depositional environments.
- To examine the lithologies and depositional settings to identify key components of the petroleum system.
- To construct and interpret a lithostratigraphic log.

1.3 Geologic setting of the study area

1.3.1 Evolution of the East African Rift System

The Semliki Basin is situated within the Albertine Graben, a Tertiary intracontinental rift that developed on the Precambrian orogenic belt of the African craton. The East African Rift System (EARS) consists of an elongated network of normal faults, extending approximately 3,500 km in length and 50–150 km in width. It connects to the Gulf of Aden and the Red Sea via the Afar Triangle and is divided into two branches: the eastern and western rifts.

The Rift System comprises rift escarpments, the distinct Rwenzori Massif, and a vast rift valley or graben extending northeast from the Kanungu and Rukungiri districts along the border with the Democratic Republic of the Congo (DRC) to the Moyo and Adjumani districts near the Sudanese border. Crustal extension, which eventually led to the formation of the East African Rift System, began between the Late Jurassic and Early Cretaceous as the South Atlantic gradually opened northward. This intraplate extension resulted in the creation of failed rift basins in regions such as the Benue Trough in West Africa and basins in Central and East Africa. Some of these Cretaceous rifts evolved into continental margin basins, many of which hold significant hydrocarbon potential, such as the Muglad Basin in Sudan.

Between the Late Eocene and Early Miocene, rifting in East Africa accelerated, continuing to the present day (Bumby & Guiraud, 2005). The initial phase of the East African Rift System's development was marked by the emplacement of carbonatites and associated peralkaline rocks in East Africa, collectively referred to as the Chilwa Alkaline Province, named after Chilwa Island in Lake Chilwa, southeastern Malawi.

The East African Rift System consists of an eastern branch that extends from below Lake Nyasa (Lake Malawi) northward through the Afar Triangle in Ethiopia and beyond into the Red Sea, the Gulf of Aden, and the Dead Sea rift basins, where the Earth's crust is actively pulling apart. The Western Rift separates from the Eastern Rift north of Lake Nyasa (Lake Malawi) and forms a 1,500 km arc that extends northward beyond Lake Albert in Uganda. The EARS consists of interconnected rift basins separated by transform faults, transfer zones, and accommodation zones within the continent.

Mantle plume activity has played a crucial role in the evolution of the East African Rift System over time (Chorowicz, 2005). The formation of plume-related domes led to lithospheric weakening, followed by localized upper mantle thinning, asthenospheric intrusion, and thermal uplift of rift shoulders. The first plume activity, which occurred approximately 30 million years ago, is believed to have originated near Lake Tana in Ethiopia rather than the Afar region. Divergent movements, influenced by kinematic factors, caused the continental breakup along pre-existing lithospheric weaknesses. Ancient tectonic patterns concentrated the extensional strain, particularly along the Pan-African suture zone bordering the future Afar region. This plume, estimated to have been around 1,000 km in diameter, significantly weakened the lithosphere, facilitating the initial rifting phase.

The Western Branch of the East African Rift System (EARS) developed within a zone of lithospheric weakness at the intersection of the Ubendian, Kibaran, and Pan-African fold belts, located between the Tanzania and Congo Cratons. This is evident in the distribution of alkaline complexes that formed following the breakup of Rodinia and Gondwana. The rift predominantly extends in a north-south direction, originating from the Afar region, with localized lithospheric failure occurring along pre-existing weak zones. These structural weaknesses are primarily suture zones, where low-angle detachment faults have been partially reactivated, altering former thrust faults that originally faced opposing directions within ancient double-verging belts. As a result, rift asymmetry has reversed from one basin to another.

1.3.2 Overview of the Albert Rift

The formation of the Albertine Rift and the mountains is due to tectonic activity causing the gradual separation of the Somali Plate from the rest of the African continent. The mountains bordering the rift consist of uplifted Pre-Cambrian basement rocks, with some areas also covered by more recent volcanic rocks.

FIGURE 3: SHOWING A SIMPLIFIED GEOLOGIC MAP OF THE ALBERTINE RIFT (RING, 2008)

The Albertine Rift was formed from Proterozoic felsic and mafic gneiss and can be divided into distinct sections from north to south, including the Albert Basin, the Semliki Valley with the adjacent Rwenzori horst, and the George and Edward basins. The NE-striking Bunia fault on the western side of Lake Albert serves as the border fault segment of the Albert Basin, while the Toro-Bunyoro fault on the eastern side creates a pronounced escarpment, acting as an antithetic border fault segment.

The Bwamba border fault, which represents the primary border fault segment between Lake Albert and the Rwenzori horst, shifts from the western to the eastern side of the Albertine Rift, extending along the western flank of the Rwenzori Mountains. A network of NNE- and NW-striking faults, with the Kitimbi-Semliki fault being the most seismically active, influences the course of the Semliki River west of the Rwenzori. The western portion of the Semliki Valley is characterized by a faulted monocline, resulting in a subdued landscape. Late Pleistocene to Holocene ash layers found in the southern Semliki Valley are associated with the significant uplift of the Rwenzori Mountains.

Further south, the major border fault segment shifts to the western side of the Albertine Rift, forming the escarpment along the western shore of Lake Edward. The deepest point of Lake Edward lies directly above this border fault, with sediment accumulation reaching up to 4 km on the opposite side. The surrounding area is characterized by several small-scale faults. Lake George, a relatively shallow basin, has experienced limited extension and subsidence, forming a minor rift arm.

The highest volcanic activity in the Albertine Rift occurs between the Kazinga Channel and Fort Portal, as evidenced by numerous eruptions from the late Pleistocene to Holocene. Fractures linked to faults are observed in alluvial fan deposits around Lake George and are believed to be associated with recent movements along buried fault scarps. The pre-rift sediments of the Middle Miocene Kisegi Formation consist of eolian sands and some gypsum layers. Around 8 million years ago, significant faulting in the Albertine Rift caused subsidence to outpace sediment infill for the Kaiso Formation, leading to the formation of a deep lake, Lake Obweruka, during the late Miocene and Pliocene (Wayland, 1934).

At the base of the rift escarpments, coarse-grained proximal alluvial fan deposits accumulated, with their apexes aligned with escarpment faults, indicating a direct relationship between faulting and fan deposition. Fine-grained syn-rift sediments were deposited toward the center of the rift basin. Lake Obweruka persisted for approximately 5 million years before undergoing major changes around 2.3 million years ago, driven by a period of rifting and footwall uplift. This led to significant mountain growth along the rift flanks and the eventual separation of Lake Obweruka into present-day Lakes Edward and Albert. Concurrently, the southern part of the Albertine Rift tilted, coinciding with the initial surface uplift of the Rwenzori Mountains.

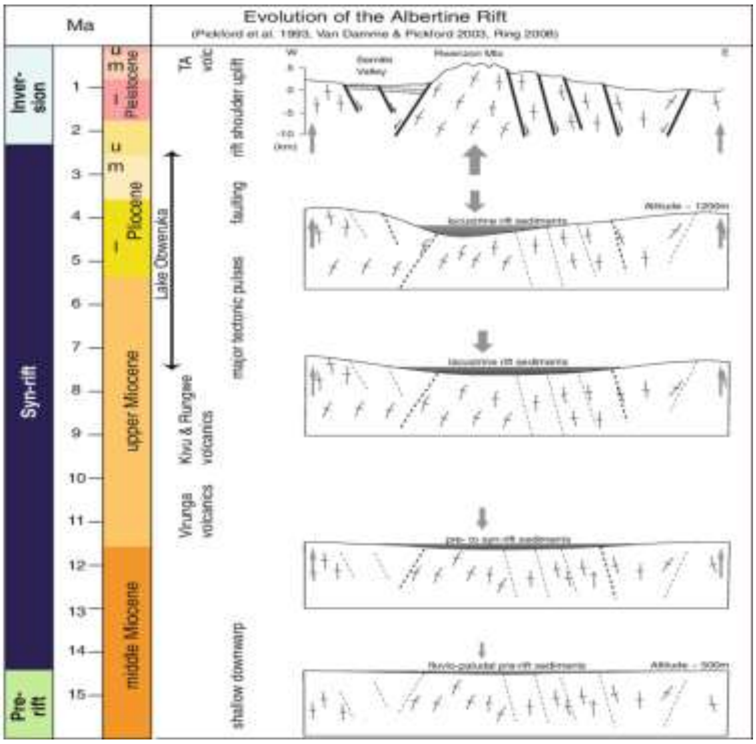

FIGURE 4: STAGES OF EVOLUTION OF THE ALBERTINE GRABEN(PICKFORD ET AL, 1993)

1.3.3 Structural setting of the Albertine graben

The Albertine Graben emerged as a rift basin during the Cenozoic era, originating from the Precambrian orogenic belts of the African Craton. The rifting process began in the late Oligocene to Early Miocene period and has been influenced by multiple tectonic events involving both extensional and compressional forces. The fault systems within the Graben exhibit various orientations and geometries, reflecting stress regimes that include both oblique and perpendicular forces in relation to the boundary faults.

The Albertine Graben concludes at a sinistral strike-slip shear zone known as the Aswa shear zone. Additional shear zones are found in the southern part of the Graben, particularly in the Kivu and Rukwa regions within the Tanzanian section of the East African Rift. The development of the Albertine Graben may have been influenced by a strike-slip dominated regime, similar to other basins within the Central African Rift System.

The Albertine Graben can be divided into three sections based on structural trends and fault geometry. The first section runs in an NNE-SSW direction and includes the Rhino Camp and Pakwach basins. The second section follows a NE-SW direction and covers the Lake Albert (Butiaba-Wanseko and Kaiso-Tonya areas) and Semliki basins. The third section also trends in an NNE-SSW direction and is associated with the Lakes Edward-George basin.

The central section of the Graben forms a complete graben, while the northern and southern sections are typically half grabens. Overall, the Graben generally follows a NE-SW trend along most of its length, which may align with the pre-existing fabric of the basement.

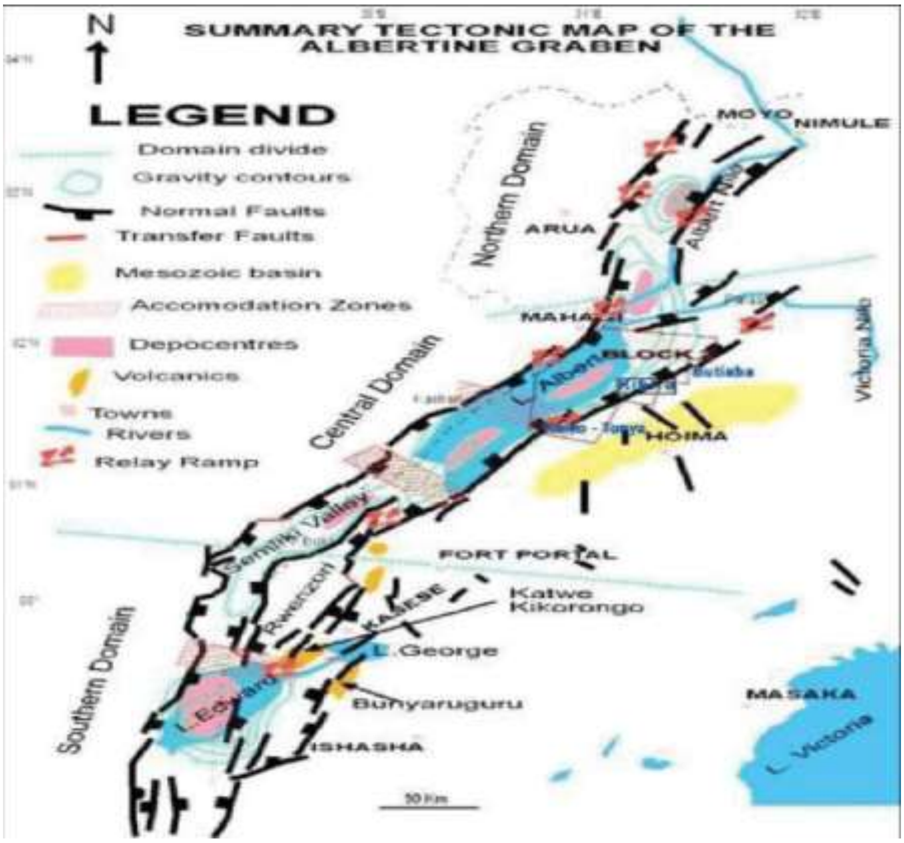

FIGURE 5: A MAP SHOWING THE STRUCTURAL ELEMENTS IN THE ALBERTINE GRABEN(DOZITH, 2012)

1.3.4 Geochronology and Sedimentology of the Albertine Graben

Various formations have been identified in the Albertine Graben. The lower sections of the Nkondo Formation in the subsurface consist of claystones with occasional thin sandstone stringers, which are the primary oil reservoirs in the region. The age of this formation is debated, with some suggesting mid-Miocene and late Pliocene ages based on palynomorphs found in the cuttings of the Mputa-1 and Waraga-1 wells. These deposits were formed in marginal lacustrine to deltaic environments near the lake shores, while coarser alluvial fan and fluvial deposits are more common near the graben's marginal escarpment.

The Nyaweiga Formation is believed to date back to the mid-Miocene and late Pliocene to early Pleistocene, while the Mputa Formation, also of mid-Miocene age, has been identified in the Mputa-1 and Waraga-1 wells based on palynomorphs. RPS Energy suggests a late Pliocene age for this formation, and the sandstones in this formation are interpreted to represent deltaic to fluvial sequences.

The Kisegi Formation is considered a highly promising reservoir rock, while the Kasande Formation is identified as an excellent potential source rock. The Kisegi Formation consists mainly of thick, channeled, and cross-bedded sandstones with occasional suspected tuff, bleached silts, and clays. The age of this formation is debated, with opinions ranging from early Miocene to mid-Miocene, based on sediment samples from the Turaco wells and polymorph analysis. It is believed to have formed predominantly in a fluvial environment within a relatively stable tectonic setting, characterized by low-energy small-scale channel systems. In contrast, the Kasande Formation developed mud flats with meandering channels during a transgression, which mixed with near-shore lacustrine deposits, replacing the alluvial sand deposits seen in the Kisegi Formation.

1.3.5 Overview of the Semliki basin

The Semliki Basin is situated at a relatively low elevation of around 650 meters above sea level, in contrast to the surrounding rift shoulders, which are elevated at approximately 1650 meters. It includes the Semliki Flats, which form the eastern section of the Semliki River and Lake Albert floodplain, as well as the adjacent Toro Plain to the east, which has a slightly higher elevation. This area is bordered by significant fault escarpments and other prominent faults. The Toro Plain and the Semliki Flats are separated by a major fault, known as Makondo.

The rift trend within the Semliki Basin follows a NNE-SSW direction, although it shifts to NE-SW in the Lake Albert Basin. An accommodation zone separates the Semliki Basin from the Lake Albert Basin to the north. The orientation of the rift shifts from NE-SW in the Lake Albert Basin to NNE-SSW in the Semliki Basin, which ends at the Rwenzori Mountains in the southeast.

Rifting that began in the early Miocene led to the formation of the Semliki Basin through the stretching and thinning of the lithosphere. This normal faulting created space for sedimentary infill and initiated the deposition of sediments within the basin, resulting in the accumulation of thick fluvial, alluvial, and lacustrine sediments that exceed 5 km in thickness (Abeinomugisha & Kasande, 2009). As a result, the depositional environment of the Semliki Basin consists of fluvial, lacustrine, and deltaic settings.

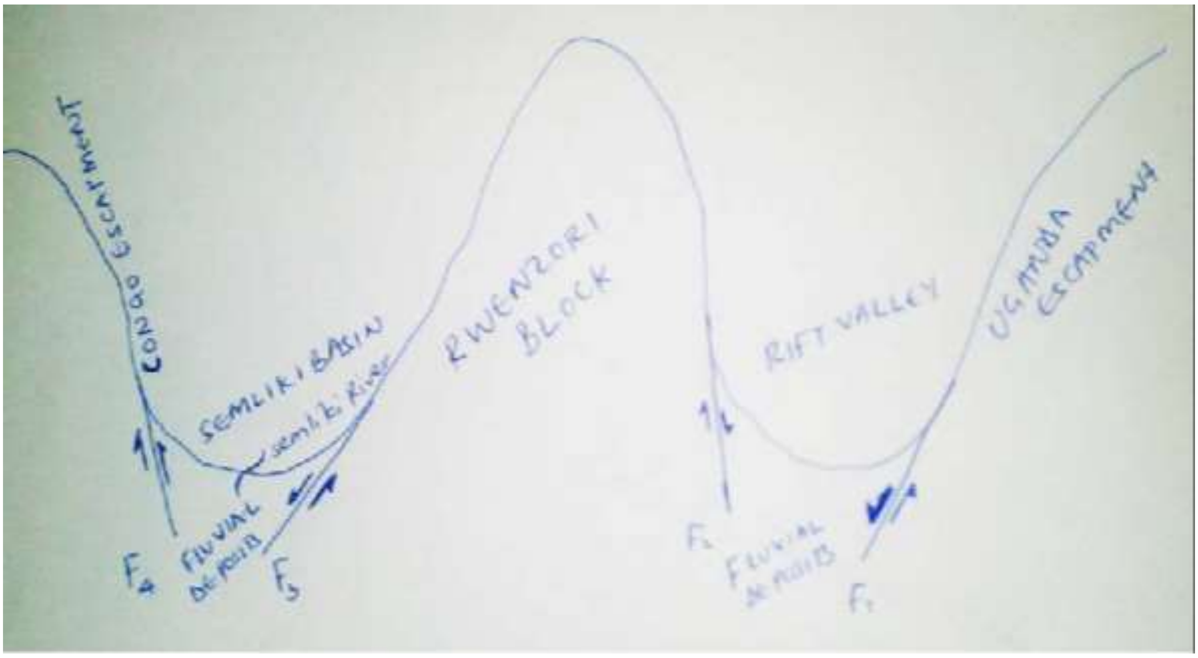

FIGURE 6:SHOWING A SKETCH OF THE SEMILIKI PLAIN

The Semliki Basin contains two main types of lithology: syn-rift and pre-rift lithology. Syn-rift lithology includes both clastic sediments, which are formed from the erosion of basement rocks, and non-clastic sediments, which result from precipitation within the deposition basin or volcanic activity. The syn-rift mega-sequence is unconformably overlaid on the pre-rift rocks, with most syn-rift rocks dating from the Cenozoic era, potentially ranging from the Paleogene (Early Miocene) to the present.

The oldest rocks in Uganda, known as the pre-rift lithology, are the Pre-Cambrian Basement rocks (2900Ma-3500Ma) located beneath the Kisegi Formation. These rocks are exposed on the rift flanks and consist of high-grade meta-sedimentary rocks, gneisses, granitic gneisses, quartzite schists, granites, basic intrusive rocks, amphibolites, and metacalcareous rocks. They form the base and are considered older than other rock groups or formations in Uganda's geology. While these rocks do not have source potential, they could potentially serve as reservoirs if fractured and sealed.

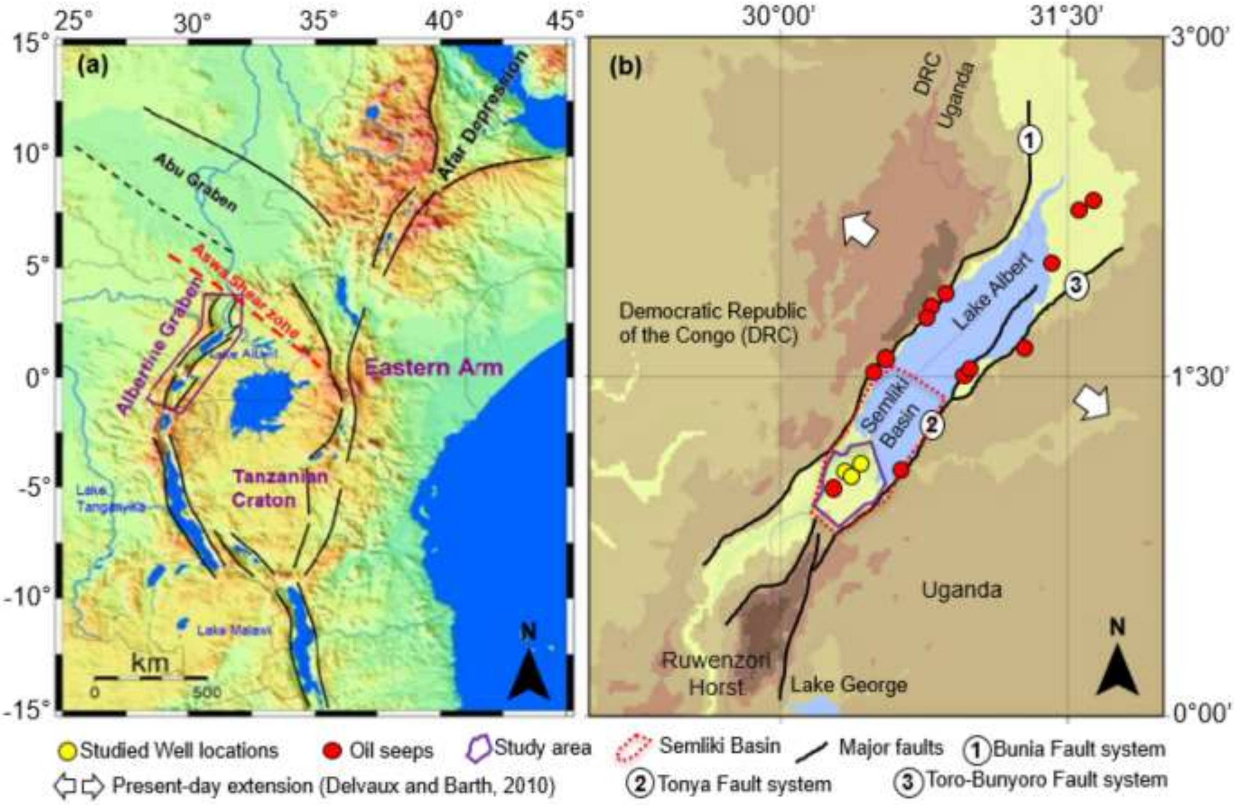

FIGURE 7:SHOWING THE GEOLOGIC CHARACTERIZATION OF THE SEMLIKI BASIN

1.3.6 Topography of the Semliki basin

The Semliki Basin stands out from the rest of western Uganda due to its lower elevation of about 650 meters above sea level, compared to the adjacent rift shoulders, which are approximately 1650 meters. Within the Semliki Basin, a significant fault separates the Toro Plain from the Semliki Flats (Kiconco, 2006). To the east of the Semliki Valley lies the Bwamba Border Fault (BBF), which faces west and trends in a NNE-SSW direction, acting as the boundary fault for the main Rwenzori Mountains horst block to the east.

The Lubero Border Fault (LBF) has experienced more movement than the BBF, resulting in an uneven graben within the Semliki Basin. On the eastern side of Mount Rwenzori, the Kichwamba Fault separates the Rwenzori microplate from the Victoria microplate and the Nubian plate. As the fault extends toward the Semliki Flats, its influence diminishes. The Kichwamba Fault appears to isolate the Rwenzori 15 microplate, potentially causing its rotation. The meandering Semliki River marks the Uganda-DRC border as it flows through the flats, leading to shifts in the border line and river course, which have contributed to border disputes.

1.3.7 Stratigraphy of the Semliki basin

The stratigraphy of the Albertine Graben is primarily composed of alluvial-deltaic and lacustrine deposits (M.W. Tumushabe, 2024) in the Exploration and Production Department. Lake Albert's stratigraphic sequence is divided into two main sequences: Pre-rift and Syn-rift. The pre-rift mega-sequence consists of Pre-Cambrian basement rocks visible along the rift flanks, including high-grade metasedimentary rocks, gneisses, granite gneisses, and quartzites. Although these rocks do not have source potential, they could serve as reservoirs if fractured and sealed. The syn-rift mega-sequence overlaps the pre-rift rocks, though with some discontinuities. Most of the syn-rift succession is of Cenozoic age, likely spanning from the Paleogene/Early Miocene to the present day.

The sedimentary section in Lake Albert might contain the oldest part dating back to the Jurassic period, though this is only inferred from the similarities in rock types observed in the bituminous black shale found in the Butaiba Waki-1 well in Uganda and the Stanleyville shales in other parts of the Congo. Although this formation is present in Lake Albert, it is unclear whether it extends into either the northern or southern parts of Block III in the Semliki Basin.

The sedimentary rocks of the Semliki Basin are classified into seven formations by Pickford et al. (1987, 1994) based on age relationships, bed successions, geometry, consolidation degree, fossil content, and radiometric dating of surface outcrops. These formations feature a sandy sequence at the base and a predominantly clay-dominated sequence with subordinate sands on top, with subdivisions based on slight variations in the sand-to-shale ratio. The identified formations, listed from bottom to top, are Kisegi, Kasande, Kakara, Oluka, Nyaburogo, Nyakabingo, and Nyabusosi, and are believed to rest on a sub-cropping, NE-SW trending promontory of the Rwenzori horst.

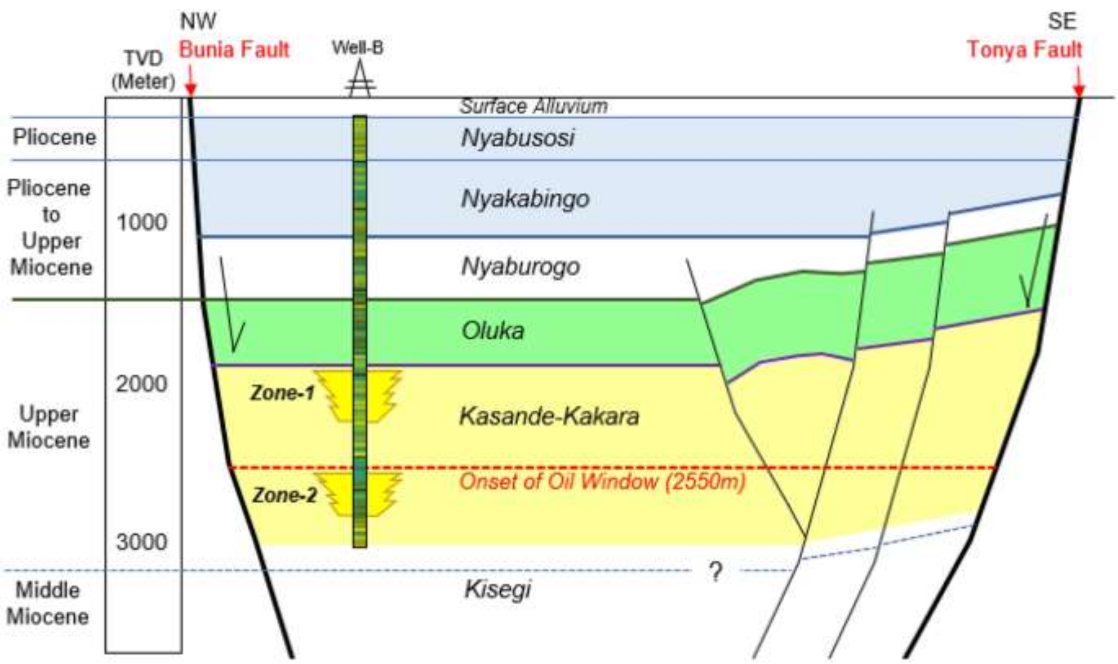

FIGURE 8:SHOWING THE STRATIGRAPHY OF THE SEMLIKI BASIN (S. MUTEBI,2021)

1.3.8 Physiography of the area

The physiography of the region is defined by the graben bounding faults on the eastern side of the rift, which offer a view of the Semliki River's floodplain. A significant portion of the floodplain consists of a gently rolling surface covered with savannah vegetation. On the western side of the graben, the towering blue mountains of the DRC rise higher than the eastern side. The Rwenzori Mountains, standing prominently in the center of the rift, reach an altitude of 4,500 meters (14,764 feet) above the surrounding Semliki flats, a height unmatched in any other extensional setting.

The Semliki plain features a mostly flat topography shaped by rifting, which led to the uplift of the Rwenzori Mountains and caused the reversal of drainage patterns, resulting in the desiccation of the ancient Shallow Obweruka Lake. Tectonic activities from the rifting process have further influenced the landscape, leading to the formation of distinct escarpments and valleys in the mapped regions. The topography of the Semliki basin stands apart from the rest of western Uganda, as it is at a lower elevation of about 650 meters above sea level, compared to the surrounding rift shoulders, which rise to approximately 1,650 meters. Within the Semliki basin, a major fault line separates the Toro plain from the Semliki flats, as noted by Lyoidah (2006).

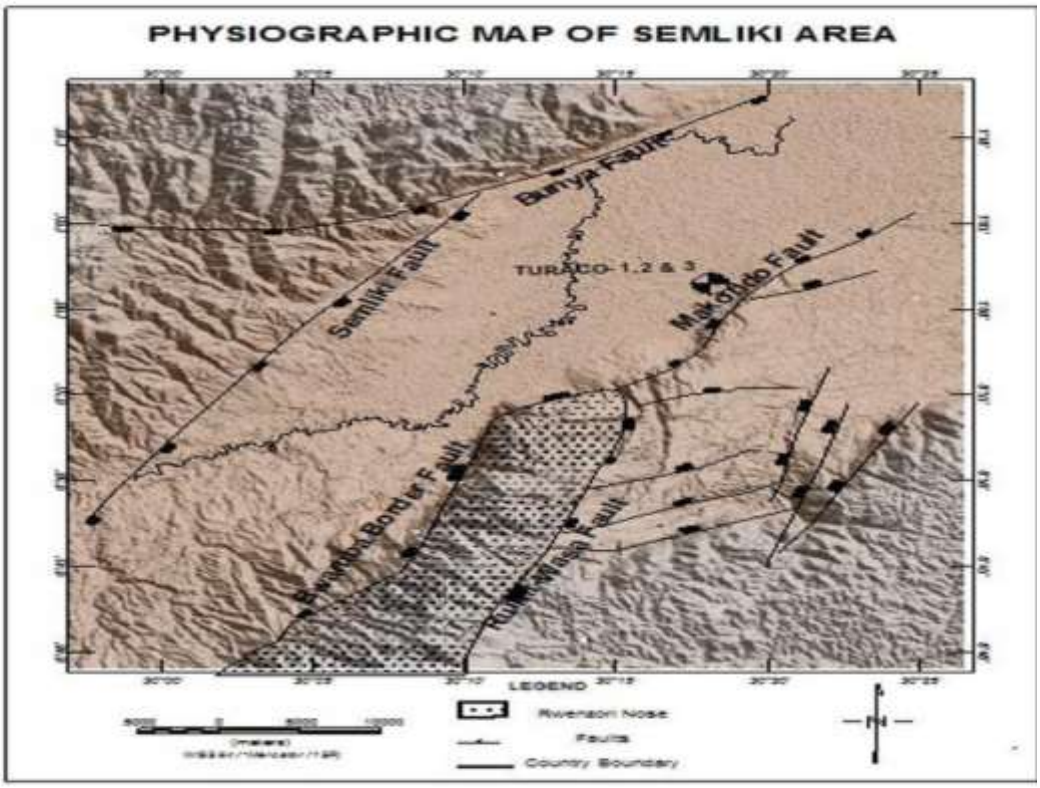

FIGURE 9: PHYSIOLOGIC MAP OF SEMLIKI AREA

1.3.8.1 Drainage of the area

The area's drainage is mainly influenced by its topography. River Semliki, which supplies water to Lake Albert, and the seasonal Kisegi river were the predominant water sources in the region. Numerous streams were seen originating from the Rwenzori highs, particularly along the weak faulted areas in the region. This type of drainage was particularly noticeable in the Kichwamba area.

