

Geochemical Characterization and Classification of Crude Oils from Eastern Lake Albert Basin, Western Uganda

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How to cite this paper: Daniel, E. A. D. (2025). Geochemical Characterization and Classification of Crude Oils from Eastern Lake Albert Basin, Western Uganda. *Journal of Geoscience and Environment Protection*, 13, 451-467.

<https://doi.org/10.4236/gep.2025.138022>

Received: June 6, 2025

Accepted: August 26, 2025

Published: August 29, 2025

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Abstract

This study aimed at characterizing and classifying crude oils with the view of inferring source rock characteristics from the chemistry of oils and thus inferring the hydrocarbon resource potential. The use of Gas Chromatographic-Flame Ionization Detector traces (GC-FID) in indicating Kibiro, Nzizi2 Murram Pit, Runga, and Sonso is heavily biodegraded oil seep samples and Mputa-1, Mputa-3, Mputa-4, Waraga-1, and Nzizi-2 oil samples are non-degraded oils. From the Ternary diagram, Mputa-1, Mputa-3, Mputa-4, Waraga-1, and Nzizi-2 oils belong to Paraffinic oils while Kibiro and Nzizi-2 Murram Pit oil seeps are classified as Paraffinic-napthenic oils, and Runga and Sonso oil seeps belong to Napthenic oils. The plots of Moretane/Hopane vs Ts/Tm, 20S/(20S + 20R) for C₂₇ sterane vs 22S/(22S + 22R) for C₃₁-homohopane, and saturates, aromatics and NSO + Asph and ratios of $\alpha\beta\beta/(\alpha\beta\beta + \alpha\alpha\alpha)$ for C₂₉-sterane and Ts/(Ts + Tm) show that the studied oil seep and oil samples originated from mature source rock which has tendency to yield significant amount of hydrocarbon. A plot of DBT/Phen vs NH/Hop, diasteranes/Steranes vs dH/29Ts and ratios of CPI, DBT/Phen, Pr/Ph suggests that oil and seep samples are derived from shale source rock which yields significant quantity of hydrocarbons.

Keywords

Biomarkers, Source Rock, Cross Plot, Hydrocarbon

1. Introduction

1.1. Background

Crude oil is a complex mixture of hydrocarbons consisting predominantly of ali-

phatic, alicyclic and aromatic hydrocarbons. It also contains small amounts of nitrogen, oxygen and sulfur compounds, some organometallic complexes, notably of sulfur and vanadium, and dissolved gases, such as hydrogen sulfide (Onojake et al., 2015). A crude oil study, utilizing detailed geochemical analysis of a representative suite of samples, is an excellent way of identifying and comparing samples sourced from source rocks located within a given basin (Onojake et al., 2015). The common methods for geochemical characterization of crude oils are the measurement of API gravity, sulfur content, biomarker fingerprints, crude oil compositions and stable carbon isotope ratio $\delta^{13}\text{C}_{\text{‰}}$ (Naglaa et al., 2014; Onojake et al., 2015). The relative amounts of normal alkanes, isoprenoid, aromatics, and sulfur compounds, are characteristics of oils derived from a particular source rock (Naglaa et al., 2014). This study investigates the oils from Lake Albert basin, a sub-basin within Albertine Graben, which, is a part of the East African Rift System (EARS).

The EARS comprise the Eastern arm and the Western arm, popularly known as the Albertine Graben. The Western arm is approximately 2100 km long and comprises a series of elongated, narrow rift valleys extending from Lake Malawi in the south to Lake Albert in the north and it is the principal potential petroleum prospect in Uganda (Lirong et al., 2004; PEPD, 2011). It comprised NE-SW trending narrow rift troughs or a series of discontinuous faulted segments formed by tectonic episodes of both extensional and compressional regimes. One such troughs located in the Albertine Graben is the Lake Albert basin (Figure 1), the focus of this study.

Eastern Lake Albert basin (Figure 1), forms part of the Albertine Graben, a frontier basin in the Western part of the East African Rift System which has seen a bee-hive of activity in the recent past. Its hydrocarbon potential is highlighted by a number of recent discoveries of oil and gas (Lirong et al., 2004). Being a frontier basin, important geological parameters that inform the resource potential therein are poorly constrained. For example, lithology, depositional environments, and the organic matter type in source rocks are unknown. This implies that the resource potential in the Graben remains unresolved with negative impact towards government efforts to attract international oil companies. The poor understanding is partly due to the fact that source rocks have not been penetrated in this part of the basin.

The understanding of source rock lithology, that is, carbonate versus siliciclastic has an important bearing on the source potential and indeed, the resource potential. For example, generation and migration through carbonate lithology is known to be very efficient compared to in siliciclastic lithology due to the surface activity. Moreover, some sections of the literature on the geological history of the Albertine Graben, indicate the possibility of thick pre-rift sediments of the Karoo, the marine carbonates that were wide-spread in Africa during the carboniferous (Abeinomu-gi-sha & Kasande, 2009; Kiconco, 2005).

In the current oil study, geochemical inversion is used as a modern approach of inferring crude source rock characteristics from the chemistry of hydrocarbon ac-

cumulations and seeps (Bissada et al., 1992). This is because pertinent source rock information is absent, because exploratory drilling focused strictly on structural highs and failed to penetrate the deeply buried, effective basinal source facies.

Biomarkers are used in crude oil study to provide information on the organic source materials, environment of deposition, thermal maturity experienced by a rock and the degree of biodegradation (Onojake et al., 2015). Biomarkers are apparently used in petroleum industry to identify groups of genetically related oils, to correlate oils with source rocks and to describe the probable source rock depositional environments for migrated oil of uncertain origin (Hakimi et al., 2011).

