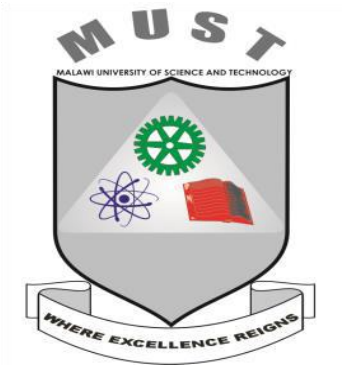


POTENTIAL PETROLEUM SYSTEM ASSESSMENT IN MALAWI: CASE STUDY OF THE THIRD BLOCK OF THE HYDROCARBON POTENTIAL AREA

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(PRE/002/18)

THYOLO, MALAWI

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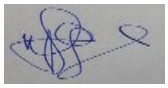
DECLARATION

I, Zubeda Bwanali declare that this research project presents my work and that it has never been submitted to this institution or any other institution for any academic purpose. All sources of information have been appropriately acknowledged.

Signature: 

Date: APRIL,2023.

DISSERTATION APPROVED BY:

SUPERVISOR:
Mr W. Tchongwe Signature:  _____

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ABSTRACT

The assessment of a petroleum system is a crucial step in petroleum exploration, since it helps to determine the petroleum potential of an area. It facilitates key decision on whether further stages of exploration can be carried out. This paper has described the assessment of the potential petroleum system in malawi, which was carried out on the third hydrocarbon block of the hydrocarbon potential areas. The study's methodology included the use of geographical Information system, TOC and rock Eval pyrolysis analysis and literature review to conduct the geological and geochemical analysis of the area. It was discovered that the potential petroleum system is located in the quaternary and tertiary deposits, the characterization of the source rock revealed that the source rock is in an immature stage of thermal maturity but has a good generative potential of 6.21mgHCg^{-1} and capable of generating a mixture of oil and gas that is predominately composed of gas. Lastly, the results indicate that the region with the highest petroleum potential is located at the central part of the third block which is also deepest section in the Lake Malawi. This research will minimize exploration problems such as drilling in dry holes and help in understanding the nature of the petroleum system. The gathering of petro physical data to evaluate the petroleum system in terms of the reservoir, seal, and trap is one of the recommendations for future study, along with more investigations must be carried out to identify the many petroleum systems that exist in the hydrocarbon block.

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ACRONYMS/ABBREVIATION

GIS	Geography Information system
TOC	Total Organic Carbon
Wt.%	percentage by weight
S_1	volatile hydrocarbon content in mg per g of sample
S_2	remaining hydrocarbon generative potential in mg per g of sample
OI	Oxygen Index
HI	Hydrogen Index
PY	Potential Yield
PI	production Index
IDW	Inverse Distance Weighting
Tmax	Maximum Temperature

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CHAPTER ONE: INTRODUCTION

1.1 Background

Hydrocarbon exploration uses surface and subsurface datasets from geochemical, geophysical, geological, petro physical, and geographical analyses to find commercially viable hydrocarbon reserves (Hamzeh & Karimipour, 2020b). As a result, a broad evaluation of a petroleum system aids in providing a fundamental understanding of the origin and natural setting of the hydrocarbon accumulation. The assessment method begins with identifying the presence of the petroleum system, followed by identifying the system's potential in terms of quantity and quality and finally naming the system (Leslie Magoon & Beaumont, 2005).

The hydrocarbon potential in Africa has been observed along the both of west and east margins of Africa. The hydrocarbon potential of the west Africa is formed along the passive continental margin of west Africa which extends from Morocco to the Cape of good hope in South Africa. The regions with significant accumulations include the Niger delta, lower Congo basin, Gabon coastal basin, Rio Muni basin and Kwanza basin (Liu et al., 2008). The reasons for such productive hydrocarbon potential include, the deposition of lacustrine sediments and evaporates which led to the formation of the source rock and seal rocks respectively, the structural and tectonic evolutions which led to the formation and preservation of traps , thick overlain of sediments which led to the maturation of the source rock, large river beds played the roles of in the formation of reservoirs and lastly high thermal conduction capability of the evaporates lead to the maturity of the source rock (Liu et al., 2008).

The East African Rift system represents the petroleum potential in East Africa. The East African Rift system stretches from the southern part of Ethiopia passing through Kenya, Democratic republic of Congo, Uganda, Burundi and Tanzania and ultimately ends in Malawi. The rift is known for its active experience in continental plate separation which has aided in the formation of a conducive environment for hydrocarbon formation and accumulation (Whaley, 2017). Some of the major petroleum discoveries along the East African rift valley include lake Albert located in Uganda and Lake Turkana in Kenya. Whereas, the lake Malawi basin which is located along East African rift valley has not

made any major oil discovery. This is despite lake Malawi basing having potential geology that suggests the presence of petroleum systems (Whaley, 2017).

Malawi lies along the western part of the Great East African Rift System, that stretches from the Arabian dessert to the Indian ocean in Mozambique. Recent Studies show that lake Malawi basin has similar features with the Albertine Graben. These features suggest the formation of a potential tertiary petroleum system (Chisenga, 2012). Regardless of the major hydrocarbon discoveries that were made in lake Albertine through field research data processing and analysis (Lirong et al., 2004), Malawi has yet to make any discovery, but this show that it has the potential for hydrocarbon formation and accumulation.

Some the evidence of the hydrocarbon potential in Malawi has been presented in various studies and observations. Firstly, the scientific study that was carried out by the Duke university lead to the discovery of thick sedimentary sequences and structures that have the potential to trap and host hydrocarbons (Chisenga, 2012). Such sedimentation structures are located along lake Malawi basin and the lower shire valley. Secondly, an airborne magnetic survey which was carried out to determine the thickness of the sedimentary sequences that could host hydrocarbon. This study revealed that the thickest sedimentary sequences section where located along the central part of lake Malawi (Mattick, 1984). The seismic study that was conducted during project CEGAL (Cenozoic Environment and geodynamics of African lakes) emphasised on the stratigraphy and sedimentology of the lake Malawi basin (Rosedahl & Livingstone, 1983). The results of the stratigraphic sections showed the presence of shelf sediment wedges, delta etc., which would act as potential reservoir, traps and seals for the petroleum system. While the results of the sedimentology analysis focused on the deep ocean similarities, biogenic oozes and the anoxic environments that could help form a conducive environment that is essential for the formation of hydrocarbon accumulations (Rosedahl & Livingstone, 1983). Lastly the observation of oil seeps over lake Malawi suggest the presences of a mature source rock in the subsurface (Whaley, 2017).

In reference with the petroleum potential that has been justified by the geological, structural and sedimentary properties of the studied area, Malawi was later divided into

six block. These divisions designate the hydrocarbon potential area for exploration. The first block covers the Vwaza marsh/ Chitipa in the northern region of Malawi, while the second, third and fourth block covers Lake Malawi north, central and south respectively. The Fifth block which covers lake Chilwa /lake Malombe Area and lastly, the sixth block which covers the lower shire rift. The hydrocarbon potential is rather high in the second, third and sixth block, this is because of the depth which plays a vital role in the formation of hydrocarbons (Chisenga, 2012).

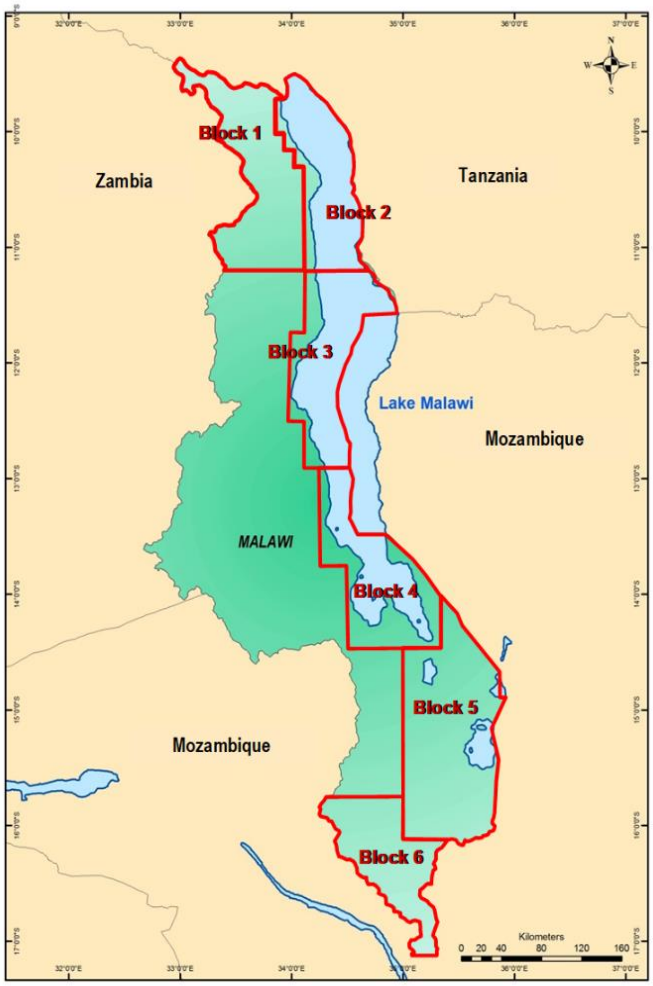


Figure 1 Map of hydrocarbon blocks of Malawi

1.2 Problem Statement

Petroleum system involves the pod of an active source rock and all the geological elements and processes essential of the formation of hydrocarbon accumulation (Leslie Magoon & Wallace, 1994). The system is described by the functional units of the geological elements and the processes to create hydrocarbon accumulations. The geological elements include the source rock, reservoir rock, seal rock, trap and overburden rock. The geological processes include; trap formation and generation - migration and accumulation (Jager, 2020).

