FACIES ANALYSIS AND SEQUENCE STRATIGRAPHY OF THE SOUTH EAST LAKE EDWARD BASIN, SOUTH WESTERN UGANDA

By

TWINOMUJUNI LAUBEN, BSC (MAK)

A THESIS SUBMITTED TO THE SCHOOL OF GRADUATE STUDIES IN PARTIAL FULFILLMENT FOR THE AWARD OF THE DEGREE OF MASTER OF SCIENCE IN GEOLOGY OF MAKERERE UNIVERSITY

DECEMBER 2010

DECLARATION

I, LAUBEN TWINOMUJUNI, hereby declare that this is my original work and has never been submitted for any degree award.

Signed...Date.............................

This thesis has been submitted for examination with my Authority as a University Supervisor.

Signed..Date.................................

Dr Immaculate Ssemmanda

Signed...Date...................................

Dr Christopher J. Nicholas

DEDICATION

This work is dedicated to my mother Mrs. Margaret B. Tukaheirwa. May God, almighty bless you.

ACKNOWLEDGEMENTS

I express my sincere appreciation to my supervisor, Dr Christopher J. Nicholas for introducing me to field relations of sedimentary rocks and Petroleum Geology. He also introduced me to Dominion Petroleum Ltd and this was the centre of my success in this project.

I thank my supervisor, Dr Immaculate Ssemmanda for the academic guidance given to me throughout this project.

Special thanks go to Dr Erasmus Barifaijo who chose me to go with Dominion to the field upon their request in February 2008. He also recommended me for a DAAD in-country scholarship to do MSc. Geology. He has helped me in all aspects of life since I joined the department.

My heartfelt thanks go to the staff, Geology Department, Makerere University for the guidance throughout the course.

I am also grateful to German Academic Exchange Service (DAAD) through Dr Gerald Heusing for sponsoring my postgraduate study at Makerere University.

I thank Dr Schumann Andreas who directed me on how to acquire a DAAD scholarship.

I specially thank Mr. Anthony Knaggs the country manager for Dominion (U) for supporting me while doing this project.

My heartfelt tanks go to Mr. Dozith Abeinomugisha and Tonny Sserubiri of PEPD for guiding me all the time I was doing my research.

Many thanks go to the management of Savanah Resort Hotel, Kihihi for being cooperative while we were staying in this hotel.

I also extend my sincere gratitude to the management of Queen Elizabeth National park for allowing us to do field survey in the National Park.

My profound thanks go to my course mates, Kasaka Moses and Guma Brian Emmanuel for their encouragements during the course.

I sincerely extend my thanks to Eng. Robert Mamgbi and Eng. Kurama Laban for being part of the whole process.

I acknowledge all the petroleum companies operating in Uganda for their information about sedimentology of the rift. Tullow Oil Plc availed data on the internet.

I acknowledge the contributions of all my brothers, sisters and friends ; Arinaitwe Justus, Akankwasa Anet, Kanyesigye Ismail, Mugisha Moses, Anet Tumwine, Kedi Vincent, Mugumya Firminus, Pule Stellah, Turyahikayo Steven, Mugabi Levison, Atwijukire Frank and Atuheire Ben.

I thank Asiimwe Charity, Niwamanya Apophia and Ainebyona Denis. I am always proud of you.

Special thanks go to my uncles; Magara M. Mujungu and Muhimbise Gad. You always supported my mother during the struggle.

Outstandingly special thanks go to my mother Mrs. Margaret B. Tukaheirwa. She made me what I am. May God our father protect you forever.

Lastly to the almighty God in whom we live and have our being.

Table of Contents

LIST OF FIGURES

LIST OF APPENDICES

LIST OF ABBREVIATIONS

EARS: East African Rift System

PEPD: Petroleum Exploration and Production Department

AZ: Accommodation Zone

LBF: Lubero Border Fault

SWM: Semliki Western Monocline

SF: Semliki Fault

BBF: Bwamba Border Fault

KFZ: Kasindi Fault Zone

NF: Nyamwamba Fault

GF: George Fault

KF: Kichwamba Fault

NASC: North American Shale Composite

BCC: Bulk Continental Crust

XRD: X-Ray Diffraction

ICP-OES: Inductively Coupled Plasma-Optical Emission Spectrometry

ICP-MS: Inductively Coupled Plasma-Mass Spectrometry

ABSTRACT

The south-east Lake Edward basin is the onshore part of the Block 4B exploration area which was licensed to Dominion Petroleum Limited in 2007. This area lies within the western branch of the East African Rift System (EARS). Dominion Petroleum Ltd is carrying out intensive oil exploration in the Lake Edward Basin whereby the researcher participated in some components of this exploration. This study impinges upon the economic potential of the Albertine graben, principally its oil reserves. It attempts to settle the stratigraphic problems within this part of the EARS with the aim of evaluating its petroleum potential. From previous reports, several formal lithostratigraphic names can be seen. However, it is hard to tell how these differ internally. During this study, a lithofacies approach was employed to look at exposed sections at a higher resolution than just recognizing formations. This approach proved flexible in studying sedimentation in fluvial dominated, tectonically controlled system with abrupt lithofacies changes. Using a combination of field surveying and section measurements, X-Ray diffraction measurements, organic, major and trace element geochemistry, it was possible to designate exposed strata into lithofacies and characterize stratigraphic intervals using the defined facies, depict presence of petroleum source somewhere in the basin, deduce sedimentary environments and tectonic events that have occurred within the basin. Results from this study have shown that rift-fill sediments in the southeast Lake Edward basin are dominated by alluvial fans and fluvial distributary fan complexes. Five individual fan complexes can be recognized fringing the edge of the rift and these merge distally towards the present day lake shoreline. Within the fan complexes, five broad Lithofacies can be recognised. All these fall under two formations i.e. Bwambara and Queen Elizabeth.

Potential source, reservoir and seal intervals can be identified within these fan complexes and sequences from outcrop studies. The ongoing petroleum exploration has also produced the first confirmed occurrence of relict oil in porous tufa limestones and on the surface of Lake Edward indicating presence of a working petroleum kitchen some where in the basin.

Structurally, the studied part of the basin is dominated by down-to-the east normal faults controlled by basin bounding faults to the east and west (DRC).

CHAPTER ONE
INTRODUCTION

1.1 Background

Lake Edward basin is part of the major Lakes Edward-George basins which lie at the southern extreme end of the Albertine graben. The Albertine graben is itself in the northern extreme end of the western arm of the East African Rift System. Like some other rift basins in the world, the East African Rift System has potential for petroleum production.

In the Albertine graben, the petroleum potential was first reported by Wayland, 1925 in his report "P*etroleum in Uganda, 1925"*. Since then various exploration activities have been carried out in this graben until of recent where commercial reserves have been reported by petroleum companies operating within this garaben. For instance Tullow Oil Company has reported that Kingfisher 2 exploration well in the Albert basin showed the highest onshore production potential within sub-Saharan Africa. This may indicate that all other areas in this graben have such potential and it could be discovered through detailed geologic mapping which has not been done.

In this project, the area (onshore block 4B-South East Lake Edward basin) that was studied is part of EA 4B that is currently being explored for petroleum by Dominion Petroleum Ltd. The researcher got opportunity to work with them in the exploration activities thus the study shows the findings in this basin with regard to petroleum geology.

All the activities carried out regarding the south east Lake Edward Basin were done with the ultimate aim of designation of strata into lithologic facies and characterization of stratigraphic intervals using defined facies to interpret depositional environments and to develop a sequence-stratigraphic framework for better understanding of the petroleum potential of the onshore block 4B (South East Lake Edward). These activities included literature review, reconnaissance and detailed field surveys, and laboratory analyses.

In the Lakes Edward-George area, various geologic studies have been done with the aim of establishing the petroleum potential of the area.

From these studies, various geologic formations have been erected. However, from their literature, it can be seen that previously described formations are difficult to correlate across the study area because of lack of clearly identifiable bounding surfaces and marker horizons.

These formations have previously been described in the field at each well exposed, loggable section. As such they remain an excellent record of the best exposures to be found in the in the area.

Whether these previously described formations can be called legitimate formations is in doubt as none at present have defined basal and top bounding surfaces.

It is difficult to see with these formations as defined before, how any of them significantly differ internally from each other.

To avoid further confusion about the stratigraphy of the area, and to describe field observations at a much higher resolution than just recognizing formations, a lithofacies approach was employed to solve the problem of stratigraphy within the area.

1.2 Location and Accessibility

The area that was investigated is part of block 4B which lies at the southern extremity of the Lakes Edward-George Basin (Fig 1).

Lakes Edward-George Basin is itself at the southern extremity of the Albertine graben which is the western arm of the East African Rift System. The project area is, in essence, the onshore block 4B.

To the Northwest and west, onshore 4B is bound by Lake Edward and Ishasha River respectively. To the north, it is bound by N-S to NNW-SSE trending Kisenyi Fault, which separates block 4A and 4B sub-basins. To the east and south, it is bound by Bushenyi, Rukungiri and Kanungu escarpments.

With the exception of the south and SE part, much of the area lies within Queen Elizabeth National park with thick forests, dense, tall grass, and thick undergrowth. This, coupled with the presence of dangerous wild life, makes the accessibility of many loggable sections very difficult.

Source: Kigezi Tourist map 1993

Figure 1. 1. ***Location of South-east Lake Edward Basin***

1.3 Climate

The rift valley lies within the rain shadow of its shoulders, and receives low rainfall and contains high temperatures (Musisi, 1991). Lake Edward basin is characterized by low annual rain fall 810 mm/year (Katwe rainfall station) due to its location in rain shadow. The Uganda and DRC escarpments cause winds to rise and drop rainfall on the high slopes facing away from the rift. By the time the winds get to the area, they are dry or contain very little moisture.

The rainfall is bimodal and is distributed between January-February and June-July.

1.4 Research Problem

Generally, the problem in the SE Lake Edward Basin lies in the fact that the sediments exposed between the shores of Lake Edward and the eastern rift border were deposited in dominantly fluvial and alluvial systems. As such, lithofacies change over very short distances is to be expected laterally, distally from source, and in the vertical stacking patterns over time.

Previously, several “formation” names were given;

Kazinga, Kankoko, Channel, Ishasha, Kirururma, Mweya, Kikorongo, Nchwera and Rwenshama Formations.

Neither any unconformities nor any stratigraphic markers were identified. As such they are an excellent record of best exposures to be found in the area. To solve the problem of stratigraphy, a lithofacies approach was required to look at sediments at a higher resolution than just recognizing formations. This is a more practical approach to stratigraphic diagnosis of fluvial dominated, tectonically controlled rift systems such as Lake Edward basin.

Previously logged sections currently remain, therefore, a random series of 'snapshots' in time rather than a coherent lithostratigraphic framework. In addition, for petroleum geology evaluation, one needs to look at the sediments at a higher resolution rather than just recognising the formations in order to build geological models for petroleum generation and accumulation.

1.5 Hypothesis

Designation of strata into lithologic facies and characterization of stratigraphic intervals using defined facies will help to interpret depositional environments and to develop a sequence-stratigraphic framework for better understanding of petroleum geology of Lake Edward basin.

1.6 Objectives

1.6.1 Overall Objective

The overall objective of this study was to carry out a sequence stratigraphic synthesis and facies modeling of the SE Lake Edward Basin to evaluate its petroleum potential.

1.6.2 Specific Objectives

i) To identify different sedimentary facies and relate them to depositonal environments and predict provenance of sediments.

ii) To map structures such as primary sedimentary structures and faults within the basin.

iii) To bundle lithofacies together using bounding surfaces to achieve a lateral correlation across the basin.

iv) To construct sequence stratigraphic and facies models, and use these models together predict petroleum generation and accumulation

1.7 Justification

The need for this study lied in the significance and relevance of the Albert Rift Valley to the prospective oil reserves in Uganda. Significant sediment accumulation occurred during the process of rifting in the Albertine graben basins. Where these sediments accumulated they formed sedimentary basins which have the potential for the generation and accumulation of petroleum. Because of high relief around these basins and the short distance from the time of erosion to deposition, these basins have immature sediments, largely arkoses and conglomerates deposited on alluvial and deltaic fans, for example in the alluvial complexes in the Lakes Edward-George Basin.

In the central and deeper parts of these basins, there is deposition of finer-grained clays such as around Lake Edward. With all the above conditions that favour petroleum generation and accumulation present, Lake Edward basin has received limited petroleum evaluation. Thus this study formed part of the studies required for petroleum evaluation within the Edward basin.

1.8 Scope of the study

In order to achieve the above mentioned objectives, the study was conducted through a series of literature reviews, field surveys and laboratory analyses.

Two field surveys were conducted. The first one was based at Savanah resort hotel just north of Kihihi and mapping was restricted to visiting all the accessible stratotype localities defined by Musisi (1991) and Byakagaba (1997). During this field surveying, a lithofacies approach was adopted to describe all sections encountered in the field. The second field survey took a period of two weeks and the surveying was restricted to mapping along seismic lines.

Laboratory analyses were carried out at Trinity College, University of Dublin by Tropical Geology and Exploration Group. Laboratory results coupled with field results were used to construct facies and stratigraphic models of the basin fill which helped to predict the petroleum potential of block 4B. As part of the field surveying, an attempt to locate and map any likely oil seeps in the area was made.

CHAPTER TWO
LITERATURE REVIEW

2.1 Regional Overview

2.1.1 The East African Rift System

The most distinctive and dramatic geologic feature in Africa is the EARS. This rift extends in two branches in a general N-S direction from 20^0S to 5^0N. Its western branch started to develop with the onset of volcanism near its northern end (Virunga basin) around 12-13Ma ago (Ebinger, 1989). Its eastern branch started to develop near its northern end with extensive flood basalt eruptions at around 33Ma ago, preceding half graben formation a few million years (Hermann *et al*., 1997).

The EARS is one of the world's most spectacular faulted land-scapes. It is part of the world's oceanic rift system. Along its course, this rift system includes major rifts, such as the Dead Sea Graben in Jordan, the Gulfs of Aqaba and Suez, the Red Sea, and the Gulf of Aden (Sunday, 1991). At Afar the main rift system veers from its NW-SE course and enters East Africa where it runs through Ethiopia to Mozambique. The EARS is divided into the eastern branch and the western branch. The western branch extends from the coastal plain of Mozambique through lakes Malawi, Tanganyika, to Lake Albert where it terminates against the Aswa shear zone. In the northern part, the terrane around Lake Kivu and the Rusizi mountains is rugged and faulted and partly drowned to form rias (Sunday, 1991).

Lake Edward occupies a well-defined rift valley which divides northward into a lowland and a trough, the Semliki trough. Towards the northern end of the western branch, Lake Albert lies in a fault-bounded trough, the scarps of which gradually decrease in elevation until they are replaced by the zig-zag fault zones in the Nile region (Nicholas *et al, 2009*).

Seismically the rift valley is very active. Lava flows and volcanic eruptions occur about once a decade in the Virunga Mountains of Lake Kivu along the western stretch of the rift valley. One volcano in the Virunga area in eastern DRC which borders Uganda and Rwanda actually dammed a portion of a river valley forming Lake Kivu as a result (Nicholas *et al, 2009*).

2.1.2 The Albertine Graben

The pattern of orogenic fold belts and shear zones in the Precambrian, the formation of the rift valley, the distribution of later volcanic centres and Pleistocene warping constitute the major tectonic elements of Uganda. Out of these, the rift valley also known as the Albertine Graben is most pertinent to petroleum exploration.

Compared to the eastern arm of the East African Rift System, the Albertine Graben contains much less volcanics and intrusives and comprises thick sequences of gneiss and schist derived sandstones and shales.

The Graben is highly asymmetrical in some places but trends NE-SW through most of its length. It trends N-S in the Pakwach and Rhino Camp Basins, to the north of Lake Albert, probably due to Pre-Cambrian lineaments.

The major tectonic forces in the graben are extensional although there is evidence of compression occurring within an extension regime. Inversion structures and compressional anticlines interpreted from seismic data confirm these episodes of compression (PEPD, 2005). However it should be noted that inversion structures can develop as a result of either compression, transpression or strike slip movements within an extension regime.

2.1.3 The Structure of the Western rift

The Western branch of the East African Rift System (EARS) has previously been subdivided into a series of rift zones, each with its own border fault characteristics and orientations (Laerdal and Talbot, 2002). These rift zones are separated by high relief accommodation zones (AZs), thought to have been formed as a result of reactivation of ancient supra-crustal discontinuities. The Lake Edward-Lake George area lies within the Kivu–Edward–Albert–West Nile rift zone located in the northern part of the Western branch (Rosendahl, 1987).

This rift zone is orientated NE-SW at Lake Albert, but becomes more NNE-SSW orientated further north around Rhino Camp and to the south of Lake Edward at Lake Kivu.

Border faults in this rift zone are thought to have undergone extension perpendicular to their trend in a generally W-E to WNW-ESE direction (Rosendahl, 1987; Ebinger, 1989a, b; Tiercelin and Mondeguer, 1991; Rosendahl *et al.,* 1992; Foster and Jackson, 1998; Calais *et al*., 2006), although extension directions may have altered over time. Extension is also thought to have occurred over a relatively narrow zone of continental crust and is estimated to have been less than 15% (Ebinger, 1989a; Rogers and Rosendahl, 1989). Morley, 1995) also note that individual half-graben basins within the rift zone are separated by accommodation zones, along which there may be a significant strike-slip component and that these accommodation zones are often orientated parallel to Precambrian discontinuities.

The Lake Edward basin

Lake Edward is bordered on its western shores in the Democratic Republic of the Congo by the major east-facing bounding fault, the Lubero Border Fault (LBF), orientated NNE-SSW. To the north, this relays NNW via the Semliki Western Monocline (SWM) to the N-S trending and east-facing Semliki Fault (SF) which continues northwards as the western border fault to the Semliki rift valley (Laerdal and Talbot, 2002).

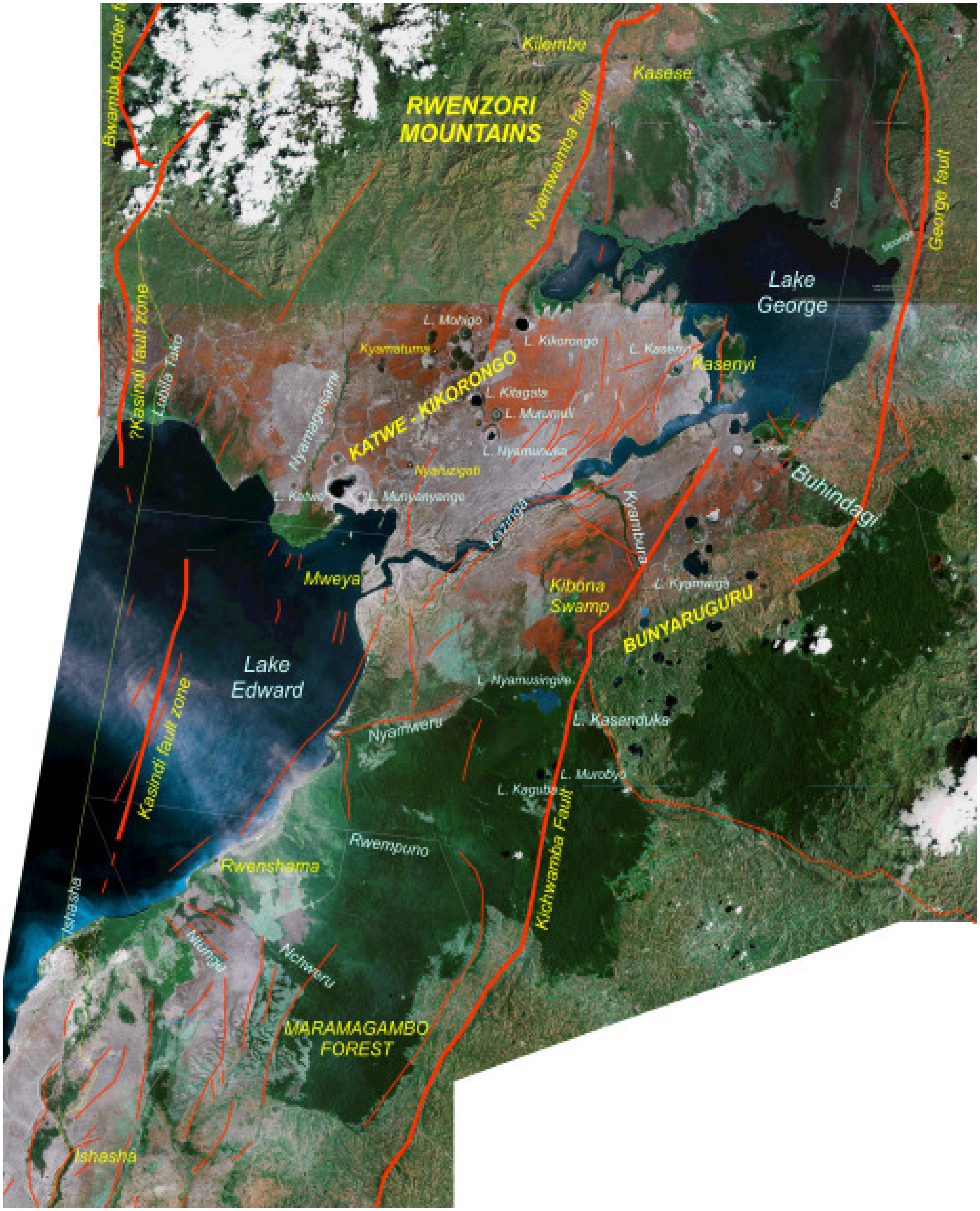


Figure 2. 1. *Regional setting of Block 4, Lake Edward and Lake George basins (Nicholas et al 2008)*

The Semliki Valley is bordered on its eastern side by the west-facing, NNE-SSW trending, Bwamba Border Fault (BBF) which forms the eastern fault-bounded margin to the main Rwenzori Mountains horst block to the east. Movement on the Lubero Border Fault (LBF) has been much greater than that on the BBF resulting in an asymmetric graben forming down the Semliki Valley.

Laerdal and Talbot (2002) show the Bwamba Border Fault cross-cut to the south by a major east-facing, but also NNE-SSW trending fault (along the DRCongo – Uganda border) which they suggest may continue out into Lake Edward via a South East relay as the Kasindi Fault Zone (KFZ), recognised on lake floor bathymetry and seismics. Thus the asymmetric graben of the Semliki Valley becomes more of an asymmetric half-graben at the northern tip of Lake Edward. The east-facing, NNE-SSW trending Kasindi Fault Zones can be traced southwards across the lake floor and trends onshore just north of Ishasha, on the south-east shore of Lake Edward, again close to the DRC – Uganda border. Laerdal and Talbot (2002) show the area around Ishasha to be cross-cut by a number of small east-facing, NNE-SSW trending normal faults, assumed to be the southern onshore manifestation of the Kasindi Fault Zone.

The Lake George basin

To the north of Lake George, the basin is bounded on the west side near the town of Kasese by the east-facing, NNE-SSW trending Nyamwamba Fault (NF). This fault becomes difficult to trace southwards between Lakes George and Edward amongst the Katwe-Kikorongo volcanic craters.

North of Lake George, the basin is bounded on its eastern side by the N-S trending, west-facing George Fault (GF). Similar degrees of movement on both the Nyamwamba Fault and George Fault have led the George basin in this area to resemble an approximately symmetrical graben with a significant fill of alluvial fan clastics sourced from the Rwenzori Mountains immediately to the west.

The George Fault is said to disappear just south of Lake George but overlaps with the fault tip of the NNE-SSW trending, west-facing Kichwamba Fault (KF) situated to the NW via a relay ramp. This ramp coincides with the Bunyaruguru vent field. Movement at this location on both the George Fault and Kichwamba Fault has been significantly less than that of the Lubero Fault to the west, producing a characteristic rift-related half-graben shape to the combined Edward-George basin, with the George Fault – Kichwamba Fault relay forming the faulted flexural margin on the east side. The Kichwamba Fault disappears to the south, east of Ishasha and just south of Maramagambo Forest in a region of pervasive NW-SE trending basement lineations. One further important fault indicated in this area is the irregular faulted boundary to the basement south and south-east of the Bunyaruguru vent field. This NW-SE trending boundary divides Toro System mica schists and younger acid gneisses to the SW from quartzites, conglomerates and mica schists of the Karagwe-Ankolean System to the NE. This boundary also marks the southern limit of a basin-wide NW-SE trending Accommodation Zone stretching from the Semliki Valley, across the Kazinga Channel to this area south-east of the Bunyaruguru volcanics.

This Accommodation Zones is expressed as an area of topographic uplift between Lakes Edward and George which contains pervasive lineaments indicated to be normal synthetic and antithetic faults parallel to the main border faults.

Volcanic Provinces

Volcanics in the Lake Edward – Lake George area are part of the regional Toro–Ankole volcanic province. This consists of four sub-provinces (Lloyd et al., 1991; Boven *et al.*, 1998): (1) the Kyatwa Volcanoes between Fort Portal and Kasese, (2) the Bunyaruguru craters just south of the Kazinga Channel, (3) the Katwe – Kikorongo craters just south of the Ruwenzori Mountains, and (4) the Kichwamba volcanoes further to the north near Fort Portal. Hot springs and vents are also located along the seismically active Nyamwambe Fault (NF) which forms the eastern edge of the Rwenzori.

The Toro-Ankole volcanic province appears to be related to the NW-SE trending Accommodation Zone (AZ) between Lakes Edward and George, marking the switch from a NE-SW rift orientation in the north (such as Lake Albert), to a dominantly N-S orientation to the south (Lake Kivu). A further volcanic province, the Virunga, is situated on a W-E trending Accommodation Zone (AZ) which lies between Lake Edward and Lake Kivu (Demant *et al.*, 1994).

Virunga volcanism commenced in the Miocene (~11 Ma) (Pasteels *et al*., 1989; Kampunzu *et al.,* 1998), whereas the Toro-Ankole province has been active intermittently only over the past 50,000 yrs. However, this also coincided with a Quaternary phase of volcanism in both the Virunga and South Kivu areas (Boven *et al.*, 1998). Volcanism during the past 50 ka also seems to have accompanied tectonic activity in the area, with repeated episodes of faulting and ash dates suggesting several volcanic phases during the Holocene (De Heinzelin, 1955; Bishop, 1969; Brooks and Smith, 1987; Musisi, 1991; Brooks et al., 1995). Laerdal and Talbot (2002) define this last 50,000 year period BP as being the current neotectonic episode, i.e. 'the period under tectonic control of the last geodynamic mechanism and still prevailing at the present time'.

Volcanism within the Bunyaruguru and Katwe–Kikorongo fields has been dominated by phreatomagmatic activity (Boven *et al*., 1998). On the rift floor, the Katwe-Kikorongo field is characterised by maars with shallow inner slopes rimmed by well-developed tuff rings (Lloyd *et al*. 1991). The topographically higher rift shoulders, such as the Bunyaruguru field, display a multitude of small craters (diatremes) with steep inner walls. This difference in morphology between the two fields has been attributed in other phreatomagmatic settings to a variable depth of the explosion epicentre (Boven *et al.*, 1998; Lorenz, 1975). Boven *et al*. (1998) conclude that these observations indicate that eruption within the Katwe-Kikorongo and Bunyaruguru fields post-dates subsidence within the Lake George – Lake Edward basin. However, they do not recognise the possibility of post-eruption uplift as at least a partial cause of the apparent difference in eruption depths.

Logged sections at Mweya and Katunguru along the Kazinga Channel expose Katwe Ash Formation (~6800 – 8000 BP; de Heinzelin, 1955; Brooks and Smith, 1987) and Katunguru Formation tephra that Boven *et al*. (1998) correlate with pyroclastics erupted from the Katwe-Kikorongo maars to the north. Underlying the Katwe Ash and Katunguru Formations at both sections is the Mweya Formation, consisting of distinct layers of reworked pyroclastics between sands that Boven *et al*. (1998) correlate with the Bunyaruguru vents to the south-east. Thus they make the inference that the Bunyaruguru volcanics are older than the Katwe-Kikorongo maars. Two lava flows and associated pyroclastics from the Kyamuhogo crater in the Bunyaruguru field were used in $^{40}Ar/^{39}Ar$ dating by Boven *et al.* (1998) and display what they considered to be characteristic compositions for this area of the Toro-Ankole Volcanic Province. The lavas were found to be composed of olivine, leucite, clinopyroxenes and phlogopite phenocrysts (or xenocrysts) set in a finely crystalline groundmass rich in clinopyroxenes, leucite, phlogopite and small amounts of possibly kalsilite. Kampunzu *et al*. (1998) observed that the hallmark feature of the Toro-Ankole Volcanic Pronvince as a whole was that of strongly alkaline, silica-undersaturated volcanics with high K and Ti content and associated incompatible lithophile elements (e.g. ≥9 wt% K_2O and TiO_2 in lavas with less than 50 wt% SiO_2).