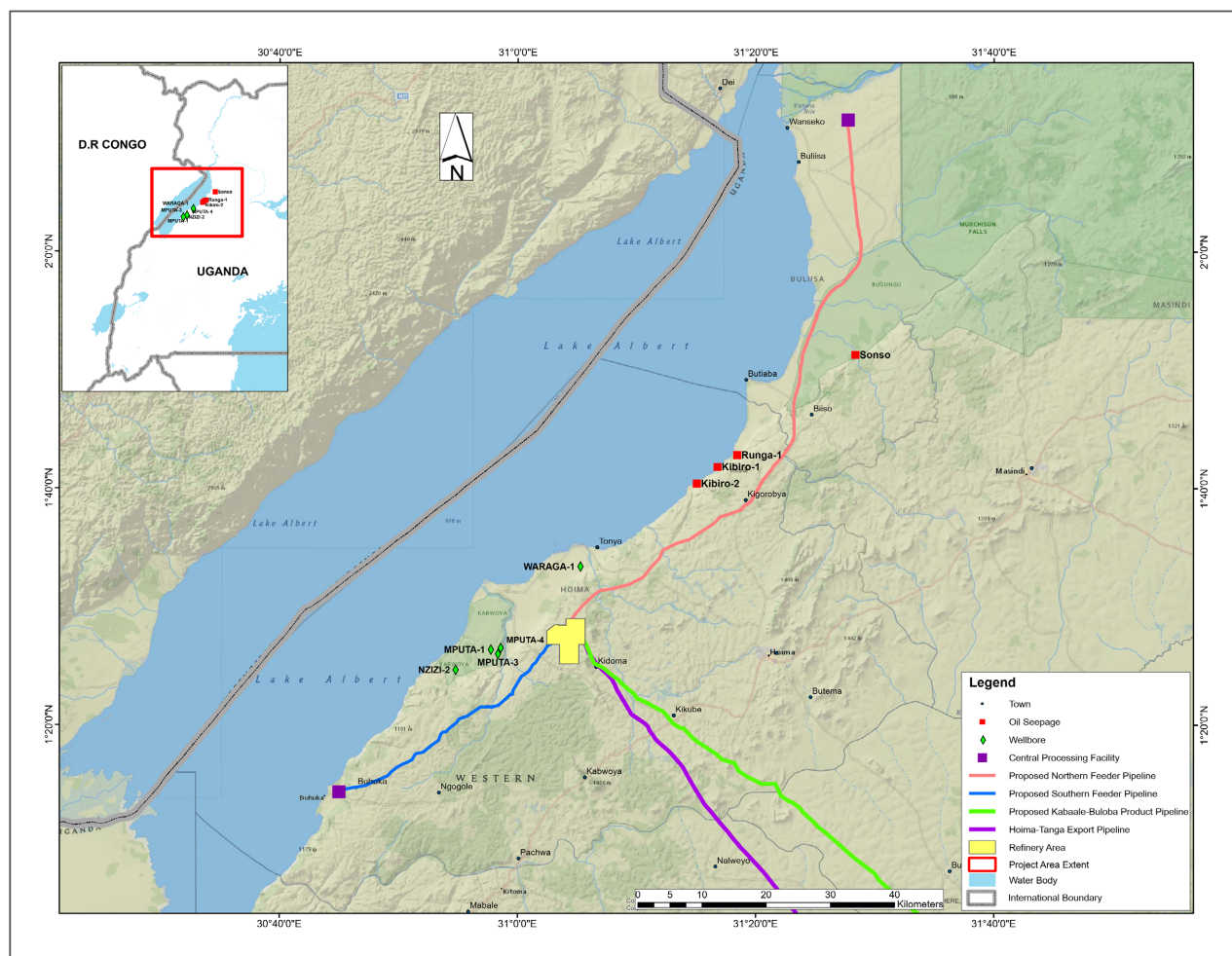


Figure 1. Map showing the location of the wells and seepages from which samples used in this study were obtained (modified from PEPD, 2011).

1.2. Statement of the Problem

In the Albertine Graben, drilling has only targeted hydrocarbon traps, with no due consideration to source rocks, the primary geological element from which the oils are derived and which, also determines how much petroleum is potentially available for entrapment. This implies that uncertainty surrounds such information about source rocks, such as their lithology, their organic matter attributes, depo-

sitional environments and maturity, with attendant impact on the resource potential of the area. Oil-source rock correlation in the Albertine Graben by Lukaye & Okello (2015) indicated a negative correlation between the oils and the suspected source rocks, and therefore implying existence of a number of source rocks. This implies that oil-source rock correlations in the Albertine Graben remains elusive thus a gap in knowledge about source rock lithology and maturity which control the hydrocarbon reserves potential.

1.3. Main Objective

To geochemically characterize and classify the oils of the Eastern Lake Albert basin with the view of projecting source rock characteristics and thus infer the petroleum potential therein.

Specific Objectives

Specific objectives included:

- (1) To establish maturity of the source rock responsible for the oils under study.
- (2) To determine source rock lithology from which the oils under study came from.

1.4. Significance of the Study

This study is invaluable to petroleum geochemists because it enables projection of source rock characteristics and potential hydrocarbon resources in the basin and thereby increasing the efficiency of hydrocarbon exploration and production in the Eastern Lake Albert basin. This research will add more knowledge and information to petroleum geochemists about source rock characteristics in the Eastern Lake Albert basin, and use it for future reference, and it will have positive impact to the economy of the country.

1.5. Justification of the Study

The information of crude oil-source rock obtained from this study will be useful for MEMD in reviewing its oil and gas policy, and on license safeguarding petroleum sector as well as use on bids to attract International Oil Companies for investment in the Eastern Lake Albert basin for feasible social economic importance.

2. Methods

Materials

This current study utilized quantitative data, mainly of geochemical data analyzed using High Performance Liquid Chromatography (HPLC) and Gas Chromatography-Flame Ionization Detector (GC-FID) and Gas Chromatography-Mass Spectrometry (GC-MS) of oil seeps and oils recovered from some of the wells in the Albertine Graben drilled by Tullow in 2007. The data from the wells, namely Waraga-1, Nzizi-2 Murram Pit, Nzizi2, MPutu-1, Mputu-3, Mputu-4, Runga, Sonso and Kibiro seep obtained from the Directorate of Petroleum (DOP), En-

tebbe, Uganda. The relevant data was subsequently selected and presented in the workflow (Figure 2) to illustrate systematic flow of the methodology and analysis.

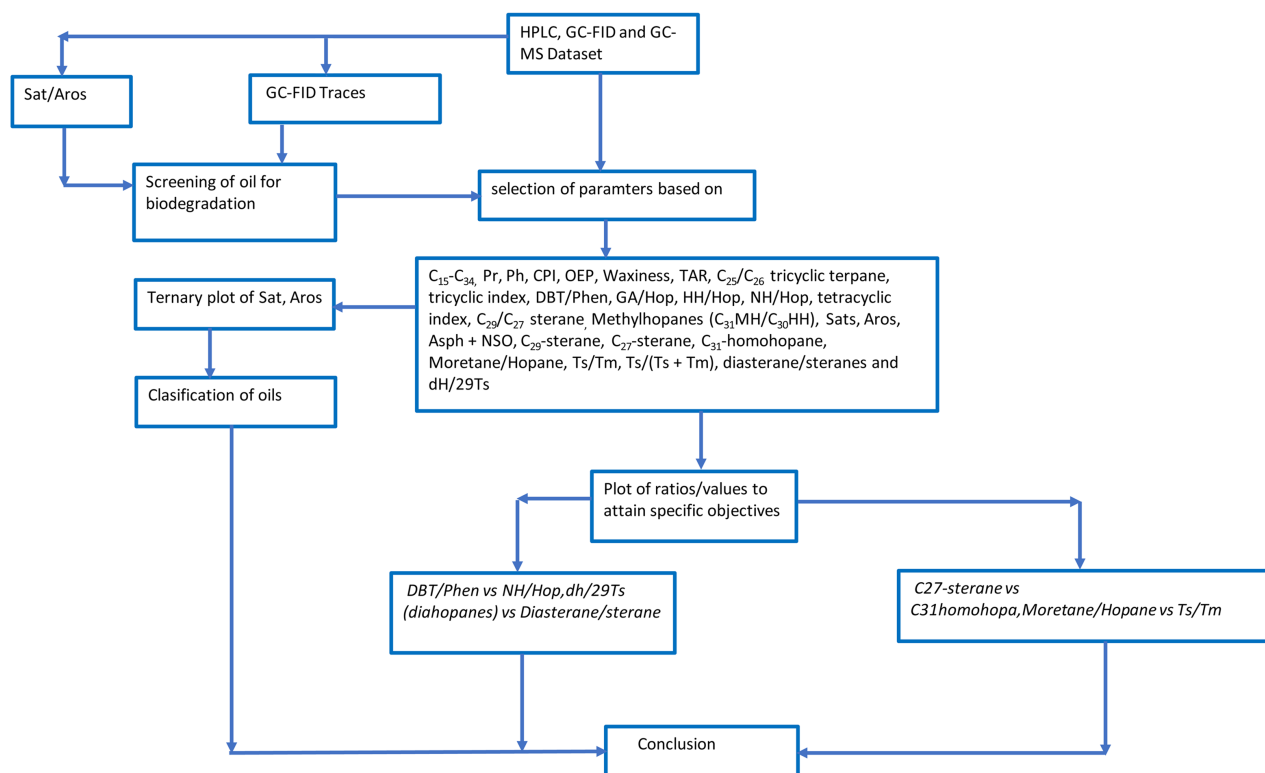


Figure 2. Workflow chart summarizing steps in methodology on how specific (I and II) and main objectives (s) were attained.