While it was not actively flowing during the mapping, the group was able to walk through the channel, and water was observed to have been retained in the sands along the course of the seasonal Kisegi river. Small, nearly circular ponds were discovered, indicating that locals likely dug them a few feet into the sand. These ponds likely collected water that was later fetched for home use.

1.3.9 Geological setting of Semliki area

The Semliki region is an important relay ramp within the graben, forming the downthrown section of the East African Rift System (EARS) and acting as a deposition area, while the Rwenzori block remains uplifted as the footwall. Two major faults border the basin: one terminates within the basin, and the other extends into the basement, propagating in opposite directions. There are also multiple crosscutting release faults within the relay ramp that influence the transverse drainage in the Semliki region. The initial rifting phase in the Semliki area likely began in the early Miocene, leading to the formation of grabens and half-grabens where the first sediments were deposited.

Relay ramps are highly productive because they provide pathways for sediment transport and direct parallel drainage into the basin. In the Semliki area, the relay ramp has been breached, resulting in what is referred to as a breached relay ramp. The region has been divided into several formations, including Kisegi, Kasande, Kakara, Oluka, Nyaburogo, Katorogo, and Nyabusozi, from oldest to youngest. These divisions are based on factors such as texture, sediment consolidation, and the timing of deposition (PEPD, 2008). Geological and geophysical data suggest that the Kisegi, Kasande, Kakara, and Oluka formations were deposited during the initial rifting phase. The Nyaburogo and Nyakabingo formations were deposited during the second rifting phase, which occurred from the Pliocene to the Pleistocene. These formations have been roughly classified by the Petroleum Exploration and Production Department (PEPD) and oil companies, primarily based on drilling conducted at the Turaco wells in the Semliki Basin. Data regarding fluctuating lake levels over time have been obtained from the fluvial and lacustrine deposits encountered during field mapping.

1.3.10 Geologic background of the region

The western rift valley of the East African Rift System (EARS) consists of interconnected half-graben basins, many of which are currently filled with large lakes. Geophysical data and radiometric dating suggest that these basins likely began forming during the Miocene period. However, no absolute age dates have been obtained for the basal synrift lacustrine sediments from the major lakes in the western rift valley. The initiation ages of rifting have been estimated by extrapolating age-depth models from shallow cores or by dating volcanic rocks near the lakes. In-situ dating of deeply subsided and buried synrift deposits is still pending and will require future drilling efforts. These basins often exhibit asymmetrical shapes, with uplifted basin-bounding border fault margins opposed by low-gradient flexural margins (Rose, 2002).

The half-graben basins in East Africa typically range from 80 to 160 km (50–99 miles) in length and 30 to 60 km (19–37 miles) in width, often interconnected along the rift valley axis. In regions with complex structures, known as accommodation or transfer zones, border fault segments of rift basins can overlap (Rose et al., 2002; Nelson et al., 1992). These zones facilitate the connection of adjacent rift basins by accommodating differential strain between the tips of propagating normal faults and are commonly found in extensional provinces worldwide. These zones often serve as entry points for coarse clastic sediments (Scholz et al., 2012).

The shape of the rift basins and fault patterns are influenced by existing differences in the Earth's crust. Seismic activity in the Lake Albert rift and focal mechanism solutions indicate an extension direction of northeast-southwest or east-west, although this direction may have shifted over time. The geological composition of Lake Albert's drainage basin includes ancient metamorphic rocks from the Precambrian period, sedimentary rocks from the Karoo era (Cretaceous), and lacustrine and fluvial deposits from the Neogene and Quaternary periods. Unlike the Gregory Rift, volcanic activity is not widespread in the western rift, although two small volcanic centers are located to the south of Lake Albert.

The upper crust deformation, as studied by Karp et al., has significantly influenced the geomorphology of the Lake Albert region due to continental extension. Normal faulting from this extension has created notable topography, with some footwall blocks rising over 2,000 m (6,562 ft) above the adjacent rift basins. The Rwenzori Mountains, which stand out in the region, rise more than 4,000 m (13,123 ft) above the Semliki Valley, the fluvial extension of the Albert Rift basin. Surface uplift linked to the formation of the Albert and Edward rifts has caused the reversal of several major drainage systems and played a key role in the creation of Lakes Victoria and Kyoga.

Depositional patterns in rift basins near lakes are strongly influenced by the half-graben basin shape and the unbalanced underwater topography (Frostick and Reid, 1989; Scholz et al., 1990; Soreghan and Cohen, 1996). The distinct asymmetry and subsiding patterns of the basins tend to create thick, wedge-shaped sedimentary layers that form during the rifting phase and grow thicker toward the fault margin (Morley, 1989). The elevated rift edges redirect major watercourses away from the surrounding low-lying areas. As a result, the fault margins often experience deep-water deposition, including gravitational flows, alluvial fan accumulation, and the settling of organic-rich sediments. In contrast, the facies patterns on the flexural margins are influenced by coastal processes such as nearshore currents, waves, and the growth of deltas. These areas may also serve as pathways for clastic sediments (Tiercelin et al., 1992; Scholz et al., 1993; Scholz, 1995).

CHAPTER 2: MATERIALS AND METHODS

This chapter entails how various materials and methods were used to achieve the aim and objectives of the study project.

2.1 Materials.

TABLE 1:SHOWING MATERIALS USED DURING THE FIELD WORK AND THEIR PURPOSES.

EQUIPMENT	PURPOSE
Base and Topographic maps	Used to show the extent of the study area.
Global Positioning System (GPS)	Used in locating outcrops and exposures, and for direction.
Geological hammer	Used in exposing a fresh surface for observation and in sampling of hard rocks.
Geological compass	Used to measure strike and dip.
Spades and hoes	Used for scrapping an area on the outcrop in order to obtain a fresh surface to log.
Field notebook, ruler, pencil pen and rubber	Used for taking notes in the field.
Hand lens	Used to magnify rock samples in order to identify microstructures and some mineral composition.
Camera	Used for taking geological photographs to be used in the field report.
Graph papers	Used to draw lithological logs.

Tape measure	Used to measure the thickness of different lithologies.
Grain size scale	Used to estimate grain size, shape and sorting.
Jacob's staff	Jacob’s staff is a pole with length markings and stabilization features. Used for taking measurements in the field. Jacob's staff was used to make qualitative judgments of the height and angle of an object/lithology layer relative to the user of the staff.
Water bottle and lunch box	Used to carry water and food respectively.

2.2 Methods

The methods used while in the field to achieve various aims include the following;

Orientation of students

A brief orientation was conducted on the camp area by the field study supervisor, Dr. Nagudi Betty on the second day. The purpose was to prepare students for the fieldwork by providing relevant literature to help them gain prior knowledge of the study area, understand what to expect in the field, and familiarize themselves with the overall process.

Desk study

This session took place at the camp, where a detailed plan outlining the various activities and their execution methods was thoroughly discussed. Led by the teaching staff and technical team, clear guidelines were provided on field data acquisition, recording, and analysis. To ensure efficiency, eight groups were formed, each consisting of four to five members. All groups were equipped with essential field tools and graph paper for constructing lithological logs.

Configuring of the GPS handset

The handset system was initially configured to Zone 36N of the Universal Transverse Mercator (UTM) coordinate system, with the map datum set to New Arc (1950) WGS84. This setup was essential to ensure compatibility between the GPS and the topographic and geologic maps used in the field. The configuration process was carried out under the guidance of Dr. J.M. Kiberu, following these steps: the GPS device was powered on, and the 'Setup' option was accessed by pressing the Enter button. Under the 'Units' menu, 'meters' was selected. Returning to the main menu using the 'Back' button, the 'Satellite' option was chosen and set to UTM Zone 36N. Readings were taken from the GPS in the "xy" format, excluding any leading zeros in the coordinates, such as (2676815, 778686).

Basement studies

On the second day of our field study, we travelled to Kichwamba to explore the basement geology around the Albertine graben. Our instructors provided an informative overview of the area's basement geology, discussing the characteristics, age, and types of rocks present.

Stop 1: KICHWAMBA AREA

Locating ourselves using the both topographic and geologic map followed the following steps

1. Oriented ourselves to see where we were with reference to the map
2. Identified where the North is , by using the title of map and GPS to locate real position (location)
3. Using the UTM coordinate system, the Location of Kichwamba is **(X-0186951 and Y-00793547 with altitude of 1610 m)**

Description of outcrop in Kichwamba station

The outcrop is a large artificial outcrop exposed by a road cut, heavily jointed, foliated since there is segregation of minerals. Granitic gneiss was the field name and observed an Amphibolite dyke cutting across the granite gneiss. It was suggested that the Amphibolite dyke may have originated from the metamorphism of gabbro. Additionally, we noted various geological structures such as joints, foliation, and faults and used a geological compass to obtain precise structural measurements, including the strike and dip of beds and fractures. Kichwamba fault was seen at the foot of the Mt. Rwenzori. However Mt.Rwenzori is younger than the Semliki Basin, this is because the mountain is still going upwards (exhumation) where the lower parts are now getting expanded. On the south of Mt. Rwenzori, there is Edward – George Basin whereas the North of Mt. Rwenzori, there is Semliki Basin hence the Rwenzori acts as the source of sediments in the basins. Fractured basement acts as unconventional reservoirs and may have a shear zone which allows passage of water into the reservoir that may cause biodegradation or water washing that reduces porosity.

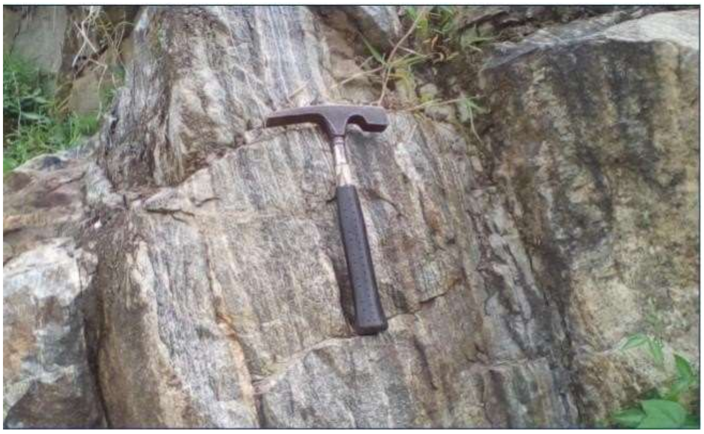

FIGURE 10: A FOLIATED GRANITIC GNEISS AT KICHWAMBA(**0186951, 00793547, 1610M**

Stop 2: ITOJO AREA

The location was **0191051; 0094332, 1037 m**

Description of the outcrop

It is artificially exposed by road cutting, a large weathered fine grained outcrop with some quartz intrusions. Field rock name is migmatite formed by partially melting of igneous and metamorphic rocks.

Structures present included joints, joint planes, folds, quartz vein trending in NE-SW and NW-SE and other structural measurements are further discussed in chapter 5.

Stop 3: KIBUKU AREA

The location is at **0192394: 0102053, 693 m** at the nose of Mt.Rwenzori.

Description of outcrop

It is a very large, natural, moderately weathered and fractured outcrop.

The outcrop is fine to medium grained with Quartz, feldspars, muscovite as it mineral composition.

Structures present included foliations, joints, and joint planes with structural measurements in appendix **1**

FIGURE 12: A QUARTZITE AT 0192394, 0102053,693M

To obtain strike, the side of the compass was placed against the plane of interest keeping the bottom edge horizontal/flat. The compass orientation was then adjusted until the air bubble in the "Bull's eye level" was centred. The value of the strike was then read off from either end of the compass. To measure the dip, the compass was positioned against the rock so that it aligns with the line of dip. The clinometer was then adjusted until the bubble was centered and the dip value it indicated by the white-tipped end of the clinometer needle was noted. It's important to remember that the dip direction should always be perpendicular to the strike direction. The measurements of these structures were utilized to create a rose diagram, with further interpretation discussed in detail in Chapter 5. Mineral analysis for determining rock types involved observing minerals in the rock, using the naked eye for macroscopic minerals or a hand lens for microscopic minerals. Basement studies yielded important insights and understanding of the tectonic episodes in the area through the analysis of structural measurements. This analysis enabled the identification and correlation of structures observed in both the basement and sediments.

Degree of metamorphism.

The analysis was conducted by examining foliation trends, which refer to the planar orientation of minerals within the basement rocks. These foliations provided insight into the direction of past stress or pressure, as the alignment of minerals typically occurs perpendicular to the applied force. The presence of gneisses within the basement indicated high-grade metamorphism, while evidence of contact metamorphism was observed in proximity to intrusive bodies. The metamorphic grade offered valuable information regarding the distribution of rock types, mineral assemblages, and textural characteristics, thereby aiding in the reconstruction of the rocks' diagenetic and metamorphic history

Sediment study

Lithostratigraphic logging.

Sediment logging along the Kibuku road cut was conducted systematically from the basal to the topmost layers, following a zigzag pattern across the exposure. Detailed observations were made regarding sedimentary structures, color, grain size, sorting, lithological composition, grain size distribution, and the nature of contacts between adjacent lithological units. This comprehensive dataset was used to construct sedimentary logs, which were instrumental in the analysis, interpretation, and understanding of the stratigraphy and depositional history of the Semliki Basin.

Logging procedure.

- Cleaning up the outcrop using a hoe to obtain a clearer view of the outcrop.
- Dividing the outcrop into different units according to lithology or other features.
- Measuring the vertical thickness each unit using a tape measure.
- Describing the outcrop fully.
- For outcrops whose basement was not seen or not clear, a zigzag shape was used at the base of the log when constructing it on the graph paper.
- Indicating structures, and fossils (if any) on the log using appropriate symbols.
- Indicating facies on the log, and determining their depositional environment and depositional processes.

In-depth observation of the exposed facies was then conducted to identify facies, primary and secondary structures. The dip and axial trend of these structures were measured and are explicitly discussed in *chapter 5*. Facies encountered included basal conglomerates, cross bedded and massive sands, white and yellow silts, brown blocky clays. Grain size was determined using a grain size scale and the sizes ranged from fine through medium to coarse. Through in-depth analysis, facies were identified, descriptions recorded and logs were plotted on graph papers. These logs were then used to deduce the depositional environments, depositional sequences and system tracts.

Determination of grain morphology

Determination of grain shape was done by observing the clasts with help of a hand lens to estimate sphericity, roundness of clasts, sorting and cementation at the exposures, road cuts and outcrops. The grain size was determined using a grain size scale.

Figure13: showing the Grain size scale

Roundness: During the transportation process, grains may be reduced in size due to abrasion resulting in the eventual rounding off of the sharp corners and edges of grains. Thus, rounding of grains gives clues on the amount of time the sediment has been in the transportation cycle. The different categories of roundness include very angular, angular, sub-angular, sub-rounded, rounded and well-rounded

Sorting: Particles become sorted on the basis of density, because of the energy of the transporting medium. The degree of sorting may indicate the energy, rate, duration of deposition, as well as the transport process like river, debris flow, wind which are responsible for laying down the sediments.

Cementation: It happens as dissolved minerals become deposited in the spaces between the sediments. These minerals act as glue or cement to bind the sediments together.

Determination of paleocurrent flow direction.

Sedimentary structures, including cross-stratification, pebble imbrication, and current ripples, were analyzed to infer the paleocurrent directions responsible for sediment deposition. The orientation of angular and tabular cross-beds observed within the sand layers provided valuable insights into the direction of sediment transport. Additionally, most of the ripples identified within the Kisegi River floodplains were asymmetrical, further supporting interpretations of unidirectional flow regimes.

Interpretation of the depositional environment.

Deposition within the Semliki Basin is predominantly characterized by fluvial and lacustrine sedimentary environments. The sediments observed include sandstones, basal conglomerates, clays, and silts. The distribution, orientation, and internal architecture of the fluvial and deltaic deposits are influenced by various factors, such as climate, water discharge, sediment supply, river mouth dynamics, wave and tidal activity, currents, wind patterns, shelf width and gradient, as well as the tectonic setting and structural configuration of the receiving basin (Selley, 1978).

In particular, the depositional environment of the Kisegi Formation is largely fluvial in nature, comprising features associated with meandering rivers, alluvial plains, inter-channel zones, floodplains, and overbank deposits. Field observations reveal a succession of meandering channels that incise into one another, with the uppermost abandoned channel infilled with a mixture of silt and sandstone.

Subsurface data from the Turaco-3 well, which penetrated approximately 300 meters of the formation, further supports a dominantly fluvial depositional environment. The evidence points to a relatively stable tectonic setting, with low-energy, small-scale channel systems. The prevailing paleoclimate during deposition was warm to hot and semi-arid. This interpretation is reinforced by the frequent presence of evaporitic minerals, particularly gypsum, observed in clay-rich layers during the logging process

Field discussions and presentations

Each group was tasked to present their findings after the stratigraphic logging and at times group members were required to discuss certain topics concerning a given area. These discussions were led by the lecturers who added knowledge to what the students discussed.

2.2 Visit to sempaya hot springs (Buranga geothermal field)

Hot springs are natural hydrothermal features that occur where groundwater is heated by geothermal energy, resulting in water temperatures significantly exceeding the mean annual air temperature of the region. On the last day of our fieldwork, one of the Semliki National Park workers led us to the Sempaya hot spring. The Sempaya Hot Springs, located in Semuliki National Park in Sempaya, Bundibugyo District of western Uganda, are among the most prominent geothermal features in the country. These springs lie approximately 40 kilometers from the border with the Democratic Republic of Congo (DRC) and are part of the Buranga geothermal field, a known zone of high geothermal potential (Bahati, 2016).

Semuliki National Park, which encompasses an area of about 220 square kilometers, is situated within the tectonically active Albertine Graben—a western branch of the East African Rift System. The park is bordered by the DRC to the west, the Rwenzori Mountains to the southeast, and Lake Albert along with the Semliki Flats to the north. The geothermal activity in this region is closely associated with the Rwenzori horst block and the surrounding fault systems that characterize the rift valley.

The Sempaya Hot Springs emerge along fault-controlled zones, where deeply circulating groundwater is heated by residual magmatic heat or high geothermal gradients resulting from crustal thinning and tectonic uplift. These springs are surface manifestations of underlying geothermal reservoirs and indicate the presence of active hydrothermal systems in the area. Their association with the Rwenzori Mountains and proximity to major rift structures supports the interpretation that the geothermal activity is tectonically driven.

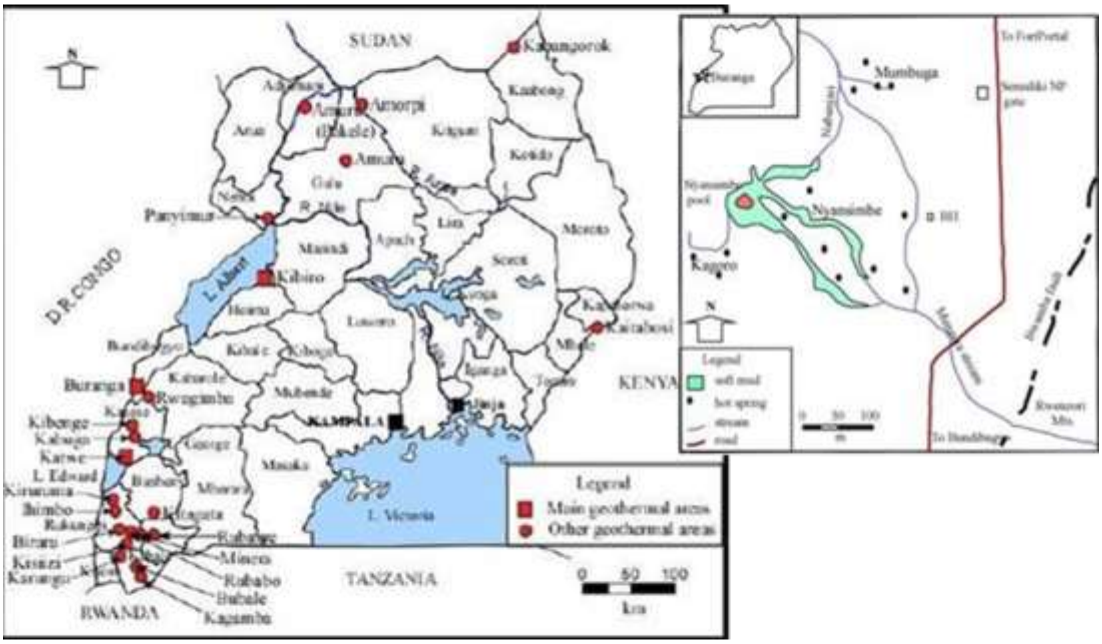

Figure 14: showing the geothermal areas of Uganda. after Bahati et al. 2016. (Right) Map of the Buranga geothermal field (Gíslason, 1994)

The Sempaya Hot Springs are divided into two distinct geothermal features, locally referred to as the female and male springs, named *Nyansimbi* and *Bamaga*, respectively. According to local folklore, the names originate from a legend about a couple who vanished at the site of the springs.

Water temperatures at the Sempaya Hot Springs range from 95°C to 100°C, a thermal intensity believed to be influenced in part by the region's low elevation (approximately 670 to 760 meters above sea level). The springs are located near the Bwamba Fault, which lies roughly seven miles above superheated rocks, contributing to the geothermal activity observed in the area.

The hot water discharged at the surface originates primarily from rainwater, which infiltrates the porous sedimentary rocks in the region. As the water percolates downward, it dissolves various minerals, including radium, sulfur, carbonates, and other salts. As it continues to descend, the water is heated by geothermal energy emanating from the Earth's mantle, which lies closer to the surface in this part of the Albertine Graben. Upon encountering structural weaknesses such as faults or fractures, the now-heated water ascends to the surface, forming hot or warm springs.

The female hot spring (Nyansimbi) consists of several vents expelling steaming water and gases, including hydrogen sulfide (H_2S) and carbon dioxide, with a noticeable pungent odor. This spring occupies an area of approximately 60 by 40 meters and has formed a travertine cone about 1 meter in height due to the precipitation of carbonate minerals. The average water temperature recorded here is approximately 98.4°C.

In contrast, the male hot spring (Bamaga) presents as a large pool of steaming water, also characterized by a strong sulfurous odor. The pool has a diameter of about 30 meters and reaches a depth of up to 5 meters. The average temperature is around 86°C, and like the female spring, it has formed a carbonate cone as minerals precipitate out of the water.

The highest recorded temperatures at the springs are 106°C for the male and 103°C for the female spring. These extreme temperatures are considered significant contributors to the elevated geothermal gradient within the Albertine Graben, one of the youngest rift basins in the world. This high geothermal gradient may have played a role in the thermal maturation of organic-rich source rocks in the region. However, while the ideal temperature range for the formation of oil—known as the "oil window"—is between 60°C and 120°C, the temperatures at the Sempaya Hot Springs exceed this range. As a result, there is a potential risk of overmaturation, where oil is thermally cracked into thermogenic gases such as methane.

Figure 15: showing a photograph showing the male hot spring

2.2.1 The Geothermal potential of Buranga area

Like a petroleum system, a geothermal system is composed of elements such as a source rock or a highly radioactive rock directly in contact with magma, a reservoir rock with high porosity to hold the fluids, a cap/seal rock for preventing heat escape from the reservoir rock and a reservoir fluid such as ground water or ordinary water that passes through the reservoir. This therefore implies that the area has potential for geothermal energy which can be used to generate electricity (which is a clean source of energy) due to high heat flow evidenced by the high temperatures that have converted organic matter to hydrocarbons in the source rocks.

2.2.2 Makondo and Turaco Field study

The Makondo Fault site, which was visited during fieldwork, is situated within the **Nyakabingo–Nyabushozi Formation** at geographic coordinates **0201154/0110008, 692**. The primary objective of the visit was to gain a clearer understanding of the **geophysical and magnetic data** previously acquired from the area. This data was collected through **airborne geophysical surveys** conducted by **Kenting Earth Sciences Limited (Canada)** between **1982 and 1984**.

During these surveys, two major faults—**the Kibuku Fault** and **the Makondo Fault**—were identified through **aeromagnetic analysis**. In **1988**, further geophysical investigation was undertaken by **Heritage Oil Company Limited**, which acquired **2D seismic data** from the region to enhance the interpretation of fault structures.

Field and geophysical data interpretation revealed the presence of **positive flower structures**—a key indicator of **transpressional tectonics**. These structures are typically associated with **strike-slip fault zones** that exhibit a **compressional component**, leading to the uplift and vertical propagation of fault-bounded blocks.

Positive flower structures are significant because they indicate zones of **crustal shortening and deformation**, which can be favorable for the formation of **structural traps** in petroleum systems. Their occurrence within the Makondo Fault zone suggests that the area has experienced a compressive stress regime, likely related to reactivation of basement faults during rifting events in the Albertine Graben

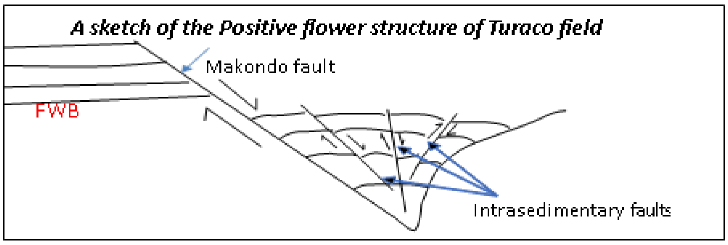

FIGURE 16:MAKONDO FAULT WITH A POSITIVE FLOWER STRUCTURE

The sediments in this area were majorly composed of laterite and clay sediments. There is also presence of animal fossils (oysters and bivalves) deposited in the clays which are oxidized in some areas. These fossils are an indicator of fresh shallow water lacustrine environment .The area is believed to have been covered by former Lake Obweruka which dried up probably due to climatic changes best explained by Milankovitch cycles.

Figure 17: Mud cracks in Kibuku river valley (flood plain)

Turaco wells

The **Turaco wells**, located at coordinates **0199712 / 0113863, elevation 632 meters**, lie on the **hanging wall block of the Makondo Fault**, a key structural feature within the southern part of the Albertine Graben. These wells were drilled by **Heritage Oil Company Limited** and represent the second phase of exploratory drilling conducted in the Albertine Graben. The primary exploration objective was to intercept **hydrocarbon-bearing reservoirs within the Kisegi Sandstone Formation**. Despite encountering hydrocarbon indications, none of the wells produced oil in commercially viable quantities.

A review of the drilling history provides the following insights:

Turaco-1, drilled in **2002** to a total depth of **2,487 meters**, encountered **hydrocarbon shows**, but the volumes were insufficient for commercial exploitation.

Turaco-2, a **sidetrack well** drilled in **2003/2004**, was positioned approximately **10 meters** from Turaco-1. It was drilled to a greater depth of **2,963 meters** and also recorded significant **hydrocarbon shows**, indicating the possible presence of a petroleum system. However, the accumulation was still below the threshold for economic development.

Following a **3D seismic survey** conducted in **2004**, a third well—**Turaco-3**—was drilled **100 meters** from the original Turaco-1 location. This well reached a depth of **2,980 meters** and encountered **natural gas**, though it was found to be **heavily contaminated with carbon dioxide (CO_2)**, significantly reducing its commercial value.

Given the repeated lack of economically recoverable hydrocarbons and the high levels of CO_2 contamination, **Heritage Oil** made the decision to **abandon further development** in the Turaco area. The wells were subsequently **plugged and decommissioned**, and exploration efforts shifted **northward within the Albertine Graben**, where structural conditions were considered more favorable.

These results underscore the **complex interplay between structure, reservoir quality, and hydrocarbon migration** in the region. Although the **Turaco area lies on a structurally favorable hanging wall block**, the absence of sufficient hydrocarbon charge, reservoir continuity, or trap integrity limited its potential for commercial exploitation.

2.2.9 Geophysical tools, procedures and methods

Geophysical studies were in form of exercises done at camp and on personal computers back at the university. During these exercises, magnetic and gravity survey field data from Semliki basin, seismic sections of data from Semliki basin and Gulf of Mexico were provided. The magnetic and gravity field data were used to create gravity anomaly and magnetic intensity maps of the Semliki basin by use of Geosoft Oasis Montaj software that were interpreted and discussed. An interpretation on the seismic sections from Gulf of Mexico and the Semliki basin in western Uganda was also done. The seismic lines from the Gulf of Mexico were interpreted by marking stratal terminations and key stratal surfaces and identifying seismic facies. Procedure for making the interpretation on the seismic lines from the Gulf of Mexico was as follows; Considering strike/seismic line S6 (which has visible/distinguishable facies).

- Reflection terminations such as truncation, onlap and downlap were located and marked.
- After identifying the types of seismic facies and listing their main properties, they were lightly colored on the section.
- This was followed by identifying the types of chronostratigrahically significant seismic surfaces that bound units with different seismic facies and color coding them.