These ultra-alkaline melts are thought to have been generated from partial melting of highly metasomatised mantle underlying this region, and this also explains the absence of any tholeiitic basalts in this area (Kampunzu *et al*, 1998). Furman (2007) used Ce/Pb as a measure of crustal contamination in EARS melts and found that Toro-Ankole Volcanic Province lavas generally plotted with mantle values for Ce/Pb, but some samples also extended into the field of lithospheric and crustal values.
This was considered consistent with the idea of a low rate of magma supply in this region of the EARS, coupled with extension of only 10-15% (Ebinger *et al*., 1989).

2.2. Current Lithostratigraphic Framework

2.2.1. Pre-Rift Basement

The Precambrian Basement in the area around Lakes Edward and George is composed of a variety of metasediments, mafic intrusives and acid gneisses. The Mbarara 1:250 000 sheet subdivides the Precambrian units of the region into Basement Complex, Toro System and Karagwe – Ankolean System (Geological Survey of Uganda, 1961).

PEPD reports do not use these divisions and instead subdivide on the basis of metamorphic facies (Byakagaba, 1997). Metasediments include irregularly-bedded silver white and reddish-brown phyllites and phyllitic shales, in some localities overlain by quartzites (Byakagaba, 1997). The quartzites are micaceous or at times schistose and ferruginous, ranging in colour from white to grey-brown. They are also found in association with metamorphosed cherts. Biotite-, quartz-, amphibole- and mica-schists are present in the region, indicative of a higher grade of metamorphism than the phyllites and quartzites. They apparently grade at times into gneisses or can be found interbedded with gneisses at some localities (Byakagaba, 1997). The gneisses themselves display a foliation parallel with the main regional structural trend. Although dominated by quartz and feldspar, they (gneisses) also contain accessory minerals of hornblende, biotite, tourmaline and muscovite. There are occasional pods of schists enclosed within the gneisses (Byakagaba, 1997). Mafic intrusions are also present in the Lake Edward – George basins. These consist of massive, little altered, dark green, porphyritic diorites and dolerites – gabbros (composed of plagioclase, augite, amphiboles, olivine, siderite, quartz and magnetite) which can be seen intruding the gneisses, quartzites and schists. However, they have not so far been observed to cross-cut the Neogene and younger rift fill sediments (Byakagaba, 1997). Thus, both their precise age and subcrop extent remain unclear at present.

2.2.2. Rift Fill Sediments

The oldest rift-fill sediments of the Albert – Edward basin have previously been considered to be of Late Miocene age and contemporaneous with the onset of volcanic activity. Age dates of between 8 Ma to 12 Ma were proposed for the earliest lacustrine sediments (Hopwood and Lepersonne, 1953; Ebinger, 1989a; Pickford *et al.*, 1993). PEPD recognise a large number of thin, Neogene and younger formations in the Lake Edward – George basin and include: *Kazinga Formation, Kankoko Formation, Channel Formation, Ishasha Formation, Kiruruma Formation, Mweya Formation, Kikorongo Formation, Nchwera Formation and Rwenshama Formatio.*

2.3 Petroleum potential of the Albertine Graben

According to Rubondo (2001) the Albertine Graben has good source and reservoir rocks, traps and seals.

2.3.1 Source rocks and oil seepages

There are over five confirmed substantial oil seepages in the Albertine Graben and these include two live oil seeps on the Victoria Nile near Paraa, two seeps at Kibuku in the Semliki basin and the Kibiro seepages on the shores of Lake Albert. The presence of these oil seeps indicates that organic rich source rocks are present.

Rubondo, 2001 reports that geochemical analysis of oils from these seepages indicates that they were generated from source rocks deposited in a lacustrine environment and dominated by Type 1 algal kerogen. There are differences between oils from the Paraa and Kibiro seeps and that of Kibuku in that the later depicts origins from source rocks deposited in a more saline lacustrine environment and with more contribution of higher land plants to the source rocks. This variation is important because it points the presence of at least two origins for oil in the graben (Rubondo, 2001).

2.3.2 Reservoir Rocks

Basement rocks along the escarpment and rift flanks of the Albertine Graben comprise mostly gneisses, granitic gneisses and quartzites. The weathering of these rocks, the subsequent transportation and deposition of their weathered products into the Graben could yield good reservoir quality sediments. Coarse clastics constitute much of the sedimentary formations outcropping in the Graben especially in the Kisegi and Kaisotonya river valleys of the Semliki basin (Rubondo, 2001).

Sandstones with good reservoir quality are present as porosities of over 30% have been measured in the shallow cores recovered from the Kibiro area. Porosities of up to 22% have also been measured in aeolian and fluvial channel deposits outcropping at Kibuku in the Semliki Basin (Rubondo, 2001).

2.3.3 Traps and seals

Structural styles in the Graben are dominated by down-to–the basement block faulting which plays a major role in the formation of hydrocarbon traps. Dip reversals against faults and fault and fault-on-fault traps are present. 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).

Relatively rapid facies changes common in terrestrial alluvial fan, deltaic and lacustrine sediments provide the potential for stratigraphic traps with or without structural components. Unconformities in the sedimentary section also provide for stratigraphic, combined stratigraphic and structural traps.

The more than 30m thick clay bed mapped on top of the good reservoir quality sandstone in the Kisegi area of the Semliki Basin is a potential regional seal (Rubondo, 2001).

CHAPTER THREE
MATERIALS AND METHODS

3.1 Desk Studies

These involved extensive literature search, acquisition of topographic maps and satellite imagery for the planned field surveys to get more insight on the stratigraphy and sedimentology of the area.

Both published and unpublished reports were acquired and studied. Stereoscopic study of aerial photographs will be done prior to field work. This helped not only in mapping the geology prior to field surveying but also in identifying existing roads and tracks within the basin.

3.2 Field surveys

Two field surveys were carried out. The first/reconnaissance field survey was meant to revisit and reassess all the stratotype localities for the formations described by Byakagaba (1997) and Musisi (1991). These localities include river valley incisions, erosional gulleys, road-cuts and quarries, and fault scarps. Field observations at a locality included sorting, colour, roundness of pebbles, grain size, thickness of beds (by use of tape measure or metre rule), geometry, progradation and aggradation patterns, and structure of bedforms.

Lateral correlation was done by making traverses along the surface and comparing lithological sections from different localities.

The second field survey was conducted along cleared seismic lines. This included making more lithological and structural observations and measurements, and comparing them with the previous ones.

3.3.1 Structural mapping

Both primary and secondary structures were traced on the surface. Primary structures that were mapped include horizontal, cross and graded bedding, ripple marks and slump structures. Secondary structures mapped included folds and faults. Geologic compass was used to measure the trend of both primary and secondary structures in order to determine depositional and post depositional movement patterns. By use of a GPS, it was possible to determine the amount of fault movements in the field (difference in elevation between the top and bottom of the fault scarp). Thickness of beds was measured using a meter rule and tape measure.

Together with Dr Chris Nicholas (supervisor), some time was spent driving along the available tracks to accurately map out the course of the fault scarps and thus the inferred fault traces on the ground which were assumed to lie at the base break in slope of each scarp. Using the GPS, the researcher was able to calculate the difference in altitude by subtracting the altitude at the bottom of the scarp from that at the top. This allowed the scarp height to be derived which corresponds to an estimate of the minimum throw on the fault.

3.3.2 Sampling

During the first survey, sampling was done according to exposures and to recognizable facies changes in the area. In the second survey, samples were collected from seismic shot-points and upholes by IMC group and were handed to the researcher for packaging and analysis. About a quarter of a kg (250g) of sediments were collected and put in sandwich transparent polythene bags. Hard rocks were sampled using a geologic hammer and labeled using a water proof marker.

All the samples collected were packed in metallic cases (metal trunks) and transported to Department of Geology, Makerere University before sending them to analytical laboratories for analysis. About 470 samples underwent macroscopic analysis. 17 of these underwent geochemical analysis.

3.4 Analysis of samples

Sample analysis was done in the Department of Geology, Trinity College, University of Dublin, Republic of Ireland and Dominion Uganda Ltd. It involved visual description of physical attributes of samples, XRD analysis for modal mineralogy, ICP-MS analysis for major elements and ICP-OES analysis for REE.

3.4.1 Macroscopic analysis

Macroscopic description of samples to assign them lithofacies was done in the field and from Dominion Petroleum Uganda Ltd in Bugolobi. This involved describing all the samples (including uphole samples) using their physical attributes such as colour, texture and sorting. Uphole samples from seismic lines were used to draw uphole lithostratigraphy to see how facies change from southeast to northwest of the area (appendix 5).

3.4.2 X-Ray Diffraction Analysis

Analytical overview

X-ray diffraction is based on constructive interference of monochromatic X-rays and a crystalline sample. These X-rays are generated by a cathode ray tube, filtered to produce monochromatic radiation, collimated to concentrate, and directed toward the sample. The interaction of the incident rays with the sample produces constructive interference (and a diffracted ray) when conditions satisfy Bragg's Law ($n\lambda=2d \sin \theta$). This law relates the wavelength of electromagnetic radiation to the diffraction angle and the lattice spacing in a crystalline sample. These diffracted X-rays are then detected, processed and counted. By scanning the sample through a range of 2θ angles, all possible diffraction directions of the lattice should be attained due to the random orientation of the powdered material. Conversion of the diffraction peaks to d-spacings allows identification of the mineral because each mineral has a set of unique d-spacings. Typically, this is achieved by comparison of d-spacings with standard reference patterns.

Procedure

10g of sample (17 samples were analysed) is powdered and placed in a sample holder of the XRD. X-rays are generated in a cathode ray tube by heating a filament to produce electrons, accelerating the electrons toward a target by applying a voltage, and bombarding the target material with electrons. When electrons have sufficient energy to dislodge inner shell electrons of the target material, characteristic X-ray spectra are produced.

These spectra consist of several components, the most common being K_α and K_β. K_α consists, in part, of $K_{\alpha1}$ and $K_{\alpha2}$. $K_{\alpha1}$ has a slightly shorter wavelength and twice the intensity as $K_{\alpha2}$. The specific wavelengths are characteristic of the target material (Cu, Fe, Mo, Cr). Filtering, by foils or crystal monochrometers, is required to produce monochromatic X-rays needed for diffraction. $K_{\alpha1}$and $K_{\alpha2}$ are sufficiently close in wavelength such that a weighted average of the two is used. Copper is the most common target material for single-crystal diffraction, with CuK_α radiation = 0.5418Å. These X-rays are collimated and directed onto the sample. As the sample and detector are rotated, the intensity of the reflected X-rays is recorded. When the geometry of the incident X-rays impinging the sample satisfies the Bragg Equation, constructive interference occurs and a peak in intensity occurs. A detector records and processes this X-ray signal and converts the signal to a count rate which is then output to a device such as a printer or computer monitor.

The geometry of an X-ray diffractometer is such that the sample rotates in the path of the collimated X-ray beam at an angle θ while the X-ray detector is mounted on an arm to collect the diffracted X-rays and rotates at an angle of 2θ. The instrument used to maintain the angle and rotate the sample is termed a *goniometer*. For typical powder patterns, data is collected at 2θ from ~5° to 70°, angles that are preset in the X-ray scan.

The intensity of diffracted X-rays is continuously recorded as the sample and detector rotate through their respective angles. A peak in intensity occurs when the mineral contains lattice planes with d-spacings appropriate to diffract X-rays at that value of θ. Although each peak consists of two separate reflections ($K\alpha_1$ and $K\alpha_2$), at small values of 2θ the peak locations overlap with $K\alpha_2$ appearing as a hump on the side of $K\alpha_1$. Greater separation occurs at higher values of θ. Typically these combined peaks are treated as one. The 2λ position of the diffraction peak is typically measured as the center of the peak at 80% peak height.

Results are commonly presented as peak positions at 2θ and X-ray counts (intensity) in the form of a table or an x-y plot (shown above). Intensity (*I*) is either reported as peak height intensity, that intensity above background, or as integrated intensity, the area under the peak. The relative intensity is recorded as the ratio of the peak intensity to that of the most intense peak (*relative intensity = I/I_1 x 100).*

The d-spacing of each peak is then obtained by solution of the Bragg equation for the appropriate value of λ. Once all d-spacings have been determined, automated search/match routines compare the *d*s of the unknown to those of known materials. Because each mineral has a unique set of d-spacings, matching these d-spacings provides an identification of the unknown sample. A systematic procedure is used by ordering the d-spacings in terms of their intensity beginning with the most intense peak. Files of d-spacings for hundreds of thousands of inorganic compounds are available from the International Centre for Diffraction Data as the Powder Diffraction File (PDF). Many other sites contain d-spacings of minerals such as the American Mineralogist Crystal Structure Database. Commonly this information is an integral portion of the software that comes with the instrumentation, and mineral determination is done automatically by the preinstalled software in the computer.

3.4.3 ICP-OES Analysis

10g of each sample (17 samples were analysed) is dissolved with an $HF/HClO_4$ mixture. This is followed by fusion (with Lithiumtetraborate at 1100^{o}C) of any resistant material not dissolved (which may retain a significant proportion of the REE e.g. in minerals such as Zircon). The diluted sample solution is loaded on an ion exchange column containing Dowex 50 resin. Major and unwanted elements are eluted using 1.7M HCl and discarded. The REE fraction is then eluted with 4M HCl. After separation, the REE are concentrated into a small volume of solution and then determined simultaneously on the ICP-OES system. The separation will not remove Sc, some of the Sr and Ba, and a small proportion of Ca in the sample. These will accompany the REE in the solution analysed. They do not cause serious analytical difficulties, although the levels of spectral interferences will be checked and appropriate corrections made. Standardization of ICP-OES system will be carried out with multi-element RE solutions. These will be prepared directly by dissolution of the separate RE oxides or from commercially available REE stock solutions. The REE concentrations are then determined simultaneously (see Walsh *et al., 1981*).

3.4.4 ICP-MS Analysis

10g of each sample (of 17 samples) are introduced in the form of a solution which is converted by a nebuliser into an aerosol dispersed in a stream of argon gas which sweeps it through the spray chamber, where larger droplets settle out, into the plasma torch. The sample aerosol on entering the high temperature region of the ICP is rapidly volatilized, dissociated and ionized. The sample emerges from the mouth of the torch as a mixture of atoms, ions, undissociated molecular fragments and unvolatilised particles. Ions are extracted due to a decrease in pressure into the mass spectrometer from the axial zone of the torch. Ion detection is accomplished using electron multiplier detectors.

Concentrations are calculated by taking the peak area for a single isotope of the element of interest.

3.5 Data analysis, Presentation and Interpretation

After sample analysis, both field and laboratory results were used to interpret depositional environments and to build facies and sequence stratigraphic models for better understanding of petroleum resource potential of the project area. Spider diagrams for rare earth elements were constructed and analyzed in MS Excel. This was done after normalizing the data with respect to the BCC, NASC, and to the basement sample which is thought to represents the source of the sediments.

This enable the researcher interpret the winnowing that the sediments underwent before final deposition, and also the provenance of the sediments.

Major elemental discrimination diagrams were drawn (in MS-Excel) using various major elemental ratios to elucidate the original provenance and indicate the mechanical processes which acted upon the sediments during erosion, transport and deposition (e.g. Bagas *et al*., 2008; Kutterrolf *et al*., 2008; Lee *et al*., 2006).

CHAPATER FOUR

PRESENTATION AND INTERPRETATION OF RESULTS

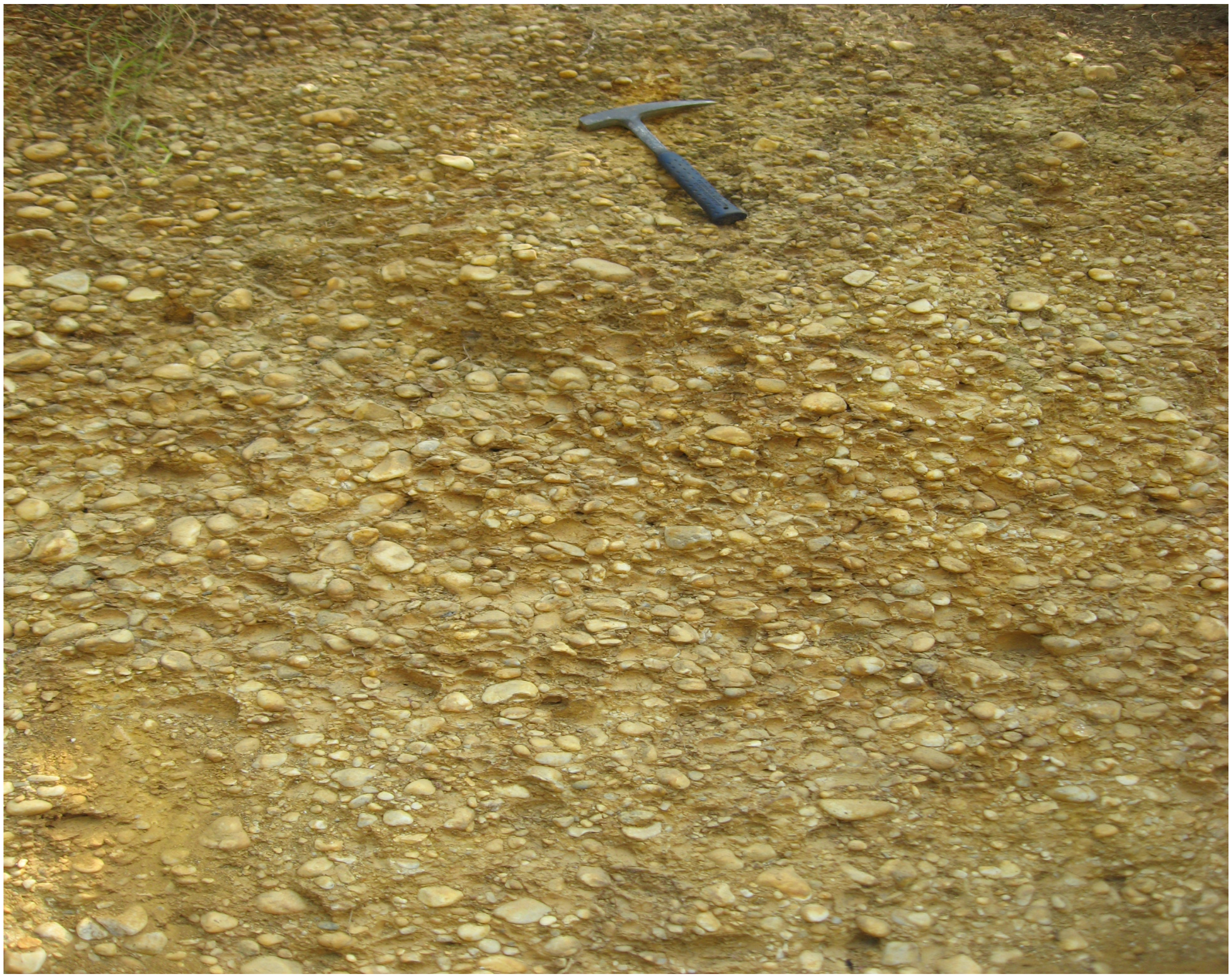
4.1 Lithofacies

Though there are some cases of mixed lithofacies, five main "lithofacies" or "lithofacies associations" were identified in the study area reflecting differences in grain size and hence depositional water energy.

4.1.1 Lithofacies A

Lithofacies A is massive, moderate brown conglomerate, with rounded pebbles and granules supported in a medium to coarse quartz sand with clay coating. This lithofacies is mostly found in high grounds near the basement edge along the road cuttings which follow the crest of the existing hills in the area. The characteristic colour of this facies is attributed to the presence of fine powdery clay coating to individual grains or in some instances a partial clay pore fill.

Lithofacies A represents high energy, concentrated mass flows depositing coarse sands, grits and pebbles as part of braided or sheet outwash. These units are not confined to flowing within single, well defined channels suggesting that they formed as a result of periodic flooding events carrying a mixture of well rounded pebbles from the basement interior, and less rounded and sorted debris from closer to the basement edge. It represents transport with high sediment/water ratio as debris flow or mudflows depositing large granules and pebbles together with fine sediments in the upper parts of the fan (Bjorlykke, 1989).



.**Figure 4. 1** ***Lithofacies A: South of Ntungamo, Butogota***

4.1.2 Lithofacies B

Lithofacies B is a massive moderate brown, coarse to medium quartz sand with clay coating. This facies is also exposed on high ground close to the basement edge. This facies is closely associated with facies A and represents medium to high flow transporting coarse sands and grits and depositing them as sheet or braided channel out wash. Similar to lithofacies A, lithofacies B is massive and tabular, with no clear bedforms or structures being visible. It represents deposition immediately down slope of facies A as the carrying capacity of the water reduces (Bjorlykke, 1989).

Clearly, typical exposure is a combination of both lithofacies A and B, where they are intercalated and pass laterally into each other. This suggests that they were transported and deposited in a network of poorly contained braids frequently undergoing flooding to form sheet floods across the fan.

Figure 4. 2. ***Lithofacies B: Massive moderate brown coarse quartz sands and grits.***

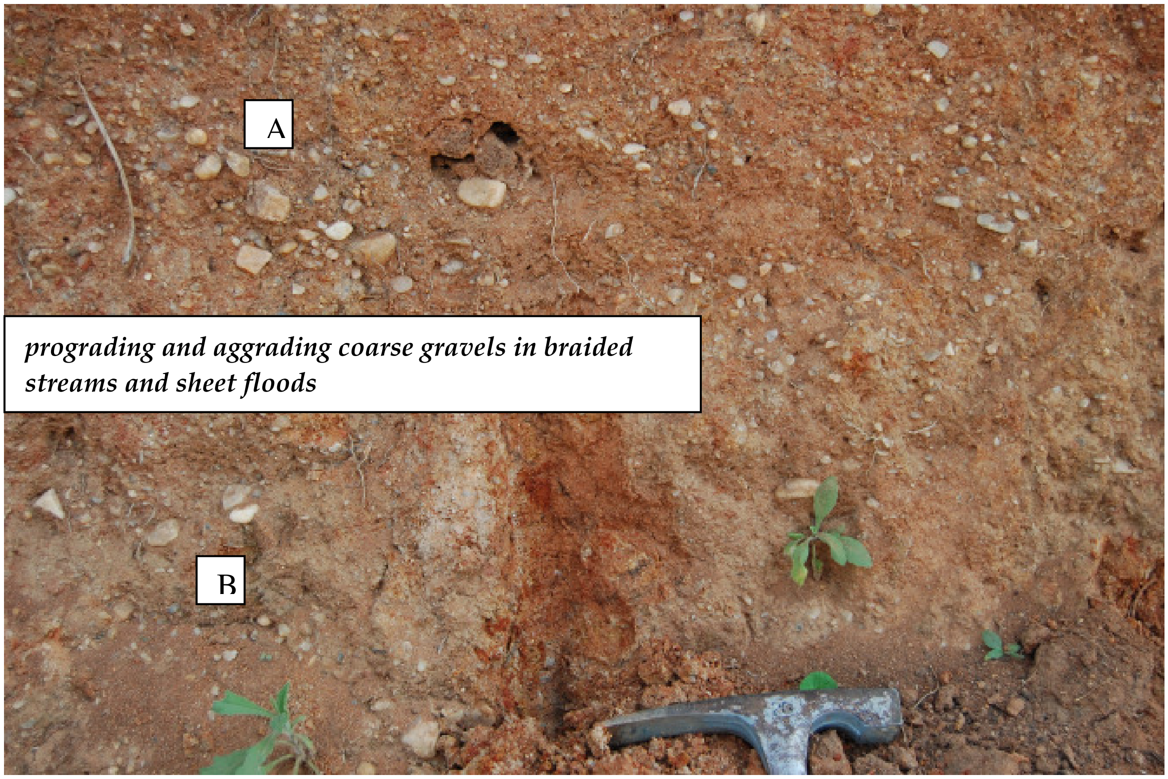


Figure 4. 3. *Lithofacies B at the base, passing up into higher energy Lithofacies A deposits. Both suggest proximal depositional environments on the fan lobe.*

4.1.3 Lithofacies C

Lithofacies C is clearly distinct from lithofacies A and B in a way that it displays sedimentary bedforms and structures. These include dune cross-bedding. Due to differences in scale of sedimentary structures and bedform scale, it is worth dividing lithofacies C into two subfacies i.e. C^{1} and C^{11}. These reflect differences in depositional environments.

Generally, lithofacies C is moderate reddish brown to dark yellowish, friable and porous, medium to coarse, well-sorted quartz sand typically exhibiting dune cross-bedding with infilled rootlets or bioturbation.

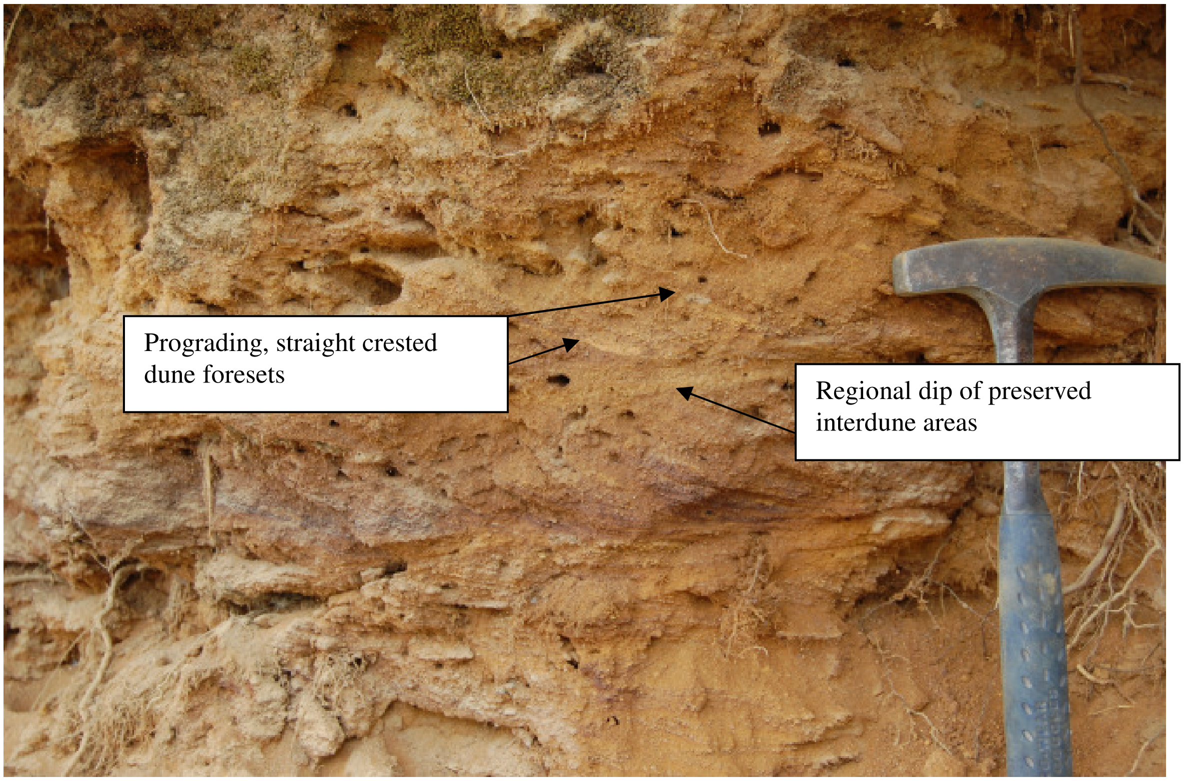


Figure 4. 4. ***Typical 'Lithofacies C¹' moderate reddish brown to dark yellowish orange, friable and porous, well-sorted and rounded quartz sands. Shown here are aggrading point bar fore-sets of medium grained quartz sands (Nicholas et al 2008).***

Subfacies C^1 represents fluvial channel dunes, point bars and crevasse sprays while subfacies C^{11} represents thick sheet flood deposits.

Compositionally in the field, lithofacies C, is however, relatively uniform in being composed of moderate brown to dark yellowish orange, often very friable and porous, medium to coarse, well-sorted and rounded quartz sands.

Where relatively thin, small-scale lobes of cross-bedded sands of facies C^1 are exposed, they may represent the more distal, relatively localized coarse size fraction of overbank crevasse splay deposits. At other localities, low-angle fore-sets on a 20cm scale are more likely to indicate a more moderate energy within a confined channel and the lateral accretion surfaces on point-bar channel sands (Boggs, 2006).