3. Results

3.1. Introduction

Data and interpretive ratios obtained from quantitative data-set were tabulated and various interpretive ratios/values and figures derived. The identification and selection of data was based on the importance of each parameter in relevant to specific objective. Where necessary, as in the case of HPLC data, data was normalised before plotting to appropriate interpretive diagram.

3.2. Assessment of Biodegradation

The extent of biodegradation among oil and oil seep samples were assessed from HPLC and GC-FID data. From the HPLC data, it can be seen that Mputa-1, Mputa3, Mputa-4, Waraga-1, Nzizi2 oil samples have saturates/aromatics ratios greater than 1 indicating non-degraded oils while Kibiro, Nzizi-2 Murram Pit, Runga and Sonso oil seep samples have sats/aros ratios less than 1 indicating biodegraded oil seeps. This is actually expected given that they have been exposed to oxidation during seepage.

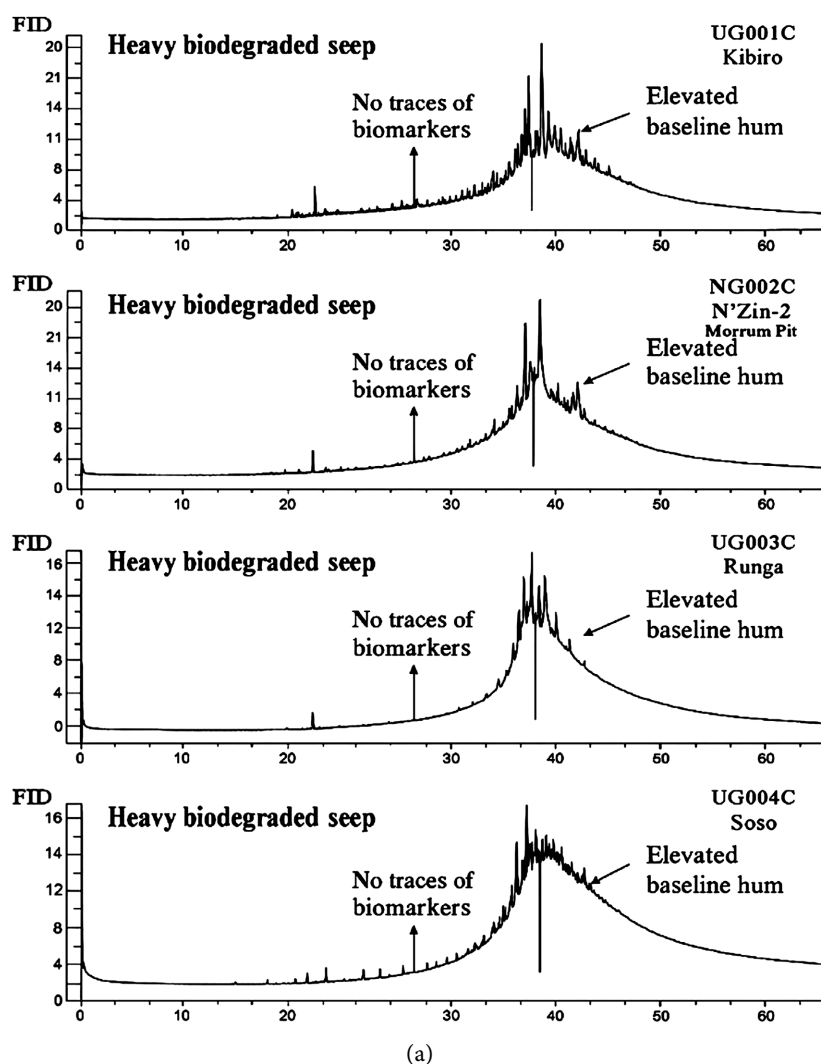
The GC-FID traces for all oil seeps are indicated in Figure 3(a). It noted that

Kibiro, Nzizi-2 Murram Pit, Runga and Sonso have no traces of n-alkanes ($n\text{-C}_{17}$, $n\text{-C}_{18}$, Pr and Ph) and their baseline humps have been elevated to greater extent, implying heavy biodegradation concurring with observations and interpretation of sats/aros from HPLC data above.

The 5 traces of GC-FID for oils (**Figure 3(b)**), show intact n-alkanes ($n\text{-C}_{17}$, $n\text{-C}_{18}$, Pr and Ph) and a relatively straight baseline humps. These samples represent oils recovered from Mputa-1, Mputa-3, Waraga-1, Mputa-4 and Nzizi-2. This clearly suggests that these oils are non-degraded.

3.3. Classification of Crude Oils

A plot of saturates, aromatics and NSO + Asph on Ternary diagram in **Figure 4**. It shows all non-degraded oil samples plot in P zone indicating Paraffinic oils, and biodegraded Kibiro, Nzizi-2 Murram Pit oil seeps plot in PN zone indicating Paraffinic-naphthenic oils, and biodegraded Runga and Sonso oil seeps plot in N zone indicating Naphthenic oils. However, the fact that oils are biodegraded implies that the classification as Paraffinicnaphthenic and Naphthenic may be unrealistic.