A region is referred to as a petroleum system if it has all the necessary components for the successful generation and accumulation of petroleum, including a source rock, migration path, reservoir, seal, and trap. It can also be justified as a petroleum system if there is a high degree of assurance regarding the existence of probable hydrocarbon evidence (Magoon & Wallace, 1994). However, despite the substantial evidence of petroleum resources over lake Malawi basin including studies that suggest that the lake Malawi basin might contain petroleum accumulation as well as geology and indicators that show the possibility of petroleum accumulations, further stages of exploration of hydrocarbons have not been carried out on the region. Therefore, the study aims at assessing the potential petroleum system in lake Malawi basin. This will help give a basic understanding of the genesis and the natural environment of the hydrocarbon accumulation within the system that could host petroleum accumulations as well as identify possible regions that could host hydrocarbons.

1.3 Main Objective

To assess the potential petroleum system of Malawi.

1.3.1 Specific Objectives

- To investigate the deposition history of the third hydrocarbon block.
- To determine the characteristics of the geological elements.
- To develop a potential petroleum map.

1.4 Research Questions

- What is the depositional timing of the lithology of the petroleum system?

- What characteristics of the geological elements affect development of hydrocarbons and how?
- What regions have a high petroleum potential and low risk for further exploration?

1.5 Significance of the study

- This study will help further the general understanding on the nature of the petroleum systems. This is in the sense that, by assessing the petroleum system through the source rock and identifying the type of organic matter that was incorporated in the sediments, one could determine the type of hydrocarbons that would be generated during the maturation of the source rock. This would be essential for planning the type of equipment, facilities required and recommended expertizes for future studies and exploration.
- This study would help minimise some of the exploration risks such as drilling in a dry hole. The development of the map will help in identifying regions that are most likely to contain petroleum accumulations.
- The study will help in understanding the behaviour of the petroleum system through hydrocarbon generation and transportation, pore pressure and the fluid flow regime within the system. (Perez-Drago et al., 2020).
- By using parameters like overburden thickness, it can be used to estimate the heating rate of the sediments, timing and the quantity of the generated hydrocarbons.

CHAPTER TWO: LITERATURE REVIEW

2.1 Deposition history of an area

The deposition history of a particular area plays an important role in assessing the petroleum potential of a system. It helps in identifying the type of lithology that make up the geological elements and the time period in which the system exists in. The geological elements include; source rock, reservoir rock, trap and seal. By understanding the faulting system of the area over a period of time, it could also help in identifying the presence of migration path and traps for the petroleum system.

There are different methodologies that can be used to determine the deposition history of an area. One of the method is the use of geophysical data for analysis, this method was exemplified in the Zhanhua depression. The research that was carried along the Bohai bay basin in the Zhanhua depression aimed at determining the deposition history by identifying the deposition system and the controlling factors for the formation of commercial oil reservoirs (Guo et al., 2016). The type of data used during the study included drilling core samples, logging data (spontaneous potential SP, true resistivity and Natural Gamma ray), structural data and 3-Dimensional seismic images. The analysis of the results led to the identification of the potential source rock due to the depositional systems, the potential reservoirs which were sandstones and the type of fault systems that allow the migration and accumulation (Guo et al., 2016). This research depicted how the use of deposition history can be used to identify the lithology that make up a petroleum system.

Time is a crucial factor in the concept of a petroleum system. This is because the correct placement and time of the formation of geological elements ensure the successful formation of petroleum accumulation (Leslie Magoon & Wallace, 1994). For the reason that it allows the system to have adequate time for petroleum generation whilst maintaining its current location for accumulation. This helps determine whether a petroleum system does exist, in terms of the generation of the hydrocarbons or the entrapment of the hydrocarbons or if they migrated elsewhere. There are different methodologies that can be used to determine deposition timing of a petroleum system from the deposition history. An example was the study was carried out on the Arabian-Iranian basin, which used the time factor to assess the petroleum system in the basin (Aladwani, 2021).

The aim of the study was to assess the petroleum system in Kuwait (the Arabian-Iranian basin) using deposition setting, tectonic evaluation of the geological elements and the depositional history. The methodologies that were used during the study were back stripping method and basin model and petro physical analysis to assess the changes of rock properties due to deposition over time (Aladwani, 2021). Back stripping method led to the definition of the geological elements related to the depositional and tectonic events. Sequence stratigraphy data was used to obtain the thickness of the units and the age. The results highlighted the potential geological elements and the thermal maturation of the source rock depending on the rate of the overburden (Aladwani, 2021).

In the absence of petro physical, structural and seismic data, alternative methodologies can be used to assess the deposition history of an area. For instance, an event chart can be used. The event charts shows the temporal relationship of the rock units, geological processes and the critical and the preservation time (Magoon & Schmoker, 2000). Lastly, the evaluation of the deposition history can also be carried out by establishing correlation of the relative ages of the rock layers through sequence stratigraphy.

2.2 The Characteristics of the geological elements

As stated earlier, the petroleum system is made up of the geological elements which includes the source rock, thermal maturity, migration path, reservoir rock, seal and trap (Selley, 2003). The analysis of these geological element helps in understanding the nature of the system and how each elements is in sync with one another to form a working system.

The ideology of assessing a petroleum system is linked to the geological elements. This because it is used to convert undiscovered resources to recoverable reserves. The some of the methodologies that are undertaken to assess petroleum system fall under three categories namely; data driven approach, knowledge driven approach and hybrid (Hamzeh & Karimipour, 2020a, 2020b). These methodologies use of algorithms such as geographic Information system (GIS) to develop models that show the petroleum occurrences. Data driven involves the spatial association of the relationship between discovered reservoirs and indirect evidence of potential petroleum and the relationship

is used to identify parameters for the model while knowledge driven methods uses expert knowledge to assign parameters for the model, the examples of such approaches include; Boolean logic, index overlay, wildcat mapping, fuzzy logic etc. (Hamzeh & Karimipour, 2020b).

The attempt of knowledge driven approach was exemplified on the red river petroleum system in Williston basin located in Canada. The studies involved the use of; optimized fuzzy preference ranking organization method for enrichment evaluation (PROMETHEE), fuzzy approach and the CS algorithm (Hamzeh & Karimipour, 2020b) and optimized fuzzy ELECTREE (OFE) approach, artificial bee colony (ABC) algorithm, fuzzy logic and outranking methods (Hamzeh & Karimipour, 2020a).

During the above studies, the characteristics of the essential elements were used to evaluate the petroleum system. where geochemical data (Rock Eval pyrolysis), structural and isopach data from wells were used. For example, the effectiveness of the source rock used total organic carbon, thickness, thermal maturity and hydrocarbon index. The reservoir focused on depth of reservoir and thickness and the effectiveness of the trap and cap rock focused on curvature, roughness and the thickness respectively. Therefore, since petroleum potential assessment is a multiple-criteria decision making method, the above methods were preferred to avoid biasness due to large datasets involved. The models that resulted from the methodologies showed high level of accuracy approximately; 83.31% (Hamzeh & Karimipour, 2020b) and 85.1% (Hamzeh & Karimipour, 2020a) which justified the advantages of using such methods to assess the potential petroleum system since they are an effective tool for dealing with uncertainty, incomplete and imprecise information.

Based on the above research papers, it can be concluded that the characteristics of the geological elements can be used as one of the tools to assess the potential petroleum systems. This implies that by looking at the individual element and comparing to the standard requirements, a conclusion can be made to state whether a particular element in the system has the requirements to signify its potential. Therefore, the requirement for a source rock potential have been stated below.

2.2.1 Generative potential of the source rock

The generative potential focuses on the quantity of the organic matter. It is evaluated using the total organic content(TOC) which is the measure of organic carbon within the source rock and is measured in percentage by weight (wt.%), as well as the addition of pyrolysis yields of amount of hydrocarbon expelled(S_2) and the volatile hydrocarbon content (Peters & Cassa, 1994). A scale for assessing the source rock was presented whereby, a rock of less 0.5wt% TOC is considered to be a poor source rock, 0.5-1.0wt% TOC is fair,1.0-2-0wt% TOC is good and a sample with more than 2.0wt% TOC is an excellent rock (Peters & Cassa, 1994). The scale is also based on the rock Eval pyrolysis data S_1 and S_2 as shown in the table below

Petroleum potential	TOC(wt.%)	S_1 ($mgHCg^{-1}$)	S_2 ($mgHCg^{-1}$)
Poor	0-0.5	0-0.5	0-2.5
Fair	0.5-1	0.5-1	2.5-5
Good	1-2	1-2	5-10
Very good	2-4	2-4	10-20
Excellent	>4	>4	>20

Table 1. Source rock geochemical parameters describing petroleum potential (quantity)

The organic matter content alone is not adequate to evaluate the source rock since the organic matter is mainly oxidized and decomposed and may or not be capable of generating even in high concentrations (Al-areeq, 2018).Therefore, the potential yield determined from the pyrolysis data can be used to determine the generative petroleum potential. This is done to determine the capability of the source rock to generate hydrocarbons. **Table 2** shows the classification (Peters & Cassa, 1994).