At several other localities across Block 4B, local sand quarries have been excavated into thick, tabular bodies of lithofacies C, such as at Kirurma and Bwambara.

The quarry walls will typically show stacked cross-sets on 0.5 to 1m scale probably representing moderate to high energy sheet flood deposits composed of straight-crested sand dunes.

In some cases, thick sheets of these sands can be seen to converge against each other, suggesting that the prograding edges of these sheets are lobate.

The difference in scale of bedforms and structures within facies C is in contrast to the majority of fluvial and alluvial exposures in Block 4B. Lithofacies A and B, though represent fluctuating water energy during deposition, with periods of non-deposition and palaeosol development, they do not tend to form massive, well sorted sheet sands.

Geochemically, there are differences in trace and rare earth elemental compositions between lithofacies C^{11} sands and other lithofacies. Lthofacies C^{II} in the area suggests a possible period of aridity possibly in mid Holocene. This would form a far reaching and very clear chronostratigraphic marker when dated in the future.

Figure 4. 5. ***Typical 'Lithofacies C^{II}' moderate reddish brown to dark yellowish orange, friable and porous, well-sorted and rounded quartz sands, with cross-bedding and plant rootlet infills.***

4.1.4 Lithofacies D

This lithofacies is composed of repetitively interbedded thin sands and clays. Quartz sands are fine to medium, but grains can go down to silt. The clays are bluish grey mottled with brown to pale yellowish orange clays and have a minor component of fine quartz sand dispersed within them. This lithofacies represents low-energy distal channel pointbar sands or overbank crevasse splay fine sands and silts, interbedded with interchannel sandy clays deposited from stagnant water. The characteristics of this facies may indicate inter-channel or flood plain deposition of fine sediments (clay and silt) settling out of suspension interbedded with crevasse-splay deposits (fine sands) where rising flood waters breach natural levees (Boggs, 2006).

Figure 4. 6. ***Typical 'Lithofacies D' composed of silts to fine/medium sands interbedded with thin, light bluish grey sandy clays***

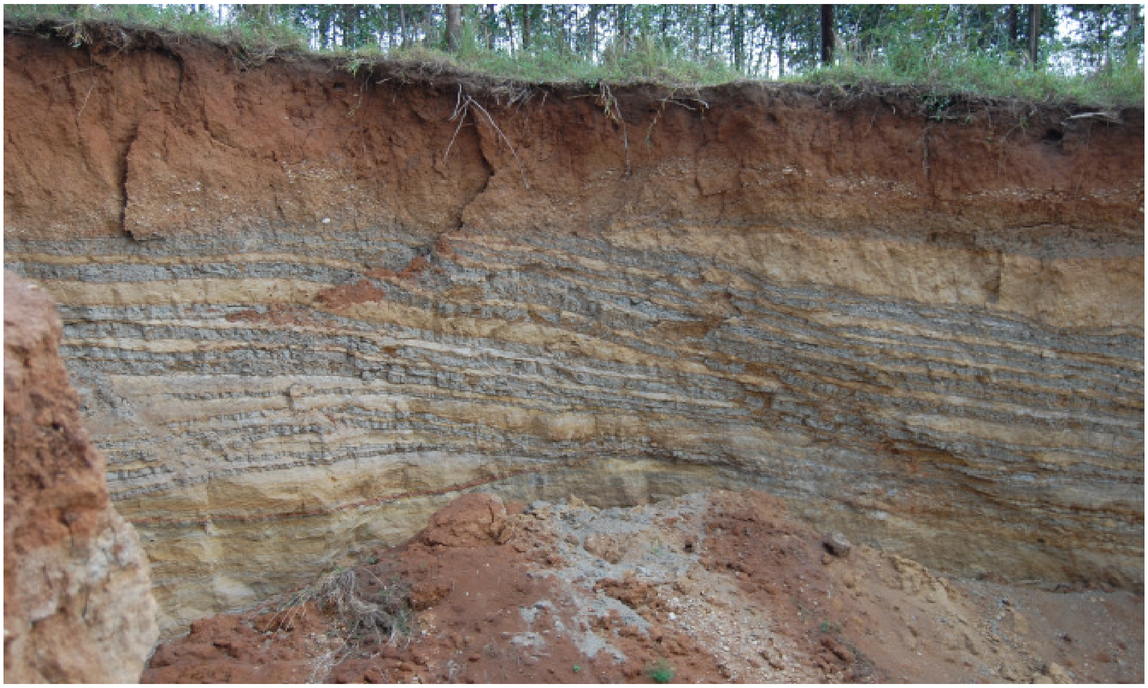


Figure 4. 7. ***Lithofacies D overbank crevasse-splay or relict distal sheet flood deposits out into the flood basin off the lobe toe.***

4.1.5 Lithofacies E

This lithofacies is composed of bluish grey or olive grey clays with medium quartz sands and plant debris.

This lithofacies represents the lowest energy depositional environment. It forms laterally continuous, metre-thick, units of massive clays with infilled plant rootlets and palaeosols. This facies represents very low energy to stagnant water environment in flood basin areas distal to the distributary lobes or in wide inter-channel areas on the distributary lobes. The presence of plant rootlets/debris is a characteristic for most flood plain deposits (Boggs, 2006). Palaeosol members represent periods of non deposition and subaerial exposure when flood waters recess.

Figure 4. 8. *Typical 'Lithofacies E' composed of thick, sandy, mottled light bluish grey clays (Nicholas et al 2008)*

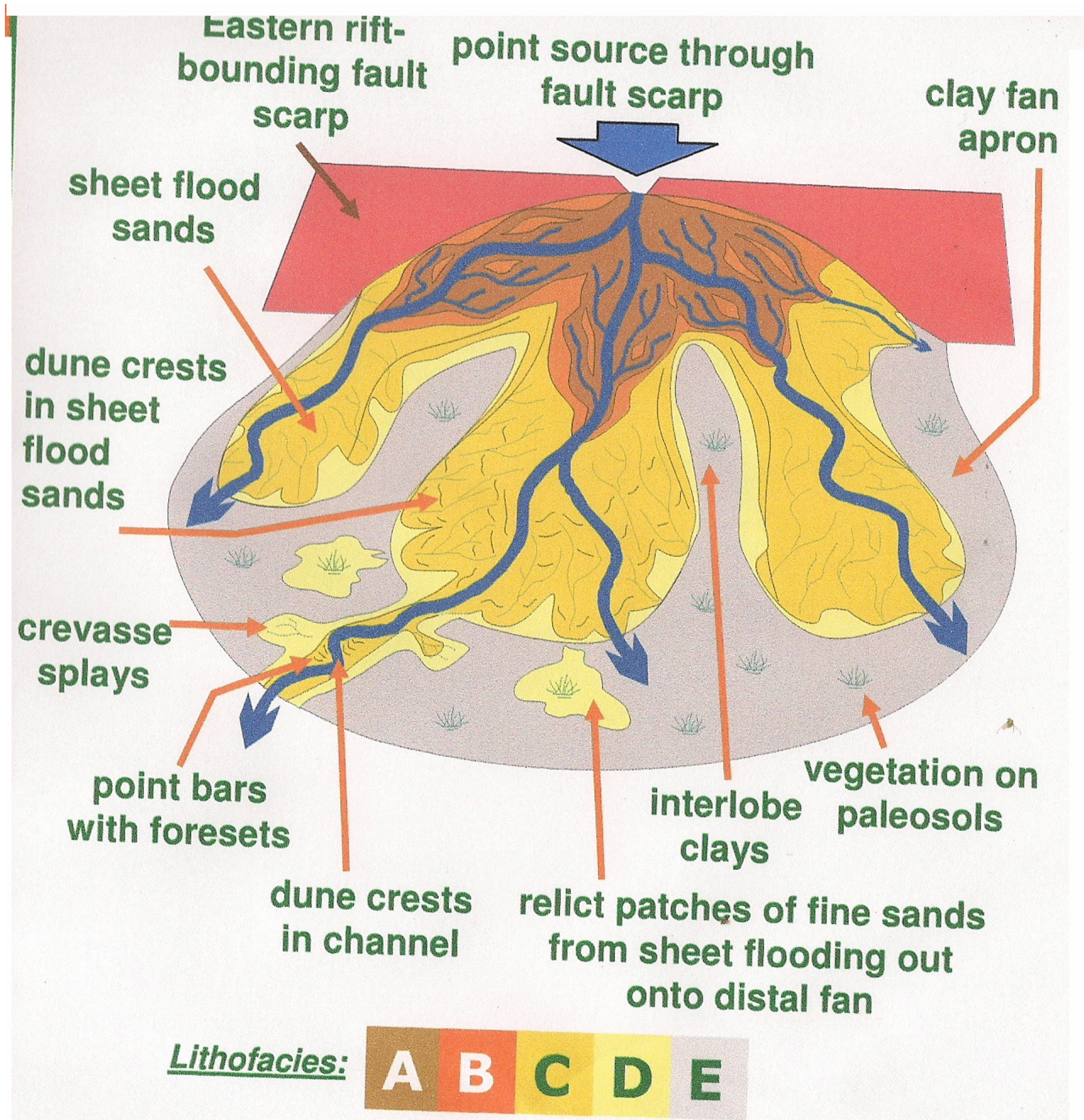


Figure 4. 9. ***Conceptual model showing relationship between lithofacies and corresponding depositional environments***

4.2 Palaeo-Alluvial Fan Complexes

The exposed sediments within SE Lake Edward Basin are dominated by alluvial fans and fluvial distributary fan complexes. These emerge from the rift margin south and southeast of the study area (onshore Block 4B). Five main fan systems were recognized in the field and include; Butogota, Katete (including Kambuga outlier), Nyamirama, Bwambara and Rushaya (figure 4.10). The palaeocurrent directions indicate that these fans prograded northwards from Butogota, northwestwards from Katete, Nyamirama, Bwambara and Rushaya.

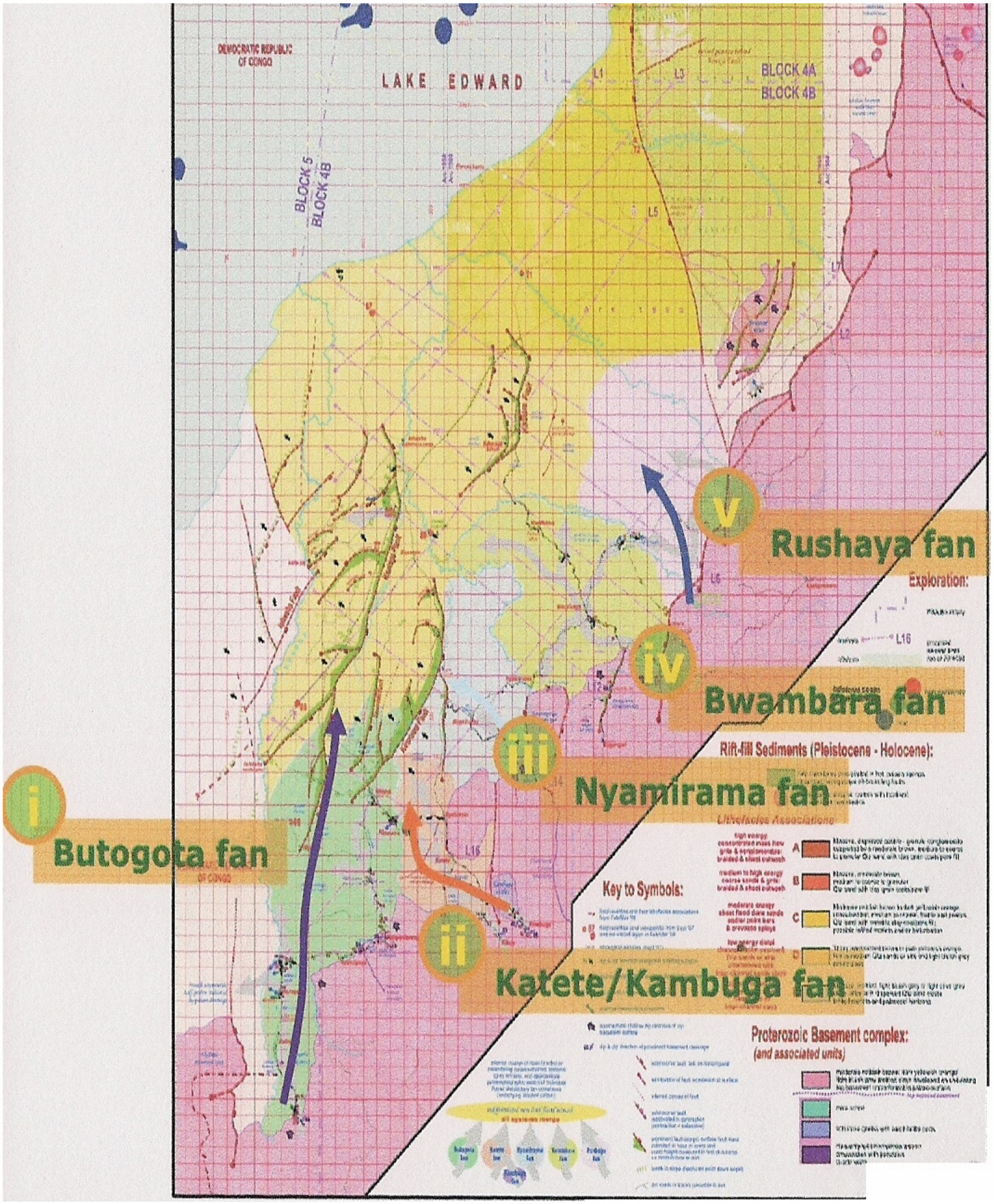


Figure 4. 10*. Map showing alluvial fan complexes in the study area*

These fans merge towards the Lake Edward and stop against KKK-FZ which marks the boundary between them and alluvial plain of finer sands and clays exposed in the Queen Elizabeth National Park.

The finer sands and clays exposed in QENP seem to be representing the footwall of the older formation that was affected during the development of KKK-FZ. This would, as it is the case at the moment, clearly show that there are essentially two kinds of formal stratigraphic units exposed in the onshore Block 4B.

The first one of the two is represented by these finer sands and clays in QENP near the shores of Lake Edward. Here it means that the hanging wall gets buried under Bwambara Formation as one goes towards the rift margin in the SE or East.

The second one is represented by the clearly exposed palaeo-alluvial fan systems that are seen to drain the rift edge in the SE and E of the basin. These are termed Queen Elizabeth and Bwambara Sequences respectively in this research (See section 4.3).

These fans are dominated by the five main lithofacies as already stated above. The five main lithofacies and facies associations within these fans operated at a much higher resolution than just recognizing formations were found to be more flexible in recording small changes in lithology.

In the field, these lithofacies are observed to fit a relatively simple spatial model that agrees with that of Nicholas *et al* (2008). In this model, lithofacies A is deposited near the mouth of the fan (where the canyon feeds the fan), lithofacies B is deposited immediately after lithofacies A, lithofacies C is deposited next to facies B downstream while lithofacies D and E are deposited far down stream (distal ends of the fan) of the fan. The gradation along the fan is the same as that one across the fan whereby sediments fine away from the channel (stream).

4.2.1 Recognition of alluvial fans in the field

Initial recognition that palaeo-fan lobes were present was made in the field because of the interplay between modern day topography, drainage and the pattern of Lithofacies exposure. It became apparent during the field surveying, that modern roads and tracks typically followed the high ground along the crest of hills. Along the margins of these tracks intermittently exposed coarse sands, grits and conglomerates were commonly observed. However, as a track dipped down the front or sides of a hill, the lithofacies changed into finer sedimentary units, with clays usually exposed around modern day river level between hills and never on their summits. Thus palaeo-fan lobe complexes form, in effect, exhumed topography which influences modern day drainage.

The present day drainage is observed to wrap around these hills and incise between them. Many of these modern streams are misfit, occupying very large valleys issuing from the basement edge. This identifies the possible point source over the rift border faults for particular palaeo-fan complexes (as shown on the accompanying geological map).

These observations combined suggest that palaeo-fan lobes with something of their original topography are exposed along the basement edge to the south-east Lake Edward Basin, effectively providing the palaeo-topography around and over which modern misfit drainage is superimposed. The incision into the toe of these lobes by modern streams is particularly interesting as it indicates a very recent relative base level fall out in the Lake Edward basin, or minor inversion of this area. There are structural reasons, outlined below in Section 5, for favouring the latter.

4.3 Lithofacies stacking patterns

Most exposures throughout the SE Lake Edward Basin were observed to be too small to display more than one of the main lithofacies. Never the less, in the more extensive road cuts, river cliffs and erosion gulleys, the interaction between lithofacies can be observed in more detail. Lithofacies A and B are closely related. The distinction between them is grain size and thus a consequence of transportation energy. In high energy braided stream and sheet flood deposits, both Lithofacies A and B can be observed to prograde and aggrade, and laterally pass into each other. Elsewhere, the interplay of lithofacies can sometimes be seen to switch abruptly between high and low energy depositional environments, with pebble conglomerates immediately interbedded between thick clay beds. Some exposures of pebble conglomerates overlain by clays demonstrate that syn-depositional loading of the underlying clays by the conglomerate horizons caused them to undergo minor slumping prior to subsequent burial.

From well logs drawn using uphole lithofacies descriptions, it can clearly be seen that lithofacies change abruptly both vertically and laterally. Bearing in mind lithofacies mixing during uphole sample collection, it can bee seen that sedimentary layers rarely exceed 30m thick and extend up to around 2km in length. Lateral correlation of these logs seems not achievable due to gaps in vertical section. It is hard to tell whether the missing section belongs to the layer above or immediately below it (see appendix 5). Lithofacies C forms the thickest beds compared to other lithofacies. This shows the presence of thick reservoir intervals in the area.

Figure 4. 11. ***Typical intergradation of Lithofacies A and B in a graded sheet flood unit composed of pebble conglomerates deposited in poorly defined braided channels, and coarse sands to grits deposited inbetween them. Note the lack of clear confining channel***

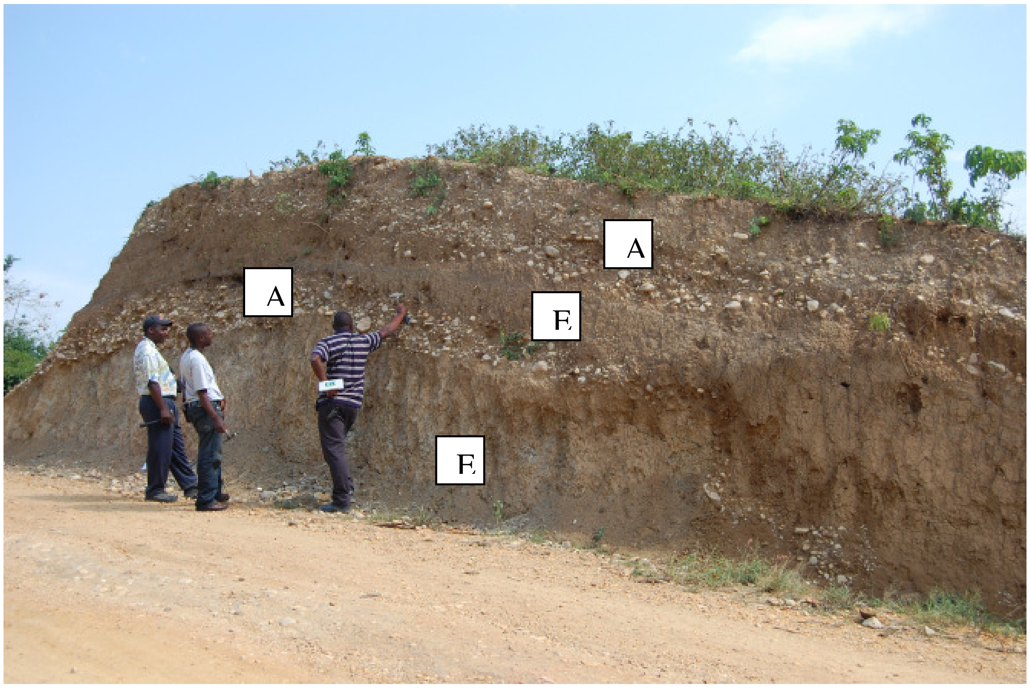


Figure 4. 12*. Oblique road cutting through a small distributary lobe which still exhibits its original palaeotopographic relief. Note the syn-depositional clay slumping outwards from the toe of the lobe.*

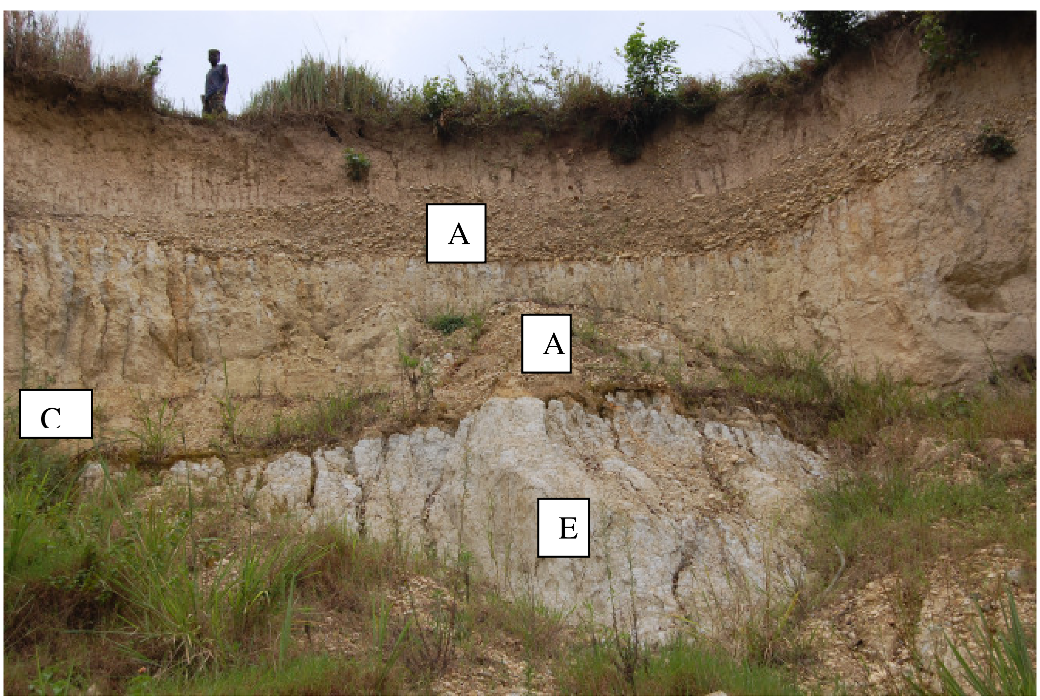


Figure 4. 13*. Thick clays of lithofacies E overlain by lenses of channel pebble conglomerate which pass laterally into cross-bedded point bar sands of lithofacies* C^{II}

4.4 Lithofacies progradation and aggradation

At some localities lithofacies progradation and aggradation are evident for instance at Kiruruma sand quarries (Fig 4.14). Here small sigmoidal clinoforms of lithofacies D, intebedded fine sands and clays, can be seen to form a prograding and gently aggrading wedge in the cliff face.

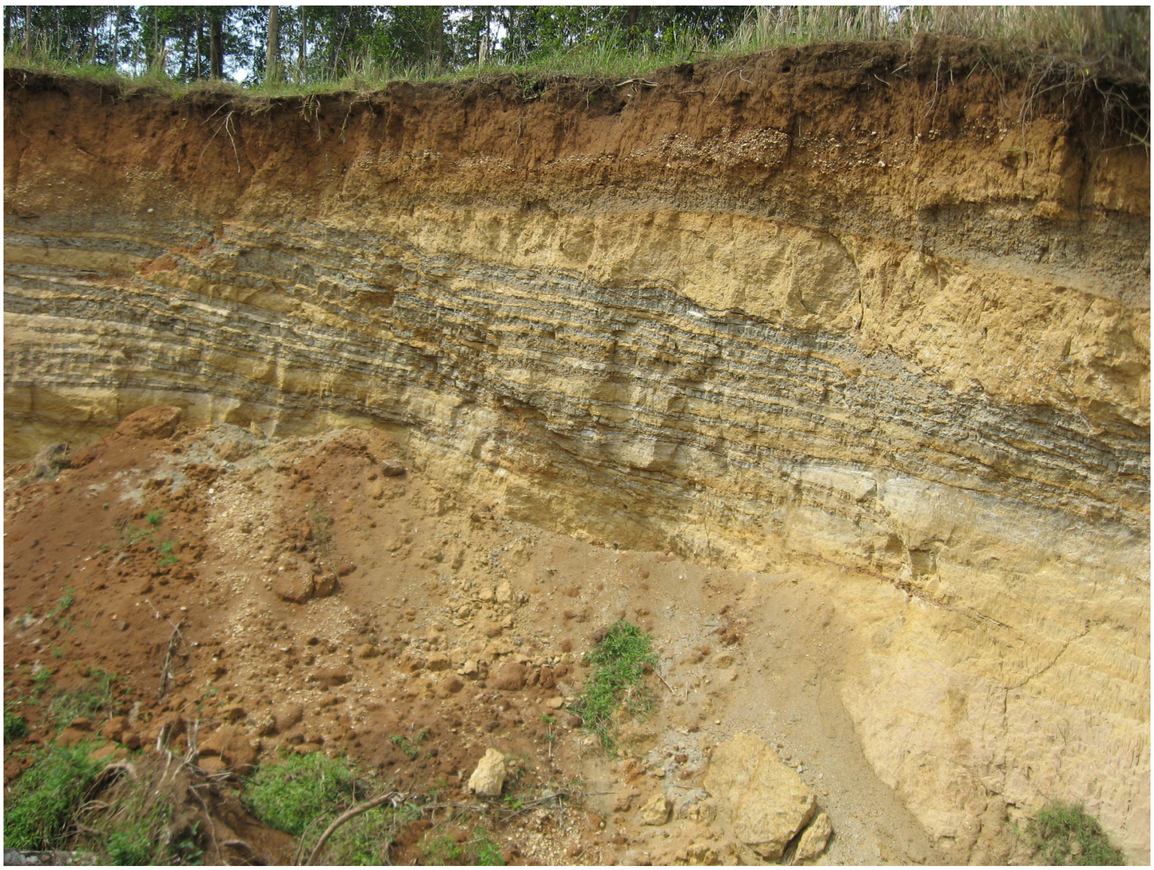


Figure 4. 14. *Prograding lobe clinoforms of Lithofacies D in the Kiruruma sand quarries.*

4.5 Provenance of Sediments and their Composition

4.5.1 Mineralogy and XRD Analyses

From XRD Analyses, two broad categories of samples are recognized, that is, clay rich and clay poor samples. The clay poor samples are quartz sand dominated while clay rich samples are poor in quartz sand.