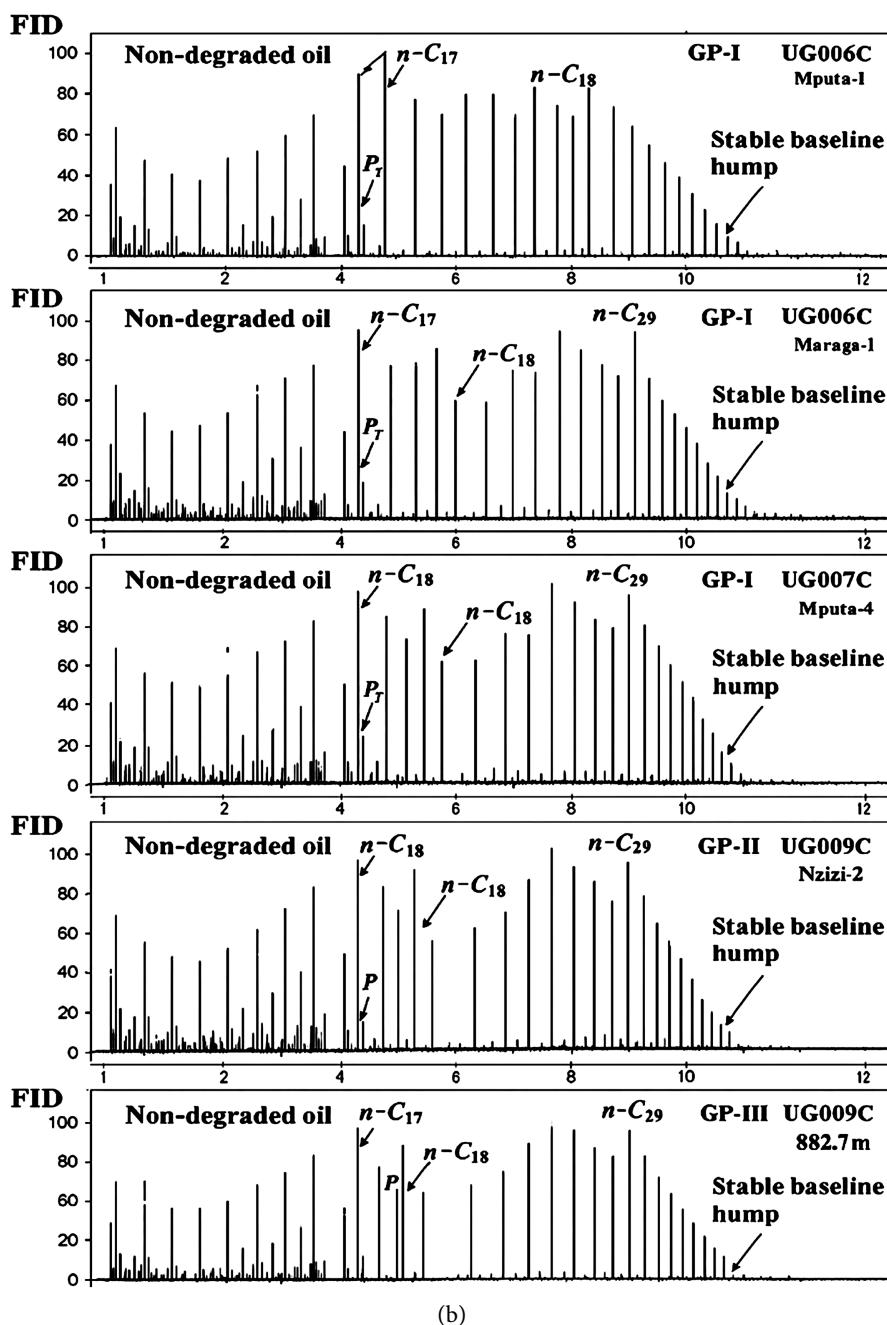


Figure 3. (a) Reconstructed GC-FID traces of saturated hydrocarbons for all oil seep samples. Note that Kibiro, Nzizi Murram Pit, Runga and Sonso samples have no n-alkanes traces, and with elevated/raised baseline humps suggesting possible heavy biodegradation; (b) Reconstructed GC-FID traces of saturated hydrocarbons for all oil samples. Note that Mputa-1, Mputa-3, Waraga-1, Mputa-4 and Nzizi-2 have n-alkanes peaks with normal baseline humps suggesting non-degraded oils.

The GC-FID data are presented in Appendix A2 as raw data, and the following values of $n\text{-C}_{15}$ to $n\text{-C}_{34}$, Pr, Ph and ratios of Pr/Ph, Pr/(Pr + Ph), waxiness, CPI, OEP, and TAR were later screened out for various interpretations and plots to attain specific objectives.

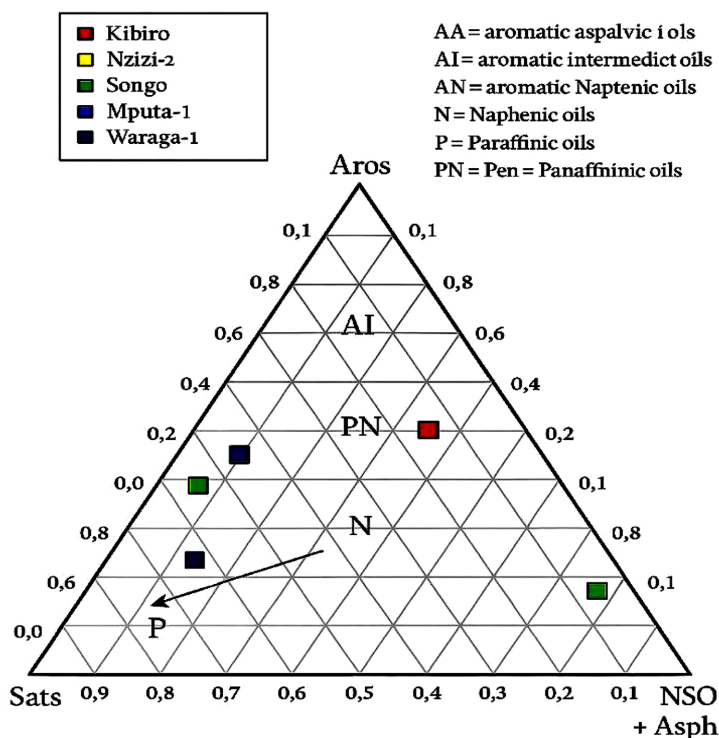


Figure 4. A Ternary diagram showing plot of sats, aros and NSO + Asph suggests all non-degraded oil samples (Mputa-1, Mputa-3, Mputa-4, Waraga-1 and Nzizi-2) plot in P zone indicating Paraffinic oils and Kibiro and Nzizi-2 Murram Pit (biodegraded) oil seeps plot in PN zone indicating Paraffinic-napthenic oils, Runga and Sonso (biodegraded) oil seeps plot in N zone indicating Napthenic oils (plot derived from Tissot & Welte, 1984) and bolded pointing arrow illustrating increasing maturity (Echegu, 2013).

3.4. Characterization of Oils

The source rock characteristics (e.g., maturity, source rock lithology) are determined from chemistry of oils using various plots and geochemical interpretive templates as discussed below.

3.4.1. Maturity of the Source Rock

The use of geochemical parameters of sats, aros and NSO + Asph as illustrated, shows that Mputa-1, Mputa-3, Mputa-4, Waraga-1 and Nzizi-2 oil has high ratios of saturates to aromatics suggesting maturity, and biodegraded seeps of Kibiro Nzizi-2 Murram Pit Runga and Sonso has low ratios of saturates to aromatics suggesting immaturity (Tissot & Welte, 1984; Echegu, 2013).

A plot of ratios of $20S/(20S + 20R)$ for C_{27} -sterane vs $22S/(22S + 22R)$ for C_{31} homohopane for all oil samples is indicated in Figure 5. All oil samples studied plot in a region that indicate high maturity illustrating that the oil samples originated from mature source rock.

A plot of Moretane/Hopane vs Ts/Tm ratios for oil and oil seep samples is indicated in Figure 6. Except for Kibiro oil seep, most of the samples (Mputa-1, Mputa-3, Mputa-4, Waraga-1 and Nzizi-2) plot in a zone that illustrates derivation from mature source rocks.