Generation Potential yield, PY(S_1+S_2)($mgHCg^{-1}$)	Interpretation
<2	Poor
2-5	Fair
5-10	Good
>10	Very good

Table 2. The interpretive values describing the generative petroleum potential

2.2.2 The kerogen type

The kerogen type is the second important parameter that can be used in assessing the petroleum potential of the source rock. This is because it influences the nature of the hydrocarbon products generated for the source rock. This depends on the type of organic matter deposited at a particular time of deposition. The classification of the kerogen type and the petroleum products can be determined using the hydrogen index(HI), S_3/S_2 and the atomic H/C ratio. By using a modified van kreven diagram which shows the relationship of the pyrolysis yields of hydrogen index (HI) and oxygen index (OI), it can distinguish the type of kerogen that is dominant in source (Peters & Cassa, 1994).**Table 3** shows the classification of hydrogen index to distinguish the type of kerogen and petroleum product.

Kerogen type	Hydrogen index ($mgHCgTOC^{-1}$)	S_3/S_2	Atomic H/C	Expelled petroleum Product
I	>300	>10	>1.2	Oil
II	150-300	5-10	1.0-1.2	Mixed oil and gas
III	<150	<5	<1.0	Gas

Table 3. Geochemical parameters describing the quality of source rock and petroleum products

Lastly, depending on the type of kerogen the organic matter can further be classified into three classes namely; Sapropelic type (type I and II), Humic type (Type III) and mixed type (Type II/III or III/II)(Al-areeq, 2018).

2.2.3 Thermal maturity of the source rock

The maturation of the source rock is influenced by the temperature increase and the geological time due to progressive burial. The thermal maturation of the source rock is in three stages; immature, mature and post mature stage. Thus, when temperature and pressure is adequate such that hydrocarbon generation occurs, it is known as a mature source rock, immature source rock is rock has not yet generated hydrocarbons while the post mature source rock is a source rock that has generated all the crude oil from the rock (Aladwani, 2021). With reference to the classification in **Table 4** (Peters & Cassa, 1994),The maturation level of the source rock can be determined using vitrinite reflectance(R°), maximum temperature (T_{max}) and thermal alteration index (TAI) while the generation is determined by bitumen and production index.

Stage of thermal maturity	T(max)	R°	TAI	Bitumen Rock	Production index
Immature	<430	0.2-0.6	1.5-2.6	<50	<0.10
Mature	430-470	0.6-1.35	2.6-3.3	50-250	0.10-0.40
Post mature	>470	>1.35	>3.3	-	>0.40

Table 4. Geochemical parameters describing the thermal maturation stage of the source rock

CHAPTER THREE: STUDY AREA

The study was carried out on lake Malawi central, the third block of the hydrocarbon potential areas in Malawi. The third block covers an area of about 10,677km^2 (Chisenga, 2012) along the Nkhotakota and Nkhatabay area. The area was chosen because of the presence of the Usisya-Mbamba basin and Dwangwa delta which are modern lacustrine depositional environments (Ellis et al., 2015). Such deposition environments are vital for the formation of the geological elements that make up a petroleum system. lacustrine deposition environments are also responsible for significant hydrocarbon resources. This area was also chosen because of the airborne magnetic survey which suggested that the thickest sedimentary sequence is allocated in central part of lake Malawi basin which is along the third block (Mattick, 1984).Lastly, since it is also along the deepest part of the basin this may provide a conducive environment to preserve the sediments and lead to the formation of the source rock.

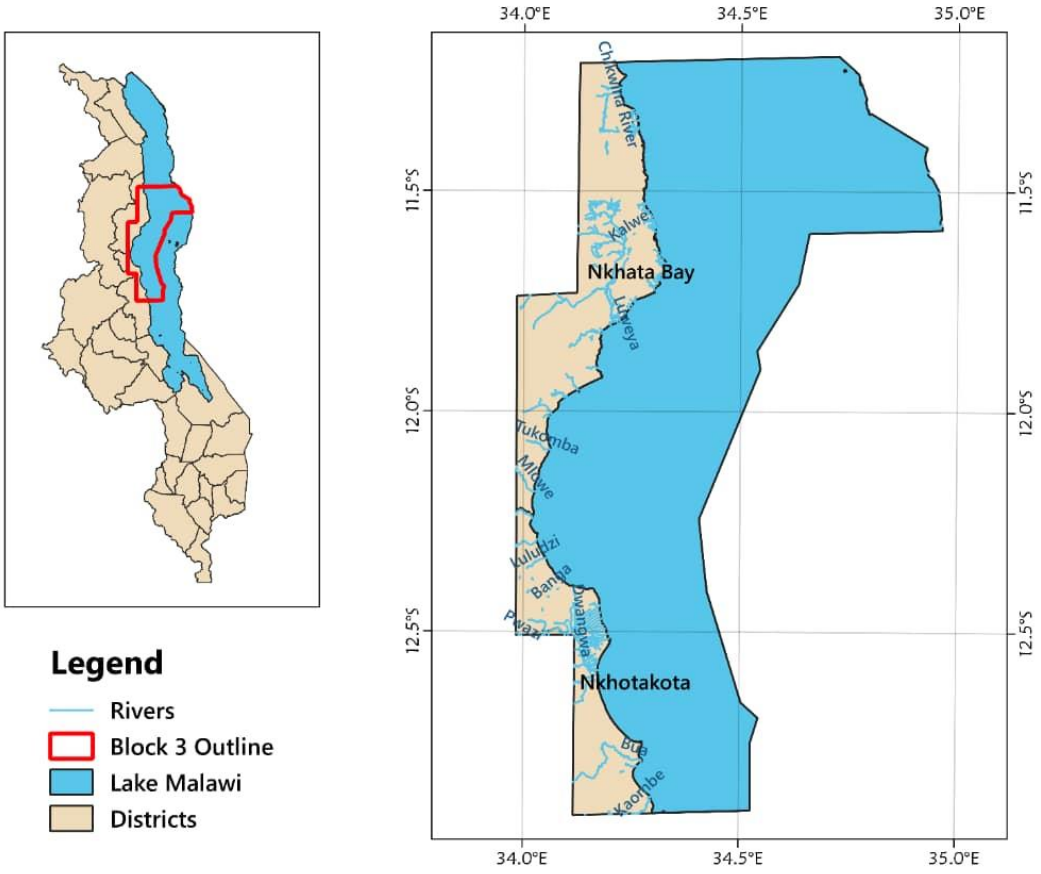


Figure 2. Map of the Third Hydrocarbon Block

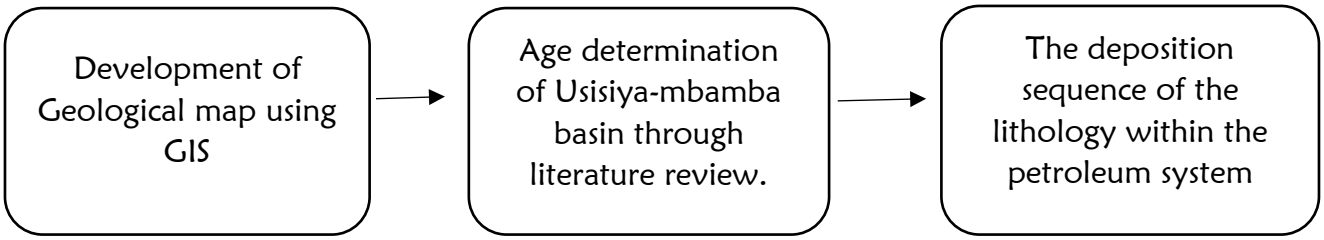
CHAPTER FOUR: METHODOLOGY

This chapter cover the following areas; research design, research dataset and the methodologies that were used to achieve the main objective of the research.

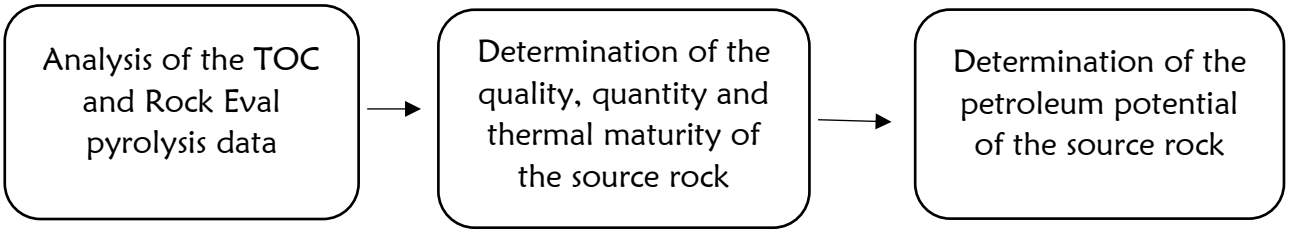
4.1 Research Design

The research was designed as a case study, which uses both qualitative and quantitative data to assess the potential petroleum system of lake Malawi central (Block 3 of the hydrocarbon potential areas in Malawi). secondary data type of data was used to answer the research questions that helped attain the main objectives of the research. The research has been divided into three stages as shown below;

Stage one: Deposition history of the area



Stage two: characteristics of geological elements



Stage three: potential petroleum map

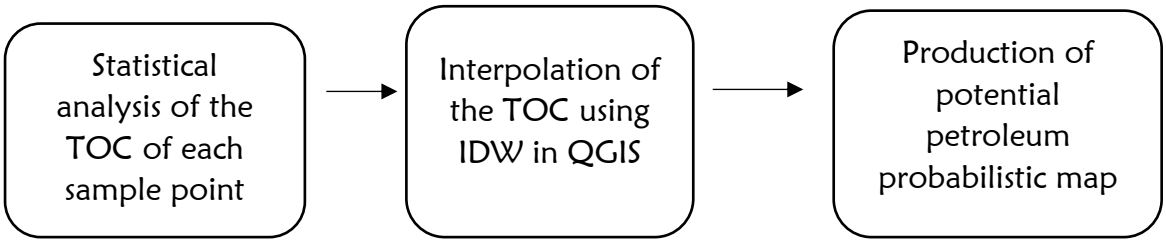


Figure 3. Research design

4.2 Research methods

4.2.1 Geological analysis

The geological map is developed to determine the general geology of the area. Using the QGIS 3.26 software, a polygon was created by adding the vector layer of the shape file of the map of Africa containing the geology, oil and gas field components and geological provinces of Africa. The clip geo processing tool was used to clip out the third hydrocarbon for the exterior polygon, then the vector layer of the faults on lake Malawi which was downloaded from the Malawi seismogenic source database was added. The desired faults were selected and added to the clip output. To classify the clip output, it was categorized by changing the single colour to random colours to represent the various geology in the area and lastly the map of the geology of the third block was created.