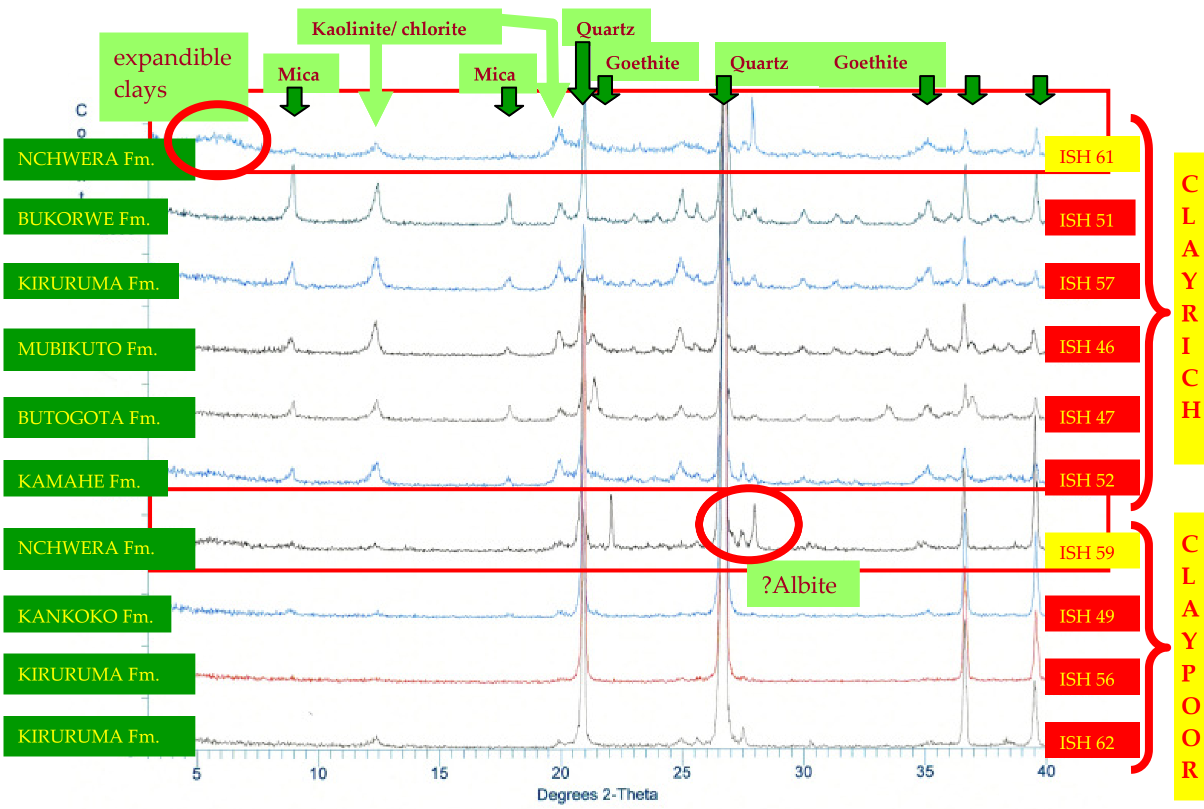


Figure 4. 15. *XRD traces for samples taken from a mixture of formations in Block 4B. The plots have been arranged into two distinct groups; clay rich and clay poor. No further mineralogical differences exist except for the presence of albite and expandible clays in samples from the Rwempunu (Nicholas et al, 2008)*

Facies A-C (quartz sand dominated) are recognized on XRD plots as clay poor subsets while D-E are recognized as clay rich subsets. There is exception on the homogeneity within both clay rich and clay poor subsets. Samples from Rwempunu River showed additional peaks from the rest of the samples.

Results from these datasets demonstrate very little differences in mineralogy between samples.

4.5.2 Major element concentrations

Discrimination diagrams using major elemental ratios were drawn such as SiO_2 versus K_2O/Na_2O. From this diagram three data sub-sets are identified.

Massive clays of lithofacies E from Butogota, Kiruruma and the Rwempunu River have low silica contents with moderate K_2O/Na_2O ratios. Remaining samples from the Rwempunu River have low K_2O/Na_2O ratios and high silica contents. The most striking data sub-sets are samples of lithofacies C^{II} from Kiruruma, Bwambara and Butogota. These samples have both high silica contents and relatively high K_2O/Na_2O.

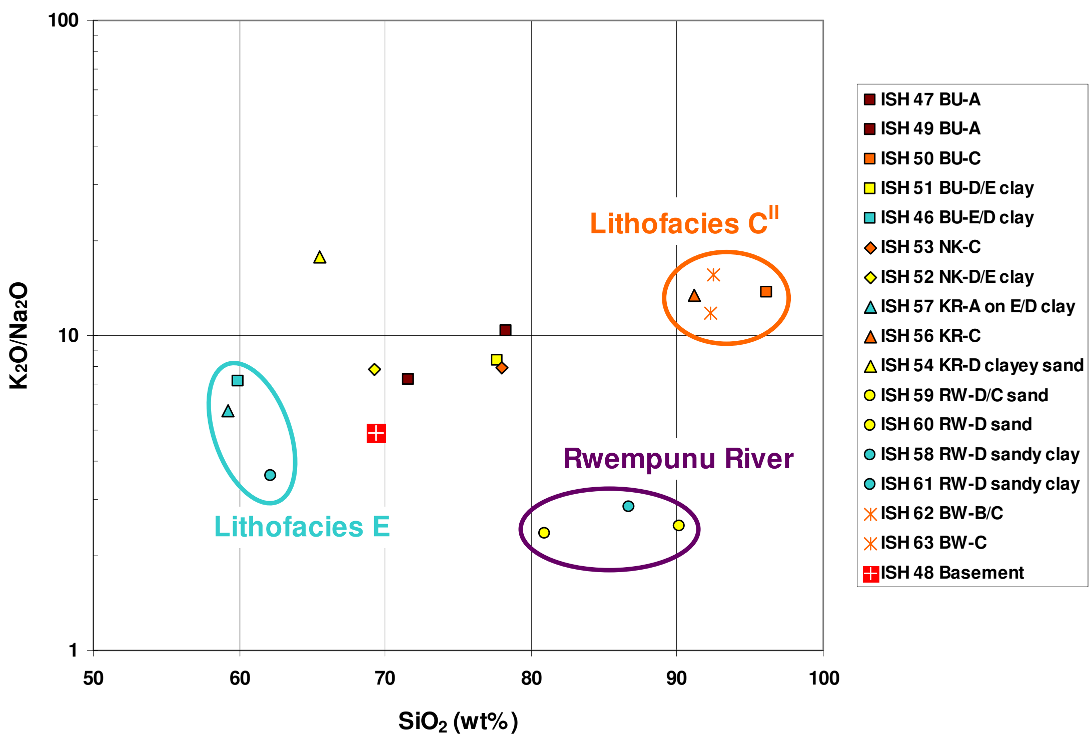


Figure 4. 16. *Major element concentration plot of K_2O/Na_2O ratios vs. SiO_2 (wt%). This helps highlight compositional differences between Lithofacies E clays, Rwempunu River samples and well-sorted Lithofacies C^{II} sands from a variety of localities. Note that symbols indicate sample localities, which are abbreviated: BU; Butogota, NK; Nkunda, KR; Kiruruma, RW; Rwempunu River, BW; Bwambara, whereas colours denote Lithofacies type: blue; E, yellow; D, orange; C, brown; A. (Nicholas et al, 2008)*

From the above plot, it can be seen that clay rich samples are discriminated as low silica and low K_2O/Na_2O sub dataset. Clay poor samples (well sorted sands) are discriminated as relatively high silica and high K_2O/Na_2O sub dataset. However Rwempunu sands and clays plot in the same area with low K_2O/Na_2O and moderate silica. Also noted is that lithofacies A from southeast of the study area plot nearly in the area as basement sample which was collected a few metres away (centre of the plot).

Another discrimination diagram of the ratio of alumina to silica against ferro-magnesian concentration was drawn to show the proportion of quartz to mica and clay content.

From this diagram, it can be seen that massive sandy clays of lithofacies E contain higher alumina and less silica, and form an end-member data sub-set with high ferro-magnesian contents. High silica to low aluminium ratios of Lithofacies CII samples are also accompanied by low ferro-magnesian concentrations, forming the other end-member sample population. On this plot, Rwempunu samples are less separated from the main data-set, but tend towards the well-sorted sand end-member of Lithofacies CII.

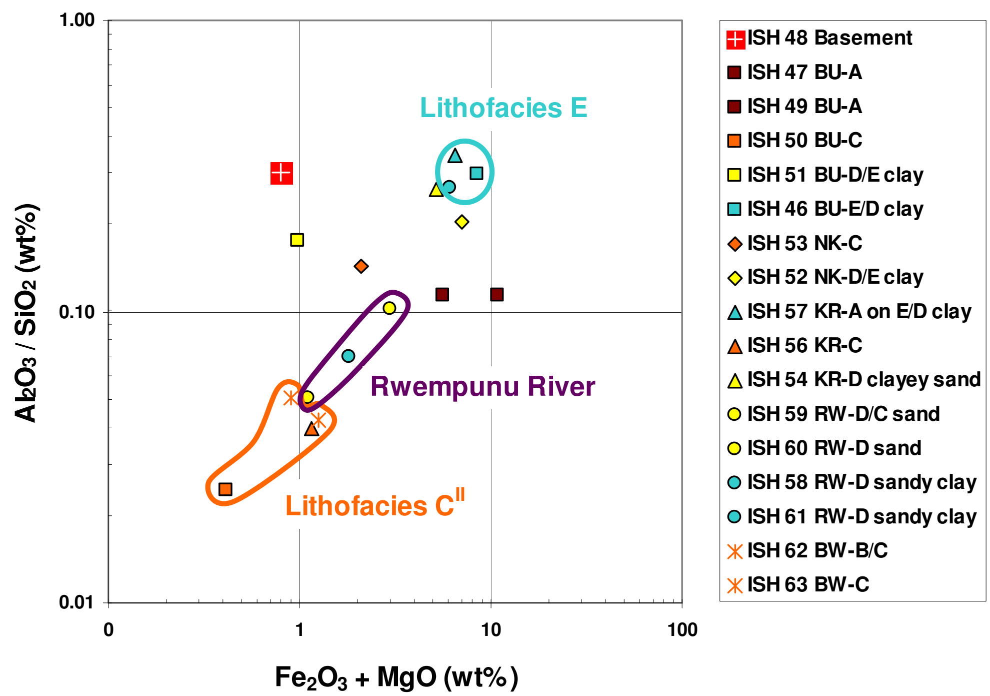


Figure 4. 17. *Major element concentration plot of Al_2O_3/SiO_2 ratios versus ferro-magnesian content (wt %). Again, this helps highlight compositional differences between grain size and sorting end members such as Lithofacies E clays and well-sorted Lithofacies C^{II} sands (Nicholas et al, 2008)*

Another similar diagram, this time, substituting total calcium plus sodium for total calcium plus sodium for silica, shows that Lithofacies C^{II} and Rwempunu River samples again form sub-sets from the main data, thus emphasising again their major elemental compositional differences from the bulk of samples.

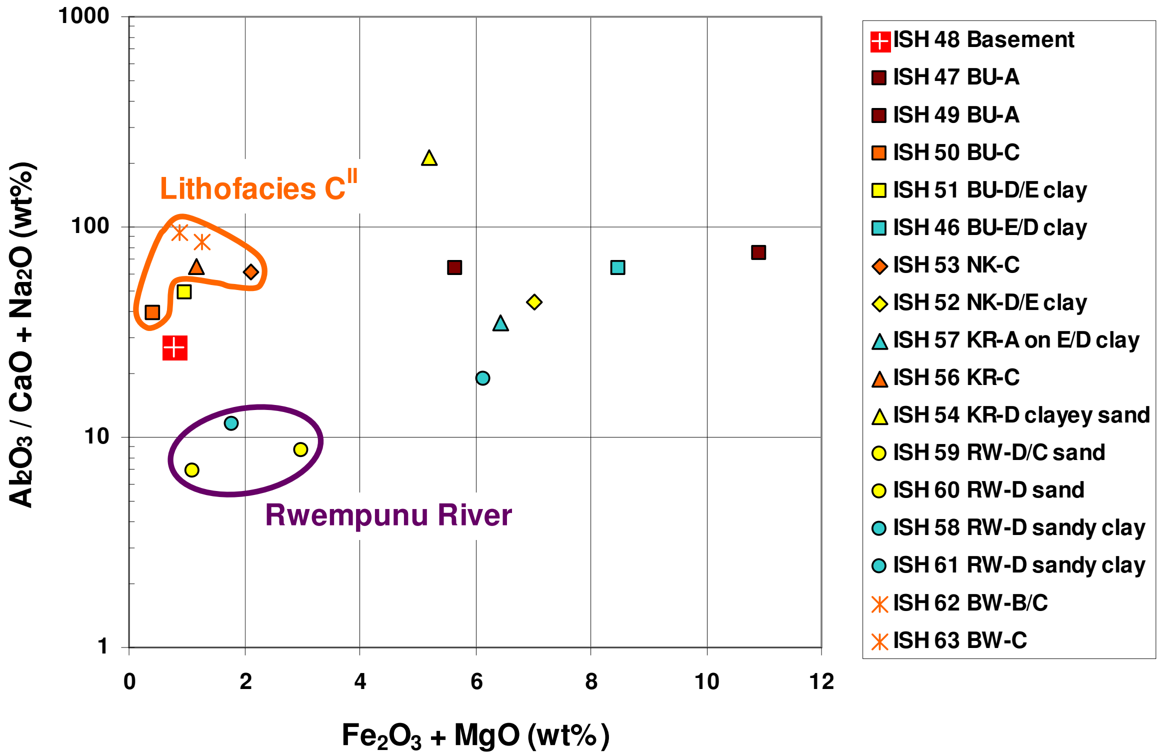


Figure 4. 18. *Major element concentration plot of Al_2O_3/CaO + Na_2O ratios versus ferro-magnesian content (wt %). Most Rwempunu samples and Lithofacies C^{II} sands again form sub-sets away from the remainder of the data (Nicholas et al, 2008)*

4.5.3 Minor and Rare Earth Elemental concentrations

In order to compare the samples for their elemental compositions, data were normalized to upper continental crust and NASC. This allowed the researcher to elucidate how different or similar the samples are, and whether they have been depleted or enriched with respect to the bulk continental crust. In this study, samples were also normalized to a basement sample since the sediments are assumed to have been sourced from a similar basement in the south and southeast of the basin. In this way one would clearly see the similarities or differences between sediments in different localities, and how they have been enriched or depleted in these elements with respect to the basement which is the source of sediments.

Discrimination diagrams emphasizing Rare Earth Element concentrations were typically employed as spider diagrams in order to elucidate the geochemical differences between the provenance of the sediments. From the spidergram below, it can be seen that in Butogota, the conglomerates of facies A are not significantly depleted in REE with respect the upper continental crust and plot alongside both clays and sands of the same area. Clays have the ability to incorporate REE in their crystalline structure and/or adsorb REE onto their surfaces and thus typically carry the bulk of REE.

This geochemical similarity between these fine sediments and conglomerates suggest the conglomerates of Butogota are immature, with little winnowing and washing away of fine sediments (matrix), and might be close to the source.

Again on this plot, sands of lithofacies C^{II} in this area are significantly depleted in REE compared to the rest of the lithofacies. This may indicate that either these sands are sourced from a different basement terrain or the source was the same but they were deposited in a different energy system and thus underwent significant winnowing and recycling before final deposition.

In the plots below, Nkunda sands of lithofacies C^{I} are partly enriched and partly depleted in these elements. This again presses the need to divide lithofacies C into two subfacies. From figures 4.16 c-e, it can be seen that sands of lithofacies C^{I} further north of Butogota at Nkunda school have a different spidergram from the rest of the sands from Kiruruma and Bwambara sand quarries. This is also a geochemical evidence for subdividing lithofacies C into two.

Rwempunu clay samples show a different spidergram from the rest of the clays. Lithofacies D and C sands and clays from Rwempunu show a different spidergram pattern from the rest of the localities. This is because of one of the two factors. Since Rwempunu samples were collected far north, it may be that these sediments were sourced from a different basement provenance. Alternatively, since they are close to Bunyaruguru volcanics, there may be admixture of these sediments with the volcanic ash.

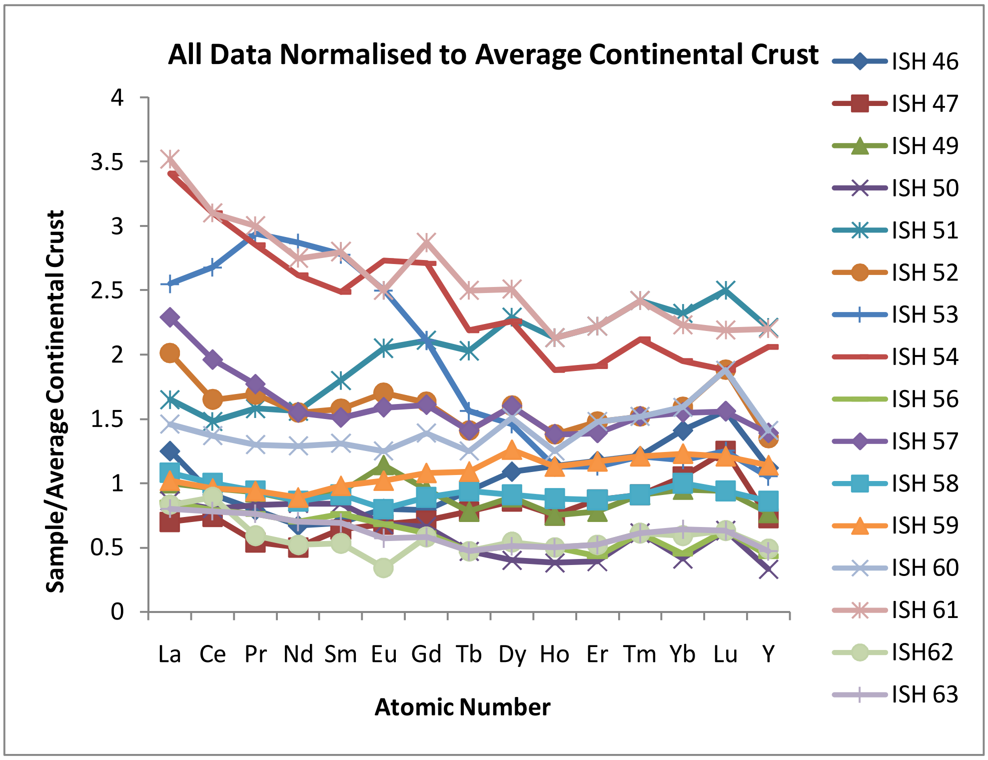
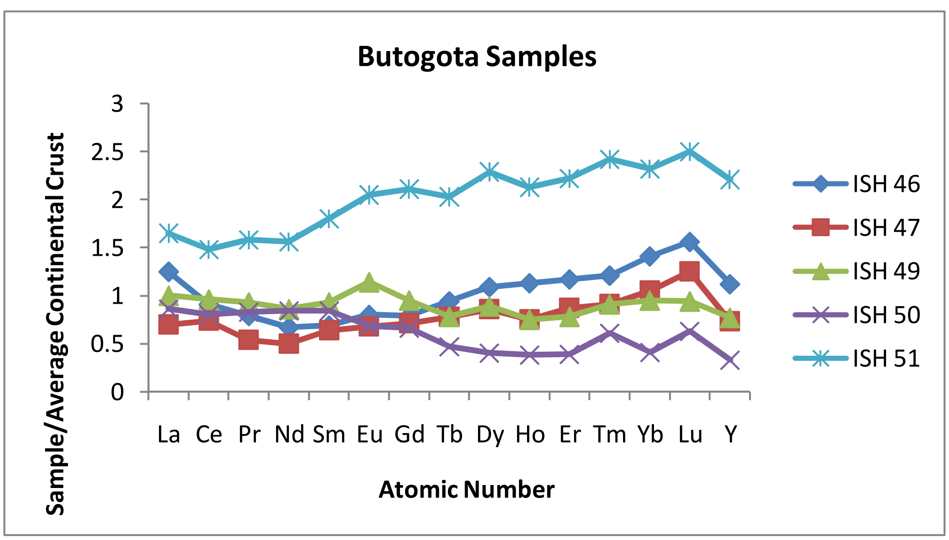
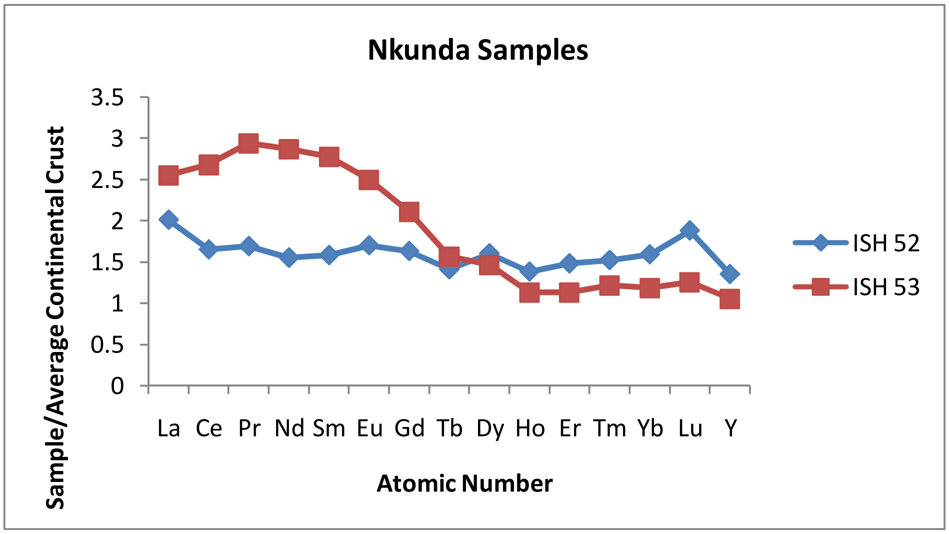


Figure 4. 19*. a) All data normalized to BCC plotted against REE*

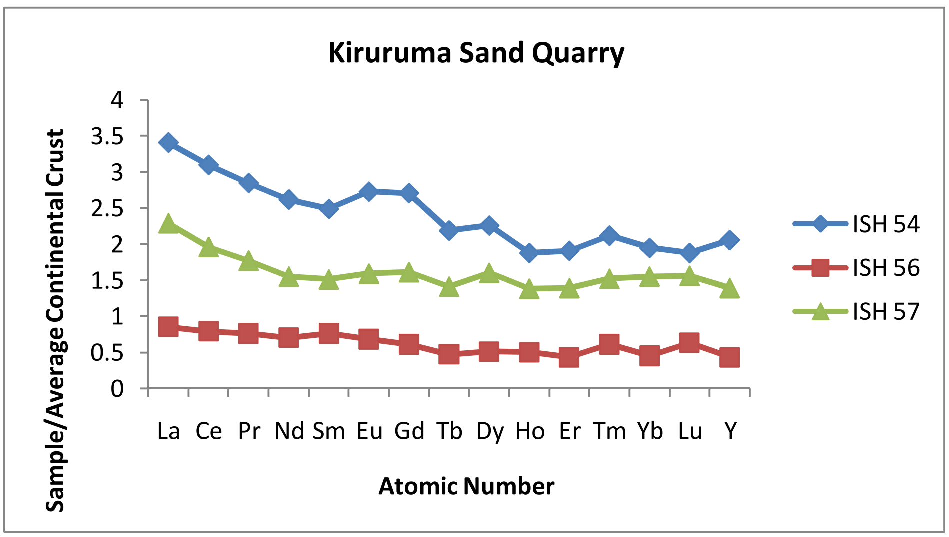
b) Butogota samples



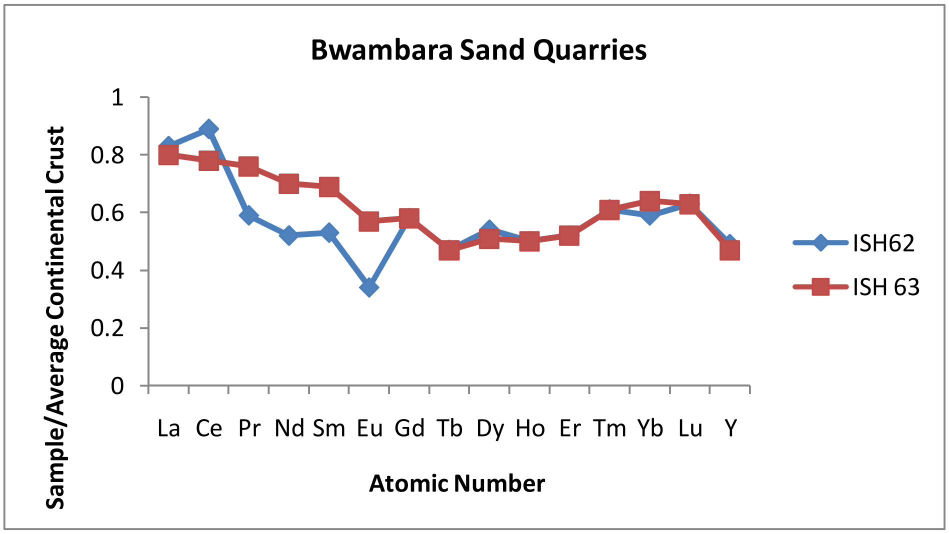
c) Nkuda samples



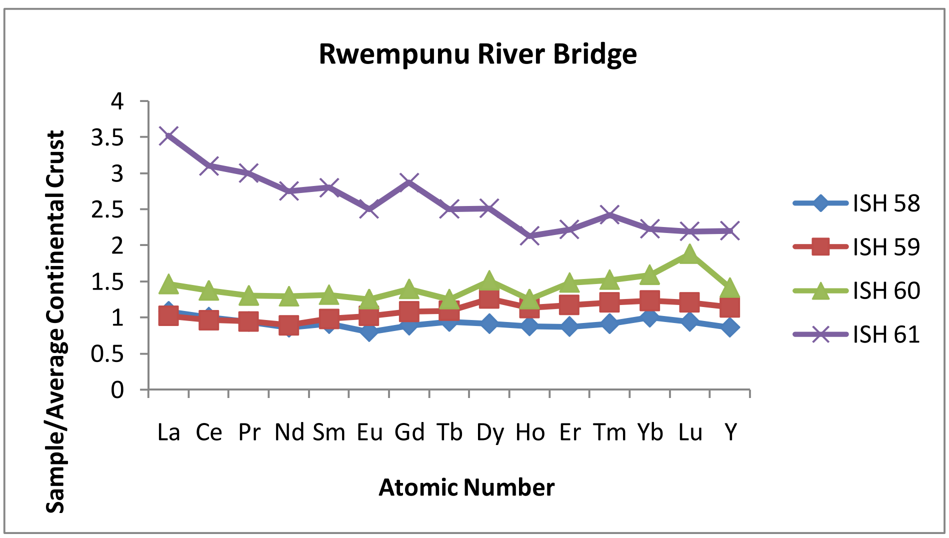
d) Kiruruma sand quarry



e) Bwambara sand quarries



f) Rwempunu River Bridge



Trace element concentrations in sedimentary rocks are usually normalized to a sedimentary standard such as average post-Archean shale and NASC (North American Shale Composite), representing average crustal material. This helps in studying the processes controlling trace element composition of sediments. Figure 4.20 a) is a spidergram showing the pattern of the various minor and REE compositions with respect to the average crustal material.

In this plot, pebbly conglomerates and clays of Butogota ebayment show relative depletion in Hf, La, Ni and Co, and enrichment in Zr, Ta, and Th with respect to NASC. Butogota and Nkunda clays and fine sands of lithofacies E and D show significant enrichment in Ta and Co and significant depletion in Ni. Rwempunu clays and fine sands still show relatively different patterns compared to the rest of the areas. Again, Bwambara and Kiruruma sands show different patterns from sands of Nkunda exposures. This is still due to the difference in depositional environments of lithofacies C^{I} and C^{II} . This adds more evidence on the fact that lithofacies C has subfacies C^{I} and C^{II}.