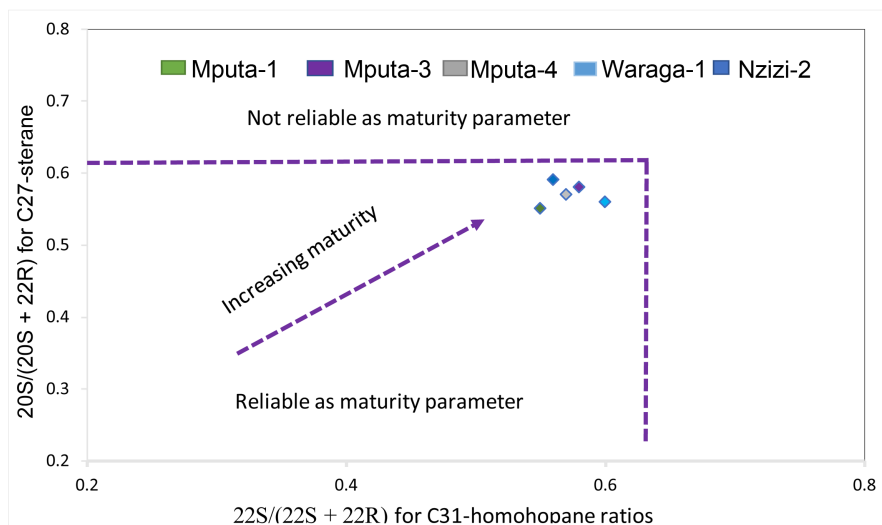


Figure 5. A plot of $20S/(20S + 20R)$ for C27-sterane vs $22S/(22S + 22R)$ for C31homohopane ratios showing all oil samples plot in a region that indicates high maturity (plot derived from Peters et al., 2005; Seifert & Moldowan, 1986). All oil samples plotted originate from mature source rock.

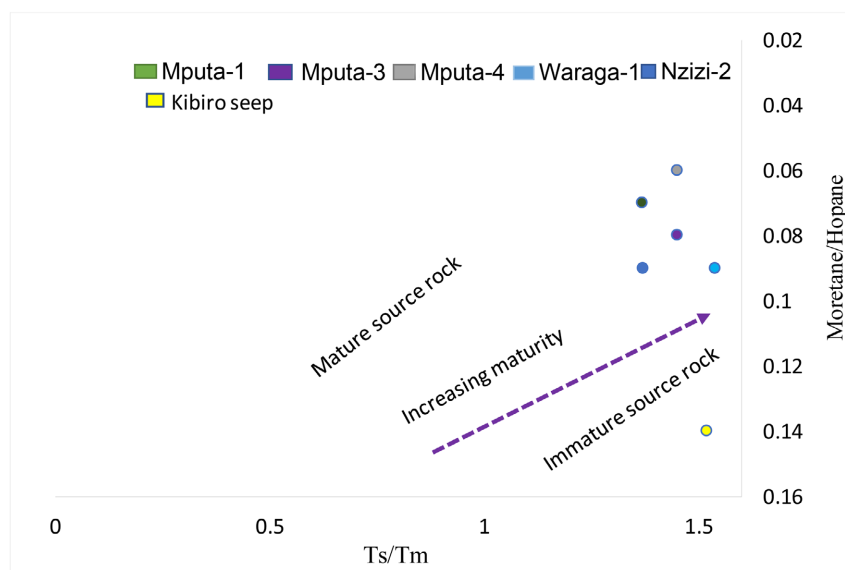


Figure 6. A plot of Moretane/Hopane vs Ts/Tm (Trisnorhopane/Trisnorneohopane) ratios illustrating most of oil samples (Mputa-1, Mputa-3, Mputa-4, Waraga-1 and Nzizi2) plot in a zone that illustrates mature source rock and Kibiro seep plot in a zone that shows immature source rock (dotted lines drawn from Mackenzie et al., 1980; Seifert & Moldowan, 1980 in Malik, 2012; Waples & Michihara, 1991).

The sterane ratio $\alpha\beta\beta/(\alpha\beta\beta + \alpha\alpha\alpha)$ for C_{29} -Sterane with values 0.67-0.71 suggests oil window maturity for the source rocks (Seifert & Moldowan, 1986). The ratio of Ts/Tm range between 1.37 and 1.54, suggesting that oils are generated from mature source rocks.

On the contrary however, data from $\alpha\beta\beta/(\alpha\beta\beta + \alpha\alpha\alpha)$ for (C_{29} -Sterane) ranges from 0.2 and 0.27 indicating a derivation from immature source rock.

The disagreement between the two maturity parameters could be as a result of the catalytic effect of siliclastics, that is, iron and aluminium in siliciclastics catalyse the transformation of trisnorhopane to trisnorhopane (Waples & Michihara, 1991).

The geochemical maturity parameter $Ts/(Ts + Tm)$ reaches equilibrium at 0-0.62 from low maturity to high (Waples & Machihara, 1991; Mackenzie, 1984) while the Homohopane maturity parameter $22S/(22S + 22R)$ for C_{31} -exhibits high maturity at 0.570.62 (Seifert & Moldowan, 1986). For the oils under study, the ratio of $Ts/(Ts + Tm)$ is ranging from 0.580.61 while $22S/(22S + 22R)$ for C_{31} -homohopane ranges 0.56-0.59. This suggests that the oils and oil seeps were generated from mature source rocks.

3.4.2. Source Rock Lithology

A plot of DBT/Phen vs NH/Hop ratios for oil and oil samples is indicated in Figure 7. All oil and oil seep samples plot in a region that shows derivation of oils from shale source rock deposited in oxic-sub oxic environment.

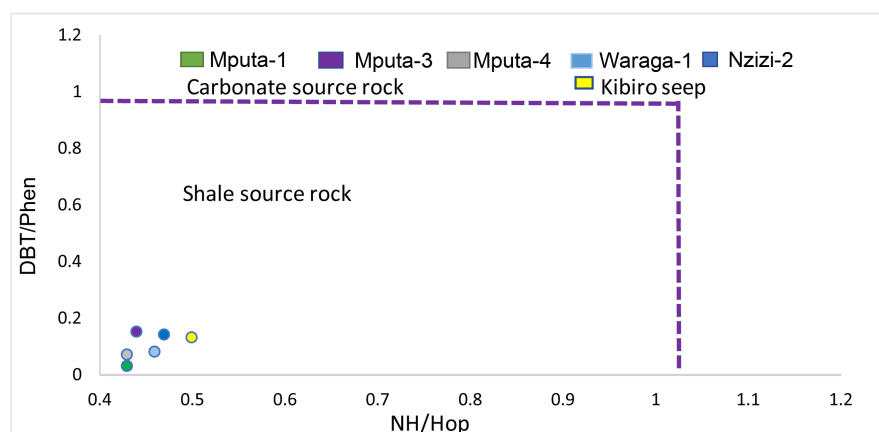


Figure 7. A plot of DBT/Phen vs NH/Hop (C_{29} norhopane/ C_{30} hopane) ratios illustrating all oil and oil seep samples plot in a region that shows shale source rock deposited in oxic-sub oxic environment (plot is derived from Peters et al., 2005; Hakimi et al., 2011).

