

ASSESSMENT OF NATURAL GAS SOURCE ROCK POTENTIAL IN USISYA-MBAMBA BASIN IN LAKE MALAWI

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DECLARATION

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

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Abstract

An essential first stage in the exploration and exploitation of hydrocarbons is the assessment of natural gas source rock, which provides insight into the origins and methods of hydrocarbon discovery. The evaluation of Malawi's Usisya-Mbamba basin's source rock potential for natural gas is discussed in this article.

The geochemical investigation of the basin was carried out by the study using secondary geochemical data, including rock eval pyrolysis analysis, vitrinite reflectance, literature review, and TOC. Additionally, geochemical parameters like PI, TOC, S2, R0, and Tmax were used in the study.

Using scatter plots of TOC versus S2, Tmax versus PI, R0 versus depth, and table reference, respectively, the study determined the organic matter content, thermal maturity, and vitrinite reflectance of the source rock.

Ultimately, the data showed that the organic richness of the source rock in the basin ranged from fair to good, with the maximum TOC being 3.51 weight percent. Low vitrinite reflectance and immaturity characterize the source rock. This implies that natural gas production in the Usisya-Mbamba basin is possible, but more maturation of the organic matter is required. As the basin shrinks and the organic debris is buried deeper, this could eventually occur. On the other hand, igneous intrusions or strong geothermal gradients may quicken maturation. To validate this potential and determine whether producing gas from the basin is economically feasible, more research is necessary.

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Table of contents

DECLARATION 2
Abstract i
Acknowledgements ii
Table of contents iii
List of figures v
List of tables vi
1. Chapter 1 INTRODUCTION 1
1.1. Introduction 1
1.1.1. Background 1
1.1.2. Problem Statement 4
1.1.3. Main objective 4
1.1.4. Specific Objectives 4
1.1.5. Research Questions 4
1.1.6. Significance of study 5
2. ChaPter 2 LITERATURE REViEW 7
2.1. Introduction 7
2.1.1. Natural gas source rock 7
2.1.2. Lacustrine source rock potential 9
2.1.3. The geology of lake Malawi and Usisya-Mbamba basin 10
2.1.4. Thermal maturity 11
2.1.5. Organic carbon matter content in the sediments 13
2.1.6. The vitrinite reflectance 14
3. Methodology 16
3.1. Introduction 16
3.1.1. Research design 16
3.1.2. Data Collection 16
3.1.3. Data analysis 16
3.1.4. Study Area 17
3.1.5. Geochemical and Vitrinite Reflectance 18
3.1.6. Core samples data and Sampling technique 19
4. Chapter 4 Results and Discussions 20
4.1 Samples definitions, Results and Evaluations 20
4.2 Interpretation of the results 22
4.2.1 Total organic matter 22
4.2.2 Thermal maturity 23
4.2.3 Vitrinite Reflectance 25
5 CHAPTER 5: CONCLUSION AND RECOMMENDATIONS 26
5.1 Conclusion 26
5.2 Recommendations 27
References 29

APPENDICES.....30

ACRONYMS/ABBREVIATIONS

TOC Total organic carbon

Wt.% Percentage by weight

S1 volatile hydrocarbon content in mg per g of sample

S2 remaining hydrocarbon generative potential in mg per g of sample

OI Oxygen index

PI Production Index

Tmax Maximum Temperature

R_0 Vitrinite Reflectance

List of figures

Figure 1: shows source rock, reservoir, trap and seal and two petroleum generation and migration 8
Figure 2: shows cross- plot of rock-Eval Tmax versus depth showing the range in thermal maturity stages of source rock (Agbor et al., 2023). 12
Figure 3: thermal transformation of kerogen(Mccarthy et al., 2011) 14
Figure 4: shows cross-plot of R_0 versus depth showing the ranges in thermal maturity stages of source rock (Agbor et al., 2023) 15
Figure 5 MAP ..... M
..... 17
Figure 6: plot showing the TOC versus depth 22
Figure 7: plot showing the quantity of organic matter 23
Figure 8: The plot of Tmax versus PI showing the thermal maturity of the source rock 24
Figure 9: Plot of water depth against R0 showing maturity profile 25

List of tables

Table 1: Source rock evaluation (McCarthy et al., 2011) 9
Table 2: vitrinite reflectance values describing the thermal maturity ..... **Error! Bookmark not defined.**
Table 3: sample location 20
Table 4: Total organic carbon and Rock-Eval pyrolysis data of Usisya-Mbamba Basin 21
Table 5: location and description of sample data..... **Error! Bookmark not defined.**
Table 6: Total organic carbon and Rock-Eval pyrolysis data of Usisya-Mbamba Basin 31