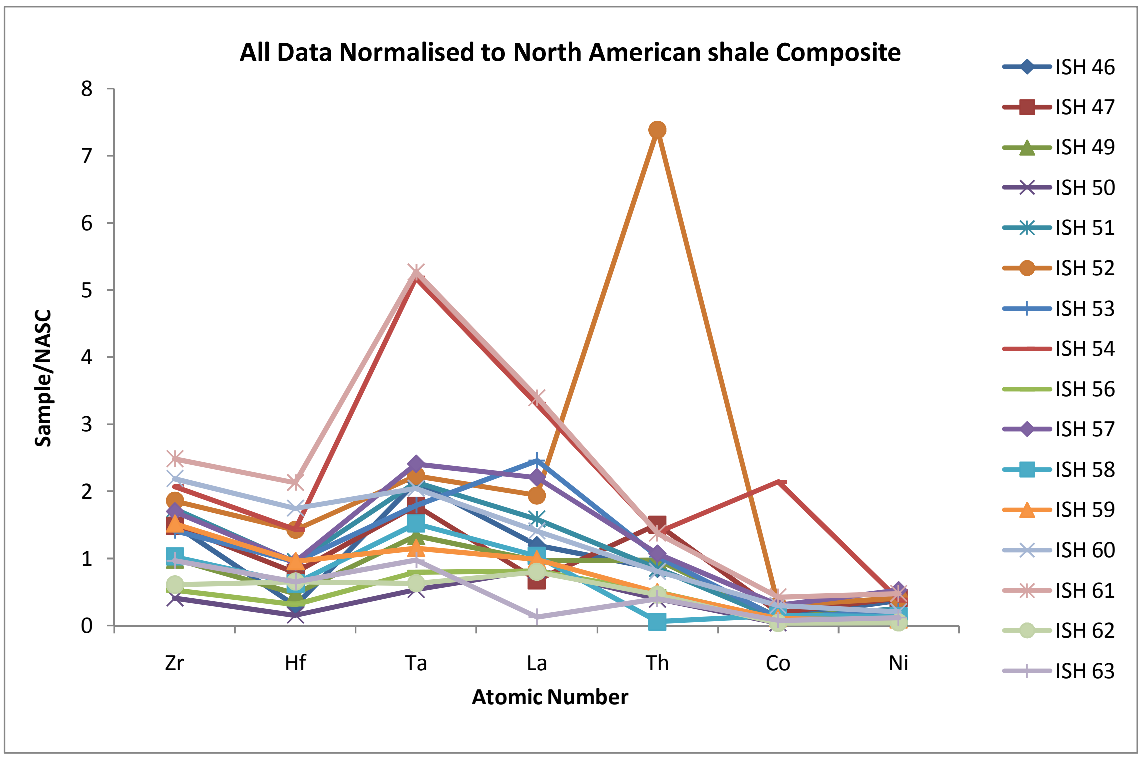
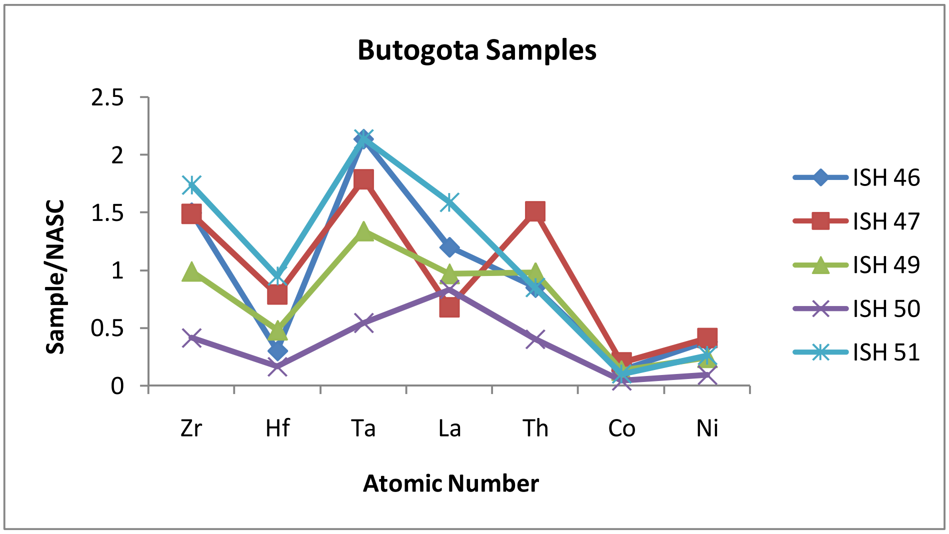
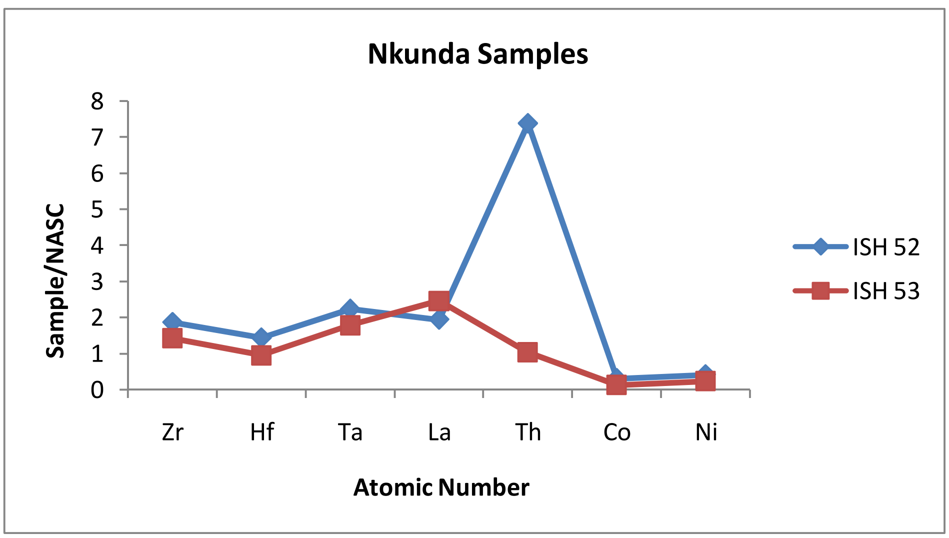


Figure 4. 20.*a) All data normalized to NASC plotted against various minor and trace elements*

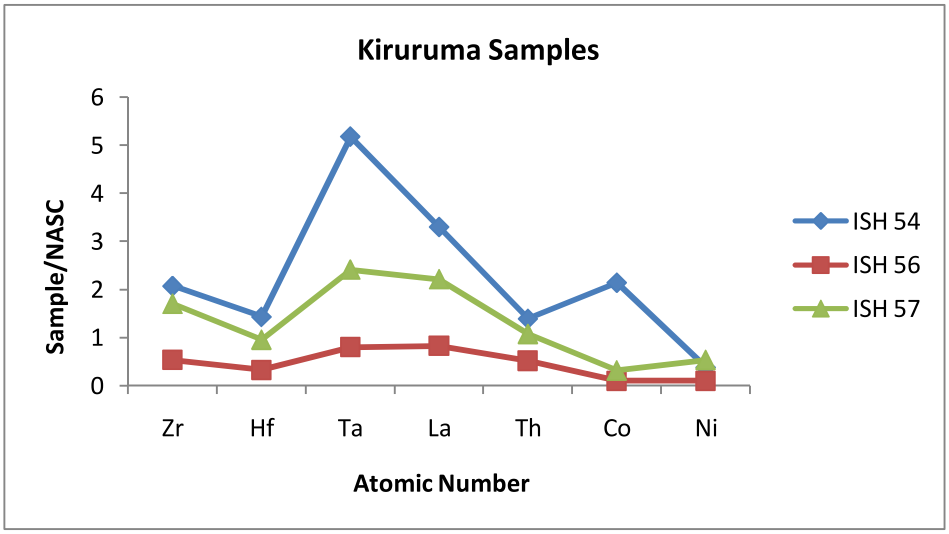
b) Butogota samples



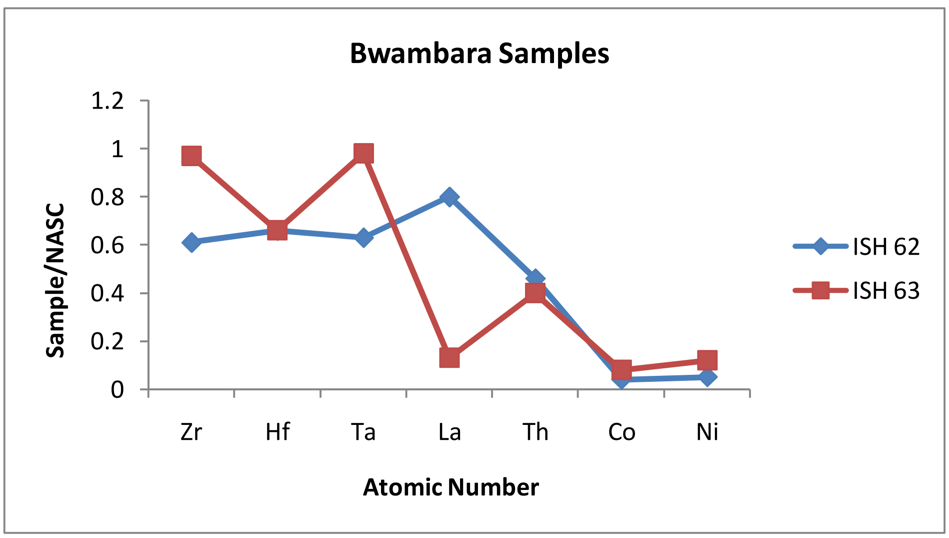
c) Nkunda samples



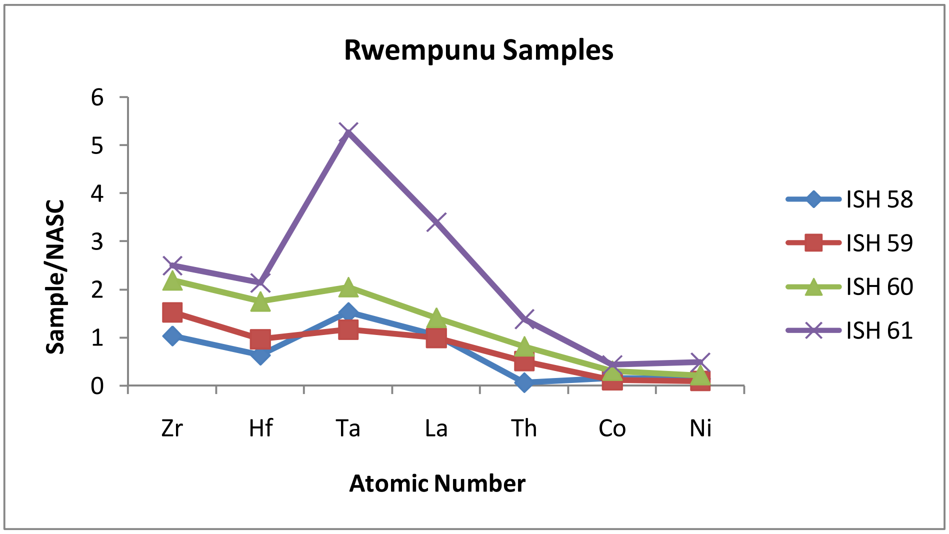
d) Kiruruma samples



e) Bwambara samples



f) Rwempunu samples



XRD traces and major, trace and rare earth elemental concentrations showed that there is no major difference in sediment composition from the study area. Porous sands of lithofacies C generally show depletion in rare earth elements compared to the rest of the samples. This probably shows higher degree of sorting and reworking possibly from flash flooding in a more arid phase.

Rwempunu samples showed additional peaks possibly from albite and expandable clays. Given proximity to Bunyaruguru volcanics, it is possible that these sediments have an admixture of expandable clays and albite from weathered volcanics.

4.3 Structural Geology

4.3.1 Nature of the basement edge along the Southeastern Rift boarder

From current topographic maps and field results, it can be seen that the on shore 4B is structurally complex. Considering the south and southeastern rift margin, the basement edge can be divided into three zones.

The first zone is composed of a distinct and the most prominent fault scarp that can be found in the area. This is observed as a major west facing fault scarp just north of Bugangari township (figures; 4.21 and 4.22).

Figure 4. 21. ***Major, west-facing normal fault scarp along the eastern rift margin, north of Bugangari and south-east of Bikurungu.***

Zone one dies into zone two of rifted basement ramps including Katerampungu basement spur.

Zone three can be seen in the southern outskirts of Butogota and consists of shallowly dipping basement ramps unconformably overlain by shallow sediments that form the beginning of Butogota and Katete embayments. This zone continues to the DRC where it terminates into the east facing scarp of the Nkabwa basement spur (figure 4.22).

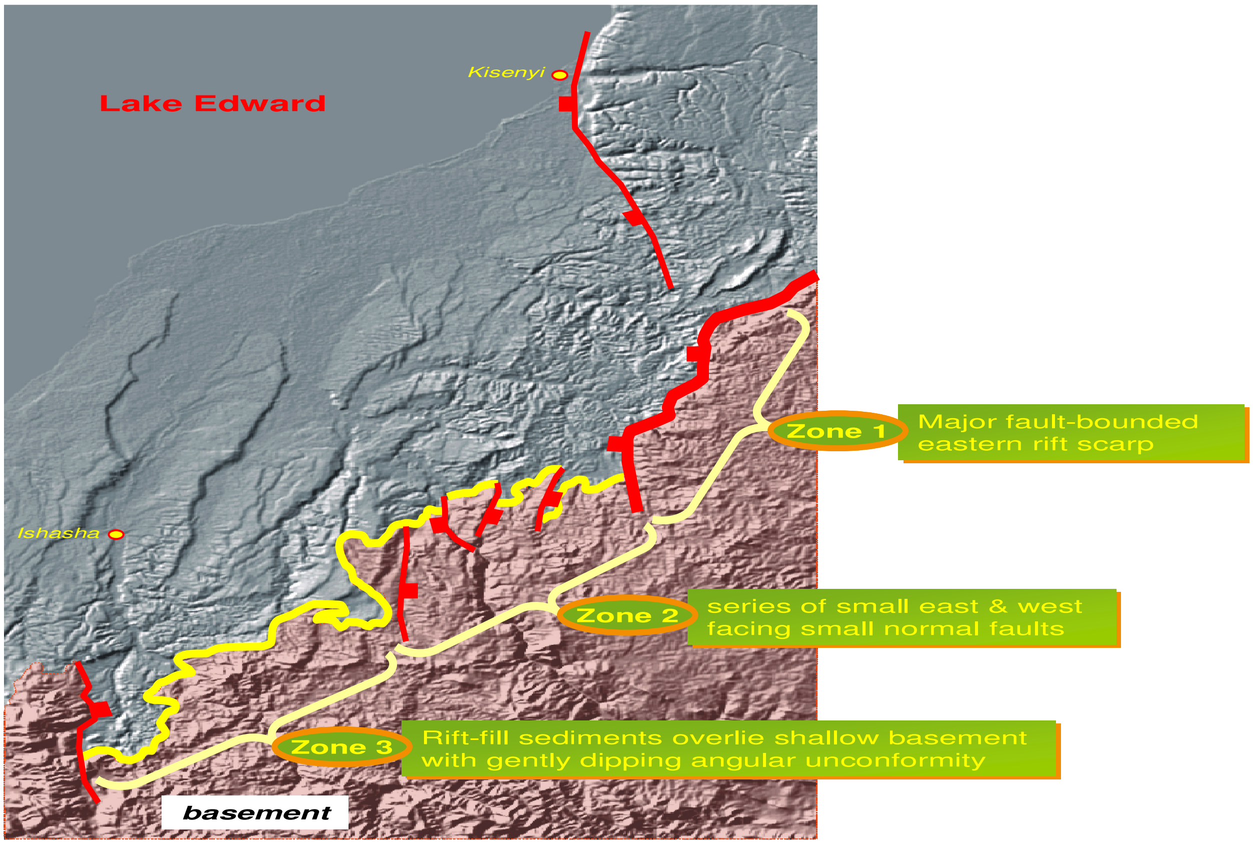


Figure 4. 22. ***DEM showing the changing structural style of the*** *basement edge along the eastern rift border in SE Lake Edward Basin (Nicholas et al, 2008)*

4.3.1 Structures in the SE Lake Edward Basin

In the entire block 4B (SE Lake Edward Basin), exposure becomes extremely poor. The vegetation is open, savannah grasslands of the Queen Elizabeth National Park (QENP). The topography is flat and level apart from abrupt changes in topography due to buried faults. Within this area, there are a series of NNE-SSW trending ridges, with prominent scarps along their ESE flanks but often they gently slope away to the WNW.

While driving the tracks in the area, one encounters several hills corresponding to the uplifted footwall of rotated normal fault blocks. Modern day topography is a direct reflection of the underlying structure in the SE Lake Edward Basin. This can be evidenced by observing the modern day drainage. Close to the south-eastern margin of the rift, streams wrap around fan complexes, however they become deflected along the front scarp of these NNE-SSW trending ridges, forming a trellised drainage pattern, and also flow as parallel drainage off the tops of these ridges down the WNW dip slopes. Three main NNE-SSW trending ridges and scarps were found. The longest was marked along the base of its scarp by the deflected course of the Kazinga River and thus can be referred to as the Kazinga Fault. A few kilometres south-east of this scarp is another fault scarp whose base is marked and followed by the Kiruruma River. On strike with this Kiruruma Fault approximately 7 km to the north-east is another scarp, on whose crest Kikarara School is located. Given their alignment, it is highly likely that the Kiruruma and Kikarara Faults are connected by a relay. Both faults strike parallel to the Kazinga Fault and it is logical to assume that they are related and originally formed during the same extensional episode. Thus, this is here, in this study, referred to as the Kazinga-Kiruruma-Kikarara Fault Zone (KKK-FZ). The main KKK-FZ scarps are linked with a series of minor fault scarps. These have trends which vary slightly around the main regional NNE-SSW axis. This is in agreement with previous workers' findings that the rift scarp is made up of several parallel normal faults (e.g Laerdal and Talbot, 2002).

Kiruruma Fault

The Kiruruma fault forms a prominent ridge to the north-east of Kihiihi town. It displays a crescent shape, with an average throw of about 61 m.

Like the Kazinga and Kikarara faults, it exhibits several antithetic and synthetic faults. Where these antithetic faults curve and join the main fault scarp, raised "pop-ups" developed. These are observed to appear in other areas of the KKK-FZ.

Kazinga Fault

The main road from the Ntungu River to the Ishasha DRC border post follows the crest of the uplifted and rotated Kazinga Fault footwall block. The scarp can be followed on the ground for ~22 km from a surface null point just north of the Ishasha Wilderness Camp to the southern outskirts of Ishasha village. The fault scarp attains its maximum height difference towards the centre, close to the summit of Nyamesi. At this point the front scarp is ~44 m high and combines with a second, small, south-facing fault scarp (~ 12 m high) striking in from the west to join it.

Thus the throw on the Kazinga Fault at its centre is ≥56 m). Within this fault, are expressions of the antithetic fault scarps which curve around the dip slope and join with the main front fault scarp.

There appear to be two sets of these antithetic faults, elevating the central 'pod' corresponding to the point of maximum throw on the main fault.

These observations, combined with those for the Kikarara and Kazinga faults, suggest that there is a common characteristic geometry developed in this fault zone.

In addition to smaller south, or south-east facing faults joining the main footwall ridge crest, at least two scarps were observed on the dip-slope and which were clearly north-west facing. These correspond to antithetic normal faults to the main Kazinga Fault, and are likely to join it further north as indicated on the map.

This characteristic of a small antithetic fault scarp being present on the dip slope of the main fault is observed again to the south with the Bukorwe Fault. This fault strikes north to join with the Kazinga Fault, and has a small but pronounced west-facing antithetic 'shoulder' on its dip slope. The effect is to have produced an elevated 'pod' in the centre of the ridge crest, striking with the main fault trend. To the north-west of the main Kazinga fault, a series of small, relaying normal and antithetic faults trend NNE in parallel with it. These produce only small scarps, typically with heights of ~10-20' (3-6 m). They are directly along strike of the large scarp across the DRC border to the south-west, and thus may correspond to the northern extremity of a dying major NNE trending fault along the Ishasha River.

Figure 4. 23. ***East facing fault scarp just near Ishasha wilderness camp a few meters west of*** *Kihihi-Kasese Road*

The Kikarara Fault

The Kikarara Fault has a slightly unusual trace at the surface. Whilst the Kazinga and Kiruruma Faults are gently crescent-shaped, the Kikarara Fault appears to have three sections each with a different trend direction. The main fault scarp trends NE and faces SE in the southern third portion. This changes in the central portion to a more or less N-S trending fault facing east. In the northernmost third, the fault switches to face NE, trending NW and crossing the main Ishasha road.

The main fault scarps are relatively well exposed along its entire length and thus the rather angular changes in fault trend are reasonably well constrained. The current possible interpretation for this is probably that this fault reflects the main regional structural NE-SW trend, with minor associated faults trending approximately N-S, possibly intersecting with some fault movement along NW-SE trending basement lineaments.

Finally, it is also worth noting that the main fault in this particular case bifurcates and forms a stacked pair of scarp and dip slopes one on top of the other just to the east of Kikarara P. School, which is built on the crest of the second, uppermost scarp. The combined height of both scarps at this point is ~157' (~48 m).

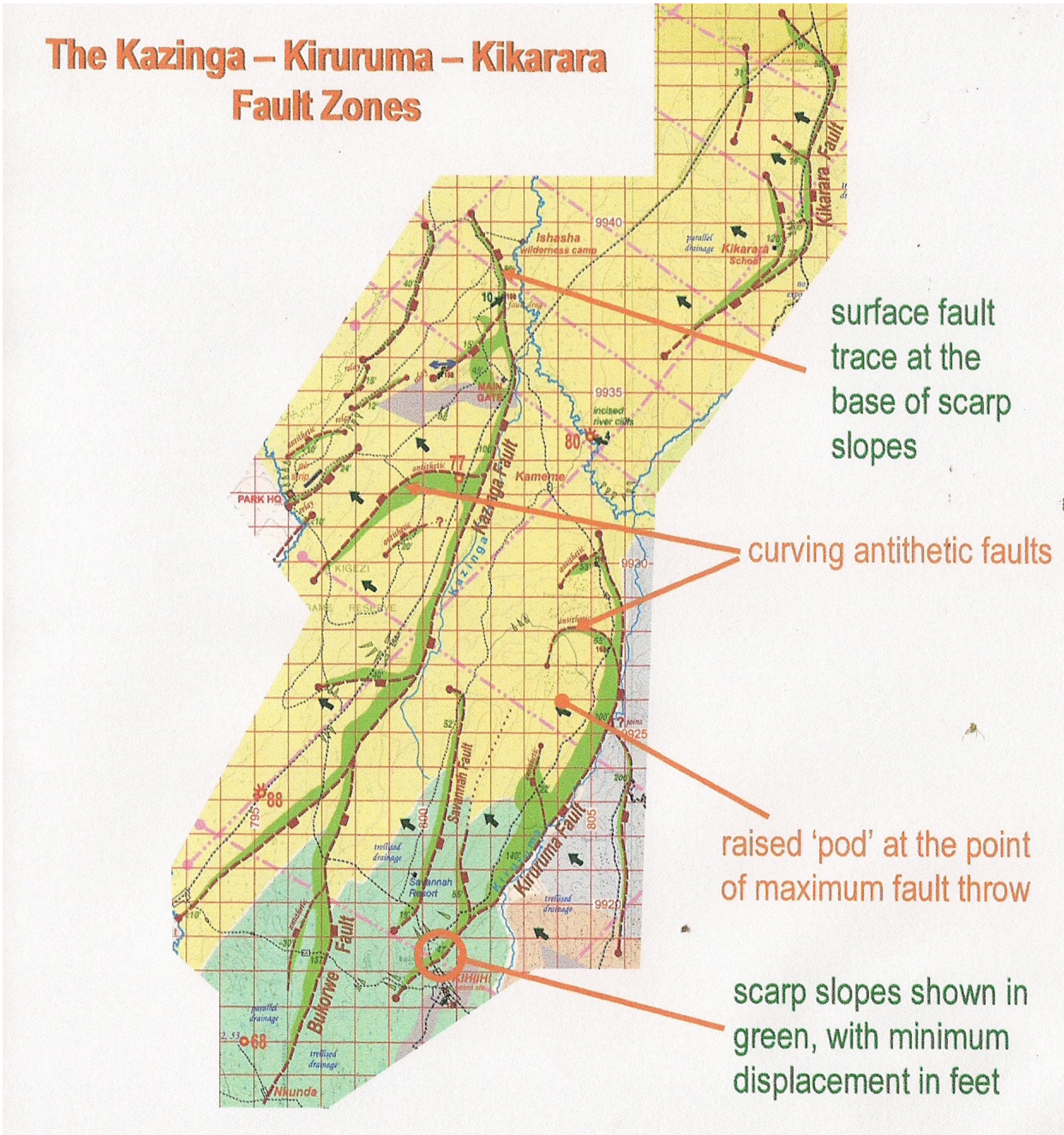


Figure 4. 24*. Kazinga-Kiruruma-Kikarara Fault zones illustrated.*

4.4 Lithostratigraphy

As mentioned already, sediments accumulated in a fluvial dominated system, thus lithofacies change over very short distances.

From the conceptual facies models, it can be seen that sediments accumulated in shifting fluvial/alluvial environments and were deposited in fan systems draining the basement to the south-east of the rift valley.

Five main lithofacies were identified, reflecting differences in grain size and hence different depositional water energies. These lithofacies make up the already described fans and formations, and include;

Lithofacies A represents high energy, concentrated mass flows as part of sheet outwash in alluvial fans or braided fluvial systems.

Lithofacies B represents high to medium energy sheet flood or braided channel outwash.

Lithofacies C was recognized in two distinct sub-facies; C^{I} and C^{II}.

Lithofacies C^{I} represents fluvial channel dunes, point bars and crevasse splays.

Lithofacies C^{II} represents thick sheet flood deposits.

Lithofacies C is clearly distinct from other facies as it exhibits bedform structures (cross bedding). Differences in bedform scale also necessitate subdividing C into C^{I} and C^{II}.

Lithofacies D represents low-energy distal channel point bar sands or crevasse splay fine sands and silts interbedded with inter-channel sandy clays deposited from stagnant water.

Lithofacies E represents stagnant water inter-channel areas and distal flood basin.

These lithofacies were deposited by fluvial processes and different forms of mass transport (e.g. mudflows and debris flows) after which the sediments were deposited in valleys and on slopes near the erosion area. These processes of transport and deposition led to the development of fans which are observed to fringe the basement fault scarps in the east and south-east of the block. Formation of these fans suggests that there has been tectonic rising of the erosion area. Their preservation indicates tectonic sinking coupled by transgression; otherwise they would have been eroded and reworked to form younger deposits towards the present Lake Edward. The features of these fans suggest deposition in different climates at some stages in their development. The presence of iron and manganese oxide within the sands of Bwambara, Katete and Kiruruma may suggest ground water evaporation during an arid phase. However it should be noted that iron rich layers can also be formed as a result of diagenetic processes whereby iron oxide precipitates from circulating water within the sediments.

Thus at one time in their development, these fans experienced an episode of aridity that deposited the beds of lithofacies C (the only chronostratigraphic marker in the area). However the general morphology of these fans shows the deposition in a relatively humid climate. The brown colour of the sediments may indicate ground water circulation hence oxidation of these sediments. The sediments in higher parts of the fan were transported and deposited with high sediment/water ratio as debris flows and mudflows.

These palaeo-alluvial fan and distributary fan systems are exposed with exhumed palaeo-topography along the eastern rift margin between River Nchwera in the NE and DRC border in the SW of the study area. These fans are characterized by massive conglomeratic deposits in the upper part, pervasive cross-bedding in the lower parts (lithofacies C), and fine sands and clays in the lowest parts (fan toes). Laterally across the fans, fine sands and clays are observed suggesting a number of branching channels with less energy that deposited sediments. Five fan systems were observed and include; Butogota, Katete, Nyamirama and Bwambara. These fans seem to coalesce towards the KKK-FZ.

Previously, various formation names have been used for Neogene and younger sediments of the area. For a stratigraphic formation to be valid- and mapped across an area, it needs to have its basal and top bounding surfaces clearly defined. None of the previously defined formations have adequately defined surfaces. Consequently, it is difficult to correlate these units with any certainty in the area.

Two formation names have been suggested in this study i.e. Bwambara and queen Elizabeth formations. However, Bwambara Formation can be fairly traced unlike the Queen Elizabeth Formation whose bounding surfaces and marker horizons are not very certain due to poor exposures. This formation is proposed here so as it can be studied more in the future as the current study could not resolve it very clearly.

The fan systems that make up Bwambara Formation were deposited from the eastern rift margin against KKK-FZ. These fans form the youngest exposed stratigraphy within 4B.

To the west and northwest of KKK-FZ, within Queen Elizabeth National Park, lies a low-lying plain with finer sands and clays poorly exposed. These sediments make up what is referred to here as Queen Elizabeth Formation.

Actually, the development of KKK-FZ, was so irregular that in some places the throw was more than in other places thus forming different contacts between these two formations. Where the throw was big we have sediments of Bwambara Formation just deposited against the fault scarp of the KKK-FZ. And where the throw was small, we have the distal fan toe clays of Bwambara Formation just sealing the edge of Queen Elizabeth Formation. Thus formation of KKK-FZ faulted Queen Elizabeth formation creating Bwambara trough thus initiating the development of Bwambara Formation.
Thus the contact between Queen Elizabeth and Bwambara formations is an angular unconformity.

4.4.1 Queen Elizabeth Formation

This formation perhaps corresponds to Sequence 2 of McGlue *et al* 2006 with an age range of late Pleistocene at around 20,000 yrs B.P to about 14500 B.P. It was deposited during a widespread arid event during the Late Glacial Maximum in East Africa (Laerdal, 2000; Russel *et al,* 2003; Russel and Johnson, 2005). In the Kisenyi Fault area, which separates Block 4B from Block 4A, it has been reported that there is presence of fine sands and clays exhibiting gypsum, desiccation cracks and minor caliche development suggesting deposition during a relatively arid interval (Senut and Pickford, 1988; Pickford *et al.*, 1993; Byakagaba, 1997). However, another arid phase has been reported in East Africa between 5000 and 2000 yrs to which, according to the logical interpretation of field results, and previous reports, represents the timing of the of the development of thick palaeosol and thick iron bands observed across the onshore Block 4B. Further investigations may show the presence of Caliche development in exposures far south of the Lakes Edward-George area.
This formation represents the oldest basin-fill sediments to be found exposed in the study area. This sequence is poorly exposed in the QENP and is composed of fine sands and clays which represent the more distal part of this sequence. No good exposures can be seen in the areas towards the eastern rift margin.
The only manifestation of this formation is the low-lying alluvial plain with distal fine sands and clays of older fan systems that emerged from the rift margin in the Pleistocene and have been faulted and obscured up-dip by the newly exposed palaeo-alluvial fan

systems which are exposed in the study area towards the rift margin in the South and SE. This formation is only exposed in the distal part towards the present day Lake Edward shore line. It forms low lying outwash plains that form most part of QENP.