Well log data was used to create shale volume and effective porosity petrophysical log for Turaco-2 well found within semliki basin of Albertine Graben.

2.2.10 Report writing

This was the final stage of this project that involved the formal writing of a report comprising of the comprehensive study done in the field, data acquisition, analysis, interpretation procedures, discussions and conclusions about the petroleum system of the study area.

The report is organized into eight chapters describing field work in Semliki basin. In their order, the chapters include; Introduction, Materials and methods, Lithology and stratigraphy, Basin and facies analysis, Structures, Geophysics of semliki sedimentary basins, Discussion and Conclusions and Recommendations with other sections which include references and appendices.

CHAPTER 3: LITHOLOGY AND STRATIGRAPHY

Lithology, the study of rock types and their physical characteristics, focuses on parameters such as rock type, color, mineral composition, grain size, and texture. In the Semliki Basin, two major lithological categories are identified:

- Pre-rift lithology, consisting of Precambrian crystalline basement rocks.
- Syn-rift lithology, which includes both clastic and non-clastic sedimentary rocks deposited during the rifting phase.

The sedimentary succession ranges from Middle Miocene to recent sediments at the top, underlain by Jurassic or Permo-Triassic to Early Tertiary sediments, all resting unconformably on the Precambrian basement. The overall stratigraphy of the basin reveals a sandy sequence at the base, which transitions upward into a clay-dominated unit with minor sand interbeds.

Stratigraphy, the branch of geology concerned with rock layers and their organization, deals with the form, arrangement, distribution, chronological order, classification, correlation, and interrelationships of rock strata. In the Semliki Basin, stratigraphic units have been identified through surface observations, well data, and seismic interpretations.

The Semliki Basin forms part of the Albertine Graben, a Meso-Cenozoic rift basin with proven hydrocarbon potential. This potential has been revealed through geological mapping and outcrop logging, providing insights into its structural and sedimentary evolution

TABLE 2 SHOWING THE DIFFERENT SUB DIVISIONS OF STRATIGRAPHY USED DURING THE MAPPING;

Lithostratigraphy	Deals with lithological characteristics that is rock types, their lateral extinction, mineralogical content, color, grain size and other observable features on the outcrop.
Biostratigraphy	It is the branch of stratigraphy which focuses on correlating and assigning relative ages of rock strata based on fossil content in the rock layers.
Chronostratigraphy	This is a branch of stratigraphy that deals with the relative time relations and ages of rock strata. It is based upon deriving geochronological data for rock units both directly and inferring, so that a sequence of time-relative events of rocks within a region can be derived.
Magnetostratigraphy	This is a chronostratigraphic technique used to date sedimentary and volcanic sequences by analyzing and determining the samples detrital remnant magnetism
	(DRM), that is the polarity of Earth's magnetic field at the time a stratum was deposited
Chemostratigraphy	A technique of sediment characterisation and correlation using subtle variations in the elemental composition of the sediments. The technique relies upon the fact that even apparently homogenous sediments show changes in their chemical composition, these changes reflecting minor fluctuations in variables such as sediment source, facies, palaeoenvironment, palaeoclimate and diagenesis.
Sequence stratigraphy	This is a branch of sedimentary stratigraphy that deals with the order, or sequence, in which depositionally related strata successions (time-rock) units were laid down in the available space or accommodation

Stratigraphy relies mainly on six principles to understand the geologic history and these are described in the table below. These principles were applied in the interpretation of rock sequences semliki basin.

- ***Principle of original horizontality*****:** "Strata either perpendicular to the horizon or inclined to the horizon were at one time parallel to the horizon." (Steno, 1669). This principle states that layers of sediment are originally deposited at their angle of repose which is always horizontal, under the action of gravity. It is important to the analysis of folded and tilted strata.

- ***Principle of superposition*:** The principle of superposition states that in an undisturbed sequence of rock strata, the younger strata lie on top of older strata. These strata can be aligned in form of sheets, thin and/ or thick sheets of sedimentary rock that, as a group, are visibly distinct from those above or below.
- ***Principle of cross-cutting relations***: ―If a body or discontinuity cuts across a stratum, it must have formed after that stratum‖ (Steno, 1669). This is a principle of geology that states that a geologic feature which cuts another is the younger of the two features.
- ***Principle of lateral continuity*:** "Material forming any stratum were continuous over the surface of the Earth unless some other solid bodies stood in the way." (Steno, 1669). The principle states that layers of sediment initially extend laterally in all directions i.e., they are laterally continuous.
- ***Principle of inclusions***: This states that clasts/fragments in a rock are older than the rock itself. A xenolith, for example, which is a fragment of country rock that fell into passing magma during the formation of a magmatic rock is an indication of this very principle.
- ***Principle of faunal succession***: This law was developed by William "Strata" Smith who recognized that fossil groups were succeeded by other fossil groups through time. Also known as the law of faunal succession, it is based on the observation that sedimentary rock strata contain fossilized flora and fauna, and that these fossils succeed each other vertically in a specific, reliable order that can be identified over wide horizontal distances according to their relative ages. This principle has allowed geologists to develop a fossil stratigraphy and provided a means to correlate rocks throughout the world.

The different rock (lithology) types are discussed in detail below;

3.1 Basement lithology

Studies on the basement lithology were conducted in the northern foothills of Mt. Rwenzori, specifically beyond the Kichwamba trading center in the direction of Bundibugyo, at coordinates (0186942, 0079610) and an elevation of 1606 meters. Mt. Rwenzori is a block mountain that is actively uplifting due to its detachment from the rigid continental crust. This region lies within the western branch of the East African Rift System, and the segment on the Ugandan side is referred to as the Albertine Graben. Geologically, Mt. Rwenzori is considered a relatively young horst structure, having formed approximately 4.5 million years ago—so recent that it is sometimes not classified as a fully developed horst

The basement at this location was selected for study for the following key reasons:

- To gain insight into the uplift mechanisms of the underlying rocks, offering clues about the geology beneath the sedimentary cover, which is difficult to examine directly in other areas.
- To analyze the characteristics of the basement rock to assess the potential presence of unconventional hydrocarbon reserves, possibly trapped within the basement itself.
- To examine the basement's weathering profile and correlate it with the overlying sediments, helping to determine the sediments' provenance and to evaluate whether the basement could be a primary source material.

Figure 18: showing the basement lithology at the foothill of Mt. Rwenzori after Kichwamba trading centre towards Bundibugyo

The basement in this region is composed of metamorphic rocks that served as the foundation upon which younger sedimentary layers were deposited. These rocks are part of both the Basement Complex and the Buganda-Toro rock systems found in Uganda. They formed before the onset of rifting—during the Miocene epoch—and are therefore categorized as pre-rift basement rocks.

Exposed along the flanks of the rift, these rocks primarily include high-grade metamorphic and metasedimentary units. Typical lithologies observed in the area include gneisses, granitic gneisses, dolerite dykes, mafic and amphibolite intrusions, mica schists, and, in some zones, quartzites and granites. The presence of intense shearing and metamorphism in certain areas is attributed to the effects of active faulting.

A more detailed characterization of the observed rock types is provided below.

Granitic gniesses

The granite gneisses were the most abundant rock type observed in the basement. Granite gneisses were observed at two localities which included Kichwamba and at the quarry behind Kisegi hill. The lithology was interpreted as granitic gneisses which to belong to the Basement Complex and Buganda-Toro systems. Structures identified within this lithology included; joints, quartz veins, foliations and banding. The foliations trend generally in NE direction and cut across the joints, implying that their tectonic episode occurred much earlier than that of the joints by inference from principle of cross cutting relationships. Joints in the basement portrayed two distinct trends that is NW and SW strike directions. The outcrops were massive and fine grained. They contained minerals such as quartz, feldspars, hornblende, amphiboles.

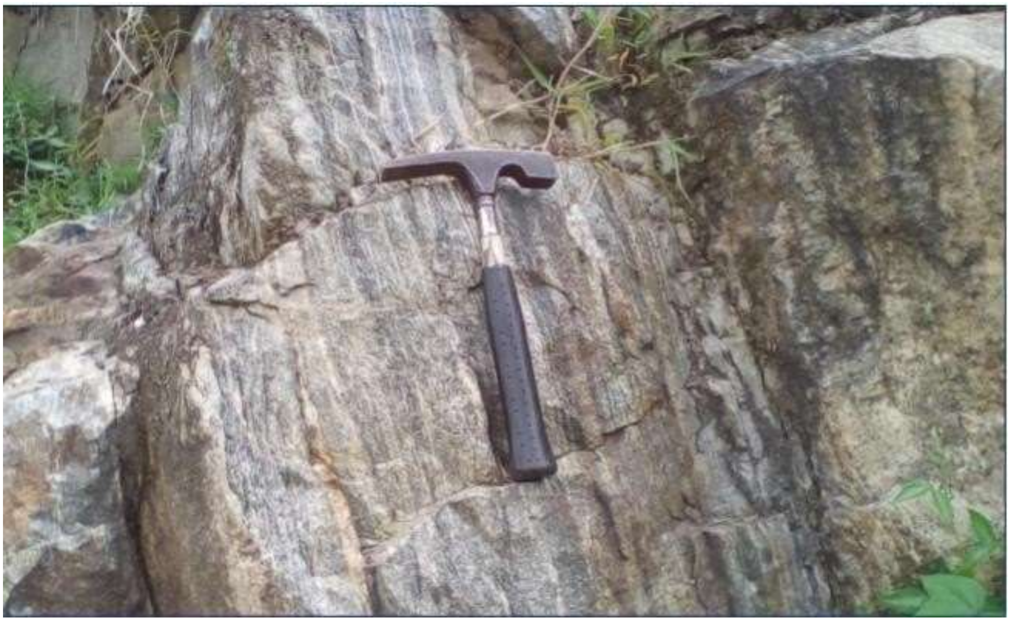

FIGURE 19: FOLIATED GRANITE GNEISS AT KICHWAMBA

At a station established at (0192399, 0101769, 678), a second set of granitic gniesses was encountered in Kibuku area at a quarry behind the Kisegi hill. The basement rock was a large outcrop and was artificially exposed due to quarrying taking place in the area. The granitic gneiss was undifferentiated basic and acid gnisses. It was grey in color and was heavily weathered.

Structures observed in this area included Joints, cracks, cleavage, a fault and foliation. The dominant joints are in the direction of that fault. The major set of joints strike in NW whereas the minor set strike NE and SE directions. The foliations strike in the SW direction. Rock mineralogy included, feldspars, quartz, hematite and micas (biotite, muscovite), and Albite. The rocks, due to exposure to agents such as running water, are heavily weathered, as confirmed by the presence of reddish-brown material on rock surfaces, implying iron minerals. The outcrop is a potential reservoir (unconventional reservoir) especially if the dips of the joints are in the direction of the source beds. These joints would act as migration pathways for the hydrocarbons. The fractured basement reservoir is a poor for storage of hydrocarbons. This is due to compartmentalization caused by a thick layer of clay running from top to bottom. This could have resulted from shearing of rocks along weakness lines such as the joints, creating void space which was later filled by the sediments. The oil, if present, would be affected by biodegradation indicated by weathering, making the oil heavy and sour, which could pose production challenges. The potential geohazards in the area included rock falls, dust that leads to air pollution and rock slides. The possible recommendations to prevent such hazards include installation of wire mesh, decommissioning plan and environmental impact assessment

Amphibolites

While traveling along the Fort Portal–Bundibugyo highway near Kichwamba, an amphibolite outcrop was identified at a road-cut exposure located at coordinates (186930, 79637) and an elevation of 1614 meters. This exposure featured dark-colored rocks recognized as mafic intrusions, composed primarily of amphiboles, plagioclase, pyroxenes, and olivine, with minor amounts of biotite and quartz.

The amphibolite is interpreted to have formed through the metamorphism of gabbro and dolerite, which had intruded the granitic gneiss along tectonic zones of weakness. These intrusions led to localized shearing, which in turn induced foliation within the granitic gneiss host rock. The outer portions of the dolerite cooled and solidified more rapidly than the interior, generating differential stress along the intrusion margins and promoting further fracturing.

Over time, water infiltrated these fractured zones, facilitating mineral precipitation along the surfaces. This resulted in a visually distinctive mix of dark and light minerals on the rock surface. Compared to the surrounding basement rocks, the amphibolitic intrusion exhibits significantly more fracturing, suggesting that it was mechanically weaker and more brittle than the adjacent basement material.

FIGURE 20:AN AMPHIBOLITE AT KICHWAMBAROAD CUT(0186905, 79691, 1069M)

Schists

Schists are medium grade metamorphic rock, comprising of platy minerals such as muscovite and biotite. They were encountered at (0191055, 0094035, 1034m) GPS location. They are brown in colour and exhibit prominent foliation. They are formed by the metamorphosis of mudstone / shale, or some types of igneous rock, to a higher degree than slate. These were encountered with schistose texture, coarser foliation containing both mafic and felsic minerals probably plagioclase feldspars, micas (Muscovite, Biotite) and quartz and iron oxides. Due to the more extreme formation conditions, schist often shows complex folding patterns.

FIGURE 21: SCHIST OUTCROP

Granites

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

FIGURE 22:A HIGHLY JOINTED GRANITE OUTCROP

Quartzite.

Quartzite is a non-foliated metamorphic rock composed almost entirely of quartz. It is formed from the metamorphism of a quartz rich sandstone under conditions of temperature and pressure. These conditions recrystallized the sand grains and the silica cement that binds them together. The end product was a highly robust network of interlocking quartz grains. Quartzite's interconnecting crystalline structure gives it a hard, resilient, and long-lasting quality that is resistant to weathering. this feature distinguishes genuine quartzite from sandstone. In in the field, a quartz vein was observed. It is created when hydrothermal fluid solidifies in fractures found in the basement and country rocks. The quartz vein was folded and was near large oucrop with schist, and migmatite. White-coloured quartzite was found in the Kichwamba fault.

Migmatite

Migmatite is a unique rock formed through the process of partial melting of a pre-existing rock, typically within the Earth's crust. It is characterized by a mixture of both igneous and metamorphic features, giving it a distinct appearance and composition. Migmatite typically forms from a pre-existing rock, often a metamorphic rock such as gneiss or schist. These rocks undergo high temperatures and pressures, leading to partial melting.

In the field, a migmatite was observed contained quartz, feldspar (both orthoclase and plagioclase), mica (such as biotite and muscovite), amphibole and garnet based on its felsic and mafic composition concluded basing on the light and dark minerals(white and black) respectively. The structures observed were bands resulting from the segregation of the molten material and a quartz vein that was folded

Figure 23: showing migmatites with the Disharmonic folds

3.2 Lithology and stratigraphy of sediments

The sediments found in the Semliki Basin are believed to have originated from the basement rocks of the surrounding highlands, particularly the Rwenzori Mountains. This inference is based on the mineralogical and color characteristics of the sediments, which reflect the composition of the underlying basement. These sediments are likely of Miocene age, as suggested by Abeinomugisha (2008). However, the contribution from Mt. Rwenzori itself is considered relatively minor due to the mountain's relatively recent uplift.

The Semliki Basin is predominantly composed of unconsolidated sandstones, mudrocks, evaporites, and conglomerates. The presence of sandstones, mudrocks, and conglomerates—rich in detrital grains—indicates deposition in a terrigenous environment. It is postulated that the sediments were primarily sourced from the ancient Lake Obweruka (modern-day Lake Albert) and transported into the basin by river systems.

These sediments rest directly above the basement rocks, with a basal conglomerate marking the base of the sedimentary sequence. This is overlain by a sand-dominated interval, which is in turn capped by a clay-rich sequence. The dominant lithologies within the Semliki Basin include sandstones, siltstones, conglomerates, and shales.

Seismic data suggests that sediment accumulation in the Albertine Graben reaches thicknesses of 5–6 kilometers (Heritage Oil and Gas Limited, 2001), with the thickest succession located to the north of the Turaco area. This section contains the most complete sedimentary record in the entire graben. Stratigraphically, the succession includes both pre-rift and syn-rift deposits. The pre-rift units, largely Proterozoic in age, are prominently exposed along the flanks and shoulders of the Albertine Graben.

According to Harris et al. (1956), the Semliki Basin has been subdivided into seven formations based on sediment geometry and degree of consolidation. These formations become progressively younger upward, with the oldest unit exposed at the Kibuku outcrop identified as the Kisegi Formation. This formation is characterized by stacked channel-fill sands and has an onlapping relationship with the basement schists and quartzites of the Rwenzori Mountains.

Above the Kisegi Formation lies a predominantly clay-rich sequence, interspersed with subordinate sand units. This sequence has been further divided into the Kasande, Kakara, Oluka, Nyaburogo, Nyakabingo, and Nyabusosi formations, differentiated primarily by variations in the sand-to-shale ratio.

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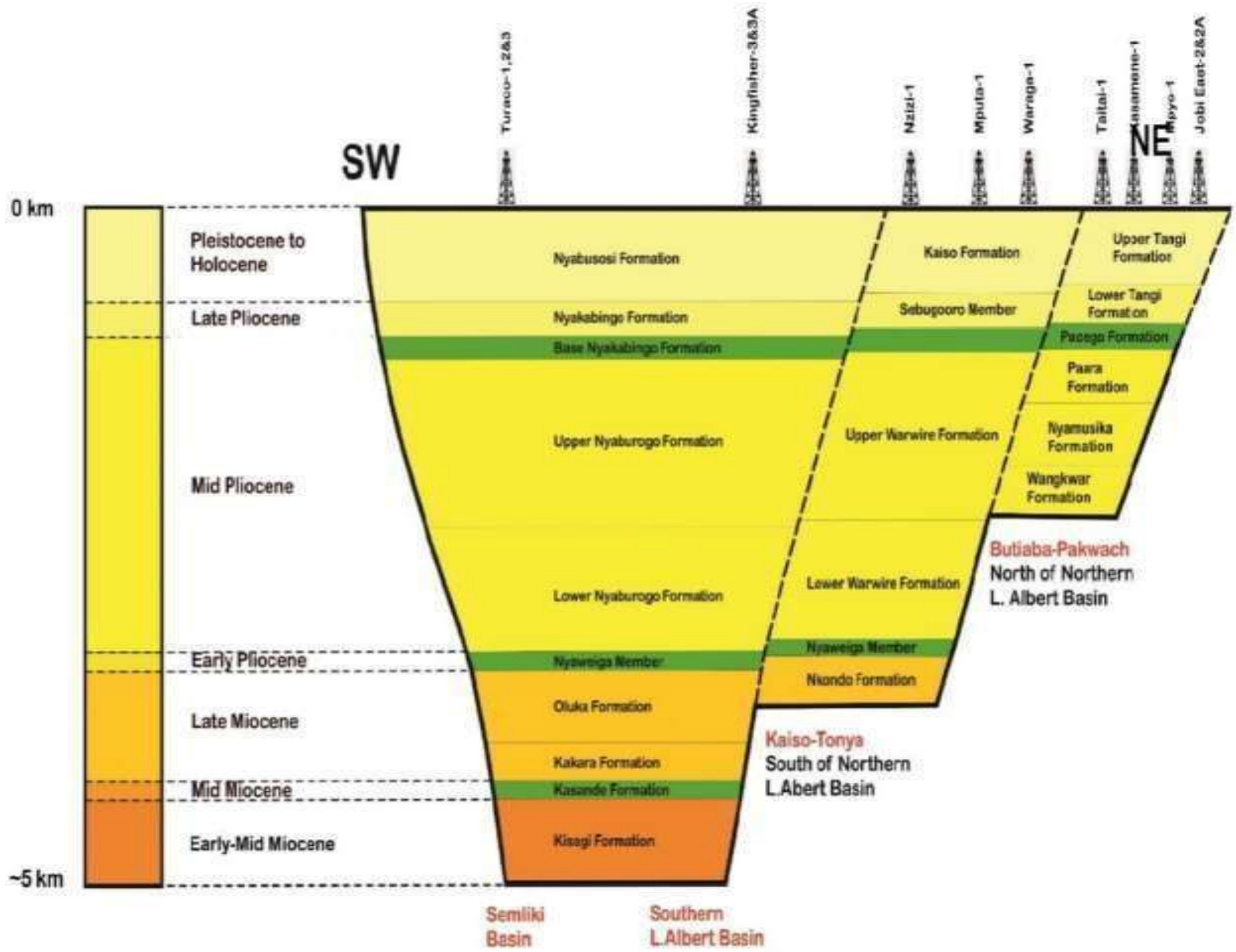

FIGURE 24:PROPOSED DIPOSITIONAL MODEL OF THE ALBERTINE GRABEN(TULLOW OIL'SINTERNALREPORT, 2003)

3.2.1 The different sediment lithologies in the Semliki basin are discussed below;

Conglomerates:

The conglomerate in the area at location (0192521, 0102107, 703m) is observed in a clear contact where it overlies the basement rocks (Figure 4.3.2). The conglomerates observed were poorly sorted, with varying color but mostly brown due to the presence of iron rich minerals, they are coarse grained, the beds were quite discontinuous with varying thickness within (0.3-0.5m) and there was no cyclicity observed.

The conglomerates observed were polymictic, clast supported and consist of angular to sub angular clasts. The conglomerates in the basin were polymictic and clast-supported in nature, largely consisting of sub-angular gravel and pebbles of varying grain sizes and color. The pebbles and cobbles were mainly made up of quartzite and granite gneiss. The provenance of these pebbles and cobbles is believed to be in the basement rocks in the Rwenzori mountains.

These conglomerates formed when very high energy water, laden with large masses of sediments, moving from an uphill provenance suddenly lost all its energy and dynamism leading to an instantaneous settling of the sediments. This is consistent with the fact that the conglomerates in the field were observed to be poorly-sorted. The sub-angularity of pebbles and cobbles indicates that they moved a rather short distance from their provenance thus the minimal textural reworking.

Sands

In terms of stratigraphy, the sands cover the basal conglomerate and are primarily yellow in color. However, some of the sands were white, moderately sorted, fine to coarse grained, and showed repeated sequences of coarsening and fining upward on a small scale, indicating different flow energy regimes of the transporting medium, as well as a general sequence of fining upward on a larger scale. In certain places the top and younger sands were unconsolidated, and in other places the sands were consolidated. The consolidated sand sitting on top of the unconsolidated sand was one of the uncommon occurrences we discovered in our logged area. This may be explained by some fluids that solidified the structure by seeping into the upper sands such as gypsum and iron minerals shown by the brown hue. The yellow or reddish-brown colour is a result of $Fe2+$ oxidation, which suggests that oxidizing conditions were prevalent in the deposition environment. There are thin clay beds intercalated with sand beds. The formation has become compartmentalized as a result of this cyclic deposition, which has also given rise to changes in the environment and depositional energy.

Sandstones may have been produced during times of regression by highly energetic and dynamic waters, while clays may have been deposited during transgression periods when the waters were placid. The yellow sands also have gypsum crystals imbedded in them.

FIGURE 25:SHOWING AN INTERCALATION OF SAND AND CLAY BEDS WITH SOME GYPSUM

Clays.

Clays are very fine-grained sediment that exist in various colours. The clays observed in the area were mainly grey in colour and some are reddish brown and yellowish brown intercalations. The grey color indicates the presence of organic matter with potential to reach maturity and generate hydrocarbons. Thickness ranged from a few centimetres to tens of centimetres (about 5-20cm) but less thick than the sands primary gypsum was also evident on its top layers which could possibly have resulted from precipitation of calcium sulphate-rich waters.. There was 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. Clays could have also been deposited during periods of flooding when the rivers overflowed their banks, deposited silts and clays. Most of the clays discontinuous and some clays are seen to terminate with in the sand beds.

FIGURE 26:SHOWING A GREY MUDSTONE WITH YELLOWISH IRON MINERALS

Silts

These are fine to very fine sediments, ranging 0.004mm to 0.625mm in diameter of grain size, and act as the cross-over between mud and sands.

Silts are well sorted, yellow-white, fine-grained and have some iron mineralization in them. They occur as thin discontinuous beds within sand beds or as thin, continuous beds and there is small scale cyclicity observed.

The observed siltstones contained clay minerals, feldspars, quartz and sedimentary structures such as laminations

The color of the silts ranged from grey to white, though some exhibited a yellow color as a result of presence of iron oxides (figure 3.3.4). They were well sorted and fine grained. Most of the silt beds were thin and did not laterally extend far.

3.2.2 Other Lithology

The other lithologies were encountered within the main beds of sand and clays as intrusions and concretions. These include;

Gypsum

This evaporate rock was observed as a soft colorless rock that turned white when scratched,gypsum ($CaSO4.2H2O$) precipitation often occupied weak bedding planes and joints (Figure 3.3.5.1). These were formed when a highly alkaline solution rich in calcium and sulphate ions invaded the sediments via planes of weakness and were subsequently precipitated. Depositional environments that are interpreted from the presence of these gypsum veins include; ephemeral lakes and supratidal flats in hot arid settings.

FIGURE 28:SHOWING GYPSUM VEINS AND THE CLAY BEDS

Hematite

This manifested in some layers as the pigment in reddish-brown and red sediments. It is formed through precipitation of iron III hydroxides, and is therefore indicative of, oxidizing conditions. A concretion like structures with hematite were observed mostly in Group one and they were seen to intrude sand beds (figure 3.3.5.2). However once formed, it is known persist in slightly reducing alkaline conditions.

FIGURE 29:SHOWING A CONCRETION LIKE STRUCTURE WITH HEMATITE THAT INTRUDED A SAND BED (GROUP 1)

Travertine

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

Contact between basement and sediments

The contact between the basement and sediments was observed at GPS location (192594, 102088) at an elevation of 706m. This contact is a nonconformity that is, a metamorphic rock overlain by younger sedimentary rocks (conglomerate). These conglomerates are about 40 cm thick basically composed of gravel and are overlain by coarse sands with fining upwards sequence (Figure 3.4.1). The conglomerates were deposited by highly dynamic medium that has that capacity to transport the cobbles and pebbles. As the strength of the depositing medium reduced, the water deposited coarse sands with troughs and cross beddings at the base. These sandstones are about 1.4m thick and are overlain with poorly sorted sands and some pebbles; the sand bed is about 23cm thick. The granitic gneiss at the base, was faulted and jointed, quartz veins were observed to have intruded in these faults and joints. The fining upwards sequences is an indication of reduction in the dynamism of the transporting medium.

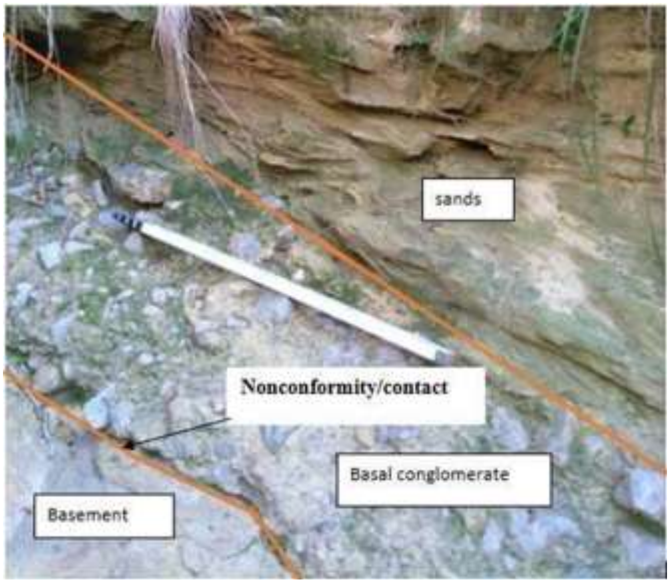

Figure 30: showing the contact between sediments and the basement (defined by the layer of Conglomerates)

3.3 Lithostratigraphic log of Group H along the road cut in Kibuku area

Refer to attached **appendix 4** for the lithostratigraphic log of group H

3.3.1 Log Description

The general lithology of the logged section is dominated by sand units, both consolidated and unconsolidated, interbedded with occasional fine-grained clay sediments. The primary cementing materials identified within the sandy units were gypsum and hematite, suggesting possible diagenetic influences related to fluid flow or mineral-rich groundwater.

Each layer was delineated based on key sedimentological characteristics, including grain size, color, rock type, and sedimentary structures. The majority of the sediments observed were moderately to highly weathered, displaying a typical yellow to pale yellow color. A fining-upward sequence was noted throughout the log, with alternating cycles of coarse to fine sediment deposition, becoming generally finer towards the topmost layers—a pattern indicative of waning depositional energy over time.

The most prominent sedimentary structures identified in the logged interval were cross-stratifications, which are typically associated with fluvial or shallow water environments and provide insight into paleo-flow directions and depositional processes.

A detailed layer-by-layer description of the 24 observed beds is provided in the following section of the report, as represented in the corresponding stratigraphic log.

3.3.3 Interpretation

From the logging observations, the following conclusions can be made; the sediments in the area were deposited in a fluvial environment due to an observed fining upward sequence. The reddish brown and yellow iron minerals present in the sandstones are an indication of sub-aerial weathering of iron minerals by oxidation. The different forms of grading observed in the sandstones i.e., reverse and normal grading indicates change in climate, variations in energy of transporting currents and change in seasons that occurred in the depositional environment. Presence of cross beds in the sandstones are an indication of fluvial conditions in the environment of deposition.

Regarding the petroleum potential of the logged area, since the sediments are loosely consolidated, they can act as reservoirs with good porosity and permeability. The area also has a fault which is a good structural trap and clay minerals which can act as seals.

However, the reservoir quality is reduced by presence of secondary minerals like gypsum and iron minerals which reduce the reservoir porosity. All the layers of clay and sandstones were all tilted implying that they had been acted upon by tectonic activities that occur in the area.

Combined stratigraphic log

Refer to attached **appendix 5** for the combined stratigraphic log

Interpretation of the combined lithostratigraphic log

Group 4 typically logs a region with bottom layers that exhibit a coarsening upwards sequence and top layers that exhibit fining upwards. The section by Group 4 consists of sandstones, claystones, and mudstones totaling 1004 cm in thickness, with a total of 21 layers that typically strike in a northwesterly direction. Sandstones differ in size, composition of clay, degree of sorting, and degree of gypsum cementation. Additionally, there are a number of primary and secondary structures, such as laminations, crossbeds, and horizontal angular troughs with gypsum-filled joints. The cross stratification in the section indicates that it is located in a river environment, and it has a potential reservoir that might be impacted by sand production or compartmentalization. Additionally, muds and basic gypsum may function as a possible seal.