1. CHAPTER 1 INTRODUCTION

1.1. Introduction

In light of rising global energy consumption and environmental concerns, the search for sustainable energy sources has become essential. A clean-burning hydrocarbon, natural gas is essential to the energy mix of many countries. Determining future energy supplies requires an understanding of the potential for natural gas source rocks (The Role of Gas in Today's Energy Transitions, 2019). This dissertation focuses on the assessment of natural gas source rock potential in the Usisya-Mbamba basin within lake Malawi, a region of significant geological and environmental importance.

1.1.1. Background

One of the African Great Lakes and the ninth-largest lake in the world, Lake Malawi is located in the East African Rift System. It is an area of great scientific interest because of its distinctive geological and ecological features. This lake system's potential as a source of hydrocarbon reserves, particularly natural gas, is one of its most alluring features (Finney & Johnson, 1991).

Exploration and production of natural gas have traditionally been focused on offshore and on land locations. Nonetheless, lacustrine (lake-based) systems have drawn more attention in studies as possible hydrocarbon sources. Under the correct geological circumstances, organic-rich lacustrine source rocks might produce substantial amounts of natural gas (Xue et al., 2023). Crow (1982) analyzed the history of petroleum exploration in Malawi; a quick synopsis of his study is included below. Following the Malawi Geological Survey's completion of a regional mapping program in 1970, it was determined that only two areas had sedimentary rocks that could potentially contain petroleum accumulations: (1) the Lake Malawi area, where lacustrine sediments are currently being deposited, and (2) the Lower Shire Valley in the southernmost part of the nation. However, due to Malawi's tiny area and the

relatively thin and youthful rock composition of the sedimentary portions, the petroleum sector was not very interested in the country at that time. The Lower Shire Valley and Lake Malawi are located within the East African Rift System, which stretches from the Red Sea to Mozambique. The rift system in its present form is a Tertiary feature (Crow, 1982) and individual grabens and tilted fault blocks are filled by terrestrial and lacustrine sediments.

East Africa's Lake Malawi contains a geological feature called the Usisya-Mbamba Basin. It depicts a complicated and fascinating geological environment with tectonic activity and a number of sedimentary strata (D.A.S. Hopkins, 1973). Determining the basin's potential as a source of natural gas and other hydrocarbon resources requires an understanding of its geology (Ellis et al., 2015).

The Karoo supergroup is one of the most promising source rocks in the Usisya-Mbamba basin. A substantial series of sedimentary rocks known as the Karoo supergroup was deposited in the Permian and Triassic eras. There is a lot of organic content in these rocks, which may have eventually turned into natural gas. The Cenozoic Shire Valley Basin and the Jurassic-cretaceous Malawi-rift system are two other possible source rocks in the Usisya basin (D.A.S. Hopkins, 1973).

Notwithstanding the Usisya-Mbamba basin's possible importance for natural gas development, there is still a significant vacuum in the body of knowledge. Very few thorough investigations have methodically looked at the organic carbon content, temperature, maturity levels, and geological characteristics of the sediments in this particular area. Furthermore, as the Ellis et al. case study on Lake Malawi illustrates, no previous study has examined the source rock potential of the Usisya-Mbamba basin in the context of recent lacustrine systems.

High-carbon sediments are currently being deposited in regions that are home to deep-water lakes with extremely anoxic bottom conditions, like Lake Malawi and Lake Tanganyika. Petroleum appears to have been thermally created from organic-rich rocks at depth in Lake Tanganyika, where bitumen balls are purportedly washed ashore (Crow, 1982), and in Lake Albert, where bitumen seepages occur (Harris and

colleagues, 1956). However, compared to Lake Malawi, Lakes Albert and Tanganyika most likely have considerably earlier geologic features. In 1974 the Institute of Geological Sciences of Great Britain published the results of a gravity survey that covered the land area of Malawi (Andrew, 1974). In 1980, Dumestre (1980) reviewed the petroleum geology of Malawi and concluded that the existence of petroleum accumulations beneath Lake Malawi and the Lower Shire Valley would depend on the presence of thermally mature source rock.