4.4.2 Bwambara Formation

Sediment aggradation and fan development observed in the study area, coupled with Laerdal, 2000; Russell *et al*., 2003's observation that there was lake level rise at around 11200 to 6700 yrs BP, show that Bwambara formation was deposited when the lake levels were high, thus, it corresponds to a high stand sequence. In the Lake Edward area, there is evidence of an extensional tectonic phase beginning from around 15000 yrs B.P. which resulted in the development of Kasindi and Kisenyi faults (McGlue *et al.*, 2006). From around 11,200 to about 9200 yrs B.P., the semliki lip lowered and there was recognizable uplift on the Kasindi and Bantu faults (Russell et al., 2003; McGlue *et al.*, 2006).

This period of major of rift extension in the northern half of the Lake Edward basin between 15000 yrs B.P and 9200 yrs B.P. is, thus, also likely to correspond to the extensional movement on the south-eastern rift-bounding faults in Block 4B and the subsequent initiation of fan complexes.

The early Holocene, from around 11200 to 6700 yrs B.P., it is reported that it was to have been a period of relatively of relatively humid and wet climate in East Africa (Laerdal, 2000; Russell et al., 2003), with lake levels possibly higher than at the present day, encouraging lacustrine high-stand deposits.

At around 5200 yrs B.P., a regional climate change occurred and East Africa experienced a drier period which lasted until around 2000 yrs B.P. (Laerdal, 2000; Russell et al., 2003; Russell and Johnson, 2005). This drier Episode is very interesting regarding the geology of the study area. It is characterized by the deposition of ferruginous or limonitic sands with iron and manganese coats and extensive iron bands.

Thus the lithofacies C^{11} sands seen at Bwambara, Katete and Kiruruma sand quarries, which are dark yellowish orange, well sorted sands, often with lenses and bands of iron and manganese, might correspond to periodic sheet flooding during this more arid phase.

At present, these thick beds of lithofacies C^{11}, are the only genuine chronostratigraphic markers found in the area and they are traceable across the Bwabara sequence from Kiruruma in the north to Bwambara in the south.

However it is not clear about the cause of this change in climate as at present we are only presented with disagreement in the existing literature about the changes in climate in East Africa in this period. There was water level fall in Lake Edward during this period but it is not clear whether it was due to tectonic lowering of Semliki outlet, by lowering due to the aridity, or as a result of both.

The above observations suggest that Bwambara Formation represents a relatively large depositional cycle with minor but recognizable high-stand and low-stand systems tracts, and formed when the accommodation space was generally more available than the sediment supply encouraging sediment aggradation rather than progradation. This gives more evidence on the observation that the onshore SE Lake Edward basin was in state of deposition rather than erosion.

The latest arid period in East Africa correlate to a certain phase during the development of the alluvial fan systems that make up Bwambara Formation. The extension of QENP Formation should be investigated in detail to see how it terminates towards Block 4A in the Kisenyi Fault area.

4.5 Event and Sequence stratigraphy

From field observations, and a review of work of Laerdal, 2000; Russel *et al.*, 2003; Russell and Johnson, 2005; McGlue *et al.*, 2006, it is possible to establish an event and sequence stratigraphy of the onshore Block 4B (SE Lake Edward basin) for the last 20,000 years i.e. from late Pleistocene to present.

In late Pleistocene, at around 20,000 years BP, there was a base level fall and deposition of McGlue *et al.* 'Sequence 2'. This low stand sequence corresponds to a wide spread arid event when there was Glacial maximum in East Africa (Russell et al., 2003; Russell and Johnson, 2005). During this period at around 15000 years BP, there was pronounced extensional tectonic movement in the Lake Edward area which resulted in normal fault movement on the Kasindi and Bantu Faults (McGlue *et al.*, 2006). This period of major rift extension is likely to correspond to extensional movement on the SE rift bounding

faults in Block 4B, resulting in the initiation of fan complexes towards the then Lake Edward shore line. Therefore McGlue *et al.* 'Sequence 2' is an outcome of base level fall coupled by rift margin extension in the late Pleistocene, and represents the oldest sediments to be found in the study area. Thus sequence 2 corresponds to Queen Elizabeth Formation defined in this study. This base level fall is said to have lasted up to around 14500 years BP. Exposures of fine sands and clays in the footwall of Kisenyi Fault, which forms the northern extremity of the study area, have been reported to exhibit gypsum, desiccation cracks and minor caliche development, demonstrating a deposition during more arid conditions (Senut and Pickford, 1988; Pickford *et al.*, 1993; Byakagaba, 1997), and since they occur at the base of a thick, dissected plateau above Kisenyi Fault within Queen Elizabeth Formation, they represent the oldest exposed sediments to be found in the region. However it should be borne in mind that there is yet another, youngest arid phase that has been reported in East Africa at around 5000-2000 years BP.
This arid phase is likely to represent a period when sands of lithofacies C^{II}, defined in this study, were deposited. The development of this sequence is likely to have terminated in earliest Holocene (at around 11,000 years BP) when this arid phase was terminated (McGlue *et al*, 2006).

The extensional fault movement in the Lake Edward basin, terminated in early Holocene at around 11,200 years BP with the development of KKK-FZ defined in this study. In the late phase of this fault movement, Bwambara trough formed, initiating the development of more fan complexes that make up Bwambara Formation. This therefore, possibly, marks the top of Queen Elizabeth Formation and the bottom of Bwambara Formation (? Angular unconformity).

The early Holocene from ~ 11,200 to ~ 6700 years BP is regarded as a period of relatively humid and wet climate in East Africa (Laerdal, 2000; Russell et al., 2003), with lake levels higher than at present encouraging lacustrine high stand deposits. However, there was a minor fall in lake levels at ~9,200 years BP leading to a minor low stand. Thus the development of fans was faster during the initial transgression to maximum flooding between ~ 11200 and ~ 9,200 years BP.

At around 5,200 years BP, there seems to have occurred a regional climate change and East Africa entered a drier period which lasted until ~ 2,000 years BP. (Laerdal, 2000;

Russell *et al*., 2003; Russell and Johnson, 2005). The significant feature of this period is said to be the deposition of ferruginous or limonitic sands and/or sands with Fe/Mn grain coats (Russell *et al.*, 2003; McGlue *et al.*, 2006). The lithofacies C^{II} observed in Kiruruma, Kambuga and Bwambara sand quarries consist of dark yellowish orange well sorted sands, often with lenses of Fe/Mn coated grains and occasional Fe/Mn bands, and may correspond to periodic sheet flooding during this more arid interval. Thus these thick lithofacies C^{II} beds represent a genuine chronostratigraphic mark to be found in the area, and may represent a fair marker horizon for Bwambara Sequence. A maximum low stand during this last arid phase is said to have occurred at ~ 2,000 years BP after which the lake levels appear to have risen again.

Still in Holocene, at ~2,000years BP, it is reported that there was compressional or tranpressional fault movement within the Lakes Edward-George area (McGlue *et al.*, 2006). This could have caused minor inversion on KKK-FZ faults and uplifted fan complexes diverting modern drainage around fans and incision through the fans.

This uplift is manifested at the surface as series of 'pop-ups' in the foot walls of KKK-FZ. Also in the east of KKK-FZ, such 'pop-ups' are evident indicating this compressional/transpressional movement affected these youngest exposed fans that make up the Bwambara Formation towards the basement in the east and southeast of the basin.

In the model presented here, the oldest sediments in the SE Lake Edward basin are the fine sands and clays exposed in the Queen Elizabeth National Park and correspond to the Queen Elizabeth Formation while the youngest are the lithofacies A-E exposed near the basement to the east and southeast of the study area. This is summarized in the model below (after Nicholas *et al*, 2008).

.

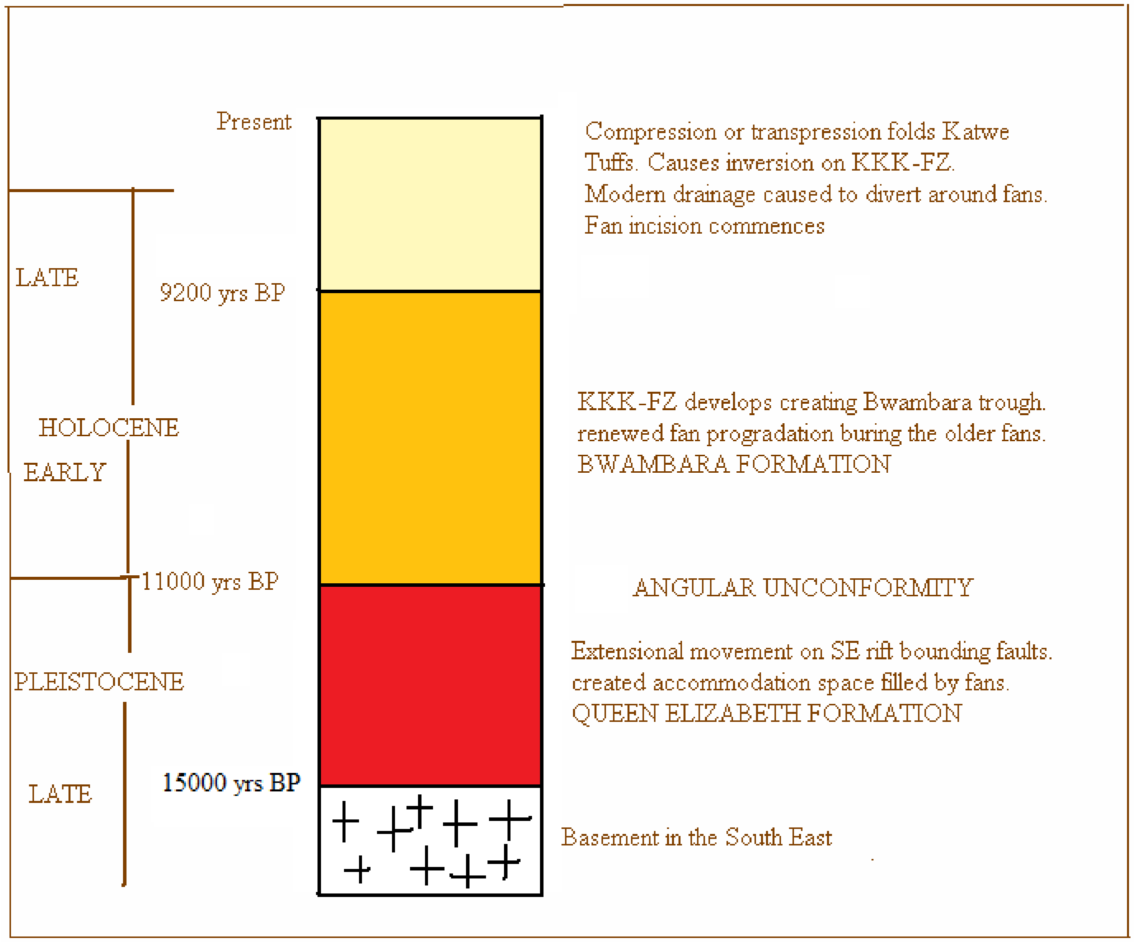


Figure 4. 25. ***Event and Sequence Stratigraphy of the South East Lake Edward Basin (data from exposed sediments within the area): After combining the current observations with the previous stratigraphic syntheses of McGlue et al., 2003; Laerdal, 2000; Nicholas et al., 2008; Senut and Pickford., 1998; Pickford et al., 1993 and Russel et al., 2003***

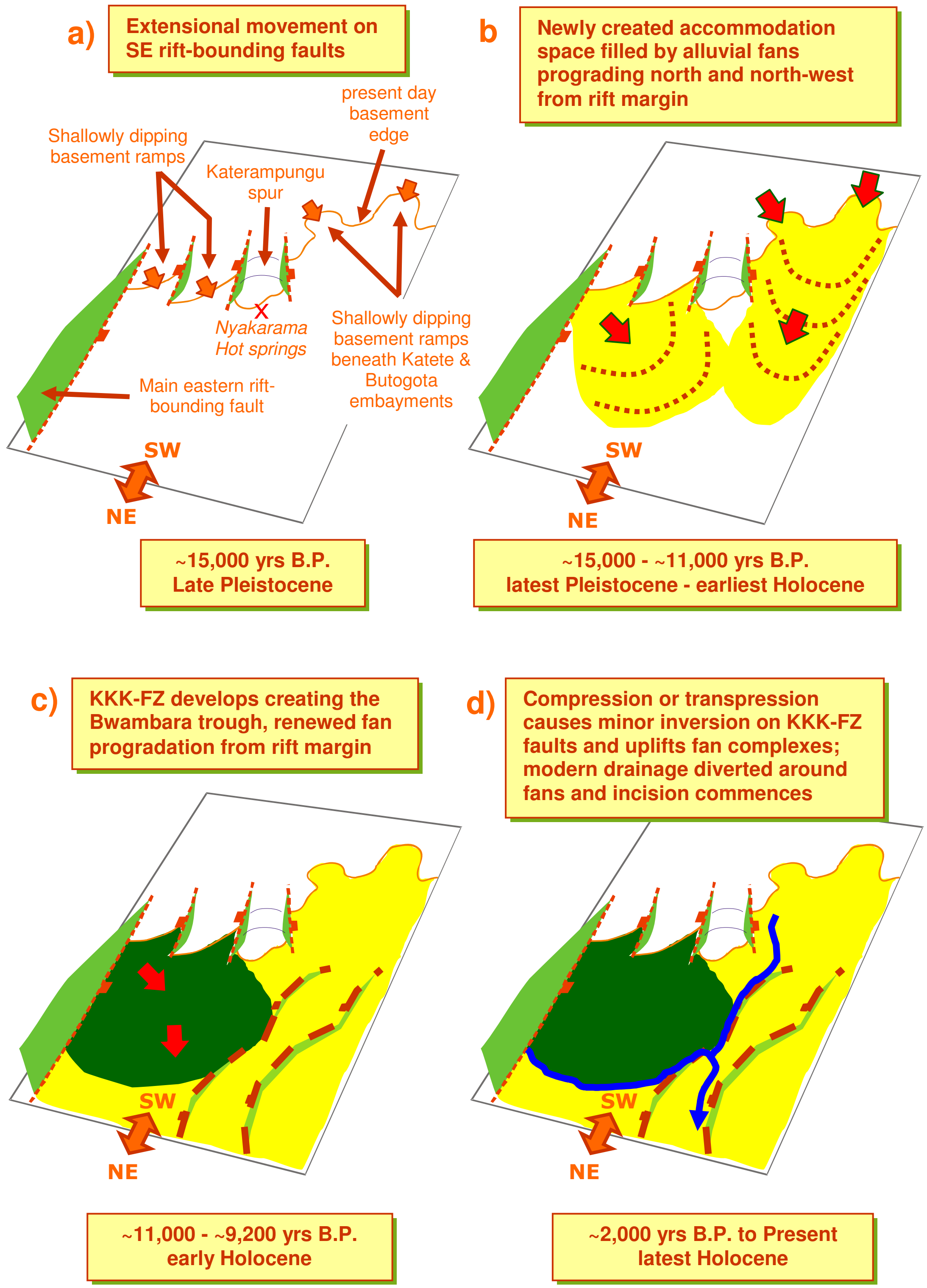


Figure 4. 26. *Summary of event stratigraphy in block 4B from Late Pleistocene to Late Holocene (Nicholas et al, 2009)*

4.6 Facies analysis, sequence stratigraphy and Petroleum Potential of Block 4B

Lake Edward basin has potential for petroleum generation and accumulation. For petroleum to accumulate in any given geologic environment, some factors must combine to allow the accumulation of organic matter, their preservation in sediments, their anaerobic 'cooking', hydrocarbon generation and migration, and their entrapment at a given stratigraphic level (Allen and Allen**,** 1990).

4.6.1 Source of hydrocarbons

Byakagaba (1997) reported that the eminent interest in the exploration in the Lakes Edward-George basins began after the aeromagnetic survey indicated the presence of a thick sedimentary cover in this area coupled with the thermally stratified nature of Lake Edward which gives it its potential to allow the accumulation, preservation and anaerobic biodegradation of organic matter. In this basin, very fine grained rocks (clays and shales) have been observed previously and in this current study. This, again coupled with the stratified nature of Lake Edward waters, one can draw a conclusion that there is presence of possible hydrocarbon source rocks. The earlier distal fan toe clays and some laterally extensive massive clay units (Facies E) could have been covered by later fans that prograded towards the lake thus providing the necessary pressure and temperature to allow the generation of hydrocarbons. Thus, the hydrocarbons could have been generated in the Lake Floor clays and shales, and migrated up-dip in the eastern and southeastern direction towards the rift margin.

4.6.2 Hydrocarbon Reservoirs

Very well sorted and porous sands are evident in this area (facies C^{II} or facies C^{I}). They form thick sequences which are clearly exposed in many localities in the study area and in many other areas in Lakes Edward-George basins. Such sand sequences may be buried deep under lithofacies D and E which are good potential regional seals.

4.6.3 Hydrocarbon cap rocks/regional seals

Thick laterally extensive sequences of clays (facies E and D) in this study are wide spread in the area. They have been reported in Lakes Edward-George basin by Byakagaba (1997) and Musisis (1991). These are likely to form good regional seals for petroleum in Block 4B.

Reservoir quality sands of facies C^{II} are observed to be under and overlain by clays of facies D and E in many localities implying that reservoir sealing is possible within the basin.

These cap rocks could have been deposited during a regression following an earlier transgression that deposited the reservoir beds.

4.6.4 Petroleum migration routs and traps

Different episodes of tectonic movements in East Africa have produced different kinds of faults in the basin. There is evidence of normal faulting that produced KKK-FZ, and the latest compressional/transpressional faulting that produced various synthetic and antithetic faults that are observed in the foot walls of KKK-FZ and other places in the area. These faults may have acted at one time as petroleum conduits and/or traps during the geologic past after petroleum generation from the source rocks.

4.6.5 Petroleum timing

It is very clear from the previous and current study that there is presence of elements that make up a petroleum system in the study area. Below are rough models that have been drawn about petroleum timing within the area of study.

Two models can be drawn about petroleum generation, migration and entrapment within 4B.

- Petroleum generation and migration occurred after the formation of KKK-FZ thus forming structural traps within the foot walls of this FZ. However the late tectonic phase that resulted in antithetic faulting, thus forming “pop-ups”, resulted in remigration of hydrocarbons towards the west or northwest to be trapped within these pods. Here the major traps would be located within the area of contact between Queen Elizabeth Formation and Bwambara Formation i.e. KKK-FZ.

- In another scenario, petroleum generation and migration occurred before the development of these faults and thus, migrated up-dip to be trapped near the sediment-basement contact in the east or southeast of the basin. Thus the hydrocarbon traps are located in the area of contact between Bwambara Formation and the basement to the southeast or east of the basin.

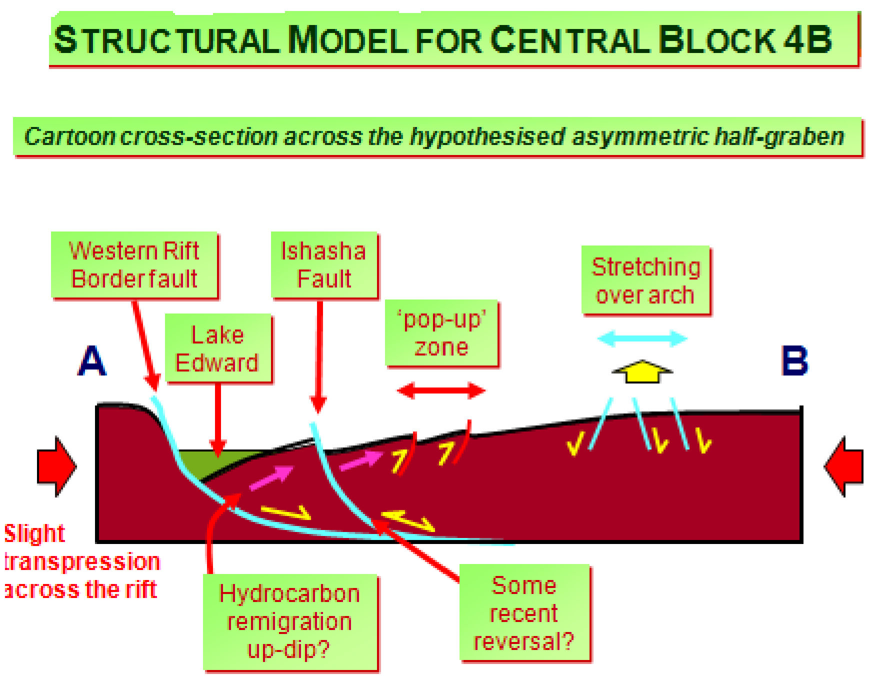


Figure 4. 27. ***Structural model of block 4B showing hydrocarbon migration (Nicholas et al 2008)***

4.7 Searching for hydrocarbons in the Lakes Edward-George area

After realizing that the geology of onshore 4B is virtually the same as in the Albert area where commercial hydrocarbon shows have been proven, a search for hydrocarbon seepages was conducted as part of the field surveying in the Lakes Edward-George area. To the north, Wayland (1925) had reported 52 seepages around the shores of Lake Albert and Semliki Valley and this led to the first exploration well Butiaba Waki-1 on the eastern shores of Lake Albert in 1938 (figure 4.26).

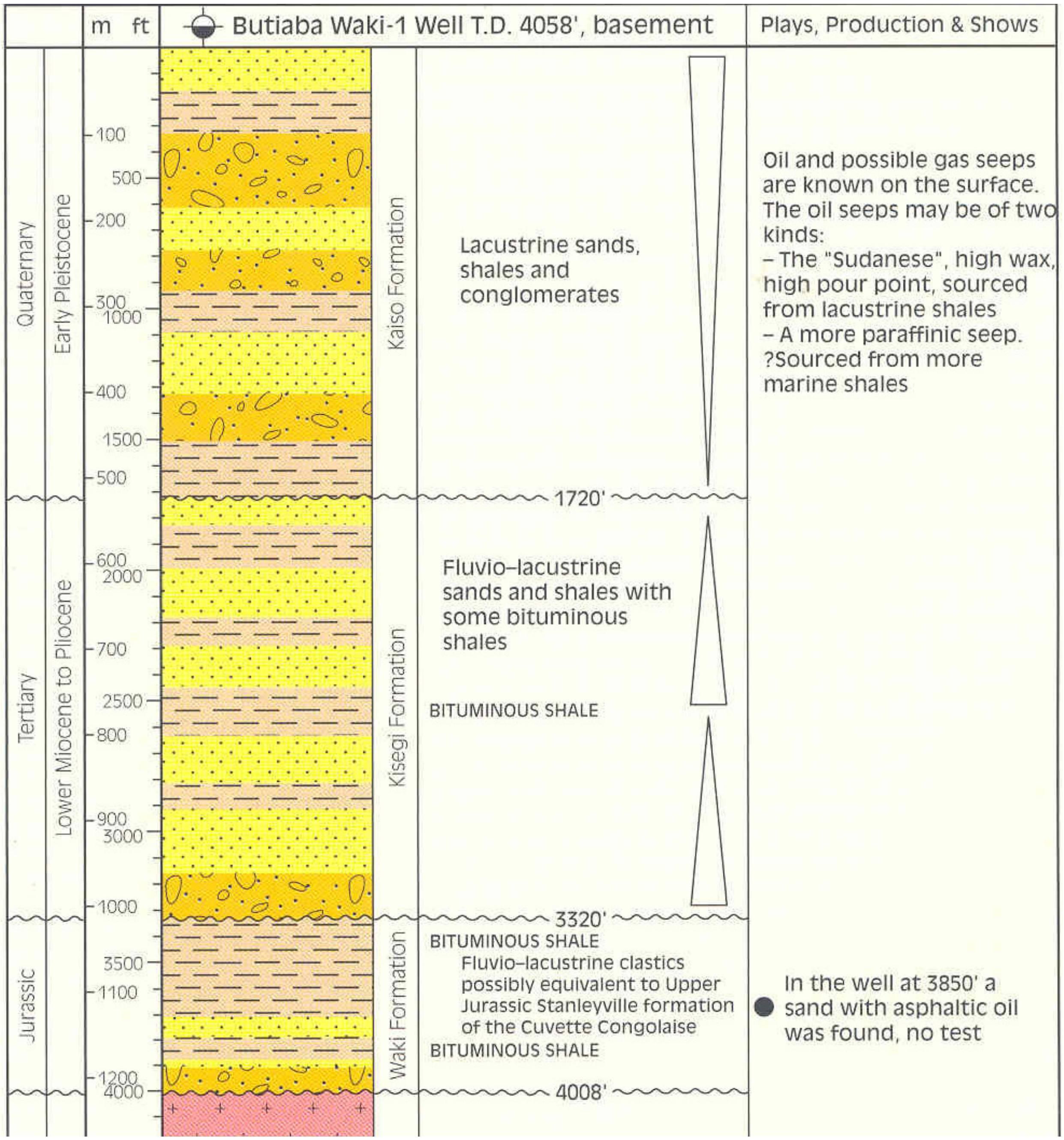


Figure 4. 28. ***stratigraphic section of the Waki 1 well (Adopted from PEPD, 2005)***

However prior to this study, no seepages of oil had been reported in the Lakes Edward-George area. This could have been due to less study within this area compared to Albert area where petroleum geology has been studied in more detail. Therefore it was not clear prior to the ongoing petroleum geological study of 4B whether the lack of recorded seeps in this area was due to their genuine absence or a dearth of observational evidence.

The following progress can be presented with regard to petroleum geology of Edward-George area. Before the search it was assumed that the most likely localities for seeps would be where there are some forms of conduits to depth, allowing fluid flow up to the surface. The most obvious of these are the major rift bounding faults identified by Laerdal and Talbot (2002) (see figure below) and other minor faults within the rift floor sediments.

The second likely localities indicating some form of fluid flow from depth would be various hot springs in the area. Many of these hot springs are actually located along these major rift bounding fault lines. In association with these modern day hydrothermal fluids, are patches of tufa limestones thought to have been deposited in palaeo-hot springs along the major faults on either side of Lake George (Byakagaba, 1997).

These limestones at Dura, east of Lake George have been dated at about 7500 yrs BP (Bishop, 1969) and were probably contemporaneous with Katwe volcanic activity.

4.8.1 Possible oil seepages in the Lakes Edward-George area

Nyakarama boiling springs

In the basement, an accommodation zone of small east- and west-facing normal faults produces a prominent basement spur at Katerampungu, just south of Nyakarama village.

At the northern edge of this spur is a series of three hot springs. An attempt was made to sample gas from one of the pools by causing it to evacuate an upturned bottle full of water held over the bubbles (Figure 4.29).

Figure 4. 29*. Sampling gas bubbles in Nyakarama hot springs*

A lit match was held over the bottle and it stayed briefly before going off. A lit match was also held over bubbles coming to the surface emerging through the organic rich mud on the floor of the pool. At one point a bursting bubble lit and flickered before disappearing (figure 4.30).

Figure 4. 30*. Testing for any hydrocarbon gas in the pool*

Also collectively witnessed was a bubble burst at the surface spreading a thin oily film across the water before it dispersed. A sample of hot pool mud was analyzed for remnant petroleum biomarkers but did not yield positive results. Thus it was assumed that the flammable gas was "marsh gas" or methane, produced by degrading algae within the pool mud and the oily film could be a byproduct of rotting plant debris at depth in hot mud.

Bugangari hot spring

This spring is located on the topographic map in block 4B about 1.5 km NW of Bugangari (figure 4.29).