The area logged by Group 6 is generally comprised of layers with fining upwards and homogeneous behaviour. The section has a total thickness of 1205cm with three depositional episodes with mainly intercalations of sand and clay. Lower beds are unconsolidated while upper beds are consolidated with a fining upward sequence which is indicative of a fluvial system together with cross-stratification. There has got a conglomerate layer with a coarsening upward sequence which could have been a channel lag, and pale yellow and dirty white sands cemented by gypsum and iron minerals in the upper layers. There‘s organic matter in layers with silt and conglomerate has silt matrix. The area also contains pitchouts indicating that there could have been an oxbow lake. The section is also marked with an unconformity known as discontinuity. The fining upwards sequence is due to climatic changes where the petroleum system element present is a reservoir.

CHAPTER 4: STRUCTURES

4.1 Structures in the Basement Rocks

4.1.1Primary structures

Foliation

Foliation is a fundamental structural feature in metamorphic rocks, defined as the planar alignment of mineral grains or compositional banding resulting from deformation under directed pressure or shearing forces. It typically develops when anisotropic minerals, such as micas or amphiboles, realign perpendicularly to the direction of maximum principal stress or parallel to shear direction (Marshak, 2009; Passchier & Trouw, 2005). This fabric reflects the orientation and intensity of the stress field active during metamorphism and provides key insights into the tectonothermal evolution of a rock body.

In the Semliki Basin, well-developed foliation was observed in basement lithologies, particularly **granitic gneisses** and **amphibolites**. These rocks display compositional layering, with alternating bands of felsic (quartz and feldspar) and mafic (biotite, hornblende) minerals. The minerals exhibit a preferred orientation forming subparallel to discontinuous bands—a texture typical of high-grade metamorphic environments (Spry, 1969). The coarseness and irregularity of the foliation are attributed to grain size variation and heterogeneity in deformation intensity. Field measurements indicate a dominant foliation trend in the **northeast (NE) direction**, consistent with the regional tectonic framework and joint orientations, suggesting a shared deformational history.

A dolerite dyke intrusion was identified within the basement complex, and its role in foliation development is significant. The intrusion likely exploited pre-existing structural weaknesses, and its emplacement introduced both thermal energy and localized shear stress into the host rock. This led to **recrystallization and differential alignment of minerals**, particularly in the granitic gneiss, where foliation is strongly developed adjacent to the dyke contact. The presence of foliation within the dolerite itself further implies that it too was subjected to later deformation phases, consistent with **polyphase tectonism** in the region (Blenkinsop, 2000).The orientation and fabric of foliation are critical in reconstructing the tectonic history of the area. Because minerals tend to elongate perpendicular to σ_1 (the maximum principal stress), the foliation serves as a reliable proxy for deducing paleostress orientations (Twiss & Moores, 2007). Thus, the NE-trending foliations in the Semliki Basin not only record metamorphic conditions but also provide a structural fingerprint of the compressional and transpressional regimes that influenced the evolution of the Rwenzori block during the formation of the western arm of the East African Rift System

Stereographic projection of foliation data.

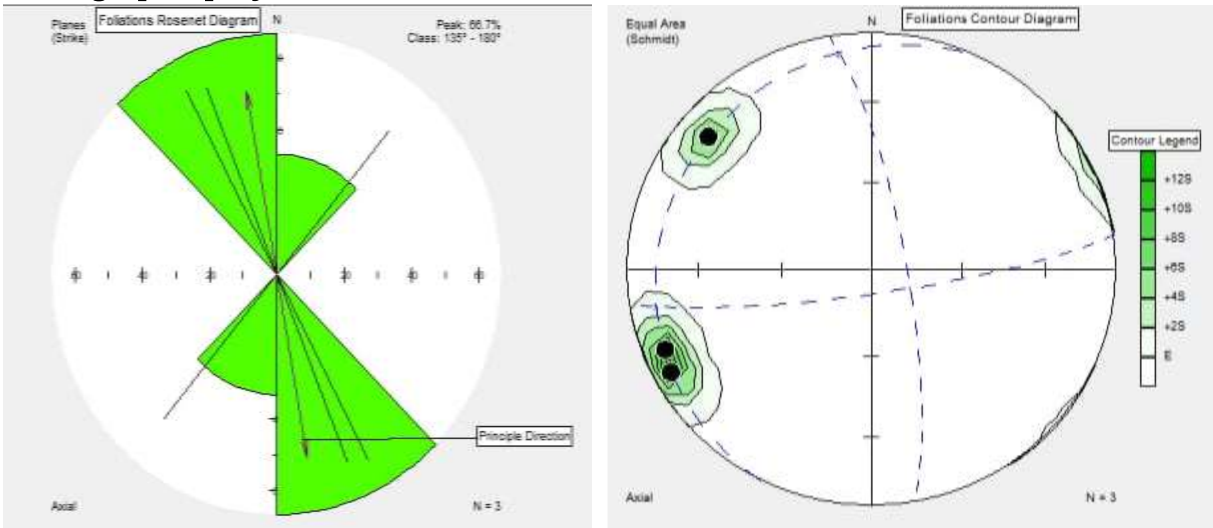

FIGURE 31:SHOWING CONTOUR DIAGRAM OF POLES (LEFT) AND ROSE DIAGRAM OF PLANES (RIGHT) TO FOLIATION IN BASEMENT ROCKS

Structural analysis of the stereonet and contour (density) diagram above reveals that the **dominant foliation orientations** within the basement rocks exhibit a primary **northeast–southwest (NE–SW)** strike trend. A subordinate set of foliations trends in a **northwest–southeast (NW–SE)** direction, which coincides with the dominant joint orientation observed in the same lithological units. This geometric alignment suggests that both the foliations and joints may have developed synchronously or during closely related tectonic events, under a shared regional stress regime (Passchier & Trouw, 2005).

The contour diagram displays a **single concentration maximum**, indicating a **single preferred orientation of dip** across the measured foliations. Because poles to planar structures are plotted perpendicular to the orientation of those planes, the cluster of poles toward the **southeast (SE)** quadrant implies that the corresponding foliation planes predominantly dip **toward the northwest (NW)**. Thus, it can be inferred that the **most preferred dip direction** of foliation is to the NW, while the corresponding **strike direction** aligns approximately **southwest (SW)–northeast (NE)**.

This structural configuration is consistent with **compressive tectonics**, where σ_1 (the maximum principal stress) acts orthogonally to the foliation plane, and aligns perpendicular to the direction of mineral elongation or compositional banding (Twiss & Moores, 2007). The parallelism between foliation and joint sets reinforces the interpretation that **foliation development was influenced, or overprinted, by the same tectonic stress field** responsible for brittle fracturing, particularly during the rifting and uplift processes associated with the formation of the Rwenzori horst block within the western arm of the East African Rift System.

Veins

Veins may be defined as fracture filled with mineral crystals that precipitated from a watery solution (Marshak et al, 2004). Quartz or calcite form the most common vein fill, but other minerals do occur in veins, including numerous ore minerals, zeolites, and chlorite. In the study area, the observed veins are of quartz precipitating from hydrothermal fluids filling former joints. **Quartz veins** are secondary rock structures composed predominantly of interlocked or sutured quartz crystals, typically formed by the **precipitation of silica-rich fluids** within zones of structural weakness such as fractures, joints, or bedding planes. These veins may originate from **hydrothermal solutions** or late-stage magmatic fluids associated with **pegmatitic intrusions** (Winter, 2010). Their occurrence and orientation offer significant insights into the fluid migration history and post-crystallization tectonic regime of the host rocks.

In the studied section of the **Semliki Basin**, quartz veins are the most prevalent vein type within the **basement lithologies**, particularly in **shales and quartzites**. Field observations confirm that these veins infill existing planes of weakness, notably joints and fractures, through hydrothermal precipitation processes. The fluids responsible for vein formation are inferred to be rich in silica and iron, consistent with the presence of both **quartz-dominant** and **iron oxide-bearing** vein material. In addition to hydrothermal quartz veins, **pegmatitic veins** were also recorded, though with lower frequency (see Figure 4.7).

The veins exhibit a dominant **NE–SW orientation**, closely mirroring the regional fault trends. This structural alignment implies a **tectonically controlled emplacement**, suggesting that the fractures into which these veins precipitated were generated or reactivated under the same stress field responsible for faulting in the area. Given their **cross-cutting relationships** with the host basement rocks, these quartz veins post-date the crystallization of the basement but pre-date the most recent episode of jointing, as evidenced by joint sets that disrupt some of the veins. This chronological sequence aligns with the **principle of cross-cutting relationships** (Davis et al., 2011), providing a relative timing framework for structural evolution.

Furthermore, several veins display evidence of subsequent deformation, including minor offsets, boudinage structures, and brecciation, indicative of **post-vein tectonic activity**. This deformation likely corresponds to **rift-related tectonism** associated with the uplift of the Rwenzori horst and the ongoing evolution of the Albertine Rift segment of the East African Rift System.

Taken together, the petrographic character, orientation, and structural relationships of the quartz veins support the interpretation that they are genetically linked to **hydrothermal fluid circulation during the early stages of rifting**, potentially coinciding with the development of extensional fracture systems and basin-bounding faults.

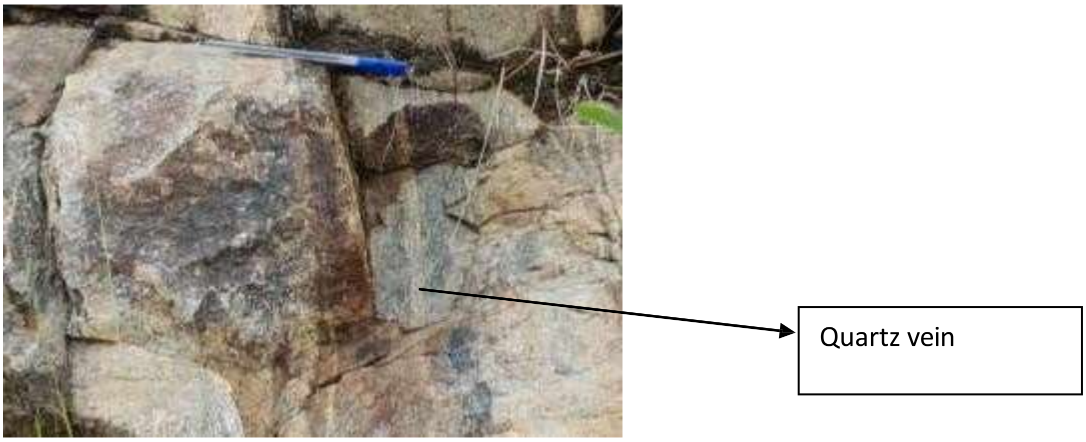

FIGURE 32:SHOWING A QUARTZ VEIN AT KICHWAMBA ROAD CUT

Folds

Folding within basement terranes is a key structural indicator of past tectonothermal regimes and deformation history. In the Semliki Basin region, multiple **fold structures** were documented within high-grade metamorphic units, particularly within **gneisses and migmatites**, which are typical of the mid- to lower-crustal metamorphic conditions. These folds occur in both ductile and brittle-ductile contexts, reflecting the polyphase deformation that affected the basement rocks during the Proterozoic and later during Neogene rifting.

The observed folds exhibit varying morphologies and origins. Some are interpreted to have formed through **compressional tectonic forces**, whereby competent lithologies such as granitic gneiss responded to horizontal stress by buckling into fold structures (Twiss & Moores, 2007). Others likely developed under **high-grade metamorphic conditions**, where **shear-induced folding** occurred in partially molten or migmatitic domains—consistent with deformation in the presence of melt, where plastic flow enhances fold development under elevated temperatures and pressures (Yoshida et al., 2005).

Horizontal (plane parallel) bedding

Horizontal bedding results into layers of sediments parallel to each other and they represent an undisturbed stratum (principal of original horizontality). Plane bed forms were observed in coarse sands and they were deposited at low flow velocities.

FIGURE 33:SHOWING HORIZONTAL BEDS

Cross bedding/stratification

Cross bedding is confined to a single sedimentation unit and characterized by internal bedding or lamination called fore set bedding, inclined to the principal surface of accumulation. The nature of cross bed is determined by the dynamism and the energy of the transporting medium, thus depending on the observed cross bed form deductions can be made about the energy of the transporting media. Several cross-bed forms were observed in the logged sediments of the Semliki basin. These include; tangential cross beds, angular cross beds, trough cross beds, and tabular cross beds.

- **Tangential cross bedding** forms in higher energy than the angular cross bedding. Both form by sediments pilling up but when the energy is higher, the sediments that fall off the pile tend to move thus forming a tangent. Contrary in **Angular;** since the energy is lower, the sediments that fall off just remain there (do not move) thus forming at a clear angle to the horizontal.

FIGURE 34:SHOWING TANGENTIAL CROSS BEDS

Figure 39: showing angular cross beds

- **Trough cross beds** are concave upward fore sets that lie within erosional scours and are elongated parallel to current flow, closed up current and truncated down current by further troughs. They are indicative of very dynamic currents/ high energy environments and they are not efficient in paleo-current direction deductions.

FIGURE 35:SHOWING TROUGH CROSS BEDS

4.3.1.1.1 Stereographic projection of bedding measurements

24 data points of strike and dip of bedding planes obtained during the field exercise were used in stereonet software to obtain the following plots i.e., rose diagram, planes to beddings and contour diagram of poles to bedding plane. These diagrams are used to show the average trend and orientation of beds in the area.

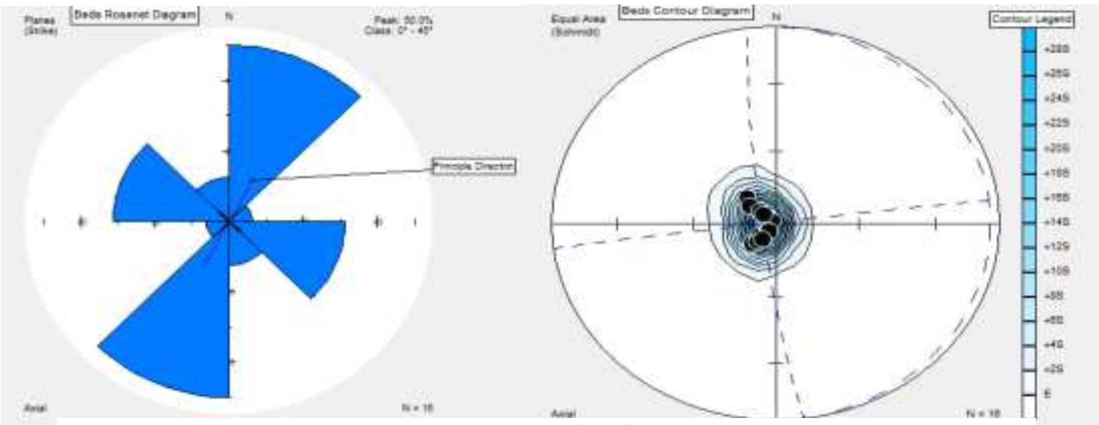

FIGURE 36: SHOWING CONTOUR DIAGRAM OF POLES (LEFT) AND ROSE DIAGRAM OF PLANES (RIGHT) TO FOLIATION IN SEDIMENT BEDDINGS

Interpretation

From the rose diagram it is observed that the bedding planes in the sediments exhibit a general NW-SE direction with an average trend of N45^{0}W. The contour diagram shows the density distribution of the data with 6% interval. The poles to bedding planes are mostly located in the South west direction hence the dip of beds is North East. The beds dip at low angles as observed from the contour diagram where the poles are close to the center.

Graded Bedding

Graded bedding, characterized by a vertical grain size variation (coarse at the base, finer at the top), was identified in both sandstone and siltstone sequences. This **normal grading** is interpreted as the product of **turbidity currents** or **fluvial flood events**, and its presence reflects **episodic sediment influx** into the basin. Such structures are particularly useful in determining **younging directions** in structurally deformed sequences and in reconstructing depositional slope dynamics.

Ripple Marks

Both **symmetrical (wave)** and **asymmetrical (current)** ripple marks were recorded in fine- to medium-grained sandstones, suggesting deposition under **shallow water conditions**. Asymmetrical ripples indicate **unidirectional flow**, consistent with river-dominated environments, while symmetrical ripples point to **oscillatory wave action**, likely in lacustrine or nearshore settings.

FIGURE 37:SHOWING RIPPLE MARKS STRUCTURE ALONG KIBUKU ROADCUT.

Laminations

Laminations are characterized by sedimentation units less than 10 millimeters thick and form a small part of fine sand (Figure 4.14). They are caused by cyclic changes in the supply of sediments. Laminations develop in fine-grained sediments when fine-grained particles settle from suspension, this possibly occurs in quiet waters like deep lacustrine environments and they occur as parallel structures in different sets that make an angle with each other. They are thinner than beds and are commonly internal structures of a bed. Laminations arise from changes in grain size between laminae, size-grading within laminae or changes in composition between laminae and form in quiet waters. Laminations were observed in the logging section in clays and silts and were both planar and lenticular.

Figure 43: showing laminations (in red circle) in sands

4.1.2 Secondary structures

Faults

Faults are fractures in the Earth's crust along which displacement has occurred (Trista L. Thornberry-Ehrlich, 2020). These structures can vary significantly in scale, ranging from the massive boundaries between tectonic plates to smaller fractures observable in individual rock outcrops. Faulting typically results from the brittle failure of previously undeformed rock or from frictional sliding along a pre-existing fault plane.

Within the Semliki Basin, both major regional faults and smaller, localized faults are present. The major faults define large-scale tectonic boundaries, while the minor faults, often visible in outcrops, may have formed during the development of these larger fault systems. The faults in this region are generally classified as either strike-slip or dip-slip types. Field evidence of faulting includes features such as slickensides, fault gouges, and measurable displacements along fault planes.

In the Kichwamba basement rocks, faults predominantly trend in a northeast-southwest (NE-SW) direction. A notable example is the Kichwamba Fault, which trends in a north-northeast to south-southwest (NNE-SSW) direction. This fault lies on the eastern side of the Rwenzori Mountains and serves as a structural boundary, separating the Rwenzori microplate from the larger Victoria and Nubian plates. It continues northward, eventually disappearing beneath the Semliki flats.

Another significant fault is the oblique Makondo Slip Fault, which also trends NE-SW and separates the Semliki flats from the Toro plains. To the southeast, the Semliki Basin is bounded by a steep fault escarpment that rises nearly 1,000 meters to the northernmost spur of the Rwenzori Mountains.

On the eastern boundary of the basin lies the steeply west-northwest to northwest-dipping Bwamba Fault. The western margin of the basin is defined by two major normal faults: the NNE-SSW trending Semliki Fault and the NE-SW trending Bunya Fault. These faults separate the Congo escarpment from the basin. Together, these normal faults exhibit a conjugate pattern—meaning they dip in opposite directions with similar angles—resulting in the formation of the graben structure that characterizes the basin.

The faults observed in the basement rocks are considered significant for petroleum exploration. They may act as migration pathways for hydrocarbons and, where conditions allow, can function as structural traps, leading to the accumulation of oil and gas—provided they are sealing faults capable of retaining fluids within the reservoir.

FIGURE 39:SHOWING THE KICHWAMBA FAULT

Joints

A **joint** is a brittle discontinuity within a rock mass, characterized by a planar or curviplanar fracture surface along which there has been negligible or no measurable shear displacement. These structures form primarily in response to extensional stress regimes, where differential tensile forces exceed the rock's tensile strength, resulting in slight aperture development between opposing fracture walls without accompanying lateral movement. Despite the absence of displacement, joints play a critical role in controlling rock mass mechanical behavior, permeability, and fluid flow.

Joint development typically occurs during the brittle deformation phase of a rock's geologic history and may be driven by a range of processes including tectonic loading, thermal contraction (e.g., during the cooling of igneous bodies), or regional uplift and unroofing. Their morphology and spatial distribution are indicative of the prevailing stress field at the time of formation and the intrinsic properties of the host lithology.

Joints can be classified based on their geometry, orientation, spatial arrangement, and genetic relationship to surrounding structural elements. The principal categories include:

- **Systematic joints**: Planar, regularly spaced joints that occur in well-defined, parallel to sub-parallel sets. These typically reflect consistent stress orientations over extended deformation episodes.
- **Non-systematic joints**: Irregular in form and spacing, lacking a discernible geometric pattern, and often reflecting localized stress perturbations or heterogeneous mechanical properties within the rock mass.
- Additional joint types include **cross joints** (which intersect primary joint sets at high angles), **oblique joints**, **sheet joints** (parallel to the Earth's surface, often formed by unloading), and **columnar joints** (polygonal fractures typically formed by cooling in volcanic flows).

In the **Semliki Basin**, the crystalline basement rocks exhibit extensive jointing due to their inherently brittle rheology and the pervasive influence of regional tectonism, particularly related to the uplift of the Rwenzori block. Jointing in this context tends to occur in well-organized sets, suggesting systematic reactivation of pre-existing weaknesses under successive tectonic regimes.

Field investigations revealed the predominance of **systematic** and **non-systematic joints**. The systematic joints are characterized by their regular, planar expression and consistent orientation, implying formation under a stable stress field likely associated with regional rift-related deformation. In contrast, non-systematic joints display more erratic orientations and spacing, reflecting more localized deformation episodes or variations in lithologic competency. These joint networks are of particular geotechnical and hydrogeological significance, as they enhance secondary porosity and can serve as preferential pathways for fluid migration. Moreover, their orientation and density can influence fracture permeability anisotropy, reservoir connectivity, and the localization of mineralization or hydrocarbon traps.

FIGURE 40:HIGHLY JOINTED BASEMENT TRENDING SW-NE. (LEFT) KICHWAMBA (0192399, 0101769, 678M)

The various aperture sizes were ranging from a few millimetres to about 20cm and some of the joints were filled with siliceous material to form veins. Exfoliation could have been another cause of jointing since it results in stress relief due to weathering and erosion of the overburden thus expansion of the rock. Exfoliation was observed in the amphibolite intrusion (188905, 79691) at an elevation of 1608m. These joints are almost parallel to the dip of the amphibolite. Two sets of joints were observed to be consistent, with the major/dominant set trending in the NW-SE direction and the minor set trending in the NE-SW direction

Stereographic analysis of Joint measurements.

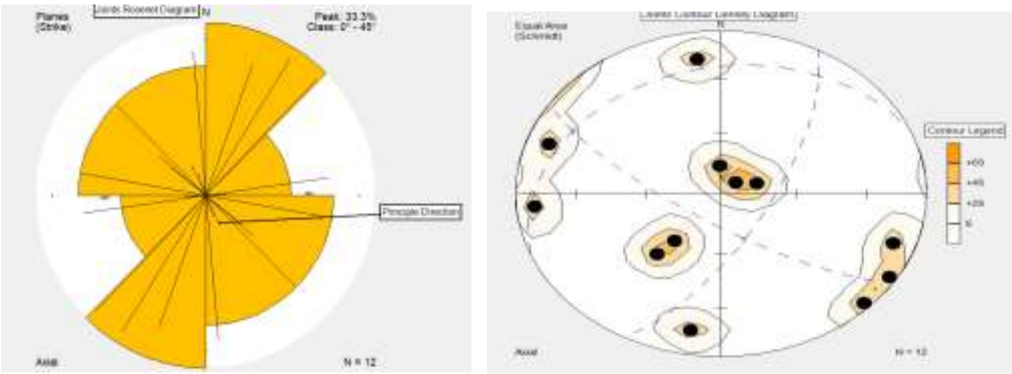

FIGURE 41:SHOWING CONTOUR DIAGRAM OF POLES TO JOINTS (LEFT) AND ROSE DIAGRAM FOR PLANES TO JOINTS (RIGHT)

Analysis of the rose diagram reveals a predominant joint orientation within the basement rocks, with principal strike directions trending northwest–southeast (NW–SE) and northeast–southwest (NE–SW). These two joint sets represent the dominant structural fabrics within the study area, and their consistent orientation suggests formation under regionally extensive, directionally consistent stress fields—likely linked to tectonic forces associated with the rifting and uplift of the Rwenzori block.

Further insight is provided by the contoured stereonet (or contour diagram), which illustrates the spatial concentration of joint plane poles. The clustering of poles near the periphery of the stereographic projection indicates that the majority of joints exhibit steep dip angles, often approaching vertical. Such steeply dipping joint sets are characteristic of brittle deformation in high-strain tectonic environments and may reflect the influence of fault-related stress fields or vertical uplift associated with horst development.

The combined analysis of rose and stereonet diagrams not only confirms the bimodal joint orientation but also underscores the tectonic significance of jointing in the basement complex. These structural patterns provide critical information regarding paleostress directions and are essential for evaluating fracture-controlled fluid migration pathways, especially in the context of hydrocarbon exploration and reservoir characterization within the Semliki Basin.

Mud Cracks

Polygonal **desiccation cracks** were observed in fine-grained mudstones and silty clay layers, particularly at the margins of paleochannels. These features suggest **periodic subaerial exposure** of sediment surfaces, indicative of **ephemeral fluvial or lacustrine settings**, and alternating wet-dry conditions likely driven by climatic fluctuations. These structures were observed in the Kisegi seasonal river flood plains. Mud cracks are important in determining the way up where the concave side indicates direction of younging while the tapered end indicates direction of maturation of rocks.

Figure 44: showing mud cracks on Nyakabingo formation sediments in the Makondo fault area

Unconformity.

An unconformity is a surface representing a break in stratigraphic sequence, involving a period of non-deposition or sub-aerial exposure (erosion). An unconformity was observed at the contact between the basement and sediments (nonconformity). Other unconformities like disconformity were also observed within the sediments as well (Figure 4.17).

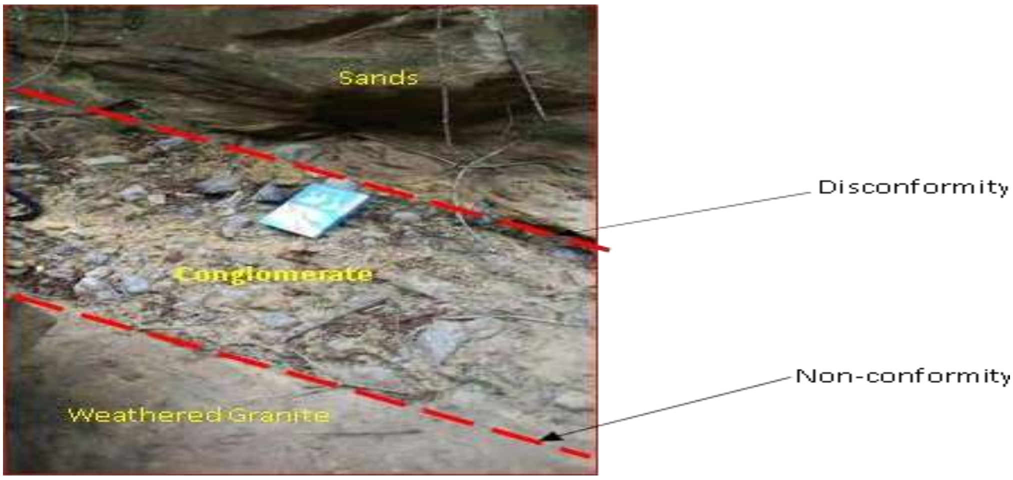

Figure 45: showing Unconformity in rocks

Pinch outs.

These are deformational structures and they refer to the termination by thinning or tapering out of a lithologically distinct body of rock against another rock body on reaching their limits of deposition as observed in most sandstone layers in the study area. These occur where porous and permeable sand is isolated above, below and at its up dip edge by non-permeable sediments such as clays or less permeable shales. This is of significance in the petroleum system since pinch outs act as stratigraphic traps if the adjacent sealing rock is a source rock. Pinching out was also observed in clay lenses bounded by sands.

showing a pinch out at Kibuku road cut

Faults

There were minor faults that were present in the sediments. A fault was observed by group 2 in their logged area. This was a normal fault because the hanging wall block (HWB) moved down relative to footwall block (FWB). It was oriented in the NE-SW direction (Figure 4.22). These minor faults have a similar trend to the major faults in the area and therefore it can be deduced that they were formed at around the same tectonic period as the major faults.

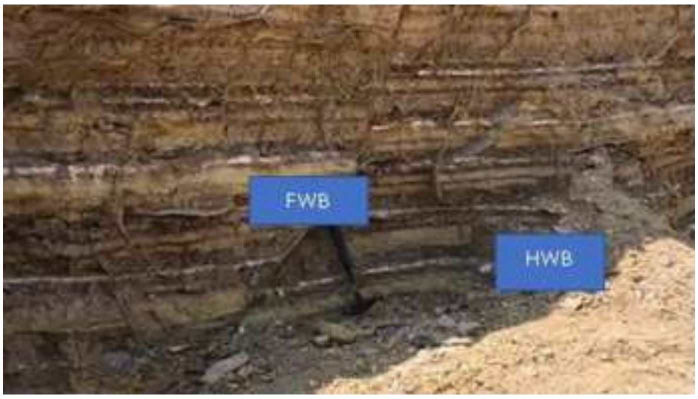

Figure showing normal fault in area of group

CHAPTER 5: BASIN AND FACIES ANALYSIS

From the small area studied, the results obtained were extrapolated to other areas using these concepts to understand and deduce the potential of the rest of the basin. Primary sedimentary structures and faults within the basin were mapped and lithofacies bounded together to achieve a lateral correlation across the basin as well as predict petroleum generation and accumulation.

Facies sequence focuses on vertical arrangement of facies as opposed to the lateral movement which tells us which type of environment the sediments were deposited. For instance, coarsening up sequence (lower sediments being finer and the upper ones being coarser) implying deltaic environment.In sedimentary geology, marine transgression refers to the landward advance of the sea over previously exposed land areas, whereas marine regression denotes the seaward retreat of the shoreline. These processes are primarily driven by changes in relative sea level, which can be influenced by global (eustatic) sea-level changes, tectonic activity, sediment supply, and glacial-interglacial cycles (Boggs, 2012). Transgression can be caused by: Global sea-level rise, often due to glacial melting, subsidence of continental margins due to tectonic activity and reduced sediment supply, allowing marine waters to encroach inland whereas regression can result from sea-level fall, often associated with glaciation, tectonic uplift of coastal or continental areas and increased sedimentation rates, causing basin infilling and progradation of coastlines.