CPI ratios greater than 1 shows shale source rock and CPI ratios less than 1 suggests carbonate source rock (Palacas et al., 1984; Moldowan et al., 1985) and ratios of diasterane/sterane less than 1 are suggestive of carbonate source rock and diasterane/sterane greater than 1 suggests shale source rock (Mello et al., 1988). The CPI and diasterane/sterane ratios amongst the oil samples under study is in the range of 1.091.11 (Table 4.3) and 1.28 - 1.50 respectively. This suggests that oil samples are derived from shale source rock. This statement may not be conclusive since CPI and Pr/Ph are usually influenced by maturity and depositional environment.

The ratio of DBT/Phen under 1 shows shale source rock while Pr/Ph ratio from 1 - 3 suggests shale source rock. On the other hand, Pr/Ph ratios greater than 3 shows shale (coal) source rock and DBT/Phen ratios above 1 indicates carbonate

sourcing (Hughes et al., 1995). The ratios of Pr/Ph and DBT/Phen for the oil samples under study range from 2.93 - 3.16 and 0.03 - 0.15, respectively. This suggests that oils are derived from shale source rock with small quantity of coal sediments, however, this may not be conclusive because Pr/Ph ratios are always influenced by depositional environment, and maturity and may not be preserved well.

A plot of dh/29Ts vs diasterane/sterane ratios for oil and oil seep samples is illustrated in **Figure 8**. All oil and oil seep samples plot in a zone that suggests shale source rock.

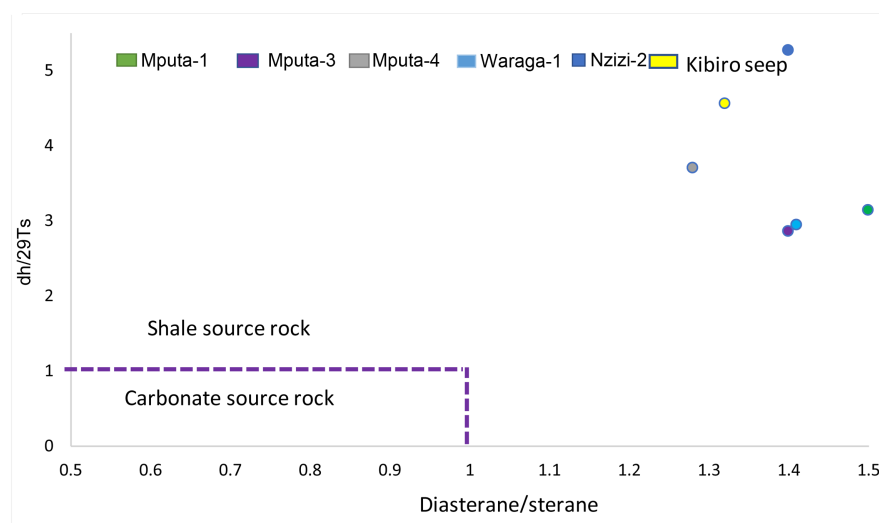


Figure 8. A plot of dh/29Ts (diahopanes) vs Diasterane/sterane ratios indicating oil and oil seep samples plot in a zone that suggests shale source rock (dotted lines drawn from Peters & Moldowan, 1993; Seifert & Moldowan, 1979).

4. Discussion

4.1. Introduction

The main aim of this study was to geochemically characterise and classify the oils with the view of inferring the source rock characteristics from the chemistry of oils. In this study, the GC-FID traces and sats/aros ratios were used to assess the biodegradation of oil and oil seep samples as highlighted in **Figure 3(a)** and **Figure 3(b)**, Chapter 4. The derived geochemical parameters, interpretive ratios/values and various plots were also used. This chapter discusses the findings of the study.

4.2. Assessment of Biodegradation

According to Hakimi et al. (2011), crude oil samples with sats/aros ratio greater than 1 shows non-degraded crude oil and that if the ratio is less than 1 it suggests biodegraded crude oil. The saturate and aromatic fractions for this study. In reference to this study, oils from Mputa-1, Mputa-3, Mputa-4, Waraga-1 and Nzizi-2 are non-degraded while Kibiro, Nzizi-2, Murram Pit, Runga and Sonso are biodegraded.

Gas chromatograms of saturated fractions from representative crude oil samples suggests non-degradation if there is dominance of n-alkanes with no change in baseline humps and biodegraded if n-alkanes are absent and there is change in baseline humps (Hakimi et al., 2011; Malik, 2012). GC-FID traces for Kibiro, Nzizi-2 Murram Pit, Runga and Sonso show these oils are therefore biodegraded. Waraga-1, Mputa-1, Mputa-3, Mputa-4 and Nzizi-2 oils on the other hand have traces of n-C₁₇ & n-C₁₈, and Pr and Ph and with normal baseline without humps. These oils are therefore not biodegraded.

4.3. Classification of Crude Oils

Oil enriched with higher saturates than aromatics, naphthene and NSO is classified as paraffinic high waxy oil type (Hammad et al., 2015). Tissot & Welte (1984) in their research, they observed that crude oil samples with high ratios of saturates to aromatics are paraffinic oils, and crude oil samples with low ratios of aromatics to asphaltenes and NSO are classified as Paraffinic-naphthenic oils. The lowest ratios of asphaltenes and NSO belong to Naphthenic oils. Based on the saturate-aromatics-NSO-asphaltene abundances in the oils studied (Figure 4), Mputa-1, Mputa-3, Mputa-4, Waraga-1, and Nzizi-2 are classified as Paraffinic oils. Runga and Sonso on the other hand are classified as Naphthenic oils, Kibiro and Nzizi-2 Murram Pit are classified as Paraffinic-naphthenic oils. These seeps might have undergone a stage of extensive migration and expulsion which exposes them to microbial activity, in actual sense, if the seeps were preserved at better conditions then, they would have been regarded as paraffinic oils. Consequently, the crude oil of Eastern Lake Albert basin yields commercial paraffinic oil.

4.4. Characterization of Oils

The geochemical characterisation of oils was used to infer the source rock characteristics from oil-characterisation covering aspects such as source rock maturity, source rock lithology. It might be apparent as the oil have suffered from biodegradation, thermal alteration and migration effects.

4.4.1. Maturity of the Source Rock

According to Peters et al. (2000), ratios of saturated to aromatic hydrocarbon components in crude oil increases with increase in maturity while polar to asphaltenes ratios decreases with decrease in maturity. This agrees with geochemical parameters highlighted in Figure 4 for the oils under study. The data shows that oils under study, with exception oil seeps, were derived from mature source rocks. The derivation of oil seeps from immature source rocks as suggested by the data may be due to biodegradation, which implies the biomarkers were not preserved well, if preserved, in which case, they could as well be derived from mature source rocks. This maturity status of source rock in the Albertine Graben is also confirmed by Kiconco (2005).

The maturity of the source rock is determined using the geochemical templates

of $20S/(20S + 20R)$ for C_{27} -sterane and $22S/(22S + 22R)$ for C_{31} -homohopane highlighted in **Figure 5** and ratios of $20S/(20S + 20R)$ and $22S/(22S + 22R)$ in the range 0.57 - 0.6 and 0.58 - 0.59 suggesting that studied oil samples are generated at high level of maturity, therefore the oil samples are derived from mature source rock.