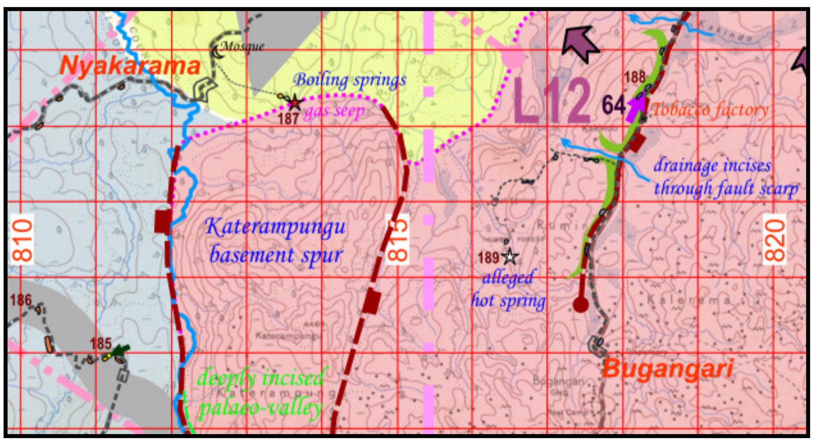


Figure 4. 31. ***Location of Nyakarama hot springs and a further alleged hot spring just NW of Bugangari, Block 4B (Nicholas et al 2008).***

On approaching this site local villagers were asked of any spring around. The researchers were led to a small stream allegedly to be hot in the morning. Given this was morning time and water was cold it must be assumed that this hot spring is no long active.

Border fault related limestones

The development of tufa or travertine limestones at certain localities along the edge of the rift valley is an interesting geological phenomenon. The relevance of such limestones in locating potential for hydrocarbon seeps lies in the fact that they identify deep-seated leaking faults which might have formed significant conduits for hydrocarbon migration toward the surface.

Visits were made to several limestone exposures. The first one was Lyembuza quarry, about 5kms SW of Muhokya lime works, and about 1km west of the main Bushenyi-Kasese road (figure below). Here the coarse, sparry calcite has large irregular cavities developed throughout giving it a high primary porosity and it would be an excellent reservoir lithofacies. Occasional gastropods are preserved and there are patches of calcite which appear to be replacing wood tissue. Indeed, ^{14}C dating of carbonized wood imbedded in tufa limestones at Dura is the main regional age constraint on these limestones (Bailey, 1969).

A sample of 'black' tufa from Lyemubuza underwent GCMS analysis. Coupling mass spectrometry with gas chromatography allowed the identification of biomarker fragments that are more resilient over time to biodegradation at the surface. Initial results have shown that the cavity lining is indeed organic and, "contains signs of a mature 'oil-like distribution' of biomarkers, such as steranes and triterpane/hopanes with phenanthrene and dibenzothiophenes". However, the distribution of biomarkers is skewed towards lower molecular weights which can suggest contamination from a refined source, such as diesel or kerosene (Nicholas *et al, 2008*).

More GC/GCMS biomarker analyses were undertaken on black cavity linings from Lyembuza and Muhokya lime works. This was undertaken in Trinity College University of Dublin. These localities about 10kms apart contain the same traces of mature oil biomarkers (Nicholas *et al, 29008*).

The level of isomerism and aromatization of biomarker compounds is very consistent with early (pre-peak) oil generation (90-125 ^{0}C) and shows mature, migrated oil.

Lake Edward slick sampling was also undertaken to in order to investigate various anomalies from satellite imagery and aerial photo interpretation of trails on the lake. Some anomalies were composed of long trails of white foam. At some localities, thin oil films were seen floating on water surface amongst the foam trails. These were sampled using special cloths which absorb low concentrations of dispersed oil into the fabric. The foam trails were phytoplankton blooms found in association with high concentrations of lake fly larvae. These indicated a high level of nutrients in surface waters which could be due to the presence of degrading oil slicks.

Lake slicks showed a mature hydrocarbon signature.

The polycyclic ring biomarkers in the lake are similar to those in Lyembuza and Muhokya. Again the levels of isomerism and aromatization in the slick samples show mature, migrated oil (Nicholas *et al, 2008*)

CHAPTER FIVE
DISCUSSION OF RESULTS

Sedimentology, stratigraphy and tectonics are applied to develop a full understanding of the rocks and sediments that fill sedimentary basins and use this information to interpret the geologic history and evaluate the economic importance of these rocks (e.g. Boggs, 1995). The ultimate goal of this study was to evaluate the petroleum resource potential of Lake Edward basin through facies analysis and sequence stratigraphic study of this basin. However the survey went on to look for any occurrences of oil seeps after recognising the excellent features of the basin with regard to its petroleum geology.

Within the Albertine Rift, depositional systems were almost the same being fluvial dominated with periodic lake water incursions landward during transgressions, thus one would expect similar lithofacies stacking patterns.

5.1 Lithofacies

As earlier mentioned, the lithofacies present in the graben consist of lithofacies A which consists massive, moderate brown conglomerate, with rounded pebbles and granules supported in medium to coarse quartz sand with clay coating. This lithofacies represents high energy, concentrated mass flows as part of sheet outwash I alluvial fans or braided fluvial systems; B which is a massive moderate brown coarse to medium quartz sand with clay coating. This lithofacies represents high to medium energy sheet flood or braided channel outwash; C is a moderate reddish brown to dark yellowish orange, friable and porous medium to coarse, well sorted quartz sand typically exhibiting dune cross bedding, infilled plant rootlets or bioturbation. This lithofacies can be recognised in two distinct subfacies i.e C^{I} and C^{II}. Lithofacies C^{I} represents fluvial channel dunes, point bars and crevasse splays. C^{II} represents thick sheet flood deposits; D is composed of repetitively interbedded thin sands and clays, and represents low energy distal channel point bar sands or overbank crevasse splay fine sands and silts interbedded with interchannel sandy clays deposited from stagnant water; E is massive sandy clays with infilled plant rootlets, and represents stagnant water in interchannel areas and distal flood basin. Lithofacies C represents very good reservoir intervals within the area whereas lithofacies E represents very good source and cap rocks.

5.2 Lithostratigraphy

5.2.1 The pre-rift section

This involves the Proterozoic basement rocks well exposed on the rift flanks and shoulders of the Albertine Graben. Like the rest of the country, it is composed predominantly of high-grade metamorphic and igneous rocks of Precambrian age.

5.2.2 The Syn - rift section

The syn - rift section of the Albertine Graben was recorded in t he Waki-B1 well, which was drilled in the 1938. A section of this well is shown in chapter 4. The well penetrated both the Lower and Upper Tertiary syn-rift section and went through the Mesozoic pre-rift section before reaching basement (PEPD, 2005).

The Kisegi and Kaiso formations of the Upper Tertiary to recent are also quite well exposed in the Graben. Although the thickest section in the Graben is Tertiary to recent, there are indications of a Mesozoic section (Jurassic or Cretaceous) at the base of the section.

Although the Lower Tertiary may overlie the crystalline basement in many parts of the Graben, there is a strong possibility that it overlies a Mesozoic section (Karoo) in the western parts of the Graben.

In Lakes Edward-George basins, biostratigraphic palynological analysis of clay samples suggests that all the exposures are Pleistocene to Holocene in age (≤ 18 ka). However palynological analyses of clay samples from Kazinga channel area yielded two sub-datasets; late Pleistocene and a set of reworked Cenomanian spores (Nicholas *et al*, 2009). The palynomorph assemblages indicated that both Mesozoic non-marine and marine clays were exposed in the Lakes Edward-George area during the late Pleistocene. Biomarker analyses of lake slick and residues in tufa indicated a mature marine shale source rock. Seismic data in 4B also indicated that some pre-rift sedimentary sequences may be present.

Since these observations have been reported before in the Lake Albert area from wells and seismic sections, then it is likely that there is a pre-rift stratigraphic section preserved below tertiary rift fill sediments in the Albertine Graben. This leads one to unresolved questions, at the moment, with regard to petroleum geology of 4B; are the hydrocarbons in the basin sourced from Upper Cretaceous (Cenomanian) pre-rift marine shales; is there karoo sequence unconformably overlain by rift fill sediments?. It should also be noted that the palaeolake Obweruka of late Miocene to early Pleistocene could have accumulated organic rich sediments which would have matured to expel petroleum.

5.2.3 Rift fill section

This includes sediments well exposed in the study area that make up lithofacies A-E within the alluvial fans described in chapter four before. These make up two formations i.e. Queen Elizabeth and Bwambara Formations where the later overlies the former. How ever from this study, the extent of Queen Elizabeth Formation is not well represented here. These two are perhaps the only genuine formations within the Lake Edward basin at present. The previously described formations are difficult to correlate across Block 4B because of lack of clearly identifiable or exposed bounding surfaces and marker horizons. It is not possible to see how these formations differ internally from each other.

5.3 Sequence Stratigraphy

The sequence stratigraphy presented in chapter four is a result of combining previous and current study.

In Late Pleistocene, there was extentional fault movement on southeast rift bounding faults. This created accommodation space that was filled by alluvial fans prograding north and north-west from rift margin. These fans makeup the Queen Elizabeth Formation. This filling lasted up to earliest Holocene. Since Queen Elizabeth Formation occupies the area which was part of Lake Obweruka in Miocene, the relationship between sediments of this formation and Lake Obweruka needs to be investigated. In future, one may find either Queen Elizabeth formation immediately overlies Lake Obweruka sediments or the lower part of this formation contains sediments deposited in this palaeolake.

This was followed by the development of KKK-FZ creating the Bwambara trough and causing renewed fan progradation from the rift margin forming Bwambara Formation.

The last important event in the basin occurred probably between 7000-2000 years BP (latest Holocene). This is evidenced by inversion of the KKK-FZ and these alluvial fans. These are contemporaneous with folding and faulting of the Katwe Tuffs in Block 4A which was dated at around 7000 years ago (Nicholas *et al*, 2008).

5.4 Petroleum Geology

From seismic and airborne geophysical data acquired by Dominion Petroleum Ltd in 2008, a deep asymmetrical sedimentary basin can be identified. This basin deepens westwards towards the DRC. This indicates that this basin contains westerly dipping sedimentary units that thicken towards the western rift border with the depocentre below the present day Lake Edward. This further indicates that the western rift bounding faults along the western edge of Lake Edward in DRC have more throw than those on the east. Thus if it can be assumed that petroleum generation occurred within this depocentre, it migrated up-dip towards the east or south east. This is true with the northern sector of the Albertine Graben (see Tullow Oil Plc, 2007). By analogy with the internet publications of Tullow Oil Plc isochron maps, Lake Edward basin can be regarded as a potential basin for oil accumulation.

From field observations, it can be deduced that;

The first phase of fault movement was accompanied by steady phase of fan lobe progradation from the basement edge out into the Lake Edward basin. This led to the deposition of fine clays of lithofacies E towards the centre of the basin. This deposition caused the preservation of organic matter already produced within the lake. With continued sediment supply, there was deep burial with associated increase in temperature and pressure necessary for maturatiuon of the kerogen preserved in these sediments. This maturation could have also been enhanced by a high rate of heat flow within the rift. Further increase in pressure and temperature caused the expulsion of the hydrocarbons towards the east or southeast.

This period of fault movement, subsidence, petroleum migration generation and expulsion was probably followed by another phase of fault movement with accompanied subsidence thus providing more accommodation space potentially initiating another phase of fan progradation. This progradation led to the deposition of fine clays of lithofacies E against the older fan system thus providing a thick seal for the already migrating hydrocarbons. The development of the KKK-FZ provided structural traps in addition the possible stratigraphic pinchouts due to abrupt l,ithofacies changes towards the basement in the east or south east of the basin.

With regard to the above model, it should be noted that no absolute dating of such events was carried out as it is beyond the scope of this study. Thus it can be done at another stage in the future when quantifying various risk elements involved in play assessment.

One important question is left unresolved i.e. whether the development of KKK-FZ predates the petroleum expulsion. The answer to this question would form one of the important ingredients required while locating possible petroleum pools prior to drilling.

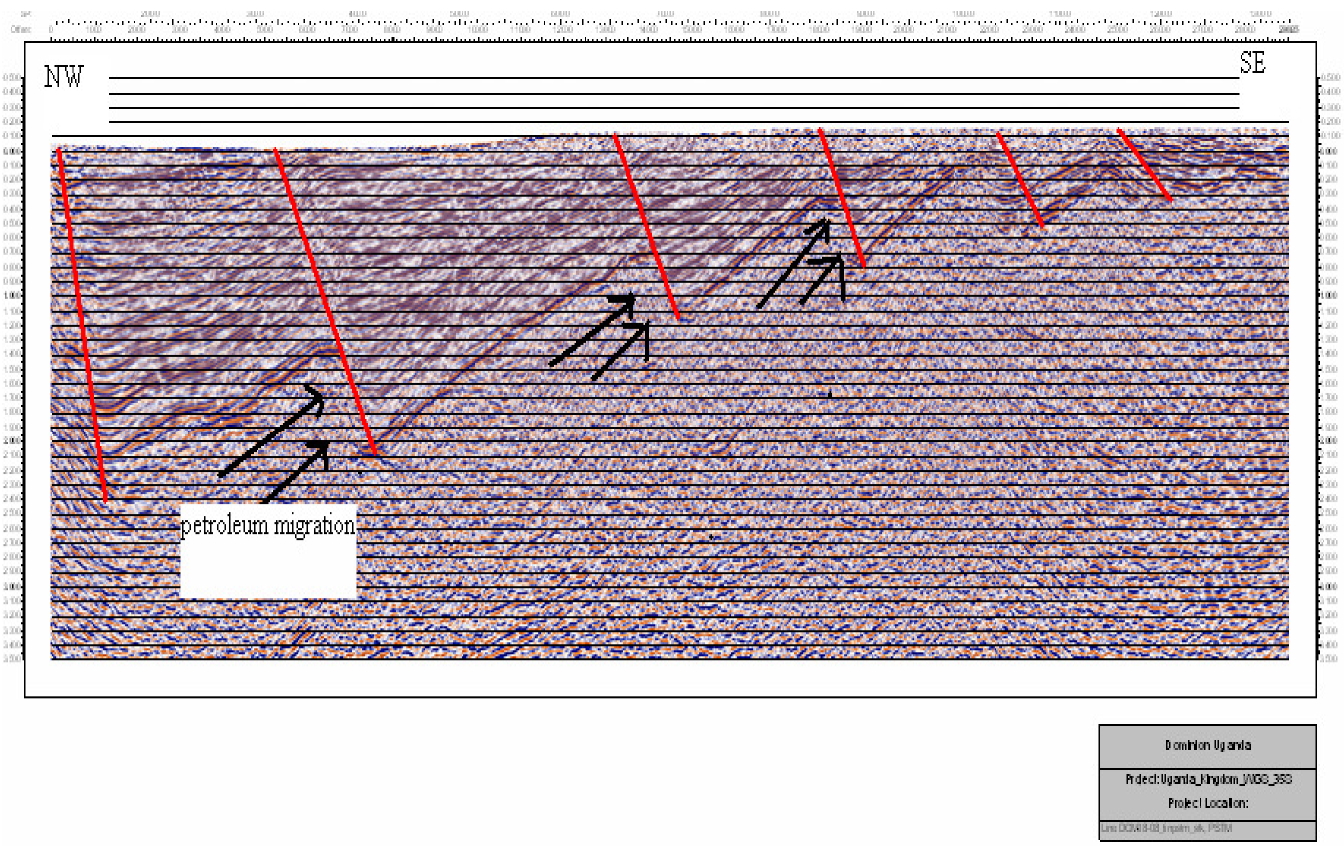


Figure 5. 1. ***Seismic section in 4B showing faults and possible oil migration to the fault traps. Red thick lines show interpreted faults while black arrows represent petroleum pathways***

CHAPTER SIX
CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

In lakes Edward-George area, we have fluvial-lacustrine packages that change lithofacies laterally over very short distances. Laterally extensive clay units are a result of lake incursions towards the South East.

Previous named lithostratigraphic formations in the Lakes Edward-George basins, i.e. Rwenshama, Nchwera, Kikororngo, Mweya, Kiruruma, Ishasha, Channel, Kankoko, Kazinga, Butogota, Mubikuto, Bukorwe and Kamahe, lack defined bounding surfaces and cannot be correlated laterally with any degree of certainty. These formations do not conform to any lithostratigraphic framework.

This study showed that onshore 4B is dominated by alluvial fan complexes consisting of branching distributary fan lobes. Several fan complexes were identified and include; Butogota, Katete, Nyamirama, Bwambara and Rushaya. Within these fans, five lithofacies were identified indicating different depositional environments. Lithofacies A; massive, dispersed pebble-granule conglomerate supported in a moderate brown, medium to coarse quartz sand with clay coating. This represents high energy channel grits and conglomerates. Lithofacies B; massive, moderate brown, medium to coarse quartz sand with clay coating. This represents channel sands. Lithofacies C; moderate reddish brown to dark yellowish orange, cross-bedded, medium to coarse, friable and porous quartz sand with variable clay coats. This represents marginal sands, point bars and crevasse splays.

Lithofacies D; thinly interbedded light bluish gray clays and brown to pale yellowish orange, fine to medium sands representing distal channel sands and/or overbank sands interbedded with interchannel clays. Lithofacies E; massive, mottled bluish gray or light olive grey clays, often with dispersed quartz sand clasts, infilled rootlets and palaeosol horizons representing distal flood basin clays.

From this study, two formal stratigraphic units were established thus; Queen Elizabeth Formation (Early Pleistocene to late Pleistocene) and Bwambara Formation (Late Pleistocene to early Holocene). Lateral correlation was achieved through combining field observations with documented palaeoclimate of East Africa. No absolute age dating was carried out as it was beyond the scope of this study.

From XRD data and geochemical data, it can be seen that the sediments were sourced from the basement rocks south and southeast of the basin apart from the samples far north of the basin that show possible admixture with the Bunyaruguru volcanics.

From the study, it seen that sediments were deposited in fluvial and alluvial systems and there are no laterally extensive strata apart from clays deposited during lake incursions towards the land.

From lithofacies characteristics and structural set up of 4B, it can be concluded that all the ingredients that define a petroleum play are present.

With event and sequence stratigraphy, possible hydrocarbon traps have been postulated to lie within the KKK-FZ or within the sediment/basement contact.

Evidence for mature migrated oil was discovered for the first time in the Lakes Edward – George area. Clay palynomorphs from Kazinga showed reworked Cenomanian assemblages indicating that there are some pre-rift sequences within this area. This is also evident from 4B onshore seismic sections, and from the Lake Albert area in the north.

6.2 Recommendations

To find oil/gas deposit, geologists have to explore basins with the right conditions for petroleum generation and accumulation, and locate suitable traps in which hydrocarbons have accumulated. Locating suitable deposits needs through understanding of the physical, chemical and biological characteristics of the basin fill. An understanding of depositional environments and depositional systems, all aspects of stratigraphy, a working knowledge of principles of geophysics, structural geology as well as knowledge on the flow of fluids in subsurface rocks. No single geologist can be capable of carrying out the many complex studies required to develop a major, successful petroleum play. Petroleum play characterization requires teams of stratigraphers, sedimentologists, structural geologists, geophysicists, and hydrogeologists.

These teams work together at different stages of basin analysis and in various combinations until a play is defined and proved to work. With the current information, all elements needed for petroleum generation and accumulation are likely to be present in 4B.

However the following is recommended. Small diameter wells for information need to be drilled. This will allow collection and analysis of samples for potential source rocks (organic-bearing shales) to see if enough organic matter (kerogen), and the right kind of kerogen, is present to generate economically significant quantities of petroleum or natural gas. Some kinds of kerogen generate liquid petroleum, others generate gas. These diameter wells also determine which potential reservoir rocks have adequate porosity and permeability to make them targets for exploratory drilling. Biomarker analyses of lake slick and residues in tufa indicated a mature marine shale source rock. There could be some other mature source rocks in 4B shales/clays that were deposited as fan toe clays and other clay deposited due to lake incursions in the geologic history of the basin.

Samples from tufa limestones of Muhokya and Lyembuza should be analysed for petroleum inclusions to understand more about the kinds of oil or gas that passed through these cavities and at what time this event occurred in the geologic history of the basin. These inclusions may also provide information about stress history of the reservoirs. Stress history is an important influence on the way the reservoir will behave during a Frac - hydrofracturing designed to enhance flow of petroleum from the reservoir into the well bore or flow of injected fluids/mud from well bore to rock. Fluid inclusions also tell about the burial and thermal history of the basin.

A more detailed chronology of Queen Elizabeth Formation is required. It is not well defined from this study apart from recognition that its field relations are different from the clearer Bwambara Formation. The field contact between these two formations was not perfectly checked due to limited time in the field and funding. However these two formations seem to be separated by KKK-FZ. Thus in places were this zone does not reach, the nature of the contact needs to be investigated.

Emphasis should also be put on the mapping migration routes, studying thermal history of the basin and timing of petroleum generation and migration.

Thus we need to solve issues such as: when the oil started to migrate, the direction it followed (mapping migration routes), relationship between tectonic movements and oil migration (timing of trap formation), thermal history of the basin and oil generating potential of possible source rocks.

REFERENCES

Bagas, L., Bierlein, F.P., Bodorkos, S and Nelson, D.R., 2008. Tectonic setting, evolution and orogenic gold potential of the late Mesoarchaean Mosquito Creek Basin, North Pilbara Craton, Western Australia. *Precambrian Research* **160**, 227-244.

Bishop, W.W., 1969. Pleistocene stratigraphy of Uganda. *Geological Survey of Uganda* Memoir **X**, 1-128.

Bosworth, W., 1985. Geometry of propagating continental rifts. *Nature* **316**, 625-627.

Boven, A., Pasteels, P., Punzalan, L.E., Yamba, T.K and Musisi, J.H., 1998. Quaternary perpotassic magmatism in Uganda (Toro-Ankole Volcanic Province): Age assessment and significance for magmatic evolution along the East African Rift. *Journal of African Earth Sciences* **26**, 463-476.

Brooks, A.S and Smith, C.C., 1987. Ishango revisited: New age determinations and cultural interpretations. *African Archaeological Review* **5**, 67-78.

Brooks, A.S., Helgren, D.M., Cramer, J.S., Franklin, A., Hornyak, W., Keating, J.M., Klein, R.G., Rink, W.J., Schwarcz, H., Smith, J.N.L., Stewart, K., Todd, N.E., Verniers, J and Yellen, J.E., 1995. Dating and context of three Middle Stone Age sites with bone points in the Upper Semliki Valley, Zaire. *Science* **268**, 548-553.

Byakagaba, A.B., 1997. Report on the geological mapping of the Lakes Edward-George basin. *Report of the Petroleum Exploration and Production Department, Ministry of Energy, Uganda,* 1-49.

Calais, E., Ebinger, C.J., Hartnady, C and Nocquet, J.M., 2006. Kinematics of the East African Rift from GPS and earthquake slip vector data. *In:* Yirgu, G., Ebinger, C.J., and Maguire, P.K.H. (Eds.), *The Afar Volcanic Province within the East African Rift System*. Geological Society, London, Special Publications **259**, 9-22.

De Heinzelin, J., 1955. Le fossé tectonique sous la parallèle d'Ishango. *Exploration Parc National Albert, Mission J. de Heinzelin de Braucourt (1950)* **1**, 1-150.

Demant, A., Lestrade, P., Lubala, R.T., Kampunzu, A.B and Durieux, J., 1994. Volcanological and petrological evolution of Nyiragongo volcano, Virunga volcanic field, Zaire. *Bulletin of Volcanology* **56**, 47-61.

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

Ebinger, C.J., 1989b. Geometric and kinematic development of border faults and accommodation zones, Kivu-Rusizi Rift, Africa. *Tectonics* **8**, 117-133.

Ebinger, C.J., Bechtel, T.D., Forsyth, D.W and Bowin, C.O., 1989. Effective elastic plate thickness beneath the East African and Afar Plateaus and dynamic compensation of the uplifts. *Journal of Geophysical Research* **94**, 2883-2901.

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

Foster, A and Jackson, J.A., 1998. Source parameters of large African earthquakes: implications for crustal rheology and regional kinematics. *Geophysical Journal International* **134**, 422-448.

Furman, T., 2007. Geochemistry of East African Rift basalts: An overview. *Journal of African Earth Sciences* **48**, 147-160.

Gawthorpe, R.L and Hurst, J.M., 1993. Transfer zones in extensional basins: their structural style and influence on drainage development and stratigraphy. *Journal of the Geological Society, London* **150**, 1137-1152.

Geological Survey of Uganda, 1961. 1:250 000 Mbarara Sheet, SA-36-1. First Edition. *Geological Survey of Uganda*.

Herman, Z., Frank, V., Veronika, W., Karl, F., Stephan, V.S and Rainer, A., 1997. Styles of continental rifting: Crust-mantle detachment and mantle plumes. Elsevier Science B.V 330-333.

Hopwood, A.T and Lepersonne, J., 1953. Presence de formations d'age miocene inferieur dans le fosse tectonique du Lac Albert et de la Basse Semliki (Congo belge). *Annales du Société géologique de Belgique* Memoire **LXXII**, 1-92.

Kampunzu, A.B., Bonhomme, M.G and Kanika, M., 1998. Geochronology of volcanic rocks and evolution of the Cenozoic Western Branch of the East African Rift System. *Journal of African Earth Sciences* **26**, 441-461.

Knut Bjorlykke., 1989. Sedimentology and Petroleum Geology. Springer-Verlag berlin Heidelberg, 55-59.

Kutterolf, S., Diener, R., Schacht, U., Krawinkel, H., 2008. Provenance of the Carboniferous Hochwipfel Formation (Karawanken Mountains, Austria/Slovenia) - Geochemistry versus petrography. *Sedimentary Geology*, doi:10.1016/j.sedgeo.2007.12.004.

Laerdal, T and Talbot, M.R., 2002. Basin neotectonics of Lakes Edward and George, East African Rift. *Palaeogeography, Palaeoclimatology, Palaeoecology* **187**, 213-232.

Lambiase, J.J., 1990. A model for tectonic control of lacustrine stratigraphic sequences in continental rift basins. *In:* Katz, B. (Ed.), *Lacustrine basin exploration: Case studies and modern analogues.* American Association of Petroleum Geologists Memoir 50, 265-276.

Lee, S.-G., Kim, J.-K., Yang, D.-Y and Kim, J.-Y., 2008. Rare earth element geochemistry and Nd isotope composition of stream sediments, south Han River drainage basin, Korea. *Quaternary International* **176-177**, 121-134.

Lloyd, F.E., Huntingdon, A.T., Davies, G.R and Nixon, P.H., 1991. Phanerozoic volcanism of southwest Uganda: A case for regional K and LILE enrichment of the lithosphere beneath a domed and rifted continental plate. *In:* Kampunzu, A.B and Lubala, R.T. (eds.), *Magmatism in extensional structural settings. The Phanerozoic African Plate*. Springer-Verlag, Heidelburg, 23-72.

Lorenz, V., 1975. Formation of phreatomagmatic maar-diatreme volcanoes and its relevance to kimberlite diatremes. *Physics and Chemistry of the Earth (First International Conference on Kimberlites)* **9**, 17-27.

Morley, C.K., 1995. Developments in the structural geology of rifts over the last decade and their impact on hydrocarbon exploration. *In:* Lambiase, J.J. (Ed.), *Hydrocarbon habitat in rift basins*. Geological Society, London, Special Publications **80**, 1-32.

Musisi, J.H., 1991. The Neogene-Quaternary geology of the Lake George-Edward basin, Uganda. *Unpublished Ph.D. Thesis, Faculty of Science, Vrije Universiteit Brussel, Belgium,* 1-298.

Nicholas, C.J and Twinomujuni, L., 2009. Lithologic well logs for uphole samples in Block 4B, South East Lake Edward Basin.

Nicholas, C. J and Dozith Abeinomugisha, Tonny Sserubiri and Lauben Twinomujuni., 2008. Stratigraphy and sedimentology of Onshore block 4B; *17th, March Dominion presentation to PEPD.*

Nicholas, C.J., Dozith Abeinomugisha, Ian Newth and Lauben Twinomujuni., 2009. Petroleum Geology of onshore block 4B- South East Lake Edward Basin.

Pasteels, P., Villeneuve, M., de Paepe, P and Klerkx, J., 1989. Timing of the volcanism of the southern Kivu province; implications for the evolution of the western branch of the East African Rift System. *Earth and Planetary Science Letters* **94**, 353-363.

Petroleum Exploration and Production Department (PEPD)., 2005. Geology and hydrocarbon potential of the Albertine Graben, 1-7.

Philip A. Allen and John R. Allen., 1990. Basin analysis; *Principles and applications.* Blaackwell science Ltd. 309-417.

Pickford, M., Senut, B and Hadoto, D., 1993. Geology and Palaeobiology of the Albertine Rift valley, Uganda-Zaire, Vol. **I**: Geology. *Centre International pour la Formation et les Echanges Géologiques - CIFEG, Publication Occasionelle,* 1993/24, 1-190.

Rogers, J.J.W and Rosendahl, B.R., 1989. Perceptions and issues in continental rifting. *Journal of African Earth Sciences* **8**, 137-142.