Using the discussion of the expert decisions on the late quaternary sequence stratigraphy of lake Malawi (Nyasa), Africa and the 2005 Lake Malawi scientific drilling project, the relative age of the Usisya-Mbamba was determined to identify the particular geological period in which the petroleum system may exist.

Having identified the age of the basin, the geology was acquired from the literature review of the bulletin of Rumphi-Nkhatabay area, Nkhotakota-Benga area and the bulletin of geology and the mineral resources of Malawi. It was used to provide more information on the deposition of the lithology.

4.2.2 Geochemical analysis for source rock

4.2.2.1 Core samples data

The study used the data from total of 68 core samples that were collected from 21 sample points along the Usisiya-Mbamba basin and Dwangwa delta. These samples were collected in form of piston core, gravity core, vibracore and surface grab data by scientists from project PROBE and Lacustrine rift basin research project(Ellis et al., 2015). **Appendix A** shows the location and the number of samples that were collected at each point.

The core samples were analysed for TOC content using Leco carbon analyser and the rock Eval pyrolysis assay at various geochemistry laboratories (Ellis et al., 2015). The analysis yielded in the determination of the total organic carbon (TOC)wt.%, hydrogen index(HI)mgHCgTOC^{-1}, oxygen index(OI) mgHCgTOC^{-1}, maximum temperature

(Tmax)°C, volatile hydrocarbon content(S_1) mgHCg^{-1} and lastly, remaining hydrocarbon generative potential (S_2) mgHCg^{-1}. The results have been presented in **Appendix B**

4.2.2.3 Interpretation scheme

After the data was collected, missing parameters such as; potential yield and production index were calculated.

Potential yield was calculated using the formula below which was presented (Al-areeq, 2018), it was necessary in establishing the hydrocarbon generative potential of a source rock.

$$\text{Potential yield (PY)} = S_1 + S_2$$

Whereby S_1= volatile hydrocarbon content(mgHCg^{-1})

S_2= remaining hydrocarbon generative potential (mgHCg^{-1})

Secondly, the production index was calculated to determine the generation potential of the source rock, and by considering the relationship between the maximum temperature and the production index the thermal maturation stage is determined.

$$\text{Production index (PI)} = \frac{S1}{(S1+S2)}$$

Whereby S_1= volatile hydrocarbon content(mgHCg^{-1})

S_2= remaining hydrocarbon generative potential (mgHCg^{-1})

The results that were calculated were later included in the dataset in **Appendix B.**

4.2.2.4 Statistical analysis

The first step involved determining the averages of TOC, S_1, S_2, Tmax, HI, and OI from the sample data to show the distribution of the sample data. To obtain more information from the data set, scatter plots were developed.

Using the results that were compiled in **Appendix A**, four scatter plots were plotted using Microsoft excel to highlight the relationships that exist between the datasets. They were used to determine the generative potential, type of kerogen and thermal maturity. The scatter plots were preferred from other graphical presentations because they visualise the correlation between points by showing the trend that exist between

parameters, they show negative and positive types of graphical representations, it is also an easier method of presentation that can be modified to show different types content. For instance, it is easy to modify a scatter plot into a van kreven diagram as compared to bar chart. The sections below explain how each graph was made.

The first graph in the results, **Figure 5** showing the organic quantity of the source rock was developed by plotting the S_2 and TOC. The classifications that were shown using orange dashed lines to classify the source rock into different categories were added in reference to **Table 1.**

The second graph **Figure 6** was developed to show the generative petroleum potential of the source rock. This was made by developing the relationship between the TOC and petroleum potential yield. The categories were made in reference with the **Table 2**

The van kreven diagram **Figure 7** was developed using the relationship between the hydrogen index (HI) and oxygen index(OI) to determine the nature of the potential hydrocarbons. The position of the curves to categorises the type of kerogen dominated in the source rock were made in reference with **Table 3.**

Lastly, the thermal maturation of the source rock was presented by showing the relationship that exist between maximum temperature and the production index which was calculated of the dataset in **Figure 8**. The lines that separates the graph into mature, immature and post mature zones were developed in accordance with **Table 4.**

4.2.3 Petroleum potential map development

The average TOC for each sample point in the Usisiya-Mbamba basin and Dwangwa delta was calculated using average tool in Microsoft excel. An attribute table showing the sample name, location (in terms of longitudes and latitudes) and average TOC was created to be used in the making the maps **Appendix C**. The shape files for the Malawi district boundaries, Malawi districts and lake malawi were downloaded from the DIVA-GIS open source website (www.diva-gis.org).

The QGIS 3.26 software was used to make the maps that show the distribution of TOC in some area of the third hydrocarbon. The maps show the distribution of TOC in the Usisiya-Mbamba basin and Dwangwa delta respectively. To make the maps, the polygon was first created by merging the vector layers of the shape files that were

downloaded, then the attribute table from excel which was saved in the form of a cvs. file was then added to the polygon. This was done to show the points at which the samples were collected from on the area and the average TOC. Since the sample points were distributed randomly within the area, the values of the unknown sample points were estimated from the known points using interpolation. This process involved of Inverse Weighting Distance(IWD) interpolation tool which resulted in the visualisation the interpolated raster layer in QGIS. The IWD process is set to show the results in a grey band colour, the colour ramp was changed to green to represent the findings in an adequate and effective manner.

The Inverse Weighting Distance interpolation method was chosen for the map because of how the sample points were distributed on the area. This is because the weights of the points that are close together are used make predictions of the unknown points and far points.

CHAPTER FIVE: RESULTS AND DISCUSSION

5.1. The deposition history of the third hydrocarbon

This section presents and discusses the findings on depositional timing of the petroleum system to determine the deposition history of the area.

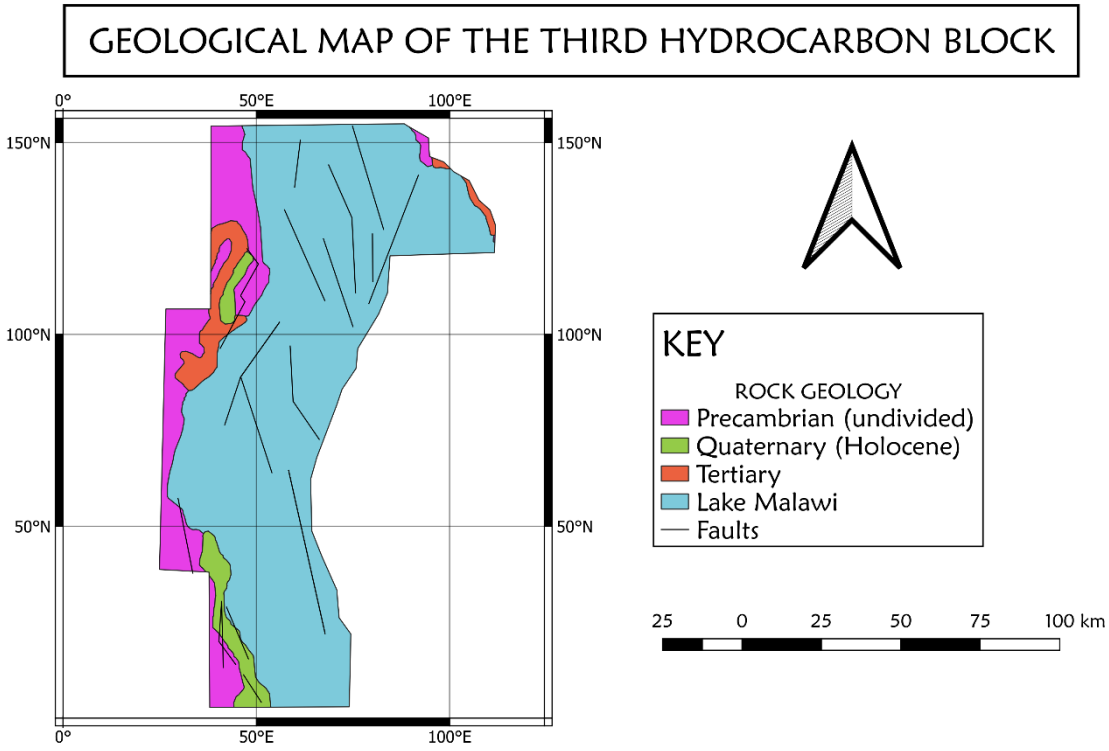


Figure 4. Geological map of the third hydrocarbon block

The overall geology of the third block is depicted on the map in **Figure 4**. The map shows that the area is covered by the Malawi basement rock of the Precambrian age, followed by the tertiary and quaternary deposits. These results are consistent with the information provided in the bulletin of Nkhotakota-Benga area and the bulletin of the Rumphi-Nkhatabay area (Harrison & Chapusa, 1975; Hopkins, 1973).