Maturity of the source rock was determined using the geochemical interpretive template for Moretane/Hopane and Ts/Tm (**Figure 6**). The data suggests that non-degraded oils are derived from mature source rocks. This is concurrence with the work of [Jarvie et al. \(2007\)](#). The biodegraded Kibiro oil seep however, plots in a zone suggesting derivation from immature source rock. [Lirong et al. \(2004\)](#) reported that Kibuku oil seep was derived from an immature source rock. Apparently, oil seeps seem to be derived from immature source rocks, an indication that the seeps are completely different in origin to the nondegraded oils. Perhaps also indicating different sourcing within the basin.

The maturity parameter of $\alpha\beta\beta/(\alpha\beta\beta + \alpha\alpha\alpha)$ for C_{29} sterane has an increasing maturity status from 0-0.70 ([Malik, 2012](#); [Onojake et al., 2015](#)). Ts/Tm ratios greater than 1 suggest mature crude oils ([Sun et al., 2016](#)). For the oil samples under investigation, the ratio $\alpha\beta\beta/(\alpha\beta\beta + \alpha\alpha\alpha)$ for C_{29} steranes ranges from 0.20-0.27 while Ts/Tm ratio range from 1.37 - 1.54 (Table 4.4) and Ts/(Ts + Tm) ratio range from 0.58 - 0.61 suggesting mature oil and oil seep samples derived from mature source rock concurring to a statement of [Sun et al. \(2016\)](#) that suggests mature source rocks.

In the above plots and interpretative ratios used in determining the maturity status of oil and oil seep samples, it is suggesting that oil samples are generated from mature source rocks and oil seep samples from immature source rocks. This interpretation, however, is conservative given that the oil seeps are biodegraded and therefore the peaks used could be unrealistic. Generation at higher maturity for both oils and oil seepages is implied. This also means that large amount of hydrocarbons could have been delivered by the source rocks.

- Biomarker ratios indicate mature oils (e.g., Trisnorhopane, trisnorneohopane, moretane, sterane and hopane isomer ratios), some inconsistencies of C_{29} sterane suggest biodegradation effects or mixing.
- C_{29} norhopane is thermally stable across a wide range of burial depths and temperatures. Its stability means it doesn't degrade or react easily, allowing it to persist in mature source rocks and crude oils.
- The $\beta\beta \rightarrow \alpha\beta \rightarrow \alpha\alpha$ isomerization of hopanes with increasing thermal maturity is well established. The C_{29} norhopane / $17\alpha(H)$, $21\beta(H)$, hopane ratio changes systematically with thermal maturity, making it a reliable maturity proxy.

C_{29} norhopane abundance can be influenced by the type of organic matter and depositional environment and severe biodegradation can eventually degrade C_{29} norhopane.

4.4.2. Source Rock Lithology

Source rock lithology is inferred using geochemical parameters of DBT/Phen vs

NH/Hop highlighted in **Figure 7** and dh/29Ts vs diasterane/sterane (**Figure 8**). Interpretive ratios of CPI, Pr/Ph suggest that oil and oil seep samples are derived from shale source rock. This is concurring with previous work by Kiconco (2005) and Lukaye (2016), who stressed that the dominant source rock in the Albertine Graben is shale source rock. Shale rocks are known as excellent source rocks, with early maturity characteristics and migration efficiency compared to carbonate source rocks. This, therefore, implies that a significant amount of hydrocarbons could have been generated by the source rocks.

5. Conclusions and Recommendations

5.1. Conclusions

- a) The summary of this study is in brief outlined below.
- The crude oil of the Eastern Lake Albert basin is of paraffinic class which yields commercial hydrocarbon.
 - The oils and oil seep samples are derived from mature source rock meaning that mature source rocks have tendency to deliver a significant amount of hydrocarbons.
 - The source rock lithology inferred is shale suggesting that shale source rock delivers a significant amount of hydrocarbons owing to its expulsion and migration efficiency.

5.2. Recommendations

- The existing geochemical data of 4 oil seep and 5 oil samples are limited, which makes the study not conclusive.
- Lack of source rock data that would help in direct correlation of source rock characteristics rather than inferring source rock characteristics from oils.
- Some of the geochemical parameters used in methodology were not preserved well and therefore could not be relevant enough in their uses as per the specific objectives. This mainly applied to oil seepages which are biodegraded.

In relation to the above identified problems, the following recommendations have been suggested for further research in the Eastern Lake Albert basin of the Albertine Graben.

- This study recommends to MEMD and DOPEP to make the source rock data available to help in characterization and correlation of source rock and oil-source rock characteristics rather than inferring source rock characteristics from oils.
- More wells in the Eastern Lake Albert basin are needed in order to have sufficient geochemical data to help in correlation of source rock and oil-source rock so that the study is conclusively attained with confidence rather than inferring source rock characteristics from oils.
- The study also recommends the use of more accurate geochemical parameters in achieving specific objective so that the research is conclusively attained.

Dedication

I dedicate this work to my educational mentor, and father, Agwang Atem-Benyelok, as well as to my beloved mother, Rebecca Yar. Special appreciation goes to my brothers: Chol Agwang, and Achiek Agwang. I also extend heartfelt gratitude to my dear wife, Mary Nyang, and my son, and daughter, Agwang Deng and Apul Deng, for their unwavering support and endurance throughout my studies at Makerere University. Above all, I give sincere thanks to Almighty God for his divine guidance, strength, and the knowledge he bestowed upon me during my academic journey.

Acknowledgements

I would like to express my sincere gratitude to my supervisors, Dr. Simon Echegu and Dr. Betty Nagudi, for their invaluable assistance in obtaining geochemical data from the Directorate of Petroleum in Entebbe, Uganda and for their constructive input throughout this project. Their guidance and support were instrumental in the successful completion of this work. I am also deeply thankful to all the staff and lecturers of the College of Natural Sciences (CoNAS), Department of Geology and Petroleum Studies for their support and for providing the resources and knowledge that contributed significantly to the success of this project.

Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

References

- Abeinomugisha, D., & Kasande, R. (2009). Tectonic Control on Hydrocarbon Accumulation in the Intracontinental Albertine Graben of the East African Rift System. *Search and Discovery*, 100, Article 10183.
- Bissada, K. K., Elrod, L. W., Darnell, L. M., & Trostle, J. L. (1992). Geochemical Inversion, a Powerful Tool for Inferring Source Rock Identity from Characteristics of Encountered Oil or Gas. In *Proceedings of the 21st Annual Convention of the Indonesian Petroleum Association* (pp. 165-199). Indonesian Petroleum Association.
- Echegu, S. (2013). *Geological and Geochemical Investigation of the Petroleum Systems of the Permian Basin of West Texas and Southeast New Mexico*. PhD Dissertation, Texas Tech University.
- Hakimi, M. H., Abdullah, W. H., & Shalaby, M. R. (2011). Organic Geochemical Characteristics of Crude Oils from the Masila Basin, Eastern Yemen. *Organic Geochemistry*, 42, 465-476. <https://doi.org/10.1016/j.orggeochem.2011.03.015>
- Hammad, M. M., El Nady, M. M., Ramadan, F. S., & Lotfy, N. M. (2015). Geochemical Characteristics of Crude Oils from Ras Gharib Oilfields in the Central Gulf of Suez, Egypt. *Energy Sources, Part A: Recovery, Utilization, and Environmental Effects*, 37, 2029-2038. <https://doi.org/10.1080/15567036.2012.717165>
- Hughes, W. B., Holba, A. G., & Dzou, L. I. P. (1995). The Ratios of Dibenzothiophene to Phenanthrene and Pristane to Phytane as Indicators of Depositional Environment and Lithology of Petroleum Source Rocks. *Geochimica et Cosmochimica Acta*, 59, 3581-3598. [https://doi.org/10.1016/0016-7037\(95\)00225-o](https://doi.org/10.1016/0016-7037(95)00225-o)