Rosendahl, B.R., 1987. Architecture of the continental rifts with special reference to East Africa. *Annual Review of Earth and Planetary Sciences* **15**, 445-503.

Rosendahl, B.R., Kilembe, E and Kaczmarick, K., 1992. Comparison of the Tanganyika, Malawi, Rukwa and Turkana Rift zones from analyses of seismic reflection data. *Tectonophysics* **213**, 235-256.

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

Sander, S and Rosendahl, B.R., 1989. The geometry of rifting in Lake Tanganyika, East Africa. *Journal of African Earth Sciences* **8**, 323-354.

Sunday W. Petters., 1991. Regional Geology of Africa. Springer-Verlag Berlin Heidelberg, 613-621.

Tiercelin, J.-J and Mondeguer, A., 1991. The geology of the Tanganyika Trough. *In:* Coulter, G.W. (Ed.), *Lake Tanganyika and its life*. Oxford University Press, Oxford, 7-48.

Tullow oil plc. 2007. Lake Albert Rift Basin-Exploration campaign. *Uganda analyst visit-October 2002, 1-33.*

Walsh, J.N., Buckley, F. and Barker, J. 1981. The simultaneous determination of rare earth elements in rocks using inductively coupled plasma source spectrometry. *Chem. Geol.* **33**,141-43.

Wayland, E. J., 1925. Petroleum in Uganda. *Geological Survey of Uganda*, Memoir I.

APPENDICES

Appendix 1

SAMPLE LOCALITIES

ISH= (Ishasha) Sample Localities

LOCALITY No. (See GeoMap)	x (ARC 1950)	y (ARC 1950)	SAMPLE NO.
64	795133	9897894	ISH 48 Basement
63	795021	9899238	ISH 46
63	795021	9899238	ISH 47
65	794031	9900612	ISH 49
66	793767	9907552	ISH 50
66	793767	9907552	ISH 51
68	794694	9915886	ISH 52
68	794694	9915886	ISH 53
69	803186	9915546	ISH 54
69	803186	9915546	ISH 56
70	802314	9916232	ISH 57
72	820100	9957872	ISH 58
72	820100	9957872	ISH 59
72	820100	9957872	ISH 60
72	820100	9957872	ISH 61
73	814745	9932484	ISH 62
73	814745	9932484	ISH 63

Appendix 2

SHOTPOINT LITHOFACIES ASSIGNMENTS

LINE 1 SHOTPOINT SAMPLES	SAMPLE NUMBER	LITHOFACIES
	161	D+E
	205	E
	221	A
	249	C
	271	C+D
	289	D+E
	317	D+E
	565	C trending to D
	597	D+B
	615	A
	689	D
	719	B+E mix
	743	D
	765	C
	793	C+D
	813	C+D
	993	E
	1013	D
	1033	E
	1063	D
	1083	E
	1103	B

LINE 2 SHOTPOINT SAMPLES	SAMPLE NUMBER	LITHOFACIES
	271	D
	293	E
	313	C
	333	D
	353	D
	383	C
	403	E
	441	E
	475	C
	813	E
	833	E
	853	E
	872	E
	1581	D+C

LINE 3 SHOTPOINT SAMPLES	SAMPLE NUMBER	LITHOFACIES
	107	E+B
	127	C+D
	147	E
	167	C+B
	187	C
	207	C
	227	C+B
	247	A
	267	B
	287	A
	307	B
	327	B
	361	C
	371	C
	391	B+A
	419	C
	527	E
	547	D
	579	E
	651	C+D
	679	B+A

697	D
741	D
787	C
817	D
847	C+E
851	D
859	B+D
879	C+E
927	E+B
947	C+E
979	D+B
995	D
1055	D
1077	C
1315	C+B
1345	A+E
1365	D

LINE 4 SHOTPOINT SAMPLES

SAMPLE NUMBER	FACIES
229	D
327	D
347	E
447	D
457	E
487	D
507	E
527	E
546	D
571	B
591	A+E
611	A+E
622	C+E
701	E
721	D
737	D
759	A
817	D
1068	B
1350	D

LINE 5 SHOTPOINT SAMPLES	SAMPLE NUMBER	LITHOFACIES
	119	C+E
	139	B+D
	159	E
	168	E
	179	E
	185	D
	221	D
	239	D
	257	D+C
	277	D
	295	D
	313	D+A
	331	D
	363	D+C
	383	C+E
	403	D
	441	D
	461	D
	497	D+E
	517	D
	542	E
	560	E
	579	D+E
	615	E
	635	C+B
	655	E
	675	E+B
	711	B
	729	A+D
	760	B+D
	887	A
	901	A
	915	D
	930	D
	1013	C+D
	1031	E
	1053	E
	1076	A+B
	1662	E
	1713	E
	1715	E

1733	E
1734	E
1745	E
1758	E

LINE 6 SHOTPOINT SAMPLES	SAMPLE NUMBER	LITHOFACIES
	119	C+D
	126	C+D
	139	B+C
	146	E
	159	C
	179	C
	199	B
	219	C+B
	237	E
	242	E
	261	C+E
	281	E
	299	E
	331	E+D
	351	A
	371	D
	421	C+E
	441	C+D
	461	D
	481	D
	519	E+D
	539	D
	567	E
	591	D
	611	D+C
	701	D
	721	D+E
	741	D+C
	761	C+E
	801	D+E
	821	E+B
	841	B+C
	861	B

LINE 7 SHOTPOINT SAMPLES	SAMPLE NUMBER	LITHOFACIES
	359	E
	427	A
	449	A+B
	471	B
	487	D
	507	B+D
	527	E
	871	B+C
	891	D
	933	B
	935	A
	951	A
	971	B
	985	A
	991	B
	1021	C+D
	1037	E+C
	1057	E
	1169	B
	1189	B
	1208	C+D
	1229	C+B
	1249	B

LINE 8 SHOTPOINT SAMPLES	SAMPLE NUMBER	LITHOFACIES
	127	D
	147	C
	169	C+B
	341	E
	357	D
	409	C+B
	433	C
	441	D
	455	C+B and E mix
	481	D
	565	B+A

581	D +large pebbles (cave in??)
613	D +large pebbles (cave in??)
629	D+A mix
655	D
691	D+B
693	B+D mix
699	B+D mix
707	B+D mix
733	B+D mix
805	D+C
821	C+ some clay
881	D
902	B+D mix
923	D
933	D
1008	C
1323	B+A

LINE 10 SHOTPOINT SAMPLES	SAMPLE NUMBER	LITHOFACIES
	101	C+D mix
	111	C+D mix
	119	D
	161	E
	173	D
	241	D
	259	C+D mix
	267	E+A mix
	269	C+B+D mix
	301	D+A mix
	322	D+A mix
	353	C+B+D mix
	375	D+C
	399	D
	413	B
	432	D
	443	D
	658	E
	680	C+E

686	C+D mix
695	C+E mix
703	D
711	D
721	D
743	D
757	E
773	D
795	C+D mix
873	C+D mix
879	D+B mix
897	D+E
903	C
919	C
1007	C+B mix
1234	E
1250	B
1253	E
1260	D

LINE 12 SHOTPOINT SAMPLES	SAMPLE NUMBER	LITHOFACIES
	101	D
	139	E
	159	D
	179	D
	215	D
	237	D +E
	339	C +D
	363	A
	464	D
	495	D
	509	D
	541	C +D
	547	B
	554	B+C
	625	C+E
	639	C+E
	667	C
	955	A+B

LINE 14 SHOTPOINT SAMPLES	SAMPLE NUMBER	LITHOFACIES
	369	B
	389	B
	410	B
	429	D
	451	B
	469	D
	489	B
	509	B
	578	A+E mix
	630	B
	659	D
	694	B
	719	D
	740	A
	755	C
	848	A

LINE 16 SHOTPOINT SAMPLES	SAMPLE NUMBER	LITHOFACIES
	375	A
	444	B
	484	A
	614	B
	644	A

Appendix 3

UPHOLE SAMPLE LITHOFACIES ASSIGNMENTS

UPHOLE I	DEPTH IN THE HOLE IN METRES	FACIES
	6 M	D
	12 M	B
	18 M	D
	24 M	E
	30 M	C+D MIX
	36 M	C+D MIX
	42 M	C
	48 M	E+C MIX
	54 M	D
	60 M	D
	66 M	D
	72 M	D+C MIX
	78 M	C+D MIX
	80 M	D

UPHOLE 2	DEPTH IN METRES	FACIES
	3 M	E
	6 M	E
	12 M	E
	18 M	E
	24 M	E
	30 M	D
	36 M	D
	42 M	D

UPHOLE 3	DEPTH IN METRES	FACIES
	6 M	E
	12 M	E
	18 M	D
	24 M	C
	26 M	C+D MIX
	30 M	C+D MIX
	36 M	C+D MIX
	42 M	B
	48 M	C
	54 M	C
	60 M	C
	66 M	D
	72 M	D
	78 M	C
	80 M	C

UPHOLE 4	DEPTH IN METRES	FACIES
	2 M	C
	6 M	C
	12 M	C
	18 M	B
	24 M	C+D
	30 M	D+C
	32 M	C
	34 M	C

UPHOLE 6	DEPTH IN METERS	FACIES
	6 M	E
	12 M	E
	18 M	E+B
	24 M	B
	30 M	D
	36 M	D
	42 M	B+D
	48 M	D
	54 M	D+C
	60 M	D+C
	66 M	D+C
	72 M	D+C
	78 M	C+D
	83 M	C+D

UPHOLE 7	DEPTH IN METRES	FACIES
	6 M	B
	12 M	D
	18 M	D
	20 M	C
	24 M	D
	28 M	C
	30 M	C
	36 M	C
	42 M	C+D
	48 M	C+D
	54 M	C+D
	60 M	C+D
	66 M	C
	72 M	C+D
	78 M	C
	80 M	C+E
	83 M	C+E

UPHOLE 8	DEPTH IN METERS	FACIES
	6 M	D+C MIX
	12 M	A
	18 M	A
	24 M	E
	30 M	D
	36-48 M	D
	48 M	D+E
	54 M	C+D
	60 M	D
	66-80 M	C+D

UPHOLE 9	DEPTH IN METRES	FACIES
	6 M	E
	9 M	C
	12 M	E
	18 M	E
	24 M	E
	30 M	E
	36 M	D
	42 M	D
	48 M	D
	54 M	D
	60 M	D
	66 M	D
	72 M	D
	78 M	D
	80 M	D

UPHOLE 10	DEPTH IN METRES	FAC IES
	6 M	E
	12 M	D
	18 M	B
	24 M	D+B
	24-40 M	A
	40-48 M	B
	54 M	C
	60 M	C+D
	60-63 M	D

UPHOLE 11	DEPTH IN METERS	FACIES
	6 M	D
	12 M	B
	18 M	B
	24 M	C
	30 M	E
	36 M	C
	42-54 M	C+D

UPHOLE 15	DEPTH IN METRES	FACIES
	6	E
	12	E+B
	18	E
	24	E+C
	30	C+D
	36	E
	42	D+B
	48	E

54	C+D
60	D
66	D
72	D
78	D+C

UPHOLE 18	DEPTH IN METRES	FACIES
	3	E
	6	E
	12	E
	18	E
	24	E
	30	E
	36	E+C
	42	C
	48	C
	54	C
	60	C
	64	C+D

UPHOLE 23	DEPTH IN METERS	FACIES
	6 M	D
	12 M	D+B MIX
	18 M	E+B MIX

24 M	C+D
30 M	C
36 M	D
42 M	D

Appendix 4

GEOCHEMICAL DATA FOR SAMPLES FROM SOUTH EAST EDWARD BASIN

Major Elements

SAMPLE NO.	SiO2 %	Al2O3 %	CaO %	Cr2O3 %	Fe2O3 %	K2O %	MgO %	MnO %	Na2O %	P2O5 %	TiO2 %
ISH 48 Basement	69.38	20.88	<0.01	0.014	0.64	3.77	0.15	0.002	0.77	0.09	0.88
ISH 46	59.94	17.75	0.02	0.019	8.36	1.86	0.13	0.009	0.26	0.18	1.08
ISH 47	71.61	10.14	<0.01	0.014	10.86	0.90	0.08	0.013	0.12	0.15	0.86
ISH 49	78.25	8.85	0.02	0.012	5.53	1.26	0.12	0.011	0.12	0.11	0.77
ISH 50	96.12	2.35	<0.01	0.002	0.38	0.69	0.03	0.002	0.05	0.10	0.22
ISH 51	77.70	13.70	0.01	0.012	0.80	2.21	0.18	0.007	0.27	0.12	1.33
ISH 52	69.24	14.04	0.12	0.012	6.80	1.55	0.22	0.016	0.20	0.18	1.05
ISH 53	78.01	11.23	0.05	0.008	1.96	1.06	0.15	0.013	0.14	0.08	0.75
ISH 54	65.48	17.24	<0.01	0.015	4.84	1.25	0.36	0.106	0.07	0.19	1.32
ISH 56	91.23	3.60	0.02	0.002	1.09	0.52	0.06	0.018	0.04	0.09	0.16
ISH 57	59.27	20.46	0.16	0.017	6.10	2.47	0.35	0.018	0.43	0.09	1.02
ISH 58	86.76	6.06	0.17	0.004	1.63	1.00	0.17	0.017	0.35	<0.01	0.32
ISH 59	90.16	4.53	0.17	0.003	0.99	1.21	0.11	0.015	0.49	<0.01	0.37
ISH 60	80.95	8.31	0.29	0.007	2.72	1.58	0.26	0.054	0.67	0.04	0.68
ISH 61	62.13	16.53	0.36	0.014	5.61	1.87	0.53	0.050	0.52	0.13	1.19
ISH 62	92.45	4.65	<0.01	0.003	0.85	0.62	0.05	0.005	0.04	<0.01	0.22
ISH 63	92.34	3.91	<0.01	0.003	1.21	0.42	0.05	0.010	0.04	<0.01	0.55

Trace Elements

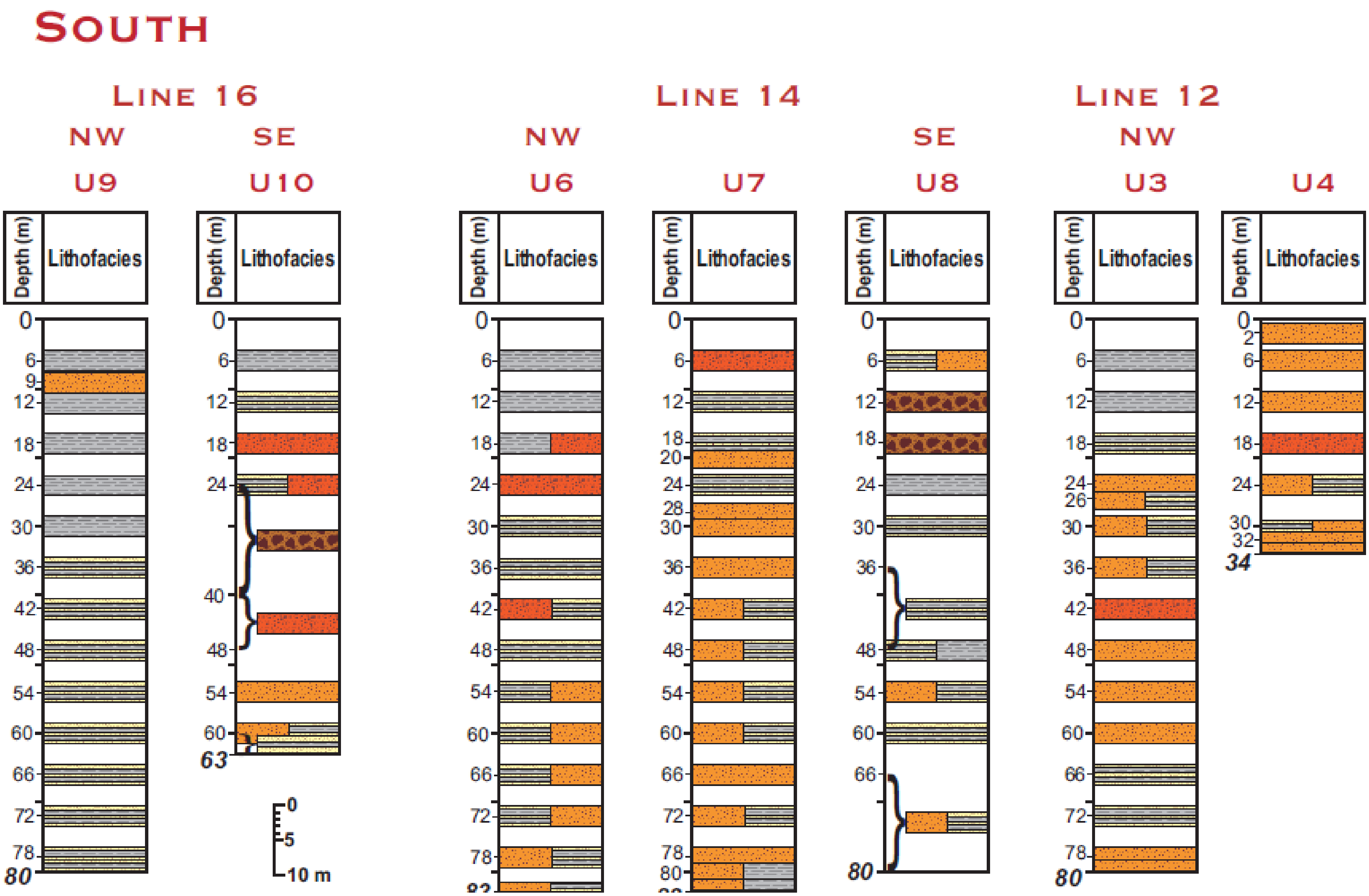
SAMPLE NO.	Ba Ppm	Ce ppm	Dy ppm	Er ppm	Eu ppm	Ga ppm	Gd Ppm	Hf ppm	Ho ppm	La ppm	Lu ppm	Nb ppm
ISH 48 Basement	851	101.1	5.7	3.2	1.7	27.1	7.2	3	1.1	54.2	0.5	14.7
ISH 46	383	58.5	3.8	2.7	0.7	26.4	3.0	2	0.9	37.4	0.5	25.6
ISH 47	177	47.5	3.0	2.0	0.6	14.5	2.7	5	0.6	21.4	0.4	21.2
ISH 49	207	61.3	3.1	1.8	1.0	12.7	3.6	3	0.6	30.1	0.3	16.8
ISH 50	119	51.2	1.4	0.9	0.6	3.3	2.5	<1	0.3	25.7	0.2	6.0
ISH 51	440	94.5	8.0	5.1	1.8	18.0	8.0	6	1.7	49.5	0.8	26.7
ISH 52	458	105.3	5.6	3.4	1.5	18.1	6.2	9	1.1	60.3	0.6	33.5
ISH 53	323	171.7	5.1	2.6	2.2	15.7	8.0	6	0.9	76.5	0.4	25.5
ISH 54	824	198.5	7.9	4.4	2.4	21.5	10.3	9	1.5	102.3	0.6	106.8
ISH 56	146	50.3	1.8	1.0	0.6	5.3	2.3	2	0.4	25.6	0.2	19.4
ISH 57	599	125.5	5.6	3.2	1.4	26.0	6.1	6	1.1	68.7	0.5	35.2
ISH 58	265	64.2	3.2	2.0	0.7	9.0	3.4	4	0.7	32.4	0.3	28.0
ISH 59	291	61.7	4.4	2.7	0.9	5.7	4.1	6	0.9	30.7	0.4	21.3
ISH 60	532	87.8	5.3	3.4	1.1	12.4	5.3	11	1.0	43.8	0.6	33.8
ISH 61	617	198.6	8.8	5.1	2.2	25.1	10.9	13	1.7	105.7	0.7	92.7
ISH 62	112	57.1	1.9	1.2	0.3	5.2	2.2	4	0.4	24.9	0.2	16.2
ISH 63	81	49.6	1.8	1.2	0.5	5.7	2.2	4	0.4	23.9	0.2	16.3

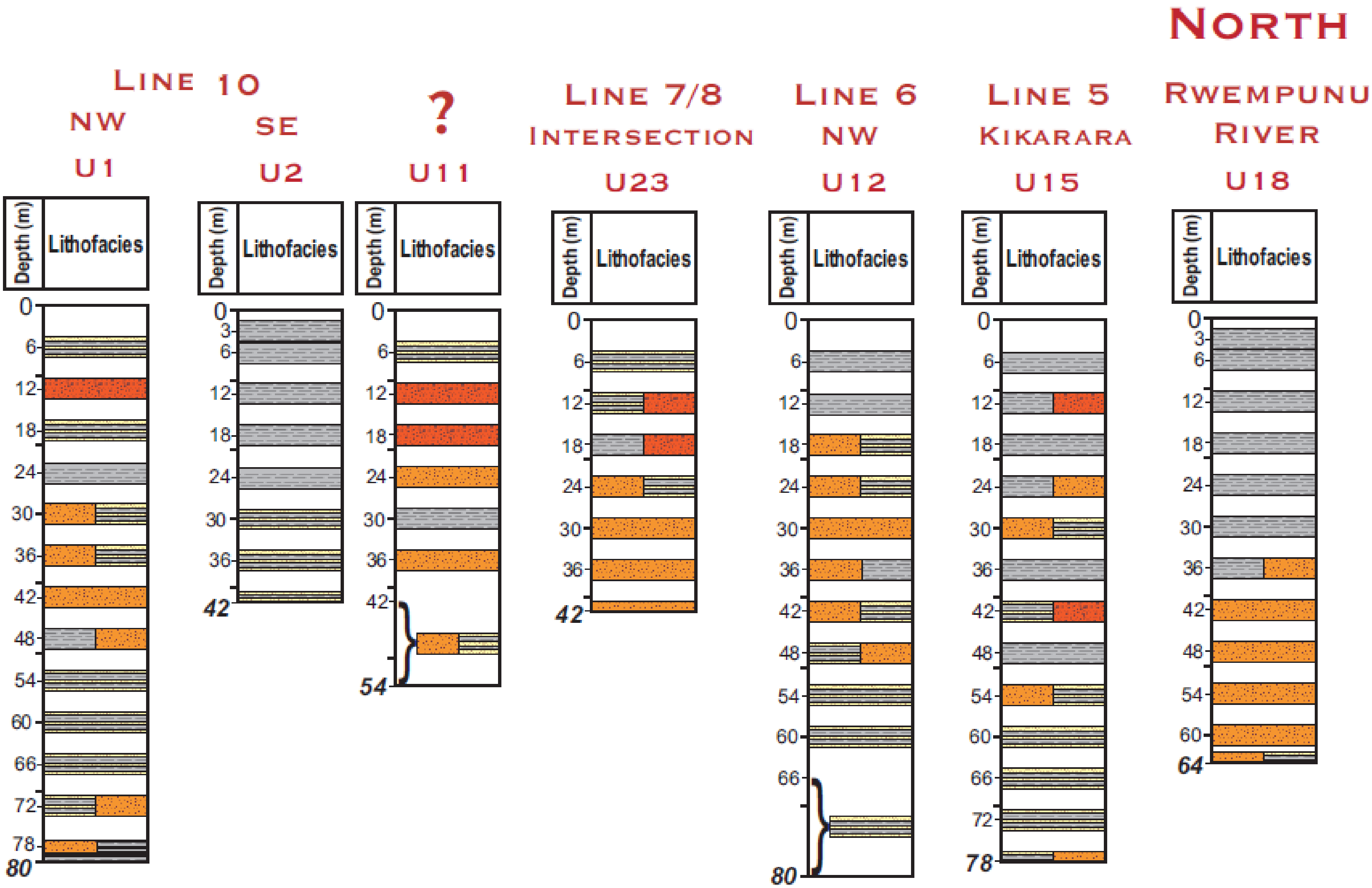
SAMPLE NO.	Nd ppm	Pr ppm	Rb ppm	Sc ppm	Sm ppm	Sn ppm	Sr ppm	Ta ppm	Tb ppm	Th Ppm
ISH 48 Basement	41.7	11.6	170.6	18	8.0	7	100.8	1.4	1.0	10.7
ISH 46	17.4	5.6	92.2	20	3.1	11	38.9	2.4	0.6	10.5
ISH 47	13.1	3.8	45.3	17	2.9	7	18.4	2.0	0.5	18.6
ISH 49	22.3	6.6	67.8	9	4.2	5	24.6	1.5	0.5	12.2
ISH 50	21.8	5.9	24.1	2	3.8	3	14.1	0.6	0.3	4.9
ISH 51	40.5	11.2	99.1	14	8.1	7	44.2	2.4	1.3	10.5
ISH 52	40.4	12.0	70.7	15	7.1	5	65.2	2.5	0.9	17.0
ISH 53	74.5	20.9	52.1	10	12.5	4	60.3	2.0	1.0	12.7
ISH 54	68.1	20.2	65.2	12	11.2	4	105.2	5.8	1.4	17.1
ISH 56	18.3	5.4	21.1	2	3.4	2	28.5	0.9	0.3	6.3
ISH 57	40.4	12.6	125.4	21	6.8	5	89.3	2.7	0.9	13.1
ISH 58	22.4	6.7	35.1	4	4.1	2	56.2	1.7	0.6	7.5
ISH 59	23.2	6.5	35.0	2	4.4	2	52.7	1.3	0.7	6.3
ISH 60	33.5	9.2	53.5	6	5.9	2	72.0	2.3	0.8	10.0
ISH 61	71.4	21.3	88.1	13	12.6	4	93.3	5.9	1.6	17.0
ISH 62	13.4	4.2	19.5	3	2.4	1	15.0	0.7	0.3	5.7
ISH 63	18.1	5.4	13.1	2	3.1	2	9.8	1.1	0.3	4.9

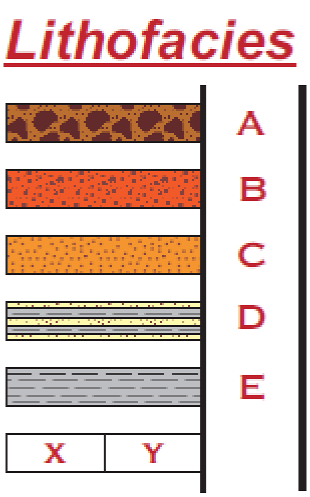
SAMPLE NO.	Tm ppm	U ppm	V ppm	W ppm	Y ppm	Yb ppm	Zr ppm	Co ppm	Ni ppm
ISH 48 Basement	0.5	2.0	86	2.2	31.3	3.3	206	1.3	28
ISH 46	0.4	3.7	145	4.9	24.7	3.1	300	3.3	22
ISH 47	0.3	3.9	127	3.2	16.1	2.3	298	5.2	24
ISH 49	0.3	2.4	72	4.8	16.9	2.1	198	3.3	14
ISH 50	0.2	1.1	11	1.3	7.2	0.9	81	0.9	5
ISH 51	0.8	3.6	71	4.1	48.6	5.1	348	2.5	15
ISH 52	0.5	5.7	124	3.3	29.8	3.5	371	7.8	24
ISH 53	0.4	2.8	47	2.3	23.2	2.6	283	3.1	13
ISH 54	0.7	5.1	76	5.1	45.4	4.3	414	54.9	22
ISH 56	0.2	1.5	17	1.5	9.4	1.0	106	2.5	6
ISH 57	0.5	5.1	117	3.6	30.6	3.4	339	7.9	31
ISH 58	0.3	2.3	33	1.0	19.0	2.2	205	3.8	8
ISH 59	0.4	2.5	24	0.7	25.0	2.7	303	2.9	5
ISH 60	0.5	3.8	42	1.2	31.1	3.5	437	7.7	12
ISH 61	0.8	7.1	93	2.8	48.4	4.9	497	11.1	28
ISH 62	0.2	1.4	15	0.8	10.8	1.3	121	1.1	3
ISH 63	0.2	1.5	18	1.0	10.3	1.4	193	2.0	7

Appendix 5

Uphole Lithostratigraphy, Block 4B Lake Edward (Nicholas and Twinomujuni, 2009)







A: Massive, moderate brown conglomerate, with rounded pebbles and granules supported in a medium to coarse quartz sand with clay coating

B: Massive moderate brown, coarse to medium quartz sand with clay coating

C: Moderate reddish brown to dark yellowish orange, friable and porous, medium to coarse, well sorted quartz sand typically exhibiting dune cross-bedding, with in-filled plant rootlets or bioturbation

D: Repetitively interbedded thin sands and clays

E: Massive sandy clays with in-filled plant rootlets

A mix of lithofacies 'x' and 'y'; where 'x' ³ 50% of the sample and 'y' is £ 50% of the sample