A petroleum system is mostly made up of sedimentary rocks which form the geological elements through deposition. Therefore this suggests that the system would not exist in the Precambrian age because the Malawi basement rock mainly consists of metamorphic and igneous rocks (Carter & Bennet, 1973).

According to the relative age of the Usisiya-mbamba basin which is at least 7800 years BP (Scholz & Finney, 1994) and not more than the 66 million year (upper Jurassic and

cretaceous age) due to the absence of the Karoo system (Carter & Bennet, 1973), this indicates that the petroleum system exists in the tertiary and quaternary deposits because they of a sedimentary nature. The deposition sequence of the tertiary and quaternary deposits is as follows; firstly, the Sungwe bed which is made up of grits and sandstones which lies unconformable on the basement rock followed by the Timbiri bed (comprising of clay, grits, sand and gravel), then the Chiwondo bed (unconsolidated calcareous marls, silt, sands, and shelly limestone), the then Chitimwe bed (red conglomerates, red sand and gravel) which is overlain by the quaternary bed (Carter & Bennet, 1973) and lastly the Songwe sequence (Scholz & Finney, 1994). Such deposition would allow the formation of the geological elements such as the source rock, reservoir and seals. The particular reason for the circumstance exists as the rocks that makes up the sequences are sedimentary in nature which is favourable for the existence of a petroleum system. secondly, the presence of fine grained, clay-rich sedimentary rocks such as calcareous marl, clay and limestone which area examples of good source rock for possible hydrocarbon generation because permeability and ability to retain sediments as well as the presence of sandstones in the area which also examples of good reservoir.

Lastly, the presence of faults in the area play a vital role as they allow the formation migration path within the system for transporting the generated hydrocarbons from the source to reservoir rock as well as the development of trap and seals to hinder the further movement of generated hydrocarbons.

5.2. Source rock characterization

This section presents the characteristics of the source rock which includes the quantity of the organic matter, quality of organic matter and the thermal maturation of the source rock.

5.2.1 Organic matter quantity

According to the examined datasets, the organic matter had an average TOC of **2.6wt%**, indicating that it is a good source rock. The organic matter also had the average of S_1 of **0.7 mgHCg^{-1}** and S_2, **5.6 mgHCg^{-1},** indicating that it is a good and fair source rock respectively. These classifications were created using **Table 1** as a guide. **Figure 5** , illustrates that there is a positive relationship between the samples data of the

source rock represented by the blue dots. This shows that the TOC contents meets the accepted standard of a source rock with an outstanding level of organic matter quantity and this has been confirmed by S_2, which also falls within the fair to excellent region. Therefore, it can be stated that the source rock has an adequate quantity of organic matter which has been preserved over time such that once the maturation stage has been reached, they would be a sufficient amount that can be converted to form hydrocarbons.

The quantity of the organic matter cannot be efficient to characterise the potential of the source therefore the generative potential of the source rock is included to verify the exist quantity has the potential to generate hyrdocarbons.

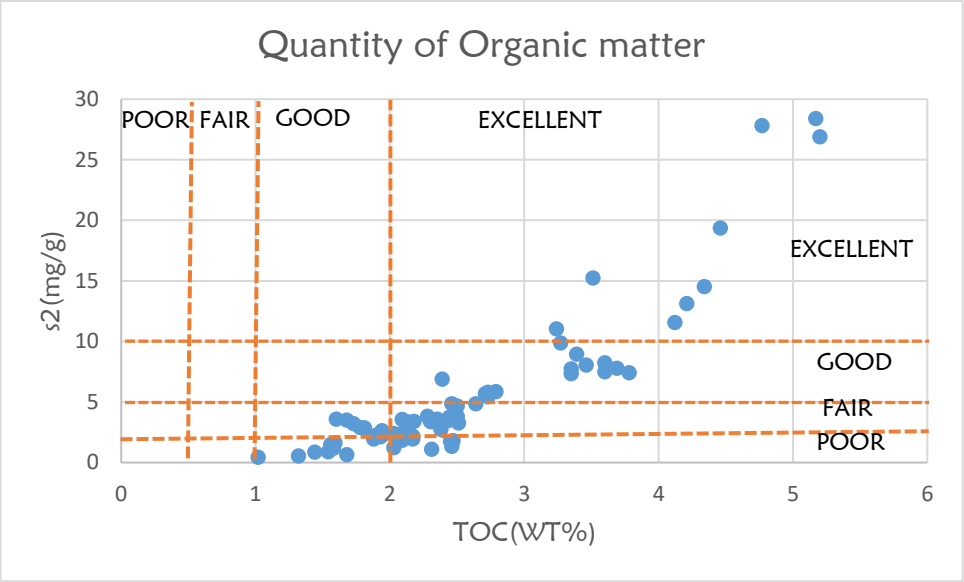


Figure 5. Plot showing the quantity of the organic matter

The results also show that the source rock has a genetic potential petroleum yield of **6.21 mgHCg $^{-1}$.** In light of **Table 2,** this demonstrates that the organic matter has a good capability for generating hydrocarbons. The results are justified by the graph below, which shows that most samples fall within the range of a good generative potential. This means that the source rock not only contains a significant amount of organic matter but also has the capability to generate hydrocarbons.

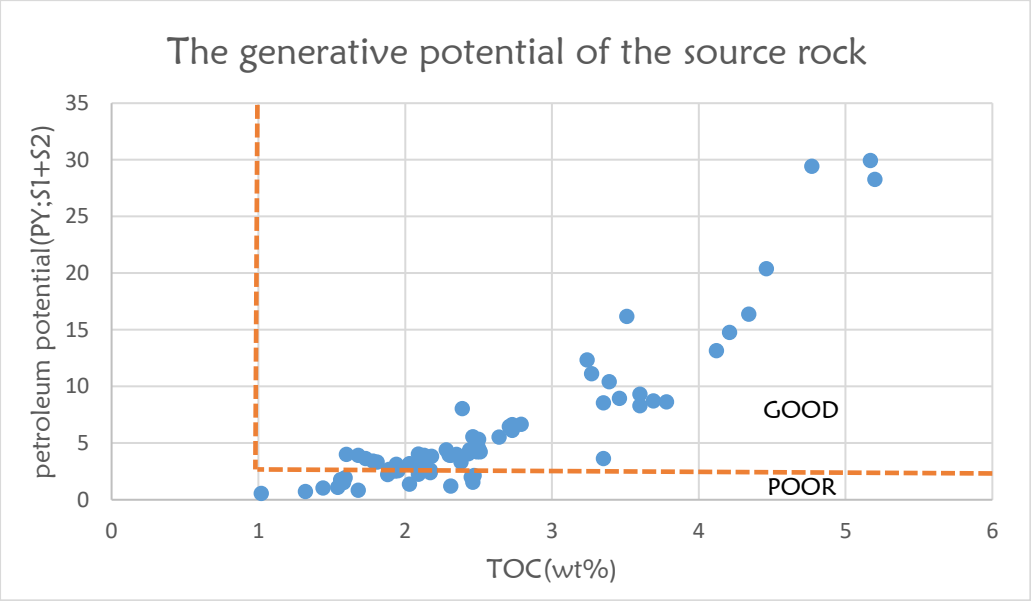


Figure 6 Plots showing the generative potential of the source rock based on the PY and TOC

5.2.2 Organic matter quality

The data identifies that the source rock has an average HI of **180 mgHCgTOC^{-1}**. This suggests, in terms of **Table 3**, that the organic materials present in the source rock is capable of generating an oil and gas mixture. According to the modified van Krevelen diagram plot of HI against OI values, the source rock is of Humic type (gas dominated), as can be seen in **Figure 7**. This is because most of the samples data are characterised by low HI and high OI. The variability of the kerogen type is dependent on the type of organisms that contributed to the organic matter and how well the organic matter was preserved. Therefore, the type of kerogen in this case suggest that the organic matter was derived from terrestrial higher plants or the organic matter was deposited in an oxidizing environment (Peters & Cassa, 1994).

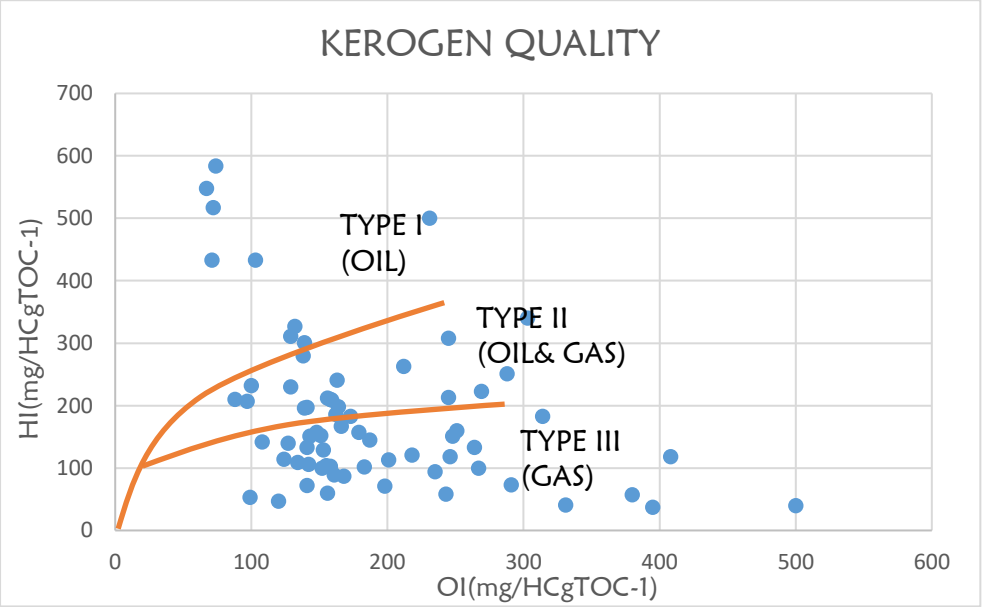


Figure 7. Plot of HI against OI showing the kerogen type (quality)

5.2.3 Thermal maturity of the source rock

The results illustrate that depending on the average maximum temperature of **419°C**, the source rock is in the immature stage of thermal maturation. The suggestion has been made with reference with **Table 4.** The figure below showing the relationship between maximum temperature and petroleum production index supports that fact that the phase of thermal maturity of the source rock lies in the immature stage as most of the samples are less than 430°C. This demonstrates that the conversion of kerogen to

petroleum has not commenced as the kerogen remains in its original state. It is so since the age of the Usisiya-mbamba basin is relatively young, which implies the sediments have not had adequate time to ensure all the conversion processes have taken place and the burial rate that has taken place over the geologic time has not been sufficient enough to increase the temperature to initiate the formation of petroleum in the source rock.