Natural gas is a fossil fuel that is created from leftover plant and animal matter. Its composition consists of methane, higher alkanes, and trace amounts of carbon dioxide, nitrogen, hydrogen sulfide, and helium. Natural gas reserves are located deep inside the ground, next to other solid and liquid strata like coal and crude oil. Three requirements need to be satisfied for natural gas to accumulate: impermeable rock that can trap the gas, a porous medium that can carry the gas, and a source rock where the gas can develop. (Economides & Wang, 2009).Malawi has petroleum resources (natural gas). Potential sites with thick sediments in Karonga, Nkhatabay, and Nkhotakota have been demonstrated by structural investigation. These basins were given the names Karonga, Usisya, Mbamba, and Mtakataka, respectively, by geologists (Malunga,2015.). Natural gas is used in homes and businesses for cooking, heating, and energy generation; this could be helpful for Malawian families who now use wood or charcoal as fuel.

It is crucial to comprehend the Usisya-Mbamba basin's geological and geochemical characteristics in order to assess the rock's potential as a natural gas source. This dissertation seeks to give a thorough evaluation of the natural gas source rock potential in the Usisya-Mbamba Basin, Lake Malawi, by addressing this study gap and utilizing knowledge from earlier studies. This study could advance our understanding of hydrocarbon resources in lacustrine settings, which could have consequences for environmental preservation and energy exploration in this important ecological area.

1.1.2. Problem Statement

Currently, Malawi gets its energy mostly from burning wood and charcoal, which poses a hazard to the environment. This accounts for 94% of the country's energy consumption (Gamula et al., 2014). But Malawi's population, urbanization, and industrialization are all increasing, and this is making energy sources more and more necessary. Natural gas, a more environmentally friendly energy source than petroleum, is one potential choice. Malawi imports natural gas at the moment, but this is costly and unsustainable. As a result, it is necessary to look for natural gas sources in Malawi.

Lake Malawi's Usisya-Mbamba basin is a sedimentary basin thought to contain source rock. The purpose of this study is to evaluate the Usisya-Mbamba basin's source rock potential. Potential for natural gas could help us save foreign cash, lessen our need on imported petroleum, and further Malawi's growth.

1.1.3. Main objective

- To assess the natural gas source rock potential in Usisya-Mbamba basin of Lake Malawi.

1.1.4. Specific Objectives

1. To determine the organic matter content in rock samples collected from Usisya-Mbamba basin
2. To estimate thermal maturity for the basin
3. To assess the vitrinite reflectance of the basin

1.1.5. Research Questions

1. What is the total organic carbon (TOC) content of the rock samples?
2. What is the thermal maturity of the basin?
3. What is the range of R_0 values in the basin?

1.1.6. Significance of study

There is a chance that this study on the natural gas source rock potential in Malawi's Usisya-Mbamba basin would have a big impact on both the nation and petroleum geology.

Economic significance: Malawi could be able to save foreign cash by reducing its dependency on petroleum imports if natural gas is found and produced in the basin. The economy of Malawi would benefit from this since it would free up funds for other important areas of development.

Importance for energy security: Natural gas is a dependable and clean energy source. Malawi's energy security would increase and its reliance on imported energy will decrease if it can capitalize on its own natural gas resources. Given the current global energy crisis, this would be extremely crucial.

Environmental significance: Malawi's greenhouse gas emissions would be decreased by the development of natural gas since it is a cleaner energy source than petroleum. This would support the international effort to battle climate change and assist Malawi in fulfilling its climate change commitments.

Significance for social development: Malawi's natural gas resources might be developed to provide employment and strengthen the local economy. It might also result in the growth of new companies and sectors. This could increase Malawians' standard of living generally and have a good effect on their livelihoods.

Contribution to petroleum geology: This work may further our knowledge of the formation and evolution of petroleum systems in Malawi and other African nations by evaluating the source rock potential of the Usisya-Mbamba basin. Future efforts to explore the area for oil and gas resources could be guided by this knowledge.

Overall, this study has the potential to make a significant contribution to Malawi, the field of petroleum geology, and the global effort to transition to a cleaner energy future.

2. CHAPTER 2 LITERATURE REVIEW

2.1. Introduction

Situated in Lake Malawi, the Usisya-Mbamba basin presents a substantial prospect for natural gas deposits (Wyson & Malunga, 2015). The purpose of this review of the literature is to evaluate this basin's potential for natural gas source rocks. Evaluating temperature conditions, organic carbon content, and maturity value are some of the specific goals. We can better understand the hydrocarbon situation and the basin's potential to produce petroleum by examining the facts and research that are already available.