During Transgression, sediments are deposited in a landward-migrating pattern. A fining-upward sequence often forms, with deep marine shales overlying nearshore sands and depositional environments shift from fluvial to estuarine to marine offshore settings which creates marine flooding surfaces that are key stratigraphic markers.

During Regression, sediments shift seaward, forming a coarsening-upward sequence. Shallow marine and coastal deposits prograde over deeper marine deposits where fluvial or deltaic systems may dominate which may result in unconformities or sequence boundaries due to erosion during falling sea levels.

From the studies carried out in the area, it was concluded that there are three sedimentary environments which include deltaic, fluvial and lacustrine environments. In addition, two depositional environments were found to exist in some areas evidenced by the situations where we had coarsening up and fining up sequences.

5.1 Integration of basin analysis concepts in interpretation of Semliki Sedimentary Basin

Sedimentary basins are areas on the Earth's surface where long-term sinking of the crust—known as subsidence—creates space for sediments to gather (Allen and John, 2008). As these sediments accumulate and become buried over time, they experience increased pressure, leading to compaction and lithification, which eventually turn them into sedimentary rocks (Boggs, 2006).

Studying how sedimentary basins form and change over time—and why they appear in certain locations at specific points in Earth's history—offers crucial insight into a variety of geological processes. The layers within these basins preserve a detailed record of the geological events that shaped them.

The sedimentary rock layers deposited during basin development are key to facies analysis, a method that reveals information about the processes of sediment deposition, ancient environmental conditions, and the basin's formation history. This analysis also helps geologists predict the shape, size, and distribution of sedimentary rock units.

Basin location

The Semliki Basin is situated within the Albertine Graben, part of the western branch of the East African Rift System (EARS). In Uganda, this basin spans the southern region of Lake Albert and the adjacent land to its south, encompassing the eastern floodplain of the Semliki River, the Semliki flats around Lake Albert, and the neighboring Toro plain.

This western segment of the EARS features a chain of half-graben basins, many of which lie beneath large lakes. The Semliki Basin itself has a half-graben structure, controlled by faults located on its western margin in the Democratic Republic of Congo (DRC), specifically the Bunya and Semliki faults (see Figure 5.1).

The basin lies at a relatively low elevation—approximately 650 meters above mean sea level—and geophysical data indicates that up to 6 kilometers of sediment have accumulated beneath the southern part of Lake Albert, just north of the Turaco area (Lukaye J. et al., 2016). These sediments are largely shaped by fluvial, deltaic, and lacustrine processes. Toward the east, the basin becomes shallower from the DRC side. On the Ugandan side, the basin extends from the Semliki River, which marks the DRC-Uganda border, and is bounded on the east by the Makondo fault (see Figure 5.1), which separates the deeper Semliki Basin from the shallower Kanywataba area.

In addition to the smaller faults associated with the basin's half-graben structure, the Rwenzori Mountains—an uplifted horst in the center of the graben—tower to an elevation of around 5,100 meters above sea level. This mountain range significantly influences the basin's structure and acts as a major source of sediment. Surrounding the Rwenzori Mountains are hot springs, which suggest elevated geothermal activity in the area.

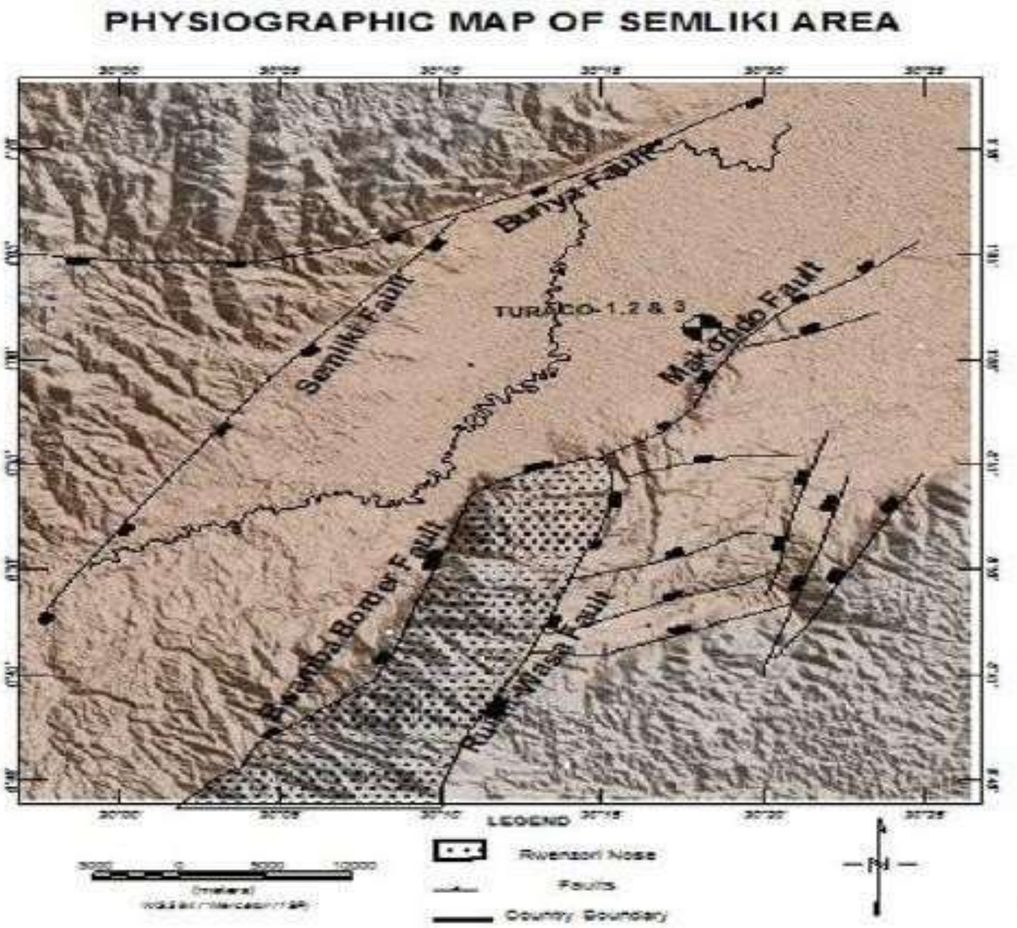

FIGURE 44:SHOWING DIGITAL ELEVATION MODEL SHOWING THE LOCATION OF THE GREATER SEMLIKI BASIN RELATIVE TO THE RWENZORI MOUNTAINS AND THE BOUNDING CLIFFS IN DRC AND UGANDA RESPECTIVELY. THE SEMLIKI RIVER, MARKS THE POLITICAL BOUNDARY BETWEEN UGANDA AND DRC

Formation mechanism of Semliki basin

The Semliki Basin is one of a series of half-graben basins located along the western branch of the East African Rift System (EARS). Its structure is strongly influenced by the prominent Semliki fault, which gives the basin an asymmetric form. The basin originated during the development of the Western Rift, and its formation has sparked ongoing debate about whether the process was driven by active or passive rifting mechanisms.

A conceptual model illustrating the formation and evolution of this rift system is shown in Figure 5.2, adapted from Morley et al. (1999). This model integrates findings from seismic refraction, seismic reflection, seismology, and surface geological observations. According to the model, the upwelling of the asthenosphere beneath the rift occurs through a combination of active and passive processes. This upwelling causes partial melting in the upper mantle, which results in the intrusion of magma bodies into the crust.

Initial rifting of the crust involved the development of steep, deep-reaching normal faults, which led to the creation of extensive half-graben structures. As rifting advanced, the brittle-ductile transition within the crust moved upward, a shift that correlates with the observed rise in earthquake epicenters in the region. Over time, lower-angle boundary faults also formed, and continued extension, accompanied by magmatic activity, resulted in the emplacement of dikes and the formation of minor fault within the crust

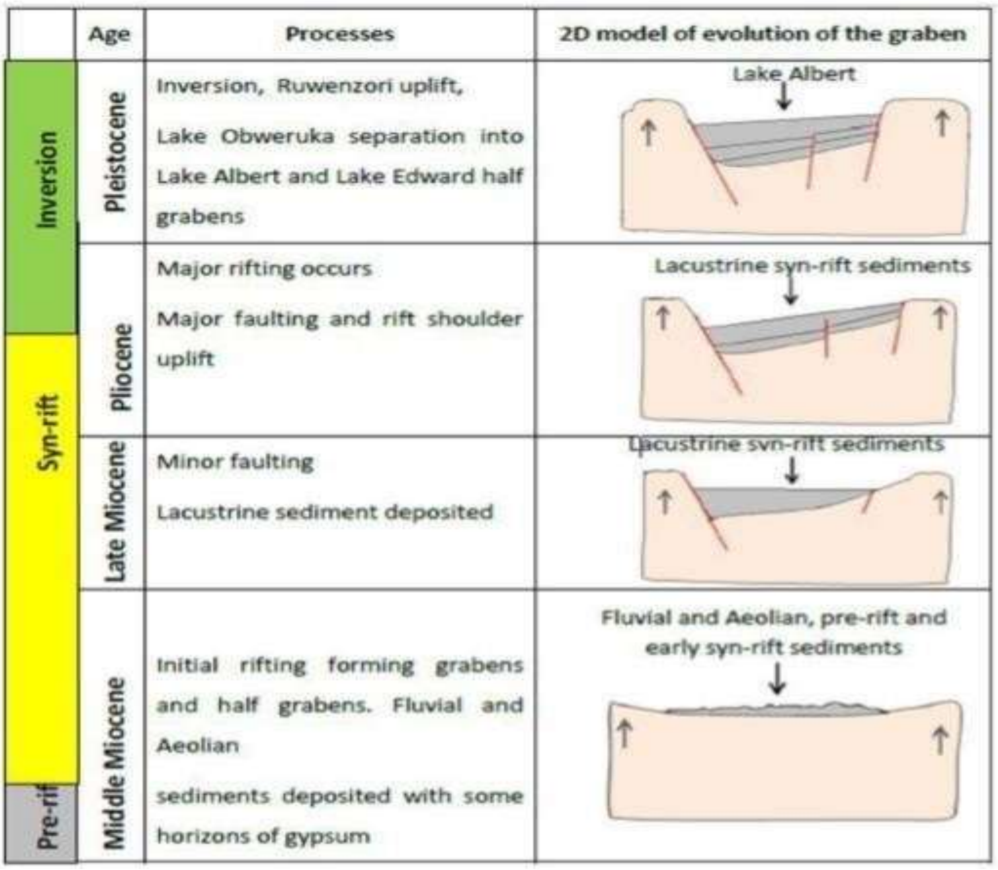

Figure showing the stages of the evolution of the Semliki basin (modified after Pickford et al 1993; Van Damme and Pickford 2003; Ring 2008)

Semliki basin structure and Sediment Accumulation

The Semliki Basin is structurally interpreted as a wedge-shaped half-graben, characterized by an asymmetric geometry controlled by extensional tectonics. The sedimentary infill is primarily composed of fluvial, deltaic, and lacustrine deposits, reflecting a complex interplay of continental depositional environments typical of rift basins.

The geometry and internal architecture of the basin have been inferred through a combination of lithologic characteristics and observed structural elements. Syn-rift source rocks are predominantly developed in the deeper depocenters of the basin, where organic-rich sediments accumulated under anoxic lacustrine conditions. In contrast, reservoir units are more commonly associated with shallow lacustrine and marginal flexural zones, as well as deeper lacustrine settings, where sub-lacustrine turbidite sands are encased within sealing mudstones or clay-rich facies.

At the base of the sedimentary succession, directly overlying the basement nonconformity, occur fluvial-deltaic deposits, often transitioning laterally into deeper water facies. These basal sediments may include turbiditic sand bodies formed in subaqueous settings. Notably, alluvial fan deposits, extending laterally for nearly 6 km, exhibit numerous pinch-outs into overlying deltaic sandstones and, in some cases, into lacustrine mudstones and clays. These features provide excellent potential for stratigraphic trapping mechanisms, particularly where intersected by later normal faulting along the basin margin.

The overall basin fill is dominated by lacustrine mudstones and clays, frequently interbedded with coarser fluvial-deltaic sandstones, indicative of repeated shifts in depositional regime. These sedimentary facies are laterally discontinuous, often exhibiting sharp facies transitions and variable thicknesses, a hallmark of deposition in tectonically active, freshwater-dominated rift settings.

Such environments—where precipitation exceeds evaporation—lead to the development of complex fluvial-lacustrine facies associations (Carroll & Bohacs, 2001). These depositional systems are particularly important for hydrocarbon exploration due to their potential for source-reservoir-seal coupling, as well as the preservation of organic-rich intervals in anoxic, low-energy lacustrine settings.

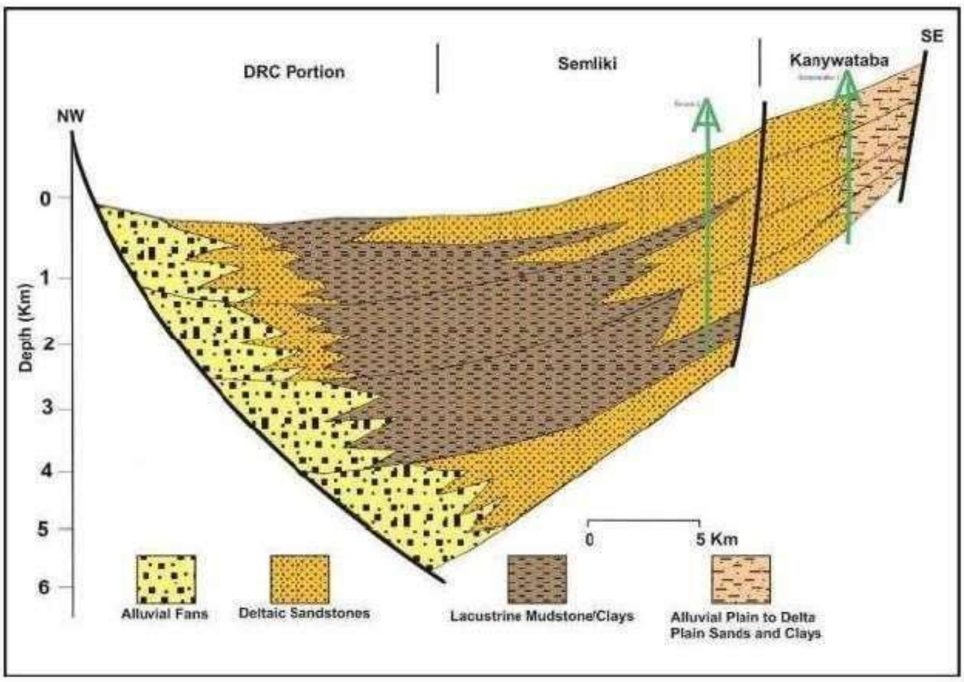

FIGURE 45:SHOWING A SIMPLE IDEALIZED NW-SE CROSS SECTION THROUGH SEMLIKI BASIN INCLUDING THE DRC PORTION (PEPD 2013). NOTE THE POSITION OF THE DIFFERENT SEDIMENT DEPOSITS RELATIVE TO THE BASIN

Basin stratigraphy

As sedimentation progressed in the Semliki Basin, continued subsidence led to dynamic modifications in basin geometry, which in turn influenced sediment transport pathways and depositional patterns. The evolution of the basin was thus not static, but marked by a complex interplay between tectonic activity, accommodation space creation, and sedimentary processes.

Shifting environmental conditions during various stages of basin filling resulted in the deposition of different sediment types in the same geographic location, but at distinct time intervals. This temporal and spatial variability in depositional environments reflects changes in factors such as climate, base level, sediment supply, and tectonic setting.

To capture this complexity, the stratigraphy of the Semliki Basin has been subdivided into seven distinct formations, each defined based on lithological composition, sedimentary facies, and depositional context. These formations collectively record the basin's transitional environments, which range from fluvial and deltaic systems to lacustrine settings. The table below (referenced in the original text) outlines the distribution and relationships of these depositional environments, illustrating their temporal succession and lateral variability.

This stratigraphic framework not only aids in understanding the paleogeographic evolution of the basin but also has important implications for hydrocarbon prospectivity, particularly in identifying potential source, reservoir, and seal intervals. These Formations are described below to further understand the basin.

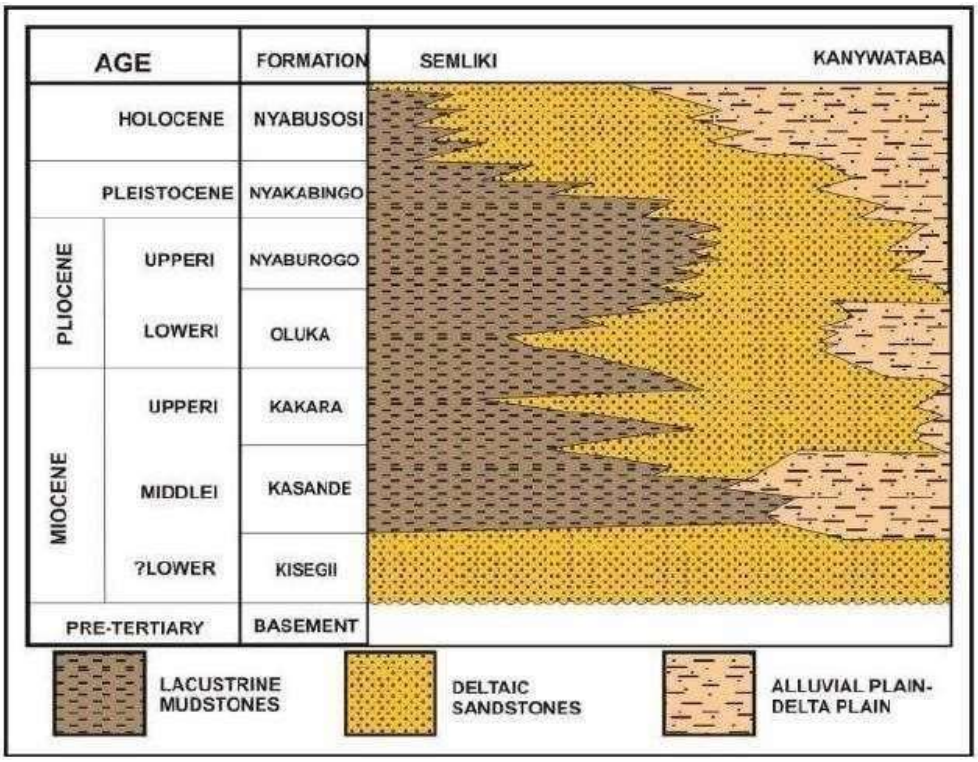

FIGURE 46:SHOWING AN ARRANGEMENT OF THE FORMATIONS OF THE SEMLIKI BASIN FROM YOUNGEST (NYABUBOSI) TO OLDEST (KISEGI) (SOURCE: PEPD 2013)

The sedimentary infill of the Semliki Basin has been subdivided into seven distinct formations, each characterized by specific lithological and stratigraphic attributes. These formations reflect varying depositional environments and mark important stages in the basin’s tectono-sedimentary evolution.

1. Kisegi Formation

First described by Pickford et al., the Kisegi Formation is prominently exposed along the River Kisegi. It represents the basal unit of the Semliki stratigraphy and rests unconformably on the crystalline basement. The lowermost part comprises basal conglomerates, which gradually transition upward into thick, channelized, and cross-bedded sandstones, occasionally interbedded with thin tuffaceous layers. These deposits indicate a fluvial-deltaic depositional environment.

2. Kasande Formation

This unit conformably overlies the Kisegi Formation and is marked by alternating dark brown to yellow-brown mudstones interbedded with yellow sandstones. The formation also includes grey to dark grey claystones and mudstones. According to Lukaye (2016), these lithologies reflect deposition under low-energy lacustrine or floodplain conditions.

3. Kakara Formation

Introduced by Pickford et al., the Kakara Formation is characterized predominantly by clays and silts with occasional ironstone beds. Although sand-dominated exposures are found along certain road cuts, these are not typical of the formation. The basal contact with the underlying Kasande Formation is not clearly observed in outcrops, but is inferred from the first appearance of ferruginous sandstones and ironstone layers.

4. Oruka Formation

The base of the Oruka Formation is well-exposed on the ridge between the Nyaburongo and Kisegi rivers. It is defined by dark shales overlying a widespread conglomeratic ironstone containing large, smooth, rounded quartz pebbles. The formation comprises interbedded claystone, shale, siltstone, and sandstone, and has been recognized as a secondary reservoir unit due to its intercalated sand bodies and permeability contrasts.

5. Nyaburongo Formation

Exposed prominently along new road cuttings, the Nyaburongo Formation features basal shales that rest on a faulted and erosional surface of the underlying Oruka shales and siltstones. This boundary displays a micro-graben structure, indicative of syndepositional faulting. The formation includes thick sequences of claystones, with frequent rusty brown to yellow-brown siltstones, pisolitic ironstones, and paleosol horizons.

6. Nyakabingo Formation

The Nyakabingo Formation is distinguished by a basal unit composed of lacustrine shales. The lithology includes light grey to greenish-grey claystones, iron-stained siltstones, and pebbly to coarse-grained sandstones. Carbonate nodules are also present, pointing to episodes of subaerial exposure or diagenetic alteration in lacustrine to marginal lacustrine settings.

7. Nyabusosi Formation

The contact between the Nyakabingo and Nyabusosi Formations is structurally obscured due to their juxtaposition across the major Makondo Fault Zone near Makondo Village. The Nyabusosi Formation is composed primarily of alternating clay and silt units, indicative of a low-energy depositional environment, possibly a distal lacustrine setting or over-bank deposits.

These stratigraphic units collectively record the tectonic and sedimentary evolution of the Semliki Basin, highlighting variations in depositional energy, provenance, and accommodation space controlled by syn- and post-rift tectonics.

5.5 Elements of facies analysis and facies analysis interpretations from observed lithologic units

A Facies is a body of rock characterized by a particular combination of lithology, texture, suite of sedimentary structures, fossil content, colour, geometry, paleocurrent pattern, etc. Sedimentary facies are bodies of sediment that are recognizably distinct from adjacent sediments that resulted from different depositional environments. Sedimentary facies reflect their depositional environment, each facies being a distinct kind of sediment for that area or environment. Facies can be; lithofacies based on lithology, biofacies based on fossil assemblage and ichnofacies based on trace fossil assemblage. In the study area, 5 lithofacies were identified and these are described in this section. This is followed by an interpretation of their processes and environments of deposition.

5.2 Lithofacies in the study field

Lithofacies 1-massive polymictic conglomerate facies.

This facies consists of massive, brown to grey conglomerates, with sub-rounded to well-rounded pebbles and matrix supported in a medium to coarse grained sand. Clay is also part of the cementing material. This facies was deposited by high energy transporting medium such as rivers and thus point at a fluvial system of deposition. The rivers could have been I their youthful due to the size of pebbles in these conglomerates and the fact that this facies is vertically followed by sands, showing a reduction in energy of deposition.

Lithofacies 2-Cross bedded medium to coarse grained sands facies

These sands are white and/or brown with medium to coarse grains. They show several forms of cross stratification such as tangential, troughs and angular cross beds.

This facies is deposited by low energy. However, Tangential beds form in relatively higher energy compared to angular beds. This faceis could have been deposited by a delta environment due to formation of sub-aqueous levees resulting into a mouth bar.

Lithofacies 3- Massive clays

These are grey, green and reddish-brown clays with thickness as high as 3meters. They mostly show no internal structures but contain organic matter.

These clays were deposited by lacustrine conditions. These are potential seals and source rocks.

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

Facies sequences, which describe the vertical arrangement of sedimentary facies rather than their lateral extent, were employed to reconstruct the depositional environments of the Semliki Basin. These sequences—primarily coarsening-upward and fining-upward trends—offer critical insights into the evolution of sedimentary settings through time.

Analysis of the stratigraphic logs and sedimentary structures indicates the presence of three primary depositional environments within the basin: fluvial Environment, deltaic Environment and lacustrine Environment

In certain sections, two depositional regimes coexist, as evidenced by the alternation of coarsening- and fining-upward sequences within the same stratigraphic column.

Fluvial Environment. The fluvial system is particularly evident in the fining-upward successions, characteristic of channel-to-overbank transitions. This interpretation is further supported by: point bar deposits observed along the Kisegi River channel, floodplain deposits, identified through fine-grained sediment accumulation.The presence of cross-bedded sands, indicative of migrating bedforms. A preserved meandering channel morphology in the coarse sands of the Kisegi Formation. Fossil evidence, such as bivalves, suggesting freshwater influence. Additionally, sedimentary structures such as ripple marks and cross-bedding were instrumental in deducing local paleocurrent directions.

Deltaic Environment. A transitional depositional setting, the deltaic environment serves as a key interface between fluvial inflow and lacustrine accommodation. This setting is inferred from, the occurrence of fine-grained sedimentary facies, including mudstones, fine sands, and silts. Mud diapirs and reworked silts, suggestive of deltaic compaction and deformation. Gradational facies relationships between coarser fluvial units and finer lacustrine deposits.

Lacustrine Environment. Lacustrine conditions are characterized by the dominance of fine-grained sediments, including clays and organic-rich layers. Evidence supporting a lacustrine setting includes: Laminated claystones and siltstones, indicative of low-energy deposition. Organic matter accumulation, reflecting anoxic bottom-water conditions. Evaporitic minerals, particularly gypsum, associated with semi-arid climatic conditions where evaporation rates exceeded precipitation. The presence of red beds and gypsiferous layers, suggesting episodic desiccation events in restricted lake environments.

The interplay between these environments, as well as their vertical succession, highlights the complex tectono-sedimentary evolution of the Semliki Basin. This analysis of facies architecture enhances our understanding of paleogeography, climatic fluctuations, and potential reservoir and seal distribution in the basin.

5.3 Petroleum Potential of the Semliki Basin

The study area has qualities that can qualify it be a good petroleum system. The massive clays can form potential source rocks since they have organic matter. These can also prevent the organic matter from escaping due to their low permeability and can thus acct as potential seals. The sands observed can act as potential reservoir rocks to the generated hydrocarbons with the faults acting as migration pathways.

Source rocks

An oil seep evidenced by dark paraffin-smelling sands observed near Kibuku town at the base of Kisegi formation/sediment-basement contact (0192691, 0101880, 677m) demonstrates that oil is being generated in this part of the Semliki Basin and this suggests that there is a regionally mature source rock is present in the area.

The widespread lacustrine clays found in the region have the potential to become excellent source rocks over time, given sufficient burial and increased temperatures. The dark grey hue of some of these clays suggests a high organic matter content, which is essential for petroleum formation. Studies have also revealed that the basin contains a sedimentary layer ranging from 4 to 6 kilometers in thickness, which is adequate to reach the temperatures and pressures necessary for organic matter to mature into hydrocarbons within the oil window.

Reservoir

The Semliki basin consists of moderately to well-sorted sandstones whose grain size ranges from medium to very coarse which implies that they have good porosity and permeability. The above qualities enable them to act as good reservoirs for hydrocarbons. The sediments are also underlain by the basement rocks such as amphiboles and granite gneisses which are highly fractured and jointed and thus could provide migration pathways for the accumulated petroleum. Also, the flow of water in Sempaya hot springs at a fast rate of about 10-15litres/second is an indicator of high permeability in subsurface rocks.

However, the reservoir quality is reduced by the presence of secondary minerals like gypsum and iron minerals (iron oxides) which have reduced the reservoir porosity. The reservoir is also compartmentalized due to intense weathering in the area which reduces communication between the reservoir productive zones, leading to production problems.

showing an oil seep encountered in the Kisegi sands.

This confirms the presence of oil within the basin

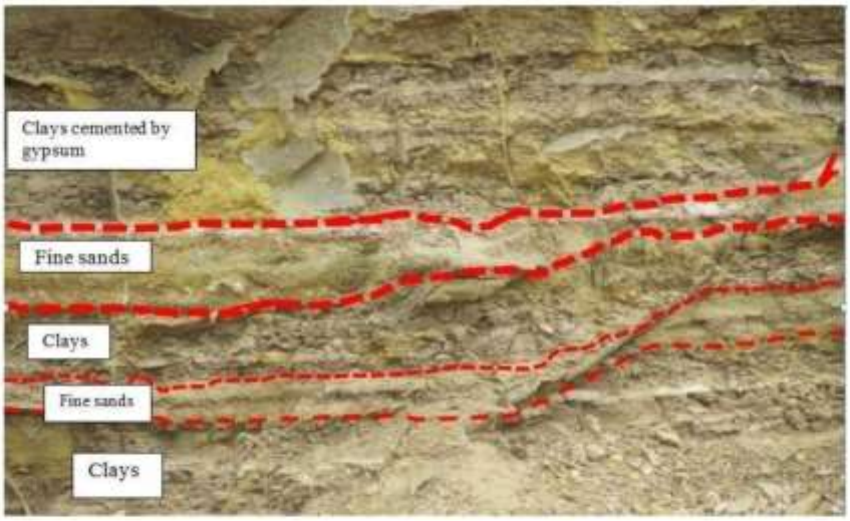

Figure showing compartmentalization in sediments

Traps

The area was found to have both structural (fault) and stratigraphic (pinch-out) traps. A large number of small tilted fault blocks, apparent rollovers as well as anticlinal features associated with listric fault block rotation were identified from the seismic data acquired in the Semliki Basin (Rubondo,2001). Unconformities that were found in the area of study also provide for stratigraphic, combined stratigraphic and structural traps. Positive flower structures, such as that displayed at Turaco can be relied on as proven exploration targets for traps in the Semliki. This can act as a good Petroleum trap

Figure showing Sealing fault along Kibuku roadcut.

Seals/Cap rocks

In the study area, the Kasande clays provide good sealing geometry for the underlying Kisegi formation. The thickness of clay beds about 20m thick could be a potential regional seal. The shales of transgressive systems tracts also form good seals for the underlying low stand systems tracts. The presence of oil seeps in the area such as Kibuku oil seep indicate that there are intervals which are inadequately sealed.