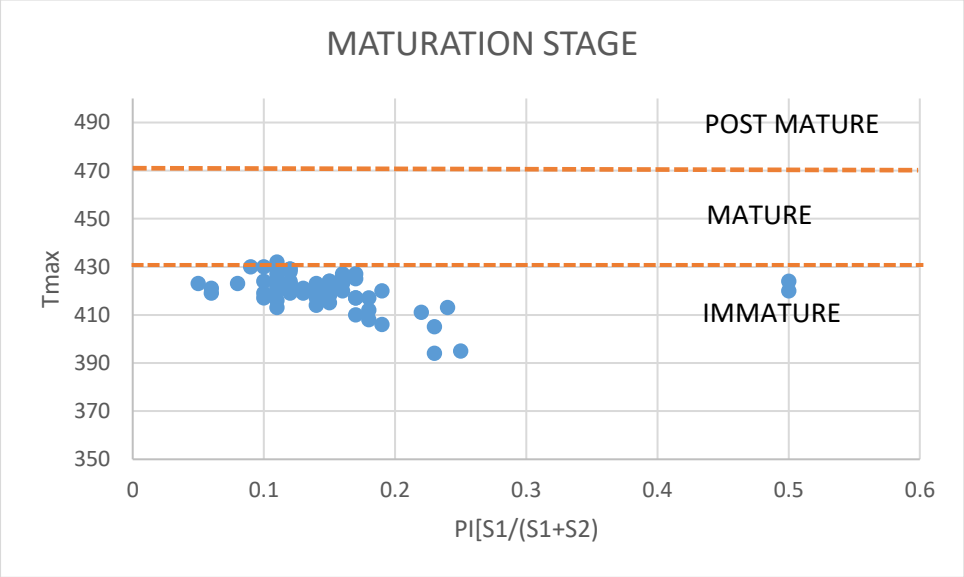


Figure 8. The plot of Tmax and PI showing the stage of thermal maturity of the kerogen samples of the source rock

5.3. The petroleum potential map

This section presents maps that display the regions in the third hydrocarbon block that have high petroleum potential for further exploration. The petroleum potential was determined in terms of the distribution of Total organic carbon in area.

5.3.1 The map of the Usisiya-Mbamba basin

The map in **Figure 9** shows how the TOC content has been distributed throughout the basin. It shows the areas of both minimum and maximum TOC content which has been represented by the different shades of green. The interpolated section on the map shows that the region with the highest petroleum potential in terms of the TOC is located at the south-western part of the basin and gradually decrease in petroleum potential towards the northern part of the map. This may imply that once the sediments are deposited at the lake's shallow end, they are then further transported to the deeper section of the lake by the action of waves and water movement where they are settled.

Therefore, the south western part which is the deeper section of the lake would have a higher concentration of organic matter as a result of the sediments settling as compared to the northern part. This may also help explain why thick sedimentary sequences are present along the central part of the basin. (Mattick, 1984).

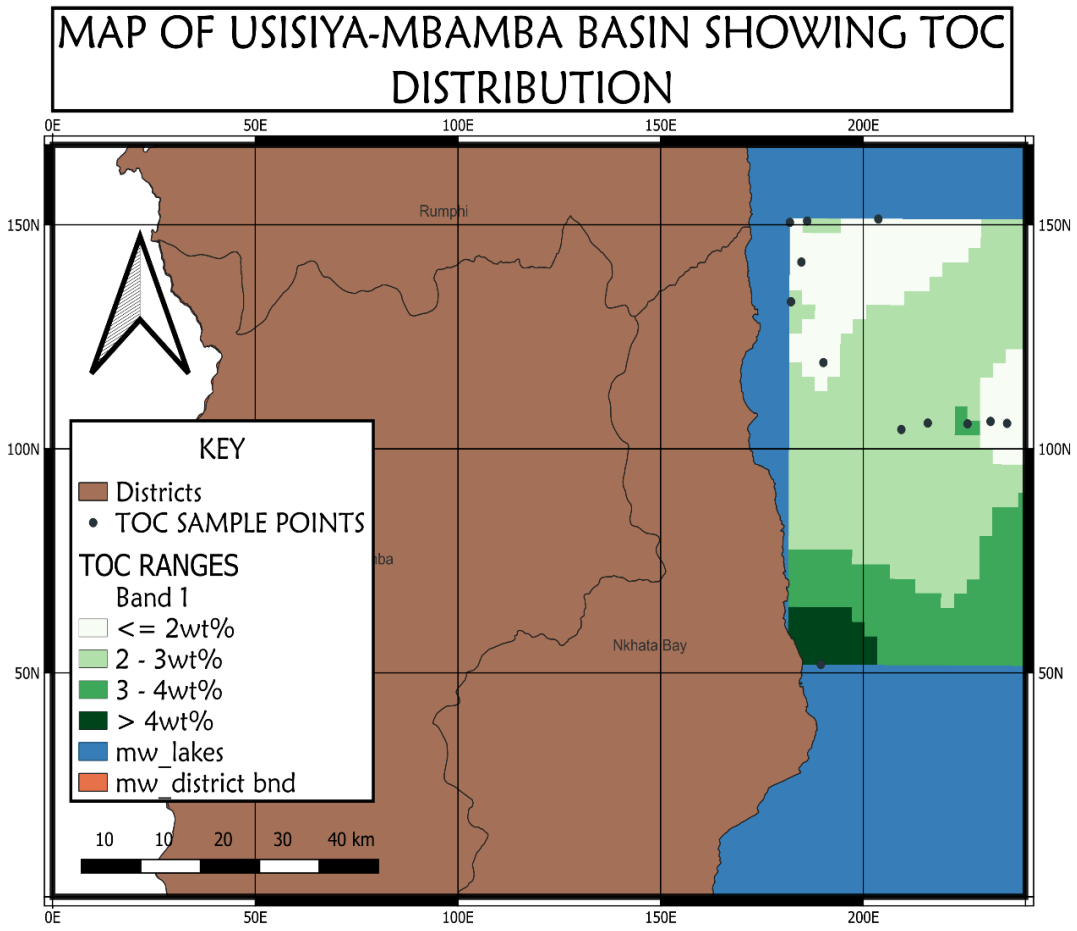


Figure 9. Map of Usisya-Mbamba basin showing TOC distribution

5.3.2. The map of the Dwangwa delta

The distribution of the TOC content across the Dwangwa delta is depicted in **Figure 10.** It displays the regions with the lowest and highest TOC content levels from which the samples were collected. The interpolated section on the map shows that the region with the highest petroleum is located at the prodelta, situated at the eastern part of the map and proceeds to decrease towards the intra delta area which is located at the western section of the area. The concentration of the TOC content may have resulted due to the physiography of the delta. This means that once the sediments from rivers such Dwangwa, Dwambadzi and other minor rivers are deposited in the intra delta area, a short distance below the water level, they are then further deposited to the

prodelta, the entire area below water level due to the delta front (Moore, 1966). The delta front is a narrow zone that divides the intra delta region from the prodelta, it is characterized by a steep gradient, this permits active deposition to take place. As a result, 75 percent of sediments deposited from the rivers can build up in the prodelta as genuine delta mass accumulates (Moore, 1966). Therefore, this explains why the petroleum potential is the highest at the eastern part of the map.