- Jarvie, D. M., Maende, A., Echegu, S., & Iumba, C. (2007). Realization of Petroleum Potential of the Albertine Graben: Production and Geochemical Perspectives. In *3rd Petroleum Conference on the Petroleum Potential and Investment Opportunities in East Africa (EAPC'07)* (pp. 1-78). Humble Geochemical Services.
- Kiconco, L. (2005). The Semliki Basin, Uganda: Its Sedimentation History and Stratigraphy in Relation to Petroleum Accumulation. In *Proceedings of the Conference on Petroleum in Uganda* (pp. 123-132). University of Cape Town.
- Lirong, D., Wang, J. J., Cheng, D. S., & Ran, X. F. (2004). Geological Conditions and Petroleum Exploration Potential of the Albertine Graben of Uganda. *Acta Geologica Sinica—English Edition*, 78, 1002-1010. <https://doi.org/10.1111/j.1755-6724.2004.tb00222.x>
- Lukaye, J. (2016). Molecular Organic Geochemistry of Crude Oils from Fields in the Albertine Graben, Uganda: Possible Implication on the Expulsion of the Oils from the Source Rock. *Journal of Earth Science and Engineering*, 7, 181-193.
- Lukaye, J., & Okello, M. (2015). Geochemical Characterization and Correlation of Crude Oils and Potential Source Rocks from the Semliki, Southern Lake Albert and Kaisotonya Basins in the Albertine Graben, Uganda. In *International Conference and Exhibition* (pp. 557). Society of Exploration Geophysicists and American Association of Petroleum Geologists. <https://doi.org/10.1190/ice2015-2210807>
- Mackenzie, A. S. (1984). Applications of Biological Markers in Petroleum Geochemistry. *Advances in Petroleum Geochemistry*, 1, 115-214.
- Mackenzie, A. S., Patience, R. L., Maxwell, J. R., Vandenbroucke, M., & Durand, B. (1980). Molecular Parameters of Maturation in the Toarcian Shales, Paris Basin, France—i. Changes in the Configurations of Acyclic Isoprenoid Alkanes, Steranes and Triterpanes. *Geochimica et Cosmochimica Acta*, 44, 1709-1721. [https://doi.org/10.1016/0016-7037\(80\)90222-7](https://doi.org/10.1016/0016-7037(80)90222-7)
- Malik, M. A. R. (2012). *Geochemical Evaluation of Source Rocks from Melut Basin, South-eastern Sudan*. Doctoral Dissertation, University of Khartoum, Sudan University of Science and Technology.
- Mello, M. R., Gaglianone, P. C., Brassell, S. C., & Maxwell, J. R. (1988). Geochemical and Biological Marker Assessment of Depositional Environments Using Brazilian Offshore Oils. *Marine and Petroleum Geology*, 5, 205-223. [https://doi.org/10.1016/0264-8172\(88\)90002-5](https://doi.org/10.1016/0264-8172(88)90002-5)
- Moldowan, J. M., Seifert, W. K., & Gallegos, E. J. (1985). Relationship between Petroleum Composition and Depositional Environment of Petroleum Source Rocks. *AAPG Bulletin*, 69, 1255-1268.
- Naglaa, S. M., El Nady, M. M., & Shahin, A. N. (2014). Physical Properties and Gross Composition of Crude Oils of Some Oil Fields, Gulf of Suez, Egypt. *Australian Journal of Basic and Applied Sciences*, 8, 360-367.
- Onojake, M. C., Osuji, L. C., & Abrakasa, S. (2015). Source, Depositional Environment and Maturity Levels of Some Crude Oils in Southwest Niger Delta, Nigeria. *Chinese Journal of Geochemistry*, 34, 224-232. <https://doi.org/10.1007/s11631-015-0035-9>
- Palacas, J. G., Anders, D. E., & King, J. D. (1984). South Florida Basin—A Prime Example of Carbonate Source Rocks of Petroleum. In *Petroleum Geochemistry and Source Rock Potential of Carbonate Rocks* (pp. 71-96). American Association of Petroleum Geologists. <https://doi.org/10.1306/st18443c6>
- Peters, K. E., & Moldowan, J. M. (1993). *The Biomarker Guide: Interpreting Molecular Fossils in Petroleum and Ancient Sediments*. Prentice Hall.
- Peters, K. E., Snedden, J. W., Sulaeman, A., Sarg, J. F., & Enrico, R. J. (2000). A New Geo-

- chemical-Sequence Stratigraphic Model for the Mahakam Delta and Makassar Slope, Kalimantan, Indonesia. *AAPG Bulletin*, 84, 1244-1266.
<https://doi.org/10.1306/c9ebcd51-1735-11d7-8645000102c1865d>
- Peters, K. E., Walters, C. C., & Moldowan, J. M. (2005). *The Biomarker Guide*. Cambridge University Press. <https://doi.org/10.1017/cbo9781107326040>
- Petroleum Exploration & Production Department (PEPD) (2011). *Petroleum Exploration and Investment Opportunities in the Albertine Graben*.
<https://petroleum.go.ug/publications.php>
- Seifert, W. K., & Moldowan, J. M. (1979). The Effect of Biodegradation on Steranes and Terpanes in Crude Oils. *Geochimica et Cosmochimica Acta*, 43, 111-126.
[https://doi.org/10.1016/0016-7037\(79\)90051-6](https://doi.org/10.1016/0016-7037(79)90051-6)
- Seifert, W. K., & Moldowan, J. M. (1980). The Effect of Thermal Stress on Source Rock Quality as Measured by Hopane Stereochemistry. *Physics and Chemistry of the Earth*, 12, 229-237. [https://doi.org/10.1016/0079-1946\(79\)90107-1](https://doi.org/10.1016/0079-1946(79)90107-1)
- Seifert, W. K., & Moldowan, J. M. (1986). Use of Biological Markers in Petroleum Exploration. *Methods in Geochemistry and Geophysics*, 24, 261-290.
- Sun, M., Zhang, P., Zhou, L., Liu, H., Li, G., Chen, J. et al. (2016). Biomarker Characteristics and Oil Accumulation Period of Well Sutan 1 in Qaidam Basin, China. *Journal of Natural Gas Geoscience*, 1, 85-91. <https://doi.org/10.1016/j.jnggs.2016.01.001>
- Tissot, B. P., & Welte, D. H. (1984). *Petroleum Formation and Occurrence* (2nd ed.). Springer.
- Walples, D. W., & Machihara, T. (1991). Biomarkers for Geologists. In *AAPG Methods in Exploration Series* (pp. 9-91). American Association of Petroleum Geologists.