Maturation and Timing

The high temperatures that exist in the Semliki basin and as evidenced by hot springs can facilitate the conversion of organic matter to hydrocarbons and its maturation. Good timing ensures that the reservoir, trap and seal are in place before the source rocks generate hydrocarbons and migration starts. Despite being the youngest rift basins of Cenozoic sediments in the world, the Albertine Graben has a high potential with recoverable reserves of about 1.4 Billion barrels of crude oil in the region. It is believed that there exists high geothermal gradient which initiated the thermal maturity in the shortest time possible.

Migration Pathways

Previous surface geological mapping combined with the interpretation of seismic reflection data has provided valuable insights into the hydrocarbon migration architecture within the Semliki Basin, part of the larger Albertine Graben. These investigations have revealed a network of steeply-dipping fault structures, complex fault systems, and unconformities—all of which play a critical role in controlling fluid flow and migration dynamics.

The seismic datasets indicate that the basin is dissected by numerous normal and oblique-slip faults, often occurring in multi-faulted arrays with associated fracture networks. These features are interpreted to act as primary migration pathways, enabling vertical and lateral movement of hydrocarbons from deeply buried source rocks to shallower reservoir horizons.

Furthermore, the tectonic configuration of the Albertine Graben suggests a regional migration trend originating from the deeper Congo basins in the west, migrating eastward into the shallower Ugandan sub-basins. This inferred cross-border migration pathway is consistent with gravitational fluid flow models and supported by structural alignments observed in the seismic profiles (refer to Figure 5.7).

Unconformities mapped in the stratigraphic column, particularly those between the pre-rift and syn-rift sequences, may have enhanced lateral migration by acting as stratigraphic conduits, while also contributing to trap formation when juxtaposed against impermeable facies. Collectively, the interconnected fault systems, fracture networks, and unconformities create a dynamic migration system. These structural features not only facilitate hydrocarbon expulsion and transport but also increase the likelihood of accumulation in structurally or stratigraphically favorable traps—making them critical targets in petroleum exploration within the Semliki Basin.

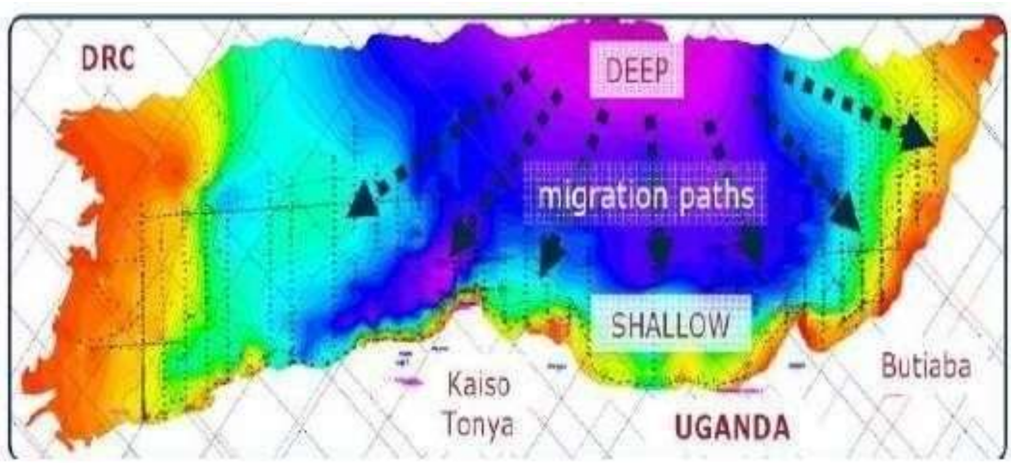

FIGURE 47:SHOWING MIGRATION PATHWAYS IN THE ALBERTINE GRABEN. (SOURCE: TULLOW OIL, 2012).

Heat flow in the Semliki basin

The Albertine Graben is characterized by a high degree of seismic and geothermal activity, primarily driven by the region's extensive fault systems. These fault networks, indicative of ongoing tectonic deformation, have facilitated the formation of numerous geothermal fields across the graben. One prominent example is the Buranga Geothermal Field, which, like others in the area, is associated with surface manifestations such as the Sempaya Hot Springs. According to Tugume and Nyblade (2009), the measured surface heat flow in the Albertine Graben ranges between 54 to 66 mW/m². While these values are somewhat lower than the average heat flow of ~80 mW/m² typically associated with continental rifting environments (Allen and Allen, 2005), they are nonetheless sufficient to significantly impact the thermal maturation of organic matter within sedimentary basins such as the Semliki Basin.

Given this thermal regime, it is reasonable to infer that source rock facies located at or just below 2000 meters depth could attain the required thermal maturity for hydrocarbon generation. This is particularly plausible when considering a consistent geothermal gradient in conjunction with a steady subsidence history, conditions which enhance burial heating and facilitate the transition of organic-rich intervals into the oil or gas window.

The implications for petroleum exploration are significant: the combination of moderate heat flow, tectonic fracturing, and adequate burial depth creates a thermal environment conducive to the development of a productive petroleum system, provided that source, reservoir, and seal conditions are also favorable.

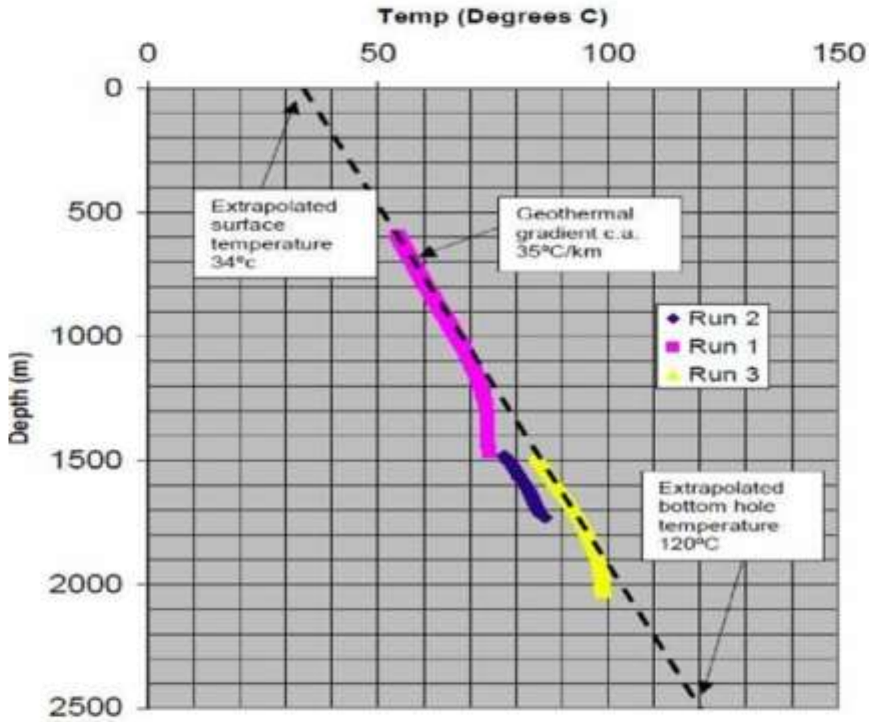

Figure showing a geothermal gradient within the Albertine graben (Heritage oil and gas, 2001

CHAPTER 6: GEOPHYSICS OF THE SEMLIKI SEDIMENTARY BASIN

6.1 GEOPHYSICAL METHODS

Geophysical methods are generally categorized into two types:

- **Passive methods**: These detect natural variations in the Earth's physical fields without introducing any external energy. Common examples include **gravity**, **magnetic**, and **radiometric** methods.
- **Active methods**: These involve generating energy that is transmitted into the ground. The responses, which relate to the source and propagation of energy through the subsurface, are then measured. Examples include **seismic** and **electrical resistivity** techniques.

While active methods tend to produce more detailed and clearer images of the subsurface, they are significantly more expensive to implement compared to passive methods.

In the Semliki Basin, several sets of geophysical data have been collected over time. Notably, **aerial surveys** conducted by **Kenting Earth Sciences** around **1983** provided essential gravity and magnetic data. Subsequent **gravity surveys** led to the identification of the **Makondo Fault**. Later, in **1998**, newly acquired **seismic data** from the same area revealed that the fault strikes in a **northeast-southwest (NE–SW)** direction. Structural interpretation of this data showed that the Makondo Fault has a **folded hanging wall** and exhibits features of a **positive flower structure**, which is typically associated with transpressional tectonic settings.

Due to equipment limitations during the Semliki Basin field study, **no new geophysical data was collected**. Instead, the focus was placed on **interpreting existing datasets** from the Semliki Basin and comparative data from the **Gulf of Mexico**. This analysis made use of **Bouguer gravity maps**, **magnetic anomaly maps**, and **seismic sections** to better understand the basin's structure and potential for hydrocarbon accumulation.

6.1 Potential fields field survey methods

The potential field survey methods of interest in this chapter are the gravity and magnetic methods. The objective of interpretation is to use the survey observations in order to:

- To improve the description of the configuration of rocks in the ground which gives rise to the anomalies.
- To set the limits to depth, size, areal extent among others, of each body causing an anomaly.
- Potential field methods essentially map lateral changes in rock properties and are extremely valuable in determining the regional geological and structural setting.

The potential field survey methods used were gravimetry and magnetometry. In gravimetry and magnetometry, the spatial and temporal variations and the absolute values of the earth's gravity and magnetic field are measured, determining either the single components in the three spatial directions (vector measurement) or the total value (scalar measurement). Interpretations of the observations made in a survey are thereafter done to improve the description of the configuration of rocks in the subsurface as well as set limits to depth, size, and areal extent of subsurface features thus better identification and mapping of anomalies. Interpretations may therefore be qualitative or quantitative and others as follows;

- **Qualitative interpretation**

This involves descriptions in terms of, rock formations, rock structures and so on. In qualitative examination of the gravity data, for example, one examines the grid of gravity values, contour maps or the gravity profiles to determine the lateral location of any gravity variation.

- **Quantitative interpretation**

This involves making numerical estimates of the depth, density and dimensions/geometry of the sources of anomalies (modeling of sources). Conceptual models of the subsurface are created and their anomalies calculated and these are compared with the observed anomalies. The model parameters are adjusted in order to ensure a better agreement between observed and calculated anomalies so as to obtain a suitable physical approximation to the unknown geology.

- **The principle of non-uniqueness**

This form of interpretation is used where no unique solution is possible. Limits to depths and dimensions of possible anomaly sources may be set basing on the known and speculated geology. This is because there is an infinite number of possible physical models which could theoretically account for a given anomaly.

6.1.1 Gravity Survey method.

Gravity surveying involves taking systematic measurements of the Earth's gravitational field at multiple locations across a target area. These measurements are analyzed to identify variations caused by differences in subsurface rock density, which help infer changes in lithology and geological structure.

These surveys can be conducted in **terrestria**l (land-based), marine (underwater), or **airborne** environments. They are widely used in exploration geophysics to help detect and map geological features beneath the Earth's surface.

For land-based surveys, precision gravimeters are employed to detect slight differences in gravity between survey stations. However, the raw data includes both geological and non-geological influences—such as elevation, latitude, and topographic effects—which must be corrected in order to isolate the signal due to density contrasts in the subsurface. The result of these corrections is referred to as a gravity anomaly.

Interpreting these anomalies effectively requires strategic planning of the survey, particularly with regard to the orientation of survey lines and spacing between measurement stations, to ensure the anomalies are clearly defined.

Positive gravity anomalies typically reflect the presence of dense materials at shallow depths, suggesting structures such as mafic intrusions or mineralized zones.

Negative anomalies are generally indicative of less dense bodies, like sedimentary basins or certain types of alteration zones.

A key product of gravity data processing is the **Bouguer anomaly**, which is corrected for both elevation (free-air correction) and terrain effects. The **Bouguer anomaly** map provides a detailed representation of subsurface density variations, making it a valuable tool in geological interpretation.

For example: High-density materials such as chromite, hematite, and barite are often associated with gravity highs conversely, low-density formations like halite, weathered kimberlite, and diatomaceous earth typically correspond to gravity lows.

6.1.1.1 Results of Gravity Data Interpretation of the Semliki Basin

Using Geosoft Montaj software, a bouguer anomaly map of the gravity data of the semliki basin was generated.

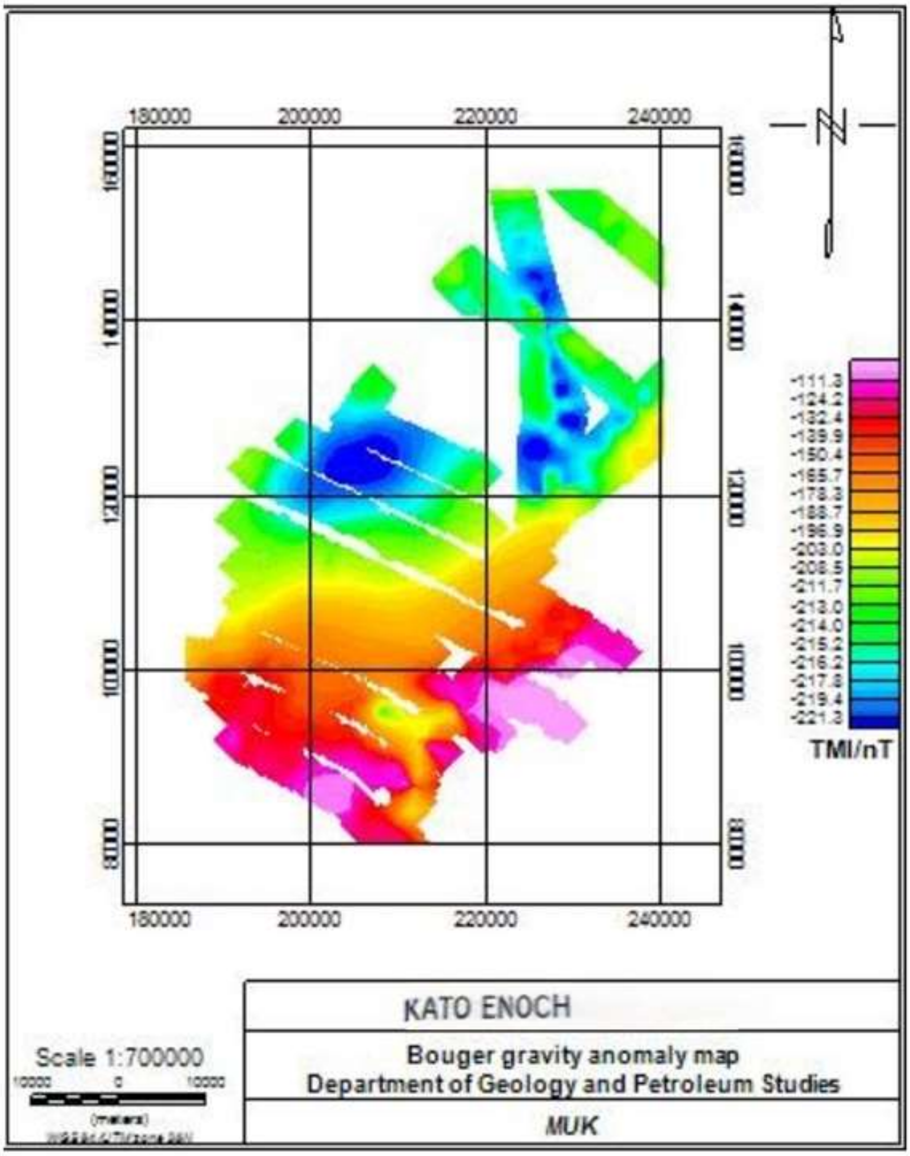

FIGURE 49:SHOWING A GRAVITY ANOMALY MAP FOR THE SEMLIKI BASIN

6.1.1.2 Interpretation

Lateral gravity anomalies are linked to abnormal rock density distributions. Semliki shows a more negative variation, ranging from -221.3 to -111.3 mGals on the Bouguer gravity anomaly map.The gravity lows range from -205.8 to -221.3 mGals and are located in the northern part of the Semliki Basin. Low-density rocks, or sediments with potential hydrocarbon accumulations or entrapments, are represented by low gravity anomaly readings. The blue colors on the gravity anomaly image indicate that the thick sedimentary depocenter is located in the northern portion of the Semliki basin. It is evident from this distribution that the northern part of the Semliki Basin remains a desirable area for additional hydrocarbon exploration.

High anomalies (red colours) are related to rocks of high density, preferably igneous or metamorphic terrains. However, these high anomalies observed in the Bouguer gravity map of Semliki may not necessarily be igneous/metamorphic rocks as it used to be in theory, since the anomalies are more negative it implies sedimentary deposits containing magnetic minerals such as magnetite/hematite. The high gravity values are found in the southern region of the Semliki Basin and range from -111.3 to -203.0 mGals. This suggests that while the southern region has the highest elevation, the thickness of collected sediments is the lowest.

6.1.2 Magnetic field survey

This method is used to determine how magnetized rocks are distributed beneath the Earth's surface, based on their magnetic properties—specifically, magnetic susceptibility and remanence. These properties cause small variations in the strength and direction of the Earth's magnetic field, also known as the geomagnetic field.

A magnetic anomaly refers to a localized change in the Earth's magnetic field caused by differences in the chemical composition or magnetic characteristics of underground rocks. When a ferrous (iron-containing) material is placed in the Earth's magnetic field, it becomes magnetized, creating an induced magnetic field. This induced field combines with the natural geomagnetic field at that location, resulting in a magnetic anomaly. The detectability of this anomaly depends on the quantity of magnetic material present and its distance from the magnetic sensor. These anomalies are usually displayed as color contour maps.

The degree of magnetization is calculated as the product of a rock's magnetic susceptibility (k) and the strength of the surrounding magnetic field (H). Magnetic susceptibility indicates how much magnetite a rock contains. Sedimentary rocks typically have very low susceptibilities, which is why this method is particularly useful for mapping the underlying basement rock.

Rocks such as basic igneous and metamorphic types, iron ores, and banded iron formations produce strong magnetic anomalies. In contrast, acid gneisses and some metamorphic rocks give intermediate readings, while sedimentary rocks produce the weakest signals.

The goal of a magnetic survey is to map variations in the geomagnetic field across a specific area and use this data to infer the shape, depth, and magnetic properties of subsurface rock structures. This method is more costly but generally more effective than gravity surveys in the context of petroleum exploration

Results of Magnetic data interpretation of the Semliki basin

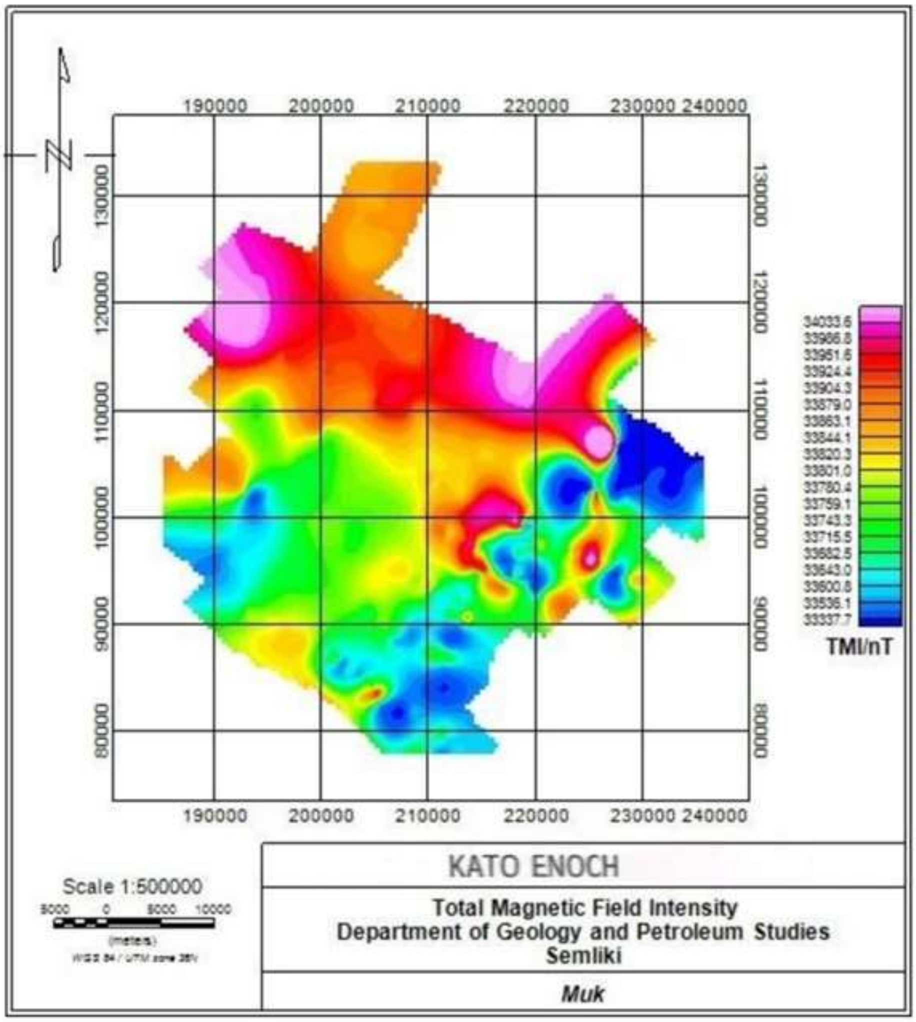

FIGURE 50:TOTAL MAGNETIC FIELD INTENSITY OF THE SEMLIKI BASIN

6.1.2.2. Interpretation

On the above map, areas with high magnetic field intensity signatures are indicated by colors from pink to yellow, and colors from green to blue indicate areas with lower magnetic field intensity signatures. The total magnetic field intensity values range from 33337.7 nT to 34033.6 nT. Higher values of magnetic field intensity are observed in the Northern part of the Semliki basin especially in the NW and NE parts; this is indicative of sediments with highly magnetic materials such as magnetite and hematite, which could have been eroded from the basement rocks that were overlying the flanks of the rift valley and the Rwenzori mountains. Smaller portions of high magnetic intensity are also observed in the southern region and this could be due igneous intrusions which contain magnetic minerals. The lower values of magnetic field intensity observed in the South could be due to demagnetized basement rocks found in the Semliki basin.

6.2 Seismic surveys

Seismic methods offer a more detailed view of the subsurface compared to other geophysical techniques. The fundamental concept involves generating a seismic pulse from a source located at or near the Earth's surface—commonly using a vibroseis truck or explosives in land-based surveys. The returning seismic waves, which are reflected or refracted at the boundaries between different subsurface layers, are then recorded.

As the seismic pulse travels through sedimentary layers, the sound waves move at varying velocities depending on the properties of each layer. These returning signals are detected using geophones in land surveys or hydrophones in marine surveys. The recorded data, which includes wave amplitudes and travel times, is subsequently analyzed to interpret the structure and composition of subsurface formations.

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

For the images refer to the attached pages in this chapter showing the random lines from the seismic shots were taken, seismic line D1, S1,S2,S3,S4,S5,S6 and S7.

In the Semliki Basin, seismic data was collected in 1998. Analysis of this data revealed that the Makondo Fault trends in a northeast-southwest (NE-SW) direction. The fault's hanging wall is folded and displays a positive flower structure, which is indicative of strike-slip faulting.

The seismic sections presented above provide high-quality imaging of the Semliki Basin, as both geological horizons and structural features are clearly distinguishable. Interpretation of the data indicates that the basin has undergone significant faulting, evident from the lateral displacement of stratigraphic layers. Faults are highlighted using orange, red, and grey lines in the sections.

The observed fault patterns suggest a tectonic regime characterized by upward-diverging faults, forming a positive flower structure. Detailed examination of these structures reveals that the region enclosed by the bounding faults contains anticlines, implying formation under transpressional tectonic forces. Most of the faults observed are normal faults, with some reverse faults also present. The overall flower structure is associated with concave-up or planar reverse faulting, which contributes to reservoir compartmentalization—a feature reported in several reservoirs within the Albertine Graben.

Transverse anticlinal structures appear to be associated with accommodation zones between the major boundary faults. These zones are long-lived, critically stressed areas where fluid pathways are more likely to remain open due to the presence of closely spaced fractures dominated by fault breccias. Accommodation zones typically occur at fault intersections and are made up of belts of interlocking, oppositely dipping normal faults. These intersecting faults can serve as favorable locations for hydrocarbon accumulation.

Rollover structures, which are antiforms developed within the downthrown blocks of growth faults, also provide effective traps for hydrocarbons. Transverse anticlines play a significant role in influencing the distribution of oil and gas accumulations. They affect the deposition of reservoirs and source rocks, control hydrocarbon migration, and can act as both stratigraphic and structural traps. As such, they offer strong potential for the closure and concentration of hydrocarbons.

6.2.2 Interpretation of Random line 1

The seismic sections clearly show both sedimentary layers and the underlying basement, with a distinct contact between the two lithologies. Interpretation of the data reveals that the Semliki Basin has undergone significant faulting, with faults marked in green and purple on the seismic sections. These faults are identified as strike-slip faults, which occur when rock masses slide past one another parallel to the fault plane. In this case, the fault system diverges upward, forming a positive flower structure.

A closer look at these structures shows that the bounding faults of the flower formations create segments that form anticlines. This suggests that transpressional tectonic forces—where both compression and lateral movement are involved—played a key role in their development. The relative movement between the footwall and hanging wall blocks further supports the interpretation of these as strike-slip faults.

Between the major boundary faults lies an accommodation zone, which is associated with the transverse anticlinal structures. These zones are long-lived, highly stressed regions characterized by networks of closely spaced fractures dominated by fault breccias. Such zones often maintain open pathways for fluid flow and are typically located at the intersections of belts of oppositely dipping, interlocking normal faults. These complex fault intersections make accommodation zones favorable sites for hydrocarbon accumulation.

Seismic interpretation also indicates the presence of a small graben—a down-dropped block—between the two major faults shown in the previous figure, further highlighting the structural complexity of the area

6.2.3 Results of seismic study and interpretation of facies/lithology for the Gulf of Mexico.

High-resolution seismic data (150–200 Hz), with a vertical resolution of approximately 3 meters, was used from an intra-slope salt-withdrawal mini-basin located in the Gulf of Mexico. This dataset served as an excellent example for studying seismic facies and depositional elements typical of many deep-water depositional systems.

The primary objective of this exercise was to provide hands-on experience in manually mapping key stratigraphic surfaces across a grid of seismic lines. This process highlighted the inherent uncertainties and challenges that can arise during seismic interpretation. The dataset was part of a training exercise originally developed by ExxonMobil and consists of eight 2D seismic lines. Line D1 serves as a strike line and ties into seven dip lines (S1 through S7), accompanied by a base map showing the layout of the seismic grid.

The interpretation procedure began by identifying and marking reflection terminations—such as truncations, onlaps, and downlaps—on Line D1. The process started with strike line S6, where these reflection terminations were used to trace and extend surfaces across seismic line D1. Through this method, major sequence boundaries were identified and mapped.

Two distinct seismic facies were recognized, and their key characteristics were documented. These facies were lightly color-coded on the seismic sections using purple and red. A facies analysis was then performed, focusing on seismic attributes such as reflection geometry and continuity, which were described and interpreted accordingly.

Features identified on Line D1 were then correlated back to Line S6. This same process was subsequently repeated for the remaining dip lines: S1, S2, S3, S4, S5, and S7

6.2.4 Interpreted seismic line S6 for the Gulf of Mexico

Seismic line 6 has five sequence boundaries, with the top most erosional and the rest gradational. From this section, it is observed that the stratal terminations on this section consist of onlap, concordant, truncation and an unconformity on which the seismic facies are onlapping. Two facies types are observed that is to say that facies A (purple) and facies B (red), deposited in a cyclic pattern above the unconformity, which both show closely spaced reflections and are probably sediments. These were differentiated basing on the characteristics of their internal reflections.

Facies A: reflections are more parallel and continuous teminating (onlapping) on an erosional surface (unconformity). This implies uniform rate of deposition on a uniformly subsiding surface. These facies are bounded by only conformable/gradational surfaces both at the bottom and top.

Facies B: This is characterized by chaotic reflections that also terminate (onlap) on an erosional surface (unconformity). This infers a relatively high energy and variability of deposition or disruption of beds after deposition. These facies are also bounded by conformable surfaces except the basal facies overlying the unconformity which is bounded by an erosional surface at the bottom and a gradational surface at the top.

Below the unconformity, the reflections are consistent and largely spaced, compared to those above. These probably indicate basement rocks (metamorphic or igneous). The unconformity is an angular unconformity. A river channel is also observed towards the extreme right of the section. The depth of the river channel has also increased compared to that of the other seismic lines 1 to 7 implying that in this region, the river does more erosion and transportation than deposition due to the V-shape of the channel. Seismic lines S1, S2, S3, S4, S5 and S7 are indicated in the pages attached respectively.

6.2.5 Geometric Observations

Seismic Line S1 reveals only two distinct seismic facies. Facies B, highlighted in red, displays some chaotic reflection patterns (refer to the figure of seismic Line S1), which are likely indicative of fluvial channel deposits formed near the mouth of a river entering the basin.

Progressing through seismic Lines S2 to S7, the basin becomes wider and deeper. This is reflected by an increase in both the number (cyclicity) and thickness of facies. The greatest basin depth is observed in seismic Line S7, suggesting that the overall geometry of the deposits is roughly cone-shaped.

By integrating the geometric data with seismic attributes, it can be interpreted that these sediments were deposited in a fluvial system, specifically within a fluvial fan depositional environment.

Additionally, the basin-fill sediments appear to have been incised by later river channels, likely during a phase of sea-level regression. This erosional activity resulted in the truncation of previously deposited strata and eventually formed abandoned river channels.

6.3 Petrophysics for formation evaluation.

Petrophysics is a branch of geoscience concerned with the study of the physical and chemical properties of rocks and their interactions with fluids, particularly within the context of hydrocarbon exploration and reservoir evaluation. It involves the analysis of key rock properties such as lithology, porosity, water saturation, permeability, and density, which are essential for understanding reservoir quality and predicting fluid flow (Tiab & Donaldson, 2015).