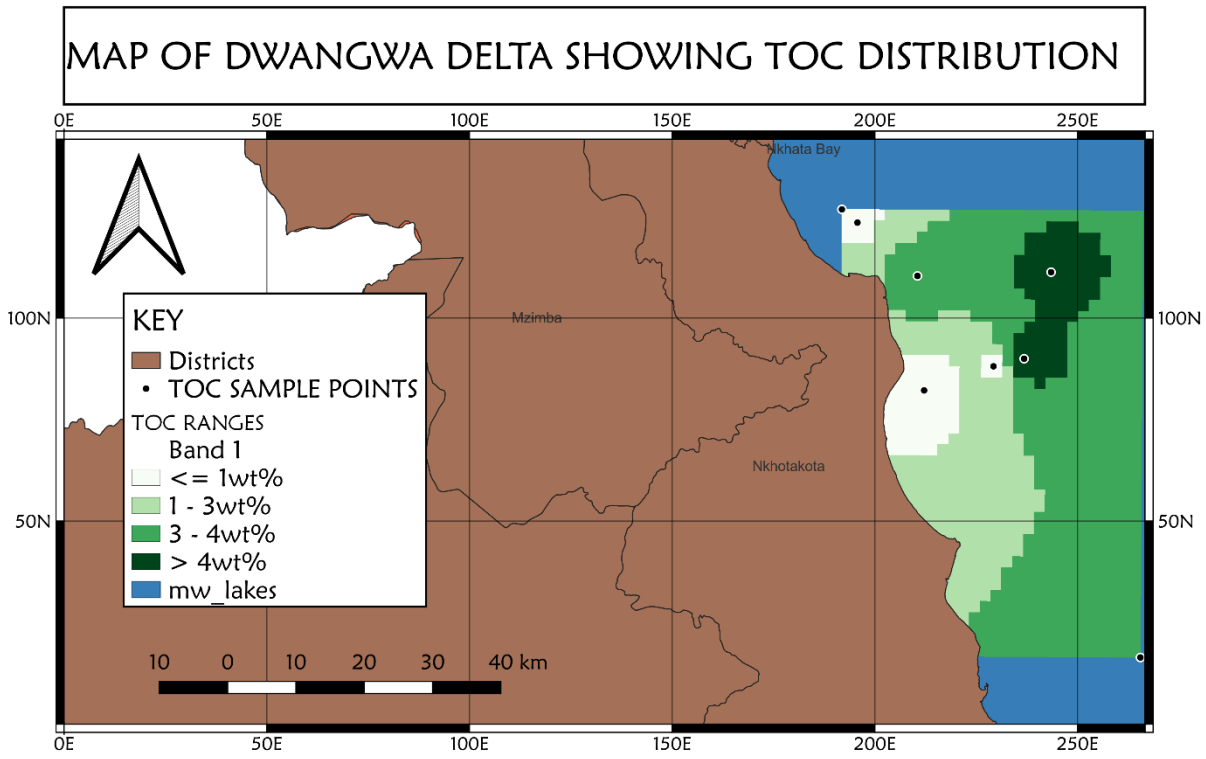


Figure 10. Map of the Dwangwa Delta showing TOC distribution

From the generated maps, it shows that the deep areas of the study area have a high petroleum potential as compared to shallow areas. This is because the sediments tend to settle in a conducive environment which allows the sediments to be preserved in the source for hydrocarbon generation as compared to the shallow end which could result destruction for the sediments through oxidation and many more.

CHAPTER SIX: CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

Petroleum system assessment is critical in the petroleum industry. This is because it provides guidance from identifying economical recoverable reserves to the extraction of petroleum. Assessment can be done using geochemical, geophysical, geological, petro physical and geological analysis.

Three different approaches were combined to assess potential petroleum system. The first method was a geological analysis to investigate deposition history of the area using GIS and literature review. The second method was geochemical analysis, which focused on the assessment of the total organic content and rock Eval pyrolysis to determine the characteristics of geological element (source rock) in terms of the quantity, quality of the organic matter and the thermal maturity of the source rock. Finally, the development of the petroleum potential map using the interpolation technique in GIS.

The study shows that the potential petroleum system in the third hydrocarbon block is located in the tertiary and quaternary deposits based on the results. The presence of faults in the area support this theory as they provide migration routes, which is one of the requirements for the presence of the petroleum system. According to the results on the characterization of the source rock, the quantity of the organic matter shows that the source rock has a good generative potential to generate hydrocarbons from the source rock. The quality of the organic matter shows that the source rock is capable of generating a mixture of oil and gas which mainly dominated gas. Lastly, since the source rock is in the immature stage of thermal maturation, hydrocarbon generation has not begun. This is because the petroleum system is located in lithology that is relatively young and has not undergone adequate burial and tectonic activity to increase the temperature and pressure that could initiate hydrocarbon generation. Finally based on the distribution of the total organic carbon content on the maps, the deepest section of the area has the highest petroleum potential for further exploration. This is because it provides a conducive environment for sufficient deposition to occur and allows the preservation of the sediments that make up the organic matter in the source rock.

6.2. Recommendation

A petroleum system can be assessed using methods such as geological, geological and GIS techniques as exempted in this research. Therefore, according to the results and existing literature, the following have been suggested for potential research directions.

Further research must be carried out to pin point the specific petroleum systems within the third hydrocarbon blocks. This is because the size of the hydrocarbon block does not represent the precise sizes of the individual petroleum systems in the area. It is important as it will allow that the assessment of the petroleum systems to be conducted specific scope which will provides high level of detail which is necessary to the research as compared to a broader scope which provides a rather narrow level of detail.

The previous assessment was based on the presence of the petroleum system and the source rock. Therefore, the collection of petro physical data such as porosity, permeability, saturation and shale and clay volume as well as data on curvature and roughness of the reservoir tops which will assist assessing the petroleum system in terms of the reservoir, trap and seal respectively.

REFERENCES

Al-areeq, N. M. (2018). Petroleum Source Rocks Characterization and Hydrocarbon Generation Petroleum Source Rocks Characterization and Hydrocarbon Generation. *Recent Insight in Petroleum Science and Engineering*, 3–30. https://doi.org/10.5772/intechopen.70092

Aladwani, N. S. (2021). Assessment of petroleum system of Arabian – Iranian Basin in Kuwait Assessment of petroleum system of Arabian – Iranian Basin in Kuwait. *All Earth*, *33*(1), 108–123. https://doi.org/10.1080/27669645.2021.1976930

Carter, G., & Bennet, J. (1973). *The geology and mineral resource of Malawi*. Government printer.

Chisenga, C. (2012). *Hydrocarbon potential of Malawi (new)*.

Ellis, G. S., Katz, B. J., Scholz, C. A., & Swart, P. K. (2015). *Organic sedimentation in modern lacustrine systems : A case study from Lake Malawi , East Africa*. *2515*(02), 19–47. https://doi.org/10.1130/2015.2515(02).

Guo, L., Jia, C., & Konhauser, K. O. (2016). Depositional system and hydrocarbon accumulation in Gubei slope zone , Zhanhua Depression , Bohai Bay Basin , eastern China. *Energy, Exploration and Expliataion*, *1*(18), 1–18. https://doi.org/10.1177/0144598716665015

Hamzeh, M., & Karimipour, F. (2020a). An ABC-optimized fuzzy ELECTRE approach for assessing petroleum potential at the petroleum system level. *Open Geosciences*, *12*(1), 580–597. https://doi.org/10.1515/geo-2020-0159

Hamzeh, M., & Karimipour, F. (2020b). Petroleum potential assessment using an optimized fuzzy outranking approach : A case study of the Red River petroleum system , Williston Basin. *Energy Exploration and Exploitation*, *38(4)*, 960–988. https://doi.org/10.1177/0144598720910264

Harrison, D., & Chapusa, F. (1975). *The geology of Nkhotakota-Benja area*. Government printer.

Hopkins, S. (1973). *The geology of the Rumphi-Nkhatabay area*. Government printer.

Jager, J. De. (2020). Concepts of conventional petroleum systems. In *Regional Geology and Tectonics: Principles of Geologic Analysis*. BV. https://doi.org/10.1016/B978-0-444-64134-2.00022-5

Lirong, D. O. U., Jianjun, W., Dingsheng, C., Xuefeng, R. A. N., Rubond, E. N. T., Kasande, R., Byakagaba, A., & Mugisha, F. (2004). *Geological condition and Petroleum Exploration potential of the Albertine Graben of Uganda*. *78*(4).

Liu, J. P., Pan, X. hua, Ma, J., Tian, Z. ji, Chen, Y. jin, & Wan, L. kun. (2008). Petroleum geology and resources in West Africa: An overview. *Petroleum Exploration and Development*, *35*(3), 378–384. https://doi.org/10.1016/S1876-3804(08)60086-5

Magoon, L., & Schmoker, J. (2000). *Chapter PS THE TOTAL PETROLEUM SYSTEM — THE NATURAL FLUID NETWORK THAT CONSTRAINS THE ASSESSMENT UNIT in U . S . Geological Survey Digital Data Series 60*.

Magoon, Leslie, & Beaumont, E. (2005). Petroleum system. In *petroleum sytems* (pp. 1–34). https://www.searchanddiscovery.com/documents/beautmont02/images/beaumount02.pdf

Magoon, Leslie, & Wallace, D. (1994). *The petroleum system - from source to trap*. The American Association of Petroleum Geologists. https://doi.org/10.1016/0920-4105(95)00059-3

Mattick, R. . (1984). *Petroleum Exploration in Malawi*. https://pubs.usgs.gov/of/1984/0384/report.pdf

Moore, D. (1966). DELTAIC SEDIMENTATION. *Earth Science Reviews*, *1*(2–3), 87–104. https://doi.org/10.1016/0012-8252(66)90001-8

Perez-Drago, G., Mouchot, N., Dubille, M., Montadert, L., Biase, D., Lacone, P., Mazzarelli, M., & Hosni, M. (2020). The Importance of Multi-Scale Petroleum System Assessment for Plays and Prospects De-Risking in the Eastern Mediterranean Basin. *Search and Discovery*, *11332*. https://doi.org/10.1306/11332Perez-Drago2020

Peters, K. E., & Cassa, M. R. (1994). Applied Source Rock Geochemistry. *The Petroleum System- from Source to Trap*, 93–114.

Rosedahl, B. R., & Livingstone, D. . (1983). *Rift lakes of east Africa;New seismic data and implications for future research*. *1*, 14–19.

Scholz, C. A., & Finney, B. P. (1994). Late quaternary sequence stratigraphy of Lake Malawi (Nyasa)Africa. *Sedimentology*, *41*, 163–179.