2.1.1. Natural gas source rock

Fine-grained silt that contains enough organic matter to produce and release enough hydrocarbons to form a commercial deposit of oil or gas is known as petroleum source rock (McCarthy et al., 2011). The most prevalent source rocks are lime mudstones and shales, which are rich in organic materials. Any rock that may produce and release enough hydrocarbons to accumulate as oil or gas is considered a petroleum source rock (Al-Ar"eeq, 2018). The fundamental components of every petroleum system are the hydrocarbon source rocks, which are also the initial prerequisite for the formation of an oil or natural gas reservoir, whether conventional or unconventional (e.g., Magoon and Dow, 1994; Jarvie et al., 2006; Botor et al., 2017a, b, c). Over the past ten years, source rocks have also been identified as possible unconventional hydrocarbon reserves (e.g., Jarvie et al., 2006). The amount of organic carbon (total organic carbon, or TOC, expressed as a percentage of weight), the thermal maturity of the organic matter, and the genetic make-up of the kerogen are the primary factors influencing the hydrocarbon potential of the source rock. Three classes of source rocks are distinguished based on how much oil they produce: immature source rocks, which have not yet produced any hydrocarbons, mature source rocks, which are currently producing hydrocarbons, and post-mature source rocks, which have produced all hydrocarbons

of the crude oil type (Al-Areeq, 2018). Nabil Mohammed al-Areeq emphasizes the importance of the total organic carbon content, or weight percent TOC, as a crucial criterion for assessing organic richness in the search for source rock identification and assessment. Al-results Areeq's indicate that a minimum TOC value of 1.0 percent is a crucial threshold that indicates a potential source rock in clastic-type formations. This criterion guides researchers in their evaluation of probable hydrocarbon sources and acts as a crucial benchmark in the examination of sedimentary rocks. By integrating this TOC threshold into our analytical framework, we are able to properly discern and assess the anticipated outcomes, offering significant insights into the hydrocarbon potential of the source rock. In order to ascertain the source rock potential in 2018, Nabil Mohammed al-Areeq employed geochemical, rock eval pyrolysis, and geophysical data. The identification of source rocks is mostly dependent on geochemical techniques. The method that connects Rock-Eval pyrolysis and total organic matter (TOC) yields critical insights on the thermal maturity and generative capacity of the source rock. (Latif and others, 2021)

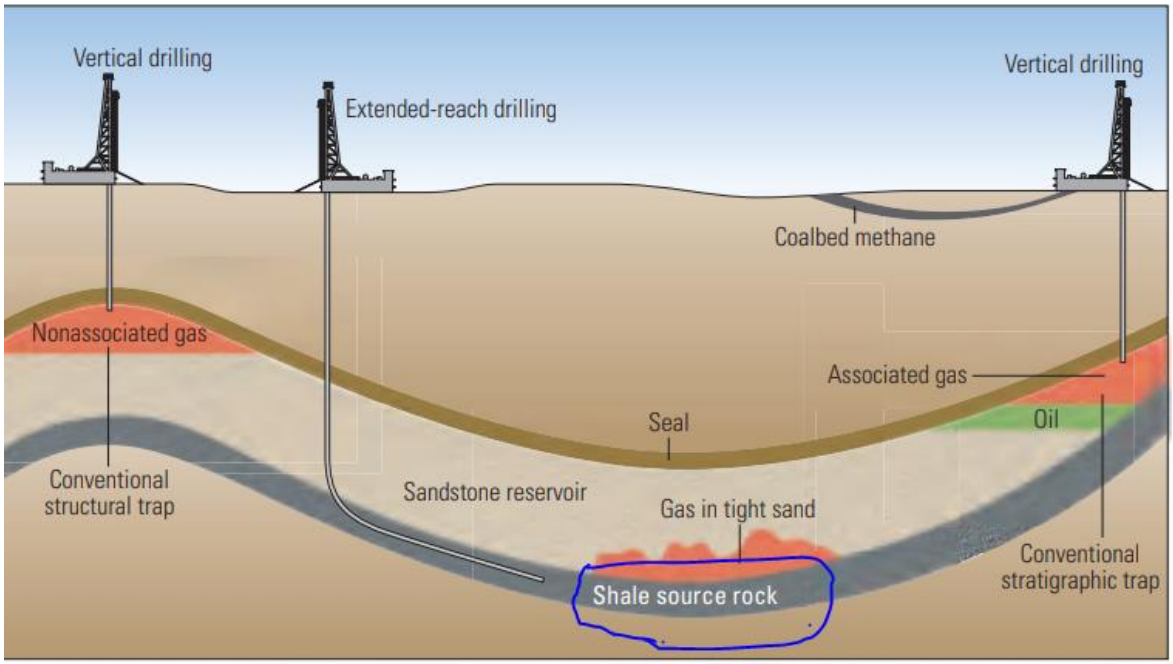


Figure 1: shows source rock, reservoir, trap and seal and two petroleum generation and migration