Results of wireline logging study for Turaco Sells

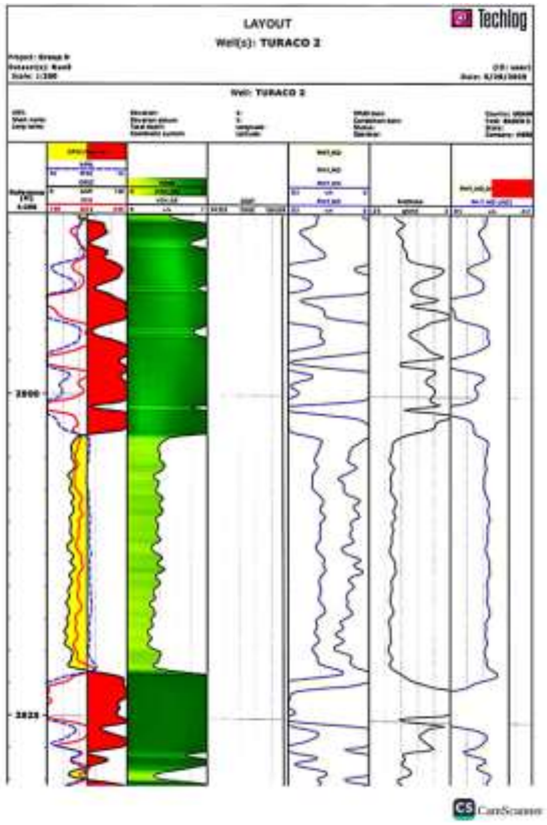

FIGURE 51:SHOWING A WIRELINE LOG FOR RUN 3 TURACO 2

In the Turaco-2 well, wireline logging was carried out using gamma ray, density, and neutron tools. The gamma ray log detects natural radioactivity in rocks and is primarily used to identify shale content, correlate formations, and mark reservoir boundaries. The density log records the bulk density of rocks, playing a key role in porosity estimation. Meanwhile, the neutron log, which responds to hydrogen atom concentration, is also used to assess porosity. Analysis of both the mud logs and wire line logs from Turaco-2 indicates that the well penetrated a sequence of alternating clay stone and sandstone layers. These subsurface formations align with those observed during surface geological mapping. The alternating sand and clay layers point to a depositional environment influenced by both fluvial delta systems and lacustrine (lake) settings.

The data obtained from the Turaco-2 logs—including gamma ray, density, temperature, and neutron porosity—were processed and analyzed using *Techlog 64 version 2014.3.0*.

Neutron/ Density Porosity Logs

These logs are shown in track 3. The Neutron porosity log (blue line) is used to measure hydrogen concentration a formation while the density porosity log (red line) measures the electron density of a formation. If the density porosity log (red) is to the right, then it is a shale. If they cross-over and the red line is to the left and the blue is to the right, this indicates that it is a gas-filled sand.

Low readings of the neutron porosity log readings indicate the presence of gas since it has low concentration of hydrogen as compared to oil/water. This implies that the density log will give a high reading when gas is present. Therefore, a wide separation of the two logs on the wireline log shows presence of gas.

When the neutron (blue) and density (red) porosity logs are tracking each other pretty much, it indicates that there is either a wet sand or an oil sand.

. From the general log, it can be observed that Turaco well 2 has more gas than oil/water. This is not very economical for a company whose major interest is oil. These logs can be used to calculate porosity where;

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

Where Φ is the porosity, $\rho\ (matrix)$ is the density of the matrix (g/cc), $\rho\ (density\ log)$ is the corresponding density read from the density log (g/cc) and $\rho\ (fluid)$ is the density of the fluids (g/cc). Average Porosities obtained for Turaco-2 well include 31%, 21%, 36%, 26%, 22%. These are very good porosities implying that the reservoirs with in this area are good.

V-Shale Log

This is shown in track 2 and 4 (Dark green Section). This log can be used to calculate the amount of shale in a formation. From the log (figure 6.4), Low volumes of Vshale show that the formation at that point has low shale content and thus porous. This means that hydrocarbons are present especially oil/water. The volume of shale can be calculated using a gamma ray log as shown below;

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

Where GR_{log} is the reading of the gamma ray log, GR_{min} is clean sand and GR_{max} is Shale.

Gamma ray Log.

High gamma ray readings are indicative of Shales since shales contain a number of radioactive minerals whereas low gamma readings are indicative of Sands, Presence of a reservoir is shown as a negative reading also known as mud cakes that form due to the interaction of the reservoir fluids and drilling fluids.

From the General log, it can be seen that the Turaco well was mostly Shaly due to the high gamma readings probably as result of encountering the Kasande, Oluka to Nyakabingo formations that are mostly intercalations of Sand and shales.

Evaluation and analysis of well log for Turaco-2 well shows that the sand/shale association reflect interaction of sandy fluvio-deltaic and muddy lacustrine systems.

Results from the field visit to Turaco drilling site.

At Turaco well site, (0199699, 0114178), elevation of 637 m which is the hanging wall of Makondo fault, the history of different wells drilled was discussed by the supervisors. Revision of previous drilling history indicted that the Turaco-1 well, drilled in 2002 up to a depth of 2487m encountered hydrocarbon shows but were not in commercial quantities while Turaco-2 well drilled in 2003/2004 10m away from Turaco-1 as a side track well to a depth of 2963m had significant hydrocarbon shows. The three dimensional (3D) seismic surveys in the area in 2004 led to drilling of Turaco-3 well 100 m from Turaco-1, to a depth of 2980m and encountered some natural gas with 90% carbon dioxide. The well was plugged and abandoned. Turaco area still stands as an important hydrocarbon prospect within the Semliki Basin if exploration is heightened in future.

Results from the field visit to Makondo fault.

At Makondo (0201071, 0110308), at an elevation of 682m within the Semliki game reserve, relevant information regarding subsurface data, geophysical data, aeromagnetic and gravity surveys carried out in the area were availed to the students by our supervisors. Different Geophysical data which include airborne surveys were obtained in around 1983 by Kenting earth sciences, which were followed by gravity data surveys from which data, the Makondo fault was identified. Seismic data was later obtained in 1998 in the same area and using this data, the strike of the Makondo fault was found to be in the NE-SW direction. The hanging wall of the Makondo fault is folded and has a positive flower structures. The basin consists of fossils of animals such as fish, bivalves, white oysters and mammals' bones and hematite minerals.

Results from the study of geophysical methods for geothermal exploration.

A geothermal field refers to a region of the Earth's surface where there is unusually high heat flow. Geothermal energy, on the other hand, is the heat stored and produced within the Earth. This energy originates both from the planet's initial formation and the ongoing radioactive decay of materials—likely contributing in roughly equal measure, though the exact proportions remain uncertain.

The East African Rift System is geologically young and represents an early-stage basin. Due to its elevated geothermal gradient, source rocks in the area may reach maturation faster than under typical conditions. This thermal energy is crucial for the early development of source rocks.

In the Albertine Graben, there is notable geothermal potential, opening up the possibility for electricity generation. For a region to be viable for geothermal energy, several key components must be present:

1. **Heat Source**: This includes rocks or magma capable of releasing significant heat. In rift zones like this, the crust is thinner, so the mantle—and its heat—is closer to the surface. Magma beneath the Earth's surface and heat-producing rocks such as granites, containing radioactive elements, serve as major sources of geothermal heat.
2. **Rising Fluid**: Groundwater plays a critical role as it gets heated by underlying magma. Once warmed, the water becomes less dense and more buoyant, allowing it to rise toward the surface through fractures or porous rock. Heated water also flows more easily due to its lower viscosity.
3. **Reservoir Rock**: This is the porous or fractured rock formation that stores the heated fluid and allows it to move. It must have good permeability and porosity to function effectively.
4. **Cap Rock or Seal**: To trap heat and fluid, a cap rock must be present. This is typically a low-permeability rock that acts as a barrier, preventing the upward escape of heat and fluids. Ideal seal rocks are poor conductors of heat, helping to maintain high temperatures within the geothermal reservoir.

6.4 Field Visit to Sempaya Hot Springs (Buranga geothermal field)

A hot spring is an area where the temperature of water is significantly above the mean annual air temperature of the region. Sempaya hot springs are located in Semliki National park in Sempaya, Bundibugyo district, western Uganda. Semiliki national park is one of the 10 national parks in Uganda lies within the Albertine graben and is approximately $220km^2$. It is bordered by D.R Congo to the west, Rwenzori mountains to the SE, Lake Albert and Semliki flats to the North. Sempaya hot springs boil at very high temperatures of up to 95-99 ^{o}C and are found in two swampy areas enclosed by the dense rain forest; the male and the female hot springs. The hot water gushed out is based on the rain water which percolates into the porous sedimentary rocks. It descends through the rock dissolving a variety of materials, from radium to sulphur. As this water and groundwater moves further beneath the surface, it heats up from the primal heat of the earth, the mantle which is closer to the surface than in other areas. When it encounters a weak zone such as a fault or crack, it then ascends along it to surface as a hot or warm spring. The female hot springs consist of a series of steamy water jetting out of the subsurface with a strong pungent smell of hydrogen sulphide (H_2S) gas, carbon dioxide gas, carbonates and other salt. Average water temperature is 98.4°C. The male hot springs on the other hand are a pool of steamy hot water with a strong pungent smell of sulphur. The recorded temperatures were as high as 106°C and 103°C for the male and female hot springs respectively and thus are thought to contribute to the geothermal gradients that have accelerated the thermal maturation of source rocks in the Albertine Graben as one of the youngest rift basins in the world. However, a suitable oil window is defined by the temperature range of 60-120°C but since the hot springs temperatures are higher than the oil window, then there are greater chances of ―overcooking‖ or cracking the oil to form thermogenic gases like methane.

Higher temperatures of about 150°C to 200°C result in almost total transformation of kerogen into carbon. At these temperatures, late methane or dry gas is evolved along with non- hydrocarbon gases such as CO2, N_2 and H_2S. The active fault system associated with the seismic activity in the Graben could provide fractures/faults which act as the migration pathways or conduits for hydrocarbons from source rock to reservoir.


Importance of hot springs

- *Maturation of hydrocarbon source rocks*. This can be effected due to the high geothermal gradient which increases with depth (29-31^{0}C per km in Semliki basin). But, to accumulate enough heat for maturation of hydrocarbons, low conductivity rocks are needed. Therefore, geothermal gradient depends on depth and rock type. Hydrocarbons, however, can be degraded when a high temperature gradient lasts for a long time.
- *Geothermal energy*. The tremendous amount of heat released by hot springs is a source of geothermal energy. For this case, Sempaya hot springs power the Buranga geothermal field.
- *Hydrothermal mineral deposits*. Here, hot water serves as a concentrating, transporting, and depositing agent for hydrothermal minerals such as travertine and sulphides.
- *Geo-medicine.* Traditionally, hot springs are believed to cure certain diseases.
- *Tourism*. Hot springs are used to attract tourists thus source of (foreign) income.

Impact of Sempaya Hot springs on Petroleum potential of Albertine Graben

The Albertine Graben, approximately 15 million years old, is a geologically young rift basin located in the western arm of the East African Rift System (EARS). Despite its youth, it exhibits significant geothermal activity, notably the Sempaya Hot Springs, where temperatures reach up to 106°C and 103°C for the male and female springs, respectively .

This high heat flow contributes to elevated geothermal gradients, which are crucial for the thermal maturation of source rocks. In the Albertine Graben, geothermal gradients are estimated between 35°C/km and 67°C/km . Such gradients can accelerate the maturation of organic matter, potentially leading to hydrocarbon generation.

However, the temperatures observed in the Sempaya Hot Springs exceed the upper limit of the conventional oil window, which is defined by temperatures between 60°C and 120°C. Temperatures above this range increase the risk of "overcooking" the oil, leading to its cracking into lighter hydrocarbons and thermogenic gases such as methane. At temperatures ranging from 150°C to 200°C, kerogen undergoes almost complete transformation into carbon, releasing late methane or dry gas along with non-hydrocarbon gases like CO_2, N_2, and H_2S .

Despite these challenges, the Albertine Graben has demonstrated the presence of a working petroleum system. Exploration activities have confirmed the existence of hydrocarbons, indicating that the geothermal conditions, although intense, have not precluded the formation and preservation of oil and gas reserves

CHAPTER 7: DISCUSSION

7.1 Introduction

The main objective of this field research was to gain hands-on experience in acquiring and analyzing stratigraphic, petrographic, sedimentological, and structural data key components in the exploration and assessment of hydrocarbon resources. Chapter 2 detailed the methods and tools utilized during the study to achieve these goals and other related aims.

This chapter presents the findings gathered during the fieldwork. It includes observations on facies types and depositional environments, outlines the geological evolution of the Semliki Basin, evaluates the petroleum system elements and hydrocarbon potential, and explores how elevated temperatures—evidenced by the presence of hot springs—may have influenced existing hydrocarbons in the area. Additionally, it examines how structural features, both in the basement rocks and overlying sediments, affect hydrocarbon distribution and behavior.

A comprehensive understanding of the rock formations and sedimentary layers within the Semliki Basin was achieved through the integration of stratigraphic studies, structural interpretation, basin modeling, and facies analysis. This approach allowed for the reconstruction of the basin's geological history, including depositional processes and settings, the definition of its structural configuration, and an informed assessment of its petroleum prospects.

7.2 Geological history of Semliki basin

The Semliki Basin is located within the Albert Rift, a segment of the larger East African Rift System, which formed as a result of intense tectonic activity. This tectonic origin is evidenced by the presence of highly fractured and faulted rocks, deformed sediments within the basin, and elevated thermal gradients—highlighted by the occurrence of hot springs—indicating ongoing tectonic processes in the region.

Tectonic forces caused the uplift and subsidence of crustal blocks, leading to the creation of a structural depression known as the Semliki Basin. This depression provided space for sediment accumulation as rivers drained into it, transporting and depositing materials over time.

The sediments within the Semliki Basin are believed to have originated primarily from surrounding highland areas, including the Rwenzori Mountains and bordering escarpments. These regions are composed of ancient basement rocks—mainly high-grade metamorphic and igneous rocks dating back to the Precambrian. The mineral composition and coloration of the sediments suggest this as their likely source.

It is also thought that Lake Obweruka (modern-day Lake Albert) may have served as a secondary source of sediments, which were transported by fluvial systems into the basin. The deposited materials consist of a variety of sediment types, including sands, clays, silts, and conglomerates. These sediment layers rest atop the older basement complex, with a distinct basal conglomerate marking the transition between the two

7.3 Facies and depositional environments

The facies recognized in the field were grouped into three major associations namely; lithofacies based on lithology, biofacies based on fossils content and ichnofacies based on trace fossils of animals. Trace fossils have been interpreted to give vital clues on the depositional environment, because particular trace fossil occurrences or suites of trace fossils are characteristic of a particular environment, and often the specific depth range. Four lithofacies were identified indicating different depositional environments and these were divided into Lithofacies 1, 2, 3, 4, and 5. Lithofacies 1 is poorly sorted and coarse-grained sediments consisting cobble/pebble-size ranging from 5-35mm cemented together with fine to coarse grained sands and formed the contact between the basement and sediments. Lithofacies 2 is a massive reddish brown, coarse to medium quartz sands. Lithofacies 3 is grey, dark brown and army green clays with medium quartz sands and plant debris. Lithofacies 4 is grey to white silt, though some exhibited a yellow colour as a result of presence of iron oxides.

Fluvial environments: Fluvial environments were characterized mainly by thick sand beds with coarse to medium to fine grains and a generally fining upwards sequence. The fining up sequence is because the river deposits coarse materials during periods of high energy and the grainsize reduces with progressive reduction in river energy. Structures like cross beds are an indicator of a fluvial system (Chapter 4). The fluvial sediments could have been deposited by a meandering river, also, alluvial fan, inter-channel, flood plain and over bank deposits exist in the study area. The change of dip direction (SE to NW) bedding structures in some areas suggests the river must have changed course at some point in time due to tectonism.

Lacustrine Environments: Lacustrine sediments are widespread throughout the Semliki Basin and are dominated by clay stones, siltstones. In the study area, lacustrine environment is evidenced by presence of thick layers of clays and blocky sands that lack sedimentary structures as observed along Kibuku road cut especially in the Kasande and Kisegi formations. The lacustrine environment has been deduced at the Kibuku road cut due to presences of clayey facies and system tracts as well as fish bones, oyster and bivalve shells in paleo- lake sediments at the Makondo area (0201154, 0110008 elevation 692m).

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

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

7.4 Petroleum Potential

7.4.1 Petroleum Prospectivity of the Semliki Basin

The Semliki Basin, part of the larger Albertine Graben, holds strong potential for hydrocarbon accumulation, as all essential components of a petroleum system were identified during fieldwork. As Rubondo (2001) noted, the Albertine Graben features favorable geological conditions for oil, including high-quality source and reservoir rocks, effective seals, and well-formed traps. The basin is widely recognized as one of Uganda's most promising regions for petroleum exploration.

For hydrocarbons to accumulate and be preserved in any geologic setting, several conditions must be met: accumulation and preservation of organic material, thermal maturation under anoxic conditions, migration of hydrocarbons, and their entrapment within suitable geological structures (Allen & Allen, 1990). These fundamental elements of a functioning petroleum system have been observed and studied extensively in the Semliki Basin.

7.4.2 Key Elements of the Petroleum System in the Semliki Basin

1.Source Rocks

Extensive deposits of lacustrine clay in the study area are believed to contain rich organic matter, making them potential source rocks. Given sufficient burial depth and elevated temperatures, these clays could generate hydrocarbons over time.

2. Reservoir Rocks

Reservoirs in the Semliki Basin fall into two categories: conventional and unconventional.

Conventional reservoirs are mainly sandstones from the Kisegi and Kakara Formations. These are well-sorted, medium- to coarse-grained sandstones with good porosity and permeability—favorable properties for storing and transmitting oil or gas.

Unconventional reservoirs include fractured basement rocks, where secondary porosity is provided by jointing and faulting.

However, reservoir quality may be affected by the presence of cementing agents like gypsum and iron oxides, which can reduce pore space and hinder fluid flow. Additionally, inter-bedded sand and clay layers may cause reservoir compartmentalization, making extraction more complex and costly. Exploratory drilling in the Turaco wells confirmed the presence of hydrocarbons within Kisegi sands, reinforced by oil-impregnated outcrops visible at Kibuku seep.

3. Traps

Traps in the area include both structural and stratigraphic types.

Structural traps are largely fault-based, with some faults sealed by gypsum. Fault systems such as Kichwamba and Makondo serve as significant trapping structures. In particular, NE-trending faults observed along Kibuku road cut may act as effective hydrocarbon traps if sealed adequately.

Stratigraphic traps include pinch-outs and unconformities, which limit hydrocarbon migration and facilitate accumulation.

4. Seals

Seal integrity is crucial to trap hydrocarbons within the reservoir. In Semliki, the Kasande clay acts as an effective seal over the Kisegi Formation. Transgressive shale units also serve as competent seals above lowstand deposits. Overburden pressure following hydrocarbon expulsion helps close fractures within the Kasande Formation, enhancing its sealing potential. However, occurrences such as the Kibuku oil seep suggest that in some intervals, sealing is incomplete. Moreover, if hydrocarbon columns are high, they may exceed the seal's holding capacity, potentially breaching the trap.

5. Maturation

High thermal gradients in the Semliki Basin, indicated by nearby hot springs, create ideal conditions for organic matter maturation. If heat-retaining, low-conductivity rocks are present, these can help maintain elevated temperatures necessary for the transformation of kerogen into oil or gas.

6. Migration Pathways

The presence of numerous joints and faults provides clear migration routes for hydrocarbons. The Kasande Formation, a potential source rock, lies directly above the Kisegi reservoir. As hydrocarbons generate under pressure, they are expelled into fractures and move toward lower-pressure zones (primary migration). When this occurs, some hydrocarbons enter the Kisegi Formation. Over time, the fractures in the source rock close, enabling the Kasande clays to also act as an effective cap rock, sealing the reservoir below.

7.5 Effects of high temperatures on hydrocarbons

Despite being geologically young at approximately 15 million years old, the Albertine Graben hosts significant hydrocarbon accumulations. This can be attributed to its elevated heat flow, which is most prominently evidenced by the Sempaya hot springs. These springs, with recorded surface temperatures reaching 106°C and 103°C at the male and female springs respectively, reflect the high geothermal gradient that characterizes the region.

This elevated thermal regime plays a key role in the maturation of organic-rich source rocks. The geothermal gradient in the area is believed to be sufficiently high to accelerate the thermal breakdown of organic matter into hydrocarbons, a process that typically occurs within the "oil window"—a temperature range between 60°C and 120°C. Within this range, kerogen transforms into liquid hydrocarbons under ideal pressure and time conditions.

However, temperatures that exceed this range pose a risk of over-maturation or "overcooking" the organic material. When temperatures rise above 120°C, particularly reaching between 150°C and 200°C, the transformation of kerogen advances to a stage where it is almost entirely converted into carbon. During this phase, the generation of late methane or dry gas becomes dominant. Additionally, non-hydrocarbon gases such as carbon dioxide (CO_2), nitrogen (N_2), and hydrogen sulfide (H_2S) are commonly released as by-products of this high-temperature thermal cracking.

These thermal conditions have significant implications for the type of hydrocarbons present in the Albertine Graben. While liquid oil is possible in areas where the temperature remains within the oil window, regions experiencing higher heat flow are more likely to yield thermogenic gases rather than oil, influencing both exploration strategies and resource valuation in the basin.

7.6 Effects of rock structures on hydrocarbons

The Semliki Basin has experienced significant tectonic deformation, which has led to the development of a wide array of geological structures. In the underlying basement rocks, features such as faults, joints, and mineral veins are prevalent. Meanwhile, the overlying soft sedimentary layers exhibit sedimentary structures including bedding, cross-bedding, laminations, unconformities, mud diapirs, and plunging folds.

Among the most prominent structural elements in the basin are the Kichwamba and Bwamba faults. These major fault systems are accompanied by numerous smaller faults and joint sets. Collectively, these structures play a critical role in the migration and entrapment of hydrocarbons within the basin. Faults and fractures can serve as pathways for hydrocarbon migration, guiding fluids from source rocks toward potential reservoirs. When sealed by fault gouge or other impermeable materials, these same faults may function as structural traps, particularly when they position a porous reservoir rock adjacent to an impermeable seal.

However, not all structural features are favorable for petroleum production. Observations from the Kibuku area reveal that sealing materials within fractures can lead to reservoir compartmentalization. This condition, where the reservoir is divided into isolated sections that do not communicate, complicates fluid flow and makes production more technically challenging and costly.

Additionally, if faults and joints remain open or inadequately sealed, they may provide escape routes for hydrocarbons, leading to losses before they reach a trap. These features can also permit the downward or lateral percolation of water, which may result in water washing of the hydrocarbons—diluting or removing them. Moreover, infiltrating water may carry microbial life capable of degrading hydrocarbons over time.

In summary, the tectonic structures in the Semliki Basin significantly influence the petroleum system by affecting migration paths, trap formation, and reservoir integrity—each with implications for the viability and efficiency of hydrocarbon extraction.

CHAPTER 8: CONCLUSION AND RECOMMENDATIONS

8.1 CONCLUSION

The Semliki sedimentary basin is situated within the central part of the western arm of the Albertine Graben. It is classified as a pull-apart basin, formed as a result of the trans-tensional strike-slip deformation that occurred when the Albertine Graben, a product of active rifting, was subjected to strain. This deformation was influenced by pre-existing NE-SW trending normal faults that were part of the rift system. The basin itself is asymmetrical, with thinner sediment layers in the southern and southeastern parts, while sediment thickness increases towards the northwest, extending into the Democratic Republic of Congo (DRC).

The lithological composition of the basin can be divided into two categories: basement rocks and overlying sediments. The basement rocks are predominantly granite gneiss, with other types such as amphibolites, quartzites (mainly in the form of veins), and granites also present. The sediments in the Semliki basin, ranging from Middle Miocene to recent in age, are composed of clays, silts, sands, and conglomerates. These sediments are organized into seven stratigraphic units, listed from the bottom upwards as: Kisegi, Kasande, Kakara, Oluka, Nyaburogo, Nyakabingo, and Nyabusosi.

The basin exhibits both primary and secondary structures, particularly within the basement and sedimentary layers. Notable structures in the basement include joints, faults, foliations, and veins. Many of these features show a common NE-SW orientation, mirroring the structural alignment observed throughout the Albertine Graben. Some of these structural features, such as faults and joints, extend into the overlying sediments, where they are further reflected in sedimentary structures like bedding, laminations, and load casts. This alignment indicates that the structural trends observed in the sediments were likely influenced by the major tectonic events in the basement rocks.

The Semliki basin is considered to possess all the necessary components of an active petroleum system. The thick clay layers, potentially rich in organic material, serve as source rocks. The sands of the Kisegi and Kakara formations present prime reservoir targets, while the overlying clay layers and gypsum-filled faults act as effective seals. Furthermore, the basin contains a variety of structural traps (such as rollover structures, compressional anticlines, and tilted fault blocks) and stratigraphic traps (including unconformities and pinchouts). The extensive fault networks throughout the basin also provide pathways for hydrocarbon migration.

The provenance of the sediments in the Semliki basin is thought to be the basement rocks of the Rwenzori Mountains and the nearby escarpments. These sediments were likely transported by rivers and streams, accumulating in a variety of depositional environments, including fluvial, alluvial, and lacustrine settings. The deposition of these clastic sediments, ranging from massive sands and cross-bedded sandstones to conglomeratic sandstones and laminated siltstones, was largely influenced by tectonic processes such as faulting, rifting, and subsidence. Additionally, climatic fluctuations, which affected lake levels through transgressive and regressive phases, played a role in controlling the sedimentary processes.

8.2 RECOMMENDATIONS

The field study proved to be an invaluable experience for the students, offering significant insight into the Semliki basin and providing a practical understanding of field activities, such as Geologic and Stratigraphic Logging. However, there were some limitations that posed challenges, and these led to the following recommendations for future improvements:

- **Geophysical Data Acquisition**, during the field study, students were provided with geophysical data (seismic, gravity, and magnetic) for interpretation, but they were not involved in the actual acquisition of this data in the field. It would be beneficial for the department to include practical data collection in future field studies, allowing students to gain hands-on experience in acquiring geophysical data themselves.
- **Software Training**, students would benefit from prior exposure to software tools like Geosoft and Techlog, particularly in the context of interpreting field data. Offering training on these platforms before the field study would help students better understand the software's application during the field activities and improve their overall data interpretation skills.
- **Rig Site Visits**, to enhance learning, the fieldwork should include visits to operational rig sites. This would give students an opportunity to observe real-world rig setups and operations, bridging the gap between theoretical knowledge learned in class and the practical realities of drilling and exploration.