Whaley, J. (2017). *GEO ExPro - Malawi Unexplored*. https://www.geoexpro.com/articles/2017/10/malawi-unexplored

APPENDICES

Appendix A

Table showing the location and description of the sample data used in the research.

SAMPLE NUMBER	LATITUDE	LONGITUDE	REGION	SAMPLES
M86-14P	-11.5783	34.3317	Usisiya- Mbamba basin	1
M86-18P	-11.3933	34.6733	Usisiya- Mbamba basin	9
M95-6V	-11.1627	34.3338	Usisiya- Mbamba basin	6
M95-12V	-10.97	34.2813	Usisiya- Mbamba basin	10
M95-13V	-10.968	34.308	Usisiya- Mbamba basin	16
M95-14V	-10.9648	34.4175	Usisiya- Mbamba basin	17
M95-16V	-11.0792	34.2835	Usisiya- Mbamba basin	15
M95-24V	-11.0245	34.2993	Usisiya- Mbamba basin	9
MOI-1GB	-11.245	34.6172	Usisiya- Mbamba basin	1
MOI-2GB	-11.2425	34.5918	Usisiya- Mbamba basin	1
MOI-3GB	-11.246	34.5563	Usisiya- Mbamba basin	1
MOI-4GB	-11.2452	34.495	Usisiya- Mbamba basin	1
MOI-5GB	-11.2543	34.4543	Usisiya- Mbamba basin	1
M86-2PG	-12.395	34.3967	Dwangwa Delta	2
M92-12G	-12.3133	34.1147	Dwangwa Delta	1
M92-13G	-12.3307	34.1357	Dwangwa Delta	1
M92-14G	-12.4008	34.2168	Dwangwa Delta	1
M92-20G	-12.5095	34.361	Dwangwa Delta	2
M95-25V	-12.5197	34.3198	Dwangwa Delta	3
M95-26V	-12.552	34.2265	Dwangwa Delta	2
M86-22PG	-12.9033	34.52	Dwangwa Delta	2

Table 5. Location and description of sample data

Appendix B

Table showing the TOC content and Rock Eval pyrolysis data that was used in the research

Core sample	TOC	S1	S2	PY	PI	HI	OI	Tmax
M95-6V-1	1.94	0.49	2.62	3.11	0.16	135	231	426
M95-6V-2	1.93	0.39	2.12	2.51	0.16	133	264	425
M95-6V-3	1.59	0.33	1.61	1.93	0.17	100	267	425
M95-6V-4	1.56	0.3	1.47	1.77	0.17	94	235	427
M95-6V-5	3.78	1.22	7.41	8.63	0.14	196	139	414
M95-6V-6	1.73	0.41	3.21	3.62	0.11	183	173	423
M95-6V-7	2.5	0.66	4.65	5.31	0.12	186	162	422
M95-6V-8	2.71	0.75	5.69	6.44	0.12	209	159	422
M95-6V-9	2.79	0.82	5.84	6.66	0.12	210	158	423
M95-6V-10	2.73	0.82	5.8	6.62	0.12	212	156	421
M95-6V-11	2.73	0.69	5.41	6.10	0.11	198	164	432
M95-6V-12	2.64	0.68	4.84	5.52	0.12	183	314	424
M95-6V-13	2.5	0.72	3.81	4.53	0.16	152	151	423
M95-6V-14	2.44	0.68	3.7	4.38	0.16	151	143	425
M95-6V-15	2.49	0.65	3.56	4.21	0.15	140	127	424
M95-6V-16	2.43	0.62	3.44	4.06	0.15	133	141	424
M95-7V-7	1.88	0.26	1.94	2.2	0.12	103	158	421
M95-7V-8	2.46	0.23	1.31	1.54	0.15	53	99	419
M95-7V-9	1.6	0.42	3.57	3.99	0.11	223	269	416
M95-7V-10	2.31	0.56	3.35	3.91	0.14	145	187	419
M95-24V-6	2.31	0.11	1.09	1.2	0.09	47	120	430
M95-24V-7	1.95	0.25	2.29	2.54	0.1	118	246	430
M95-24V-8	2.03	0.16	1.21	1.37	0.12	60	156	429
M95-24V-9	2.45	0.24	1.75	1.99	0.12	71	198	428
M95-13V-1	3.51	0.96	15.22	16.18	0.06	433	71	419
M95-13V-2	1.68	0.32	3.5	3.91	0.08	213	245	423
M95-13V-3	5.2	1.39	26.88	28.27	0.05	517	72	423
M95-13V-4	4.77	1.63	27.8	29.43	0.06	584	74	421
M95-13V-5	5.17	1.56	28.38	29.94	0.5	548	67	420
M95-13V-6	4.46	1.04	19.35	20.39	0.5	433	103	424
M95-13V-7	3.6	0.81	7.48	8.29	0.1	207	97	424
M95-13V-8	2.35	0.43	3.56	3.99	0.11	151	248	427
M95-13V-9	3.35	0.9	7.73	3.63	0.1	230	129	417
M95-13V-10	2.3	0.55	3.38	3.93	0.14	142	108	423

M95-13V-11	3.69	0.93	7.78	8.71	0.11	210	88	420
M95-13V-12	3.46	0.91	8.03	8.94	0.1	232	100	419
M95-13V-13	1.89	0.46	2.21	2.67	0.17	118	408	410
M95-13V-14	2.47	0.34	1.79	2.13	0.16	72	141	427
M95-13V-15	2.38	0.59	2.72	3.31	0.18	114	124	412
M95-13V-16	2.51	0.99	3.24	4.23	0.23	129	153	405
M95-14V-1	1.68	0.19	0.63	0.82	0.23	37	395	394
M95-14V-2	1.02	0.12	0.42	0.54	0.22	41	331	411
M95-14V-3	1.32	0.18	0.54	0.72	0.25	40	500	395
M95-14V-4	1.44	0.19	0.84	1.03	0.18	58	243	408
M95-14V-5	1.54	0.21	0.88	1.09	0.19	57	380	406
M95-14V-6	1.81	0.47	2.85	3.32	0.14	157	148	419
M95-14V-7	2.46	0.71	4.85	5.56	0.13	197	141	421
M95-14V-8	2.13	0.54	3.36	3.9	0.14	157	179	418
M95-14V-9	2.28	0.57	3.81	4.38	0.13	167	166	419
M95-14V-10	2.08	0.43	2.36	2.79	0.15	113	201	418
M95-14V-11	2.1	0.41	2.15	2.56	0.16	102	183	420
M95-14V-12	2.09	0.42	1.83	2.25	0.19	87	168	420
M95-14V-13	2.17	0.43	1.94	2.37	0.18	89	161	417
M95-14V-14	2.03	0.45	2.37	3.18	0.14	109	134	420
M95-14V-15	2.18	0.43	3.39	3.82	0.11	104	155	422
M95-14V-16	2.17	0.44	2.18	2.62	0.17	100	152	417
M95-14V-17	2.13	0.47	2.27	2.74	0.17	106	142	417
M95-16V-1	1.78	0.52	2.89	3.41	0.15	160	251	422
M95-16V-2	3.39	1.52	8.94	10.4	0.15	263	212	415
M95-16V-4	2.09	0.49	3.53	4.02	0.12	121	218	419
M95-16V-6	3.35	1.24	7.31	8.55	0.15	308	245	419
M95-16V-7	3.24	1.3	11.03	12.33	0.11	340	303	429
M95-16V-8	1.58	0.36	1.16	1.52	0.24	73	291	413
M95-16V-9	3.6	1.08	8.22	9.3	0.12	251	288	429
M95-16V-11	4.34	1.85	14.51	16.36	0.11	327	132	413
M95-16V-12	4.12	1.58	11.56	13.14	0.12	280	138	423
M95-16V-13	4.21	1.64	13.12	14.76	0.11	311	129	425
M95-16V-14	3.27	1.24	9.87	11.11	0.11	301	139	422
M95-16V-15	2.39	1.16	6.87	8.03	0.14	241	163	417

Table 6. TOC content and Rock Eval pyrolysis data

Appendix C

Table showing sample locations and averages TOC used for making the petroleum potential map.

Usisya-Mbamba data

SAMPLE NUMBER	LATITUDE(S)	LONGITUDE(E)	AVERAGE TOC
M86-14P	-11.5783	34.3317	5.1
M86-18P	-11.3933	34.6733	4.48
M95-6V	-11.1627	34.3338	2.41
M95-12V	-10.97	34.2813	1.44
M95-13V	-10.968	34.308	3.3
M95-14V	-10.9648	34.4175	1.92
M95-16V	-11.0792	34.2835	2.61
M95-24V	-11.0245	34.2993	1.85
MOI-1GB	-11.245	34.6172	1.52
MOI-2GB	-11.2425	34.5918	1.67
MOI-3GB	-11.246	34.5563	3.94
MOI-4GB	-11.2452	34.495	3.16
MOI-5GB	-11.2543	34.4543	3.1

Table 7. Usisiya-Mbamba map data

Dwangwa delta data

SAMPLE NUMBER	LATITUDE(S)	LONGITUDE(E)	AVERAGE TOC
M86-2PG	-12.395	34.3967	4.33
M92-12G	-12.3133	34.1147	1.45
M92-13G	-12.3307	34.1357	1.2
M92-14G	-12.4008	34.2168	3.55
M92-20G	-12.5095	34.361	5
M95-25V	-12.5197	34.3198	1.08
M95-26V	-12.552	34.2265	0.34
M86-22PG	-12.9033	34.52	3.4

Table 8. Dwangwa delta map data