(Mccarthy et al., 2011)

Table 1: Source rock evaluation (McCarthy et al., 2011)

Source quality	TOC (wt.%)	S2 mg hydrocarbons/g
None	<0.5	<2
Poor	0.5 to 1	2 to 3
Fair	1.0 to 2	3 to 5
Good	2 to 5	5 to 10
Very good	>5	> 10

2.1.2. Lacustrine source rock potential

In many places, lacustrine petroleum systems account for a sizable amount of the hydrocarbon resource base (Mccarthy et al., 2011). The most famous of these are Brazil, China, Indonesia, Angola, and Gabon; in some of these places, the share of oil obtained from lacustrine deposits might reach 90% of total petroleum reserves (Katz, 1990). Significant petroleum discoveries have also been made in the Albertine Graben in Uganda's Lake Albert region, and there has also been a recent upsurge in petroleum exploration activity in the East African rift's current depositional basins (Karp et al., 2012). For marine and lacustrine environments, the same standards apply to identifying a possible or effective petroleum source rock: a minimum of 1 weight percent total organic carbon (TOC) and a pyrolysis output of >2.5 mg HC g–1 rock (Bissada, 1982). The capacity for a basin to produce petroleum can be significantly impacted by the regional diversity in OM concentration in lacustrine sediments. For instance, the Aman subbasin is linked to more than 70% of the reserves in central Sumatra, whereas the Kiri subbasin, which is mostly gas-prone, only makes up <1% of the deposits (Katz, 2001). Lacustrine source rocks are deposited in freshwater lake environments. Examples of these rocks are those found in the Usisya-Mbamba basin. Because of their well-known organic-rich composition,

these sediments are favorable for the production of hydrocarbons. The kind of organic matter, the rate of sedimentation, and the lake's temperature all affect the potential of lacustrine source rock (Ellis et al., 2015).

2.1.3. The geology of lake Malawi and Usisya-Mbamba basin

Located in the East African Rift System is Lake Malawi, sometimes referred to as Lake Nyasa. The African tectonic plate is currently rupturing in this active continental rift zone. Within this system, there are multiple deep freshwater rift lakes, including Lake Malawi, which were created by geological processes related to continental rifting. A mixture of faulting, subsidence, and volcanic activity created the lakes basin (Ellis et al., 2015). Grabens are a network of parallel fault lines formed by the East African Rift System. They are distinguished by slabs of the Earth's crust that have slid downward. One of these grabens is home to Lake Malawi, whose basin has deepened throughout geological time as a result of the rift's extensional forces. Lake Malawi's geological past is intimately related to sedimentary deposition. The lake's basin filled with sediments that had been eroded from the surrounding terrain as the rift valley developed. These sediments are abundant in aquatic life and organic matter, mostly from terrestrial plants (Finney & Johnson, 1991). The narrow, approximately 1000-kilometer-long Malawi Rift Valley, which trends north-south, is where Lake Malawi originated. The continental crust stretched and thinned along the EARS, resulting in the formation of the Rift valley. The Usisya-Mbamba Basin is one of the fault-bounded basins formed as a result of extensional tectonics (Ellis et al., 2015)

The sub-basin of the Malawi Rift Valley is called the Usisya-Mbamba Basin. It is situated off the coast of Malawi in the northern portion of Lake Malawi. The width of the basin is roughly 100 kilometers. The massive sequence of sediments, estimated to be up to 4 kilometers thick, fills the Usisya-Mbamba basin (Salim & Salmi, 2014). (Malunga, 2015.). Shales, mudstones, and sandstones make up the majority of these deposits. A thin layer of volcanic rocks, such as basalts and andesites, lies on top of

a broad succession of sedimentary strata that fill the basin. The Karonga group, Usisya group, and Mbamba group are the three groups of sedimentary rocks that make up the Usisya-Mbamba Basin. In the Usisya-Mbamba basin, the Usisya group is the middle sedimentary group. It is made up of a dense series of shales, mudstones, and sandstones. There is a belief that the Usisya group was deposited in a riverine setting. In the Usisya-Mbamba basin, the Mbamba group is the youngest sedimentary formation. It is made up of a narrow series of shales and sandstones. According to Robertson (2020), the Mbamba group is believed to have been deposited in a deltaic environment (D.A.S. Hopkins, 1973). The Usisya-Mbamba faults, which are typical faults that have expanded over time as a result of the extensional forces connected to the rifting process, border the basin (Salim & Salmi, 2014).

There is a lot of potential for natural gas source rocks in the Usisya-Mbamba basin. There are multiple strata of mudstone and shales that are rich in organic matter in the Karonga and Usisya groups. It is believed that the anoxic circumstances in which these shales and mudstones were deposited were perfect for the preservation of biological materials. (Ellis and others, 2015)

2.1.4. Thermal maturity

Regardless of how old or immature the organic stuff is, it is still referred to as source rock. The most common methods for estimating thermal maturity are pyrolysis data and vitrinite reflectance measurements. The degree to which the organic content in the rock has changed over time due to heat and pressure is known as the thermal maturity value for natural gas source rock potential (Tissot & Welte, 1984). Catagenesis is the name given to this process of transformation, which produces hydrocarbons, including natural gas. The majority of natural gas is produced in the temperature range of 100°C to 200°C. The process of hydrocarbons thermally cracking is crucial to the thermogenic gas window. (2020, Pashin). According to Pashin (2020), the greatest temperature in North America at which natural gas source rock potential can be found is roughly 150°C. This temperature, with a typical geothermal gradient of 30–40°C, corresponds to a depth of about 4.5–5.0 kilometers. The kerogen in the source rock starts to break and release oil at temperatures higher than 150°C. Eventually, the oil will break and release gas as the

temperature rises. Thus, between 100°C and 150°C is the ideal temperature range for natural gas source rock potential (Pashin, 2020). This temperature ranges allows for the generation of significant amount of natural gas without the destruction of gas through further cracking.

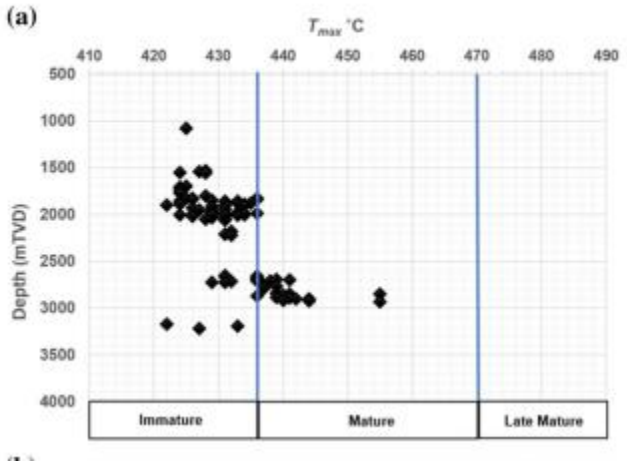


Figure 2: shows cross- plot of rock-Eval Tmax versus depth showing the range in thermal maturity stages of source rock (Agbor et al., 2023).

Figure 2 show cross-plot of rock-eval Tmax versus depth which is used to estimate/assess thermal maturity where Tmax ranging from 410-434°C indicates that the source rock is immature, from 434-470°C indicates that the source rock is mature and from 470->490 indicates that the source rock is late/post mature(Agbor et al., 2023).

2.1.5. Organic carbon matter content in the sediments

Several geological boundary conditions regulate the amount of organic matter that accumulates in sediment (Tissot & Welte,1984). The primary organic material source in marine sediments is marine phytoplankton. All sedimentary processes depend critically on the rate at which sedimentary particles deposit, and as a result, so do the concentration and preservation of organic matter (Tissot & Welte,1984). As the graphic below illustrates, diagenesis, catagenesis, and metagenesis are the three primary phases of organic matter evolution in sediments. Microbial activity is one of the primary agents of transformation in diagenesis, which starts in recently deposited sediments. At shallow levels, chemical rearrangements such as polycondensation and solubilization take place. After diagenesis, kerogen makes up the majority of the organic matter. An increase in temperature that occurs during burial in sedimentary basins is the cause of catagenesis. Most hydrocarbons, or oil and gas, are produced by the thermal decomposition of kerogen. Metagenesis is only attained at very deep depths. But this final stage of organic matter evolution starts earlier (about 2 percent vitrinite reflectance) than the mineral phase metamorphism (about 4 percent vitrinite reflectance, corresponding to the onset of the greenschist facies) (Tissot & Welte, 1984.). The TOC is a measure of the amount of organic matter in a rock sample; it does not account for other organic matter characteristics like oil and gas proneness. For thermally immature source rocks, excellent TOC concentrations are often greater than 4 wt.%(Peters et al., 2016). The TOC analyzer measures the organic richness in the shale and in the parent rock. The percentage of TOC in the shale samples serves as a gauge for the existence of hydrocarbons as follows: Low TOC indicates no hydrocarbon, high TOC indicates some possibility of hydrocarbon, good chance of hydrocarbon is represented by TOC 1-2 percent, and very good chance is represented by TOC >2-5 percent. Thermal maturity causes a decrease in total organic content (Dayal & Varma, 2017). (Mccarthy et al., 2011). Organic matter must be separated in order to calculate TOC as it is present in the majority of sedimentary rock samples. While there are other ways to calculate TOC, the geochemical method—which this study will employ—is the most used.

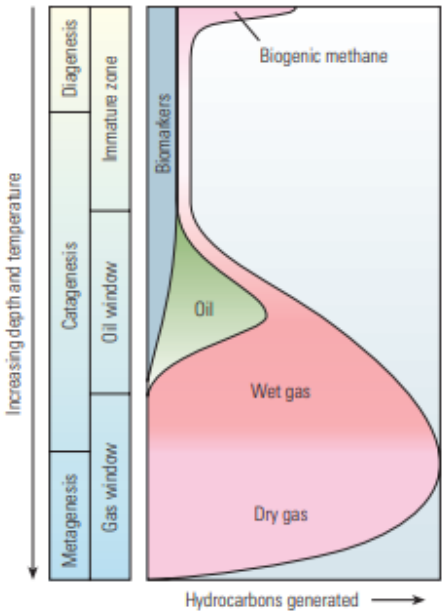


Figure 3: thermal transformation of kerogen(Mccarthy et al., 2011)

2.1.6. The vitrinite reflectance

Scientists and hard workers have talked about the most popular way to determine maturity: vitrinite reflectance (R°). The vitrinite reflectance was deemed by Tissot and Welte (1984) to be the most effective method for determining the maturity of organic matter. The type of source rock and the organic matter's composition determine the maturity value needed to generate natural gas (Pashin, 2020).

Table 2: vitrinite reflectance values describing the thermal maturity

Stages of thermal maturity	**R_0**
Immature	0.2-0.6
Mature	0.6-1.3
Post mature	>1.35

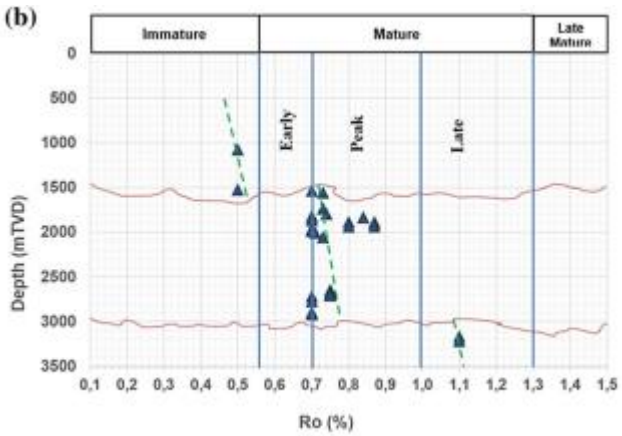


Figure 4: shows cross-plot of R_0 versus depth showing the ranges in thermal maturity stages of source rock (Agbor et al., 2023)

Figure 4 show region of source rock maturity which are immature which means that the source rock has not yet generated hydrocarbons, mature means that the source rock has generated hydrocarbon while post mature means that the source rock has generated all hydrocarbon in the source rock (Agbor et al., 2023).

3. METHODOLOGY

3.1. Introduction

A clean-burning fossil fuel that is playing a bigger role in the world's energy mix is natural gas. Source rocks, which are sedimentary rocks with organic content that has gradually transformed into hydrocarbons, are used to produce natural gas (Tissot & Welte, 1984). The sedimentary Usisya-Mbamba basin in Lake Malawi may include rocks that are prospective sources of natural gas (Ellis et al., 2015). The research design, study map, research dataset, and methods utilized to accomplish the primary goal of the study are all covered in this chapter.

3.1.1. Research design

In order to evaluate the natural gas source rock potential in the Usisya-Mbamba basin of Lake Malawi, this study used quantitative and qualitative data. The amount of organic matter in rock samples, the basin's vitrinite reflectance, and thermal maturity were all estimated using the secondary data. The data was evaluated using scatter plots of the following: R0 vs depth and reference table to evaluate the vitrinite reflectance of the basin; Tmax versus Production Index was computed using PI= S1/(S1+S2) to estimate the thermal maturity.

3.1.2. Data Collection

The geochemical data utilized in this work comes from the vitrinite reflectance and program pyrolysis of the rock samples, which were gathered at the Malawi Geological Survey in Zomba and comprise TOC, S1, S2, S1+S2, TR0(R0), HI, OI, and Tmax °C.

3.1.3. Data analysis

After the data was collected the first step involved determining the averages of TOC, S1, S2, Tmax and S1+S2 and missing parameters such as Production Index was calculated using a formula of PI=S1/(S1+S2) to be used in determining the thermal maturity. After everything, scatter plots were developed using Microsoft excel to highlight the relationships that exist between the datasets which was used to determine organic matter content and thermal maturity.

3.1.4. Study Area

Situated in the northern part of Lake Malawi, the Usisya-Mbamba basin is a sedimentary basin in a modern lakebed deposition context (Ellis et al., 2015). This basin, which is about 30 kilometers wide and 100 kilometers long, is distinguished by a significant buildup of sedimentary rock layers that include limestones, sandstones, and shales (Robertson, 2020). This basin was chosen because it is thought to be situated along the deepest part of the lake, which may provide the perfect conditions for retaining sediments and encouraging the production of source rocks.

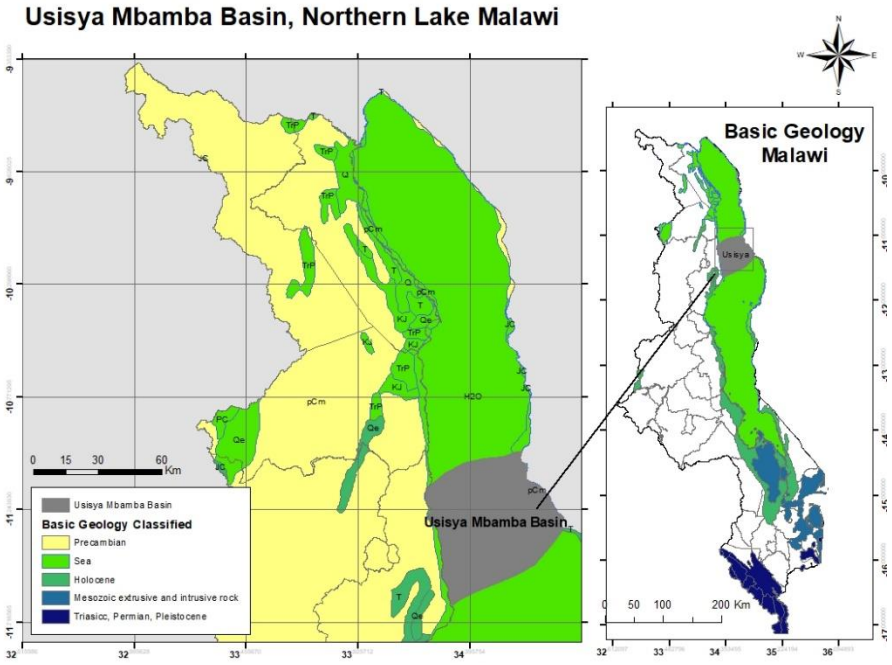


Figure 5: map of the Usisya-Mbamba basin

3.1.5. Geochemical and Vitrinite Reflectance

Two widely used approaches for assessing the source rock potential and thermal maturity of sedimentary basins are the geochemistry and vitrinite reflectance methods. These techniques can yield valuable data for natural gas exploration and evaluation (Tissot & Welte, 1984).

The Rock-Eval pyrolysis characteristics and total organic carbon content (TOC) of rock samples are analyzed as part of the geochemical approach. The total organic carbon (TOC), a measure of the quantity of organic matter in rock, is associated with the hydrocarbons' potential for generating energy. By simulating the thermal breaking of organic matter in a lab, a process known as "Rock-Eval pyrolysis" yields a number of characteristics that reveal the kind, quality, and age of the organic matter. HI (the ratio of S2 to TOC, which reflects the type and quality of the organic matter; lower HI values