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APPENDICES

Appendix 1: Joint measurements in the basement rocks

STRIKE	DIP	STRIKE	DIP	STRIKE	DIP
N68°E	80°SE	N20°E	78°SE	S28°W	76°NW
N69°E	66SE	N46°E	68°SE	S48°W	68°NW
S50°W	64°SW	N30°W	78°NE	S30°W	68°NW
N24°E	34°SE	S04°E	84°SW	S60°E	80°SW
S30°W	68°NW	N56°E	90°SE	S62°E	60°SW
N78°W	40°NE	N10°E	60°SE	S22°E	50°SW
S70°W	42°NW	N32°E	76°SE	S44°E	52°SW
N86°W	74°NE	N62°E	86°SE	N72°W	36°NE
N30°W	10°NE	N74°E	38°SE	N26°E	26°SE
N20°W	38°NE	N58°E	88°SE	N26°E	78°SE
S86°W	52°NW	N86°E	86°SE	N46°E	78°SE
N14°W	38°NE	N10W	62NE	N09°E	74°SE
N80°W	48°NE	N78°W	40°NE	N14°E	74°SE
S70°W	20°NW	N72°E	88°SE	N10°E	72°SE
N88°W	40°NE	S10°E	46°SW	S68°W	50°NW
N04°E	62°SE	S18°E	54°SW	S34°W	80°NW
N88°W	21°NE	S66°W	66°NW	S24°W	78°NW
S88°W	46°NW	N42°W	44°NE	S16°W	82°NW
N08°E	68°SE	N70°W	60°NE	S32°W	82°NW
S66°E	87°SW	S36°E	64°SW	S20°W	76°NW
N76°W	76°SE	S26°E	52°SW	N21°W	84°NE
N76°W	62°NE	S60°E	86°SW	S26°W	74°NW
N58°W	62°NE	S32°W	82°NW	S19°E	68°SW
S50°E	82°SW	N34°W	76°NE	S40°E	84°SW
N36°W	78°NE	N36°W	74°NE	S80°E	50°SW
N38°W	74°NE	N42°W	88°NE	S62°E	60°SW
N22°W	66°NE	S58°E	82°SW	N32°E	78°SE
N80°E	82°SE	S32°W	90°NW	N20°E	86°SE
S42°W	84°NW	S42°E	80°SW	N36°E	68°SE
S10°W	80°NW	S68°W	50°NW	N44°W	84°NE
S60°W	78°NW	N45°W	62°NE	N58°W	78°NE
S42°E	72°SW	N10°E	65°SE	N64°E	78°SE
S44°E	80°SW	N14°E	74°SE	N68°E	78°SE
N12°W	74°NE	N25°E	84°SE	S60°W	68°NW
N44°W	84°NE	N22°E	88°SE	S28°W	70°NW

Appendix 2: Bedding plane measurements in the sediments

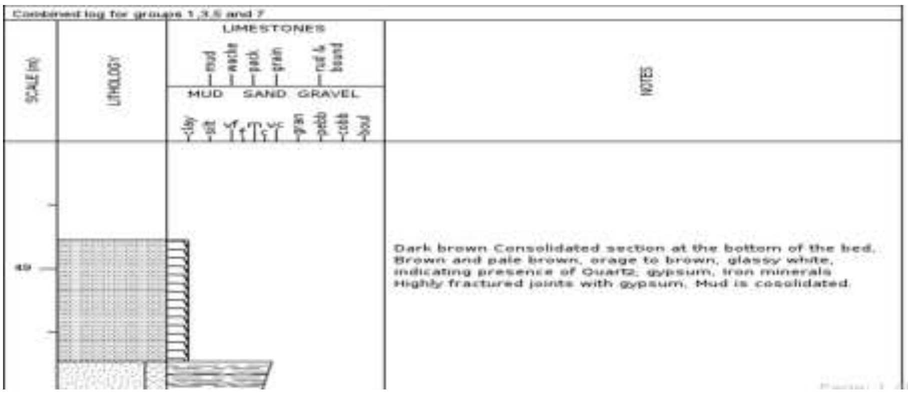
STRIKE	DIP	STRIKE	DIP
N12°W	14°NE	N14°W	36°NE
N88°E	20°SE	N34°E	12°SE

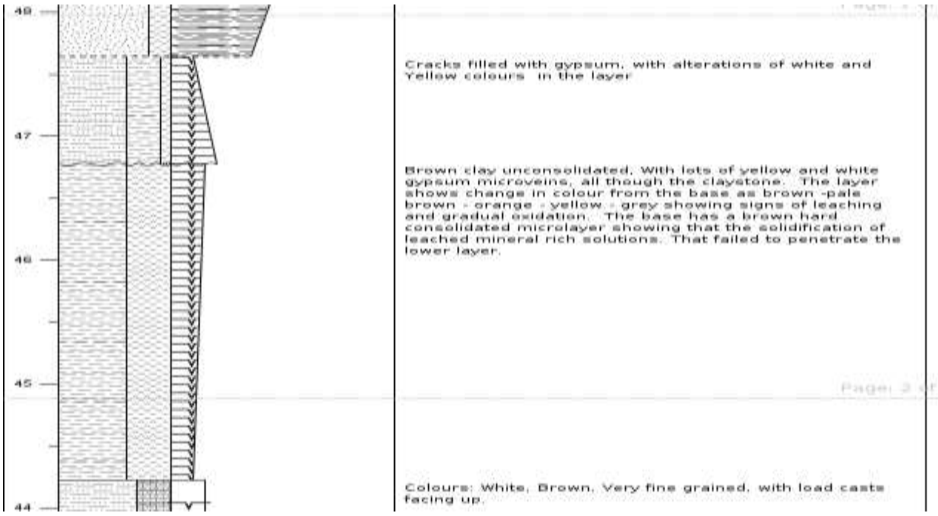
N80°E	10°SE	N20°E	28°SE
N86°E	12°SE	N14°E	14°SW
N68°E	10°SE	N12°W	8°NE
N32°E	6°SE	N26°W	18°NE
N10°E	32°SE	N30°W	2°NE
N80°E	18°SE	N36°W	14°NE
N68°E	8°SE	S18°W	6°NW
N32°E	12°SE	N38°E	8°SE
N28°E	12°SE	N40°E	10°SE
N32°E	8°SE	N44°W	

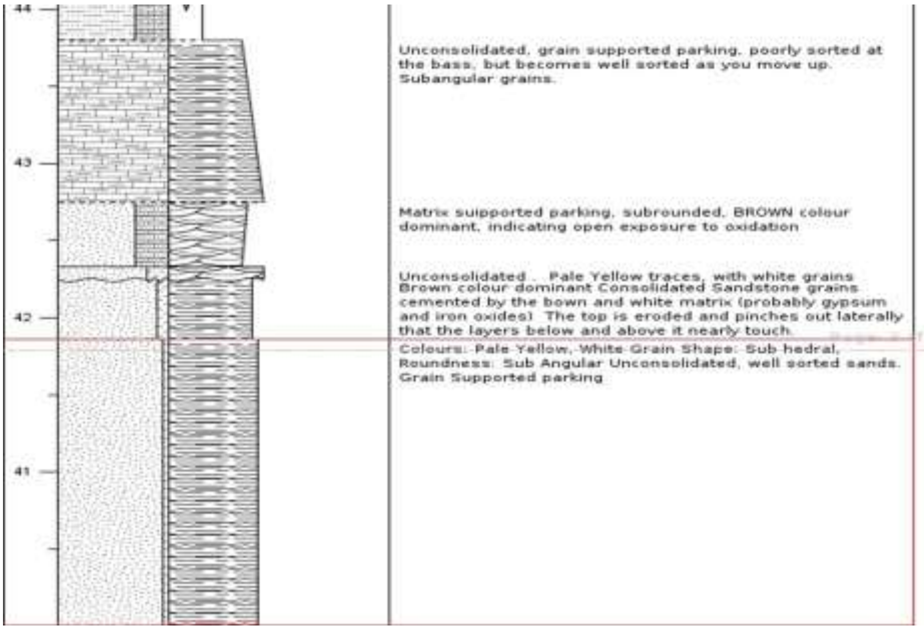
Appendix 3: Foliation surface measurements in the basement rock

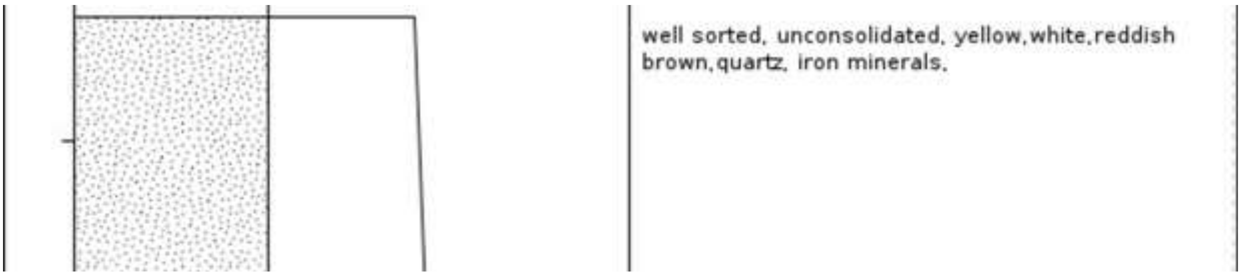
STRIKE (°)	STRIKE (°)
N50E	S50W
N28E	N64E
N22E	N70E
N58E	N66E
N48E	S85W
S66W	N81W
N64W	N36W
S84W	N24W
N88W	N86W
S82W	N70W
S72W	N56W
S86W	S82W
S60W	S48W
S82W	S18W

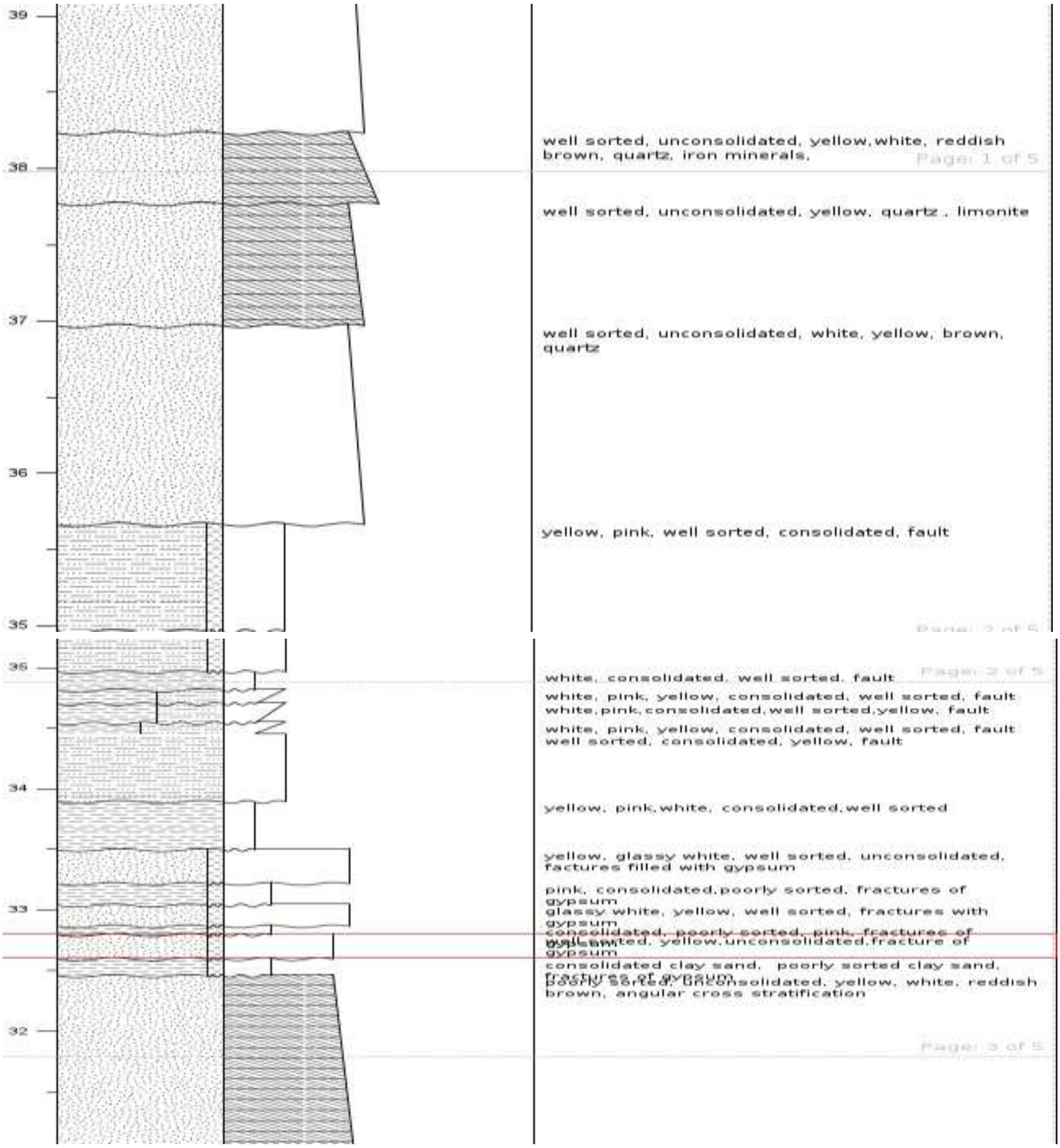
Appendix 4: Combined stratigraphic log

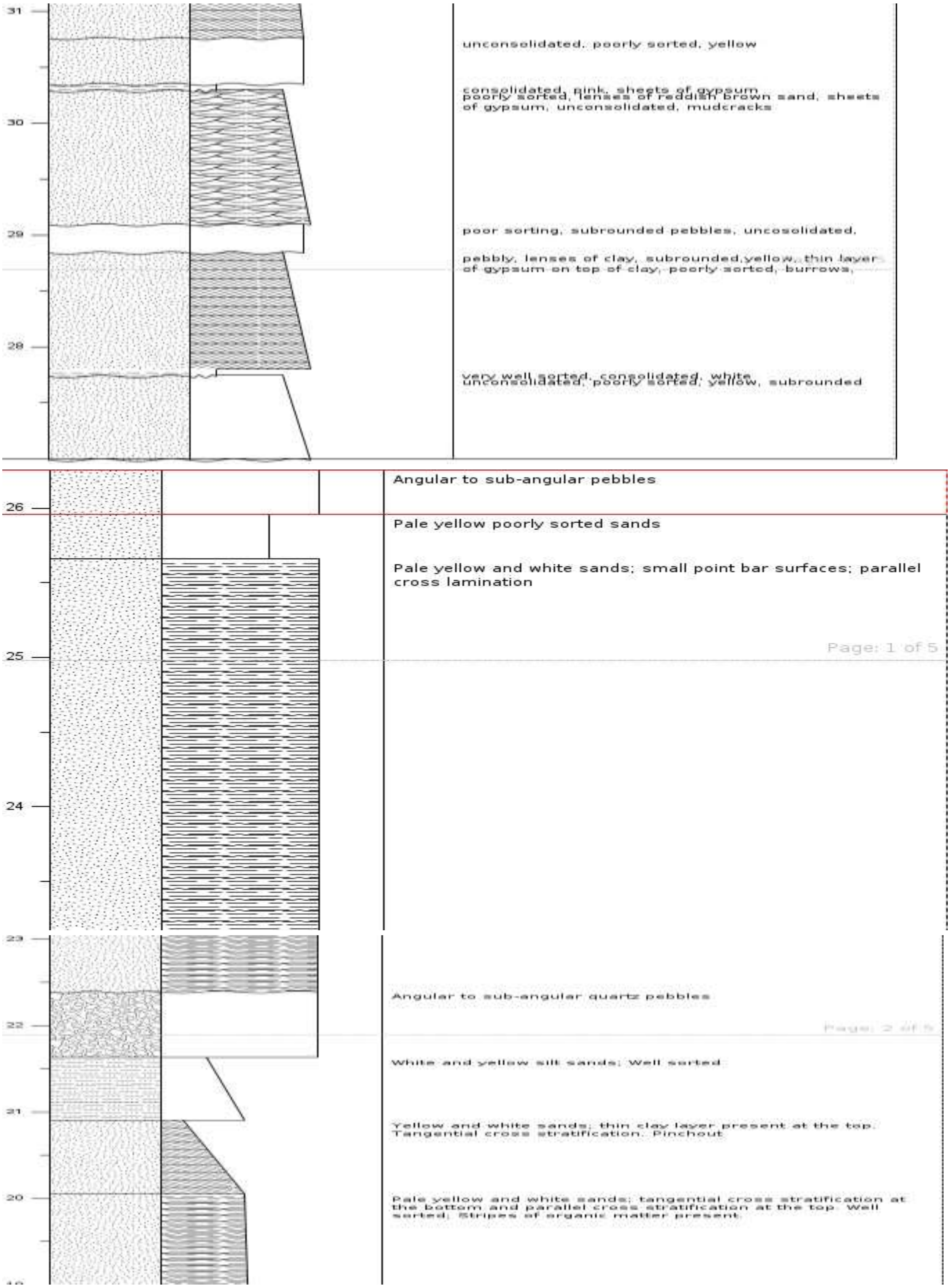



48
47
46
45
44
Cracks filled with gypsum, with alterations of white and Yellow colours in the layer
Brown clay unconsolidated, With lots of yellow and white gypsum microveins, all though the claystone. The layer shows change in colour from the base as brown -pale brown - orange - yellow - grey showing signs of leaching and gradual oxidation. The base has a brown hard consolidated microlayer showing that the solidification of leached mineral rich solutions. That failed to penetrate the lower layer.
Colours: White, Brown, Very fine grained, with load casts facing up.

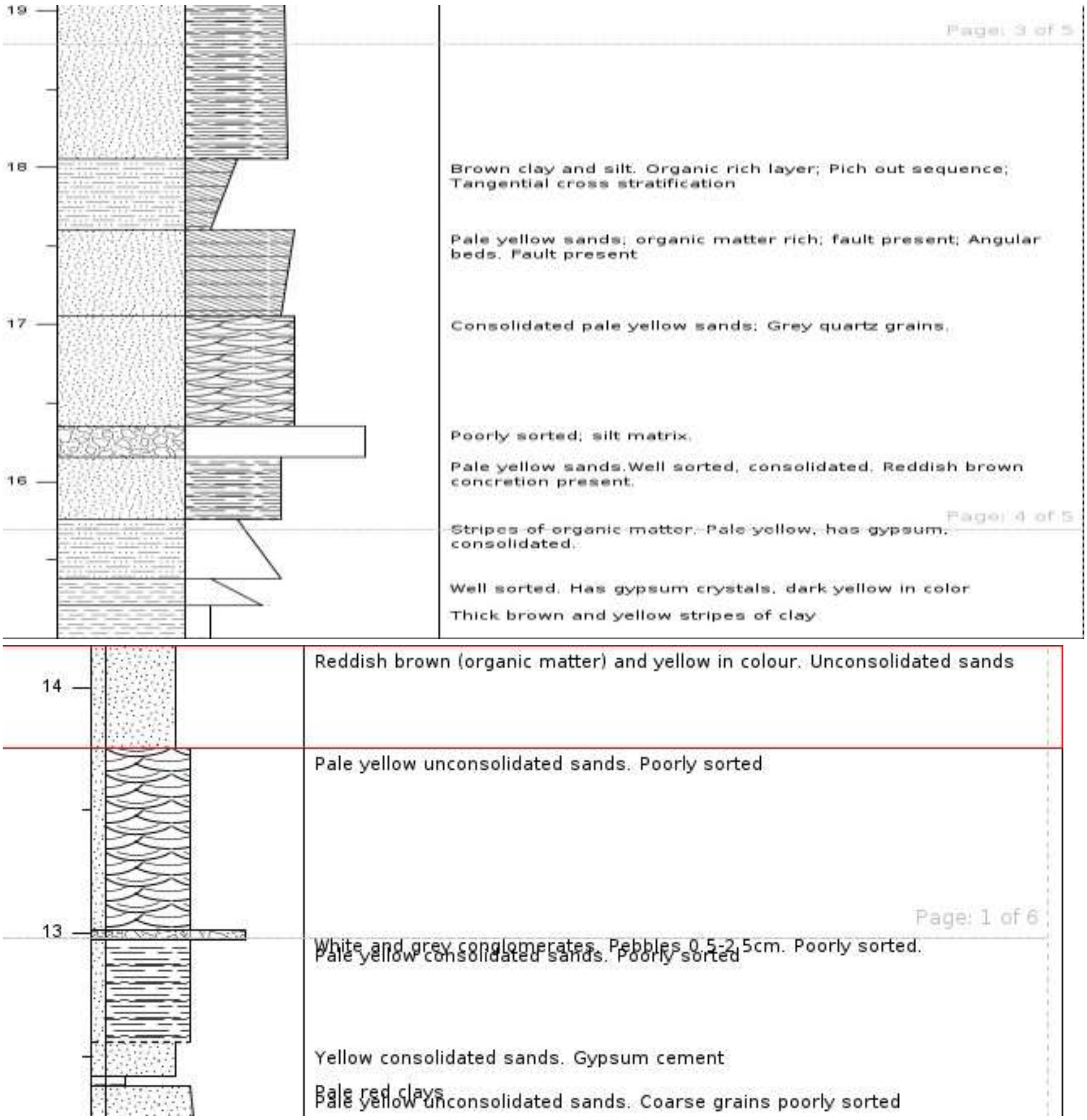

44
43
42
41
Unconsolidated, grain supported parking, poorly sorted at the bass, but becomes well sorted as you move up. Subangular grains.
Matrix suipported parking, subrounded, BROWN colour dominant, indicating open exposure to oxidation
Unconsolidated . Pale Yellow traces, with white grains
Brown colour dominant Consolidated Sandstone grains cemented by the bown and white matrix (probably gypsum and iron oxides) The top is eroded and pinches out laterally that the layers below and above it nearly touch.
Colours: Pale Yellow, White Grain Shape: Sub hedral, Roundness: Sub Angular Unconsolidated, well sorted sands. Grain Supported parking

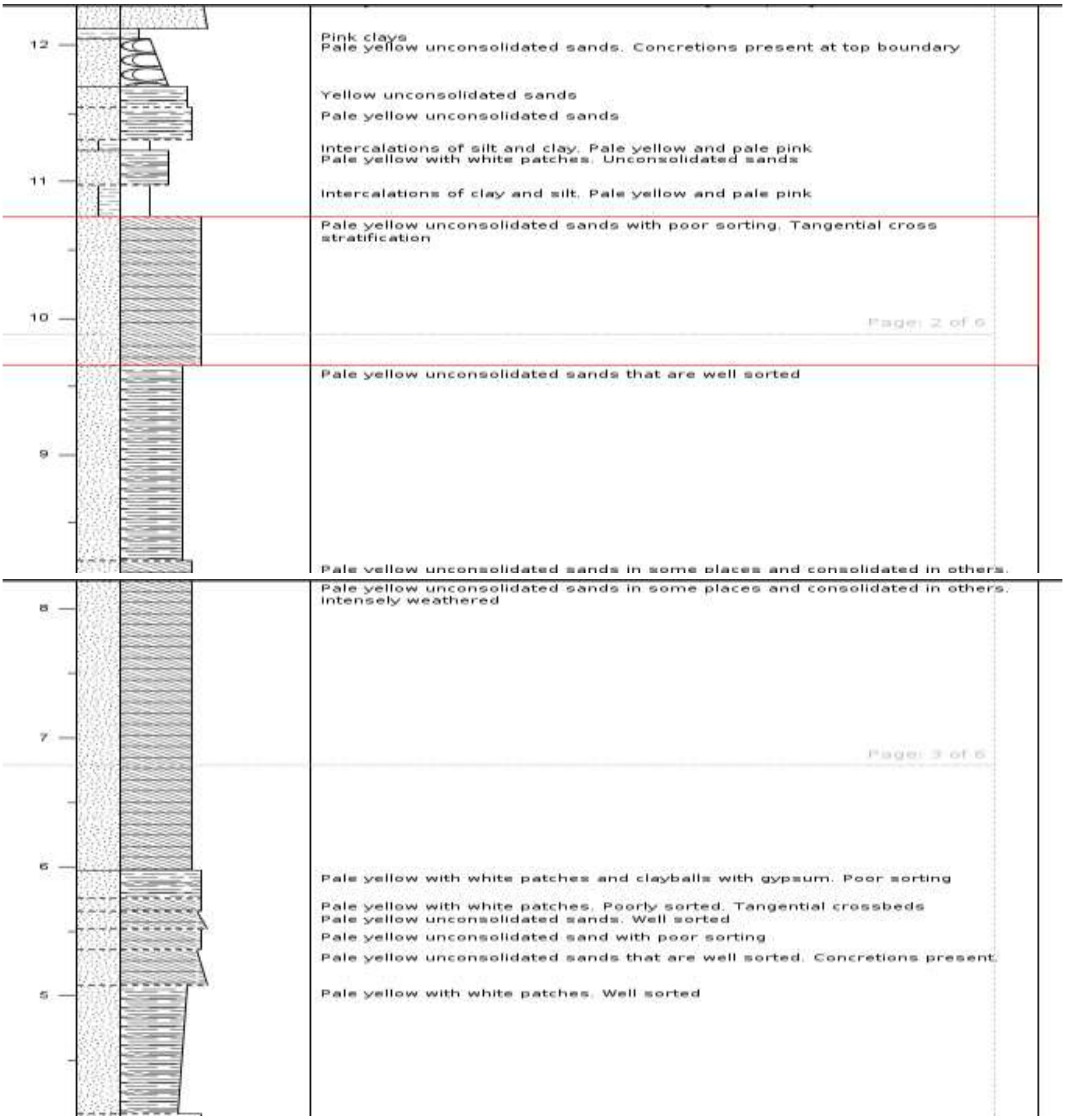

well sorted, unconsolidated, yellow,white,reddish brown,quartz, iron minerals,

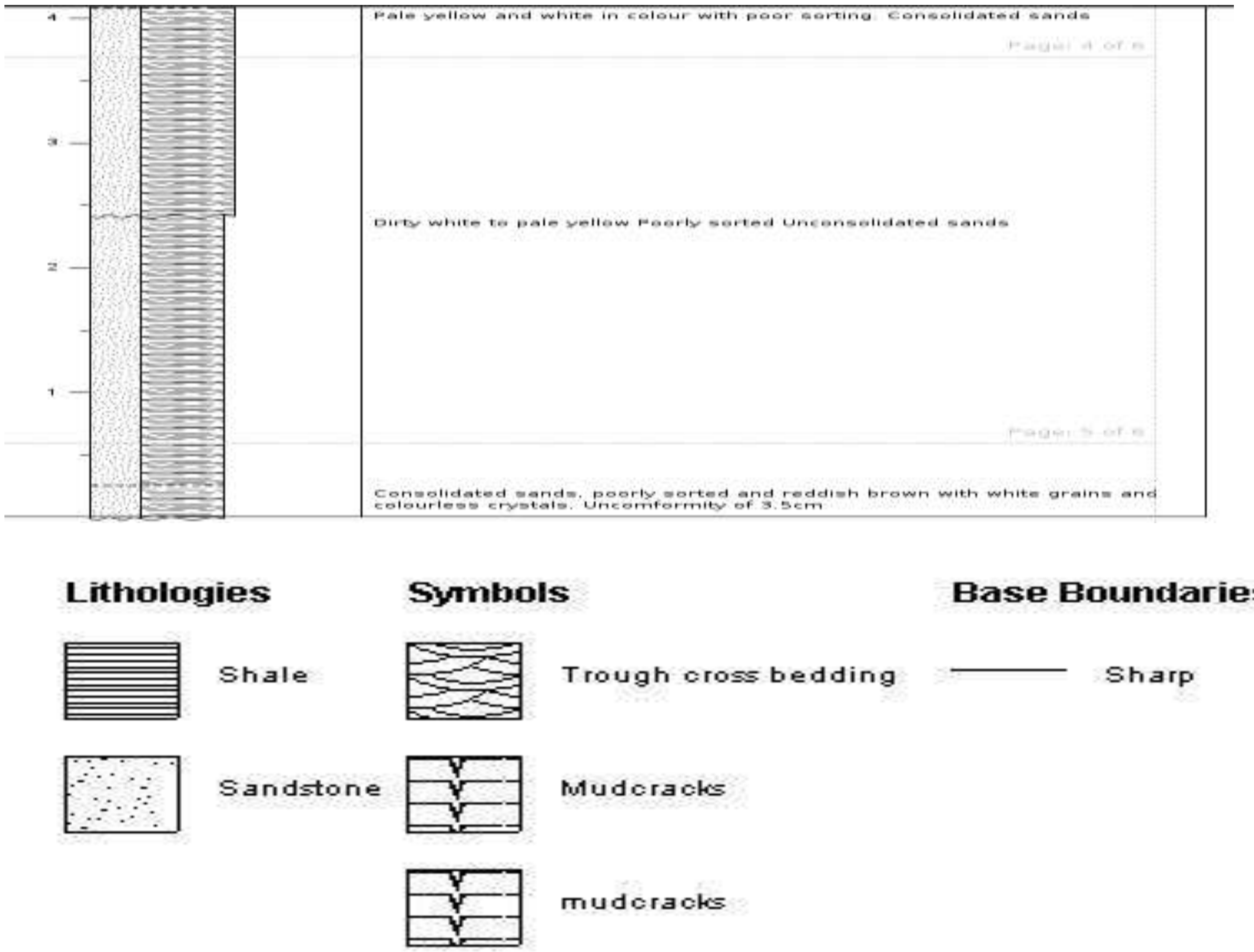

39
38
37
36
35
well sorted, unconsolidated, yellow,white, reddish brown, quartz, iron minerals,
Page: 1 of 5
well sorted, unconsolidated, yellow, quartz , limonite
well sorted, unconsolidated, white, yellow, brown, quartz
yellow, pink, well sorted, consolidated, fault
35
34
33
32
Page: 2 of 5
white, consolidated, well sorted, fault
white, pink, yellow, consolidated, well sorted, fault
white,pink,consolidated,well sorted,yellow, fault
white, pink, yellow, consolidated, well sorted, fault
well sorted, consolidated, yellow, fault
yellow, pink,white, consolidated,well sorted
yellow, glassy white, well sorted, unconsolidated, factures filled with gypsum
pink, consolidated,poorly sorted, fractures of gypsum
glassy white, yellow, well sorted, fractures with gypsum
consolidated clay sand, poorly sorted clay sand,
brown, angular cross stratification
Page: 3 of 5



31
unconsolidated, poorly sorted, yellow
consolidated, pink, sheets of gypsum
poorly sorted, lenses of reddish brown sand, sheets of gypsum, unconsolidated, mudcracks
30
29
poor sorting, subrounded pebbles, uncosolidated,
pebbly, lenses of clay, subrounded,yellow, thin layer of gypsum on top of clay, poorly sorted, burrows,
28
very well sorted, consolidated, white
unconsolidated, poorly sorted, yellow, subrounded
26
Angular to sub-angular pebbles
Pale yellow poorly sorted sands
Pale yellow and white sands; small point bar surfaces; parallel cross lamination
25
Page: 1 of 5
24
23
Angular to sub-angular quartz pebbles
22
Page: 2 of 5
White and yellow silt sands; Well sorted
21
Yellow and white sands; thin clay layer present at the top. Tangential cross stratification. Pinchout
20
Pale yellow and white sands; tangential cross stratification at the bottom and parallel cross stratification at the top. Well sorted; Stripes of organic matter present.


19
18
17
16
Page: 3 of 5
Brown clay and silt. Organic rich layer; Pich out sequence; Tangential cross stratification
Pale yellow sands; organic matter rich; fault present; Angular beds. Fault present
Consolidated pale yellow sands; Grey quartz grains.
Poorly sorted; silt matrix.
Pale yellow sands.Well sorted, consolidated. Reddish brown concretion present.
Page: 4 of 5
Stripes of organic matter. Pale yellow, has gypsum, consolidated.
Well sorted. Has gypsum crystals, dark yellow in color
Thick brown and yellow stripes of clay
14
13
Reddish brown (organic matter) and yellow in colour. Unconsolidated sands
Pale yellow unconsolidated sands. Poorly sorted
Page: 1 of 6
White and grey conglomerates. Pebbles 0.5-2.5cm. Poorly sorted.
Pale yellow consolidated sands. Poorly sorted
Yellow consolidated sands. Gypsum cement
Pale red clays
Pale yellow unconsolidated sands. Coarse grains poorly sorted


12
Pink clays
Pale yellow unconsolidated sands. Concretions present at top boundary
Yellow unconsolidated sands
Pale yellow unconsolidated sands
Intercalations of silt and clay. Pale yellow and pale pink
Pale yellow with white patches. Unconsolidated sands
11
Intercalations of clay and silt. Pale yellow and pale pink
Pale yellow unconsolidated sands with poor sorting. Tangential cross stratification
10
Page: 2 of 6
Pale yellow unconsolidated sands that are well sorted
9
Pale yellow unconsolidated sands in some places and consolidated in others.
Pale yellow unconsolidated sands in some places and consolidated in others. Intensely weathered
8
7
Page: 3 of 6
6
Pale yellow with white patches and clayballs with gypsum. Poor sorting
Pale yellow with white patches. Poorly sorted. Tangential crossbeds
Pale yellow unconsolidated sands. Well sorted
Pale yellow unconsolidated sand with poor sorting
Pale yellow unconsolidated sands that are well sorted. Concretions present
5
Pale yellow with white patches. Well sorted


4
3
2
1
Pale yellow and white in colour with poor sorting. Consolidated sands
Page: 4 of 6
Dirty white to pale yellow Poorly sorted Unconsolidated sands
Page: 5 of 6
Consolidated sands, poorly sorted and reddish brown with white grains and colourless crystals. Uncomformity of 3.5cm
Lithologies
Shale
Sandstone
Symbols
Trough cross bedding
Mudcracks
mudcracks
Base Boundaries
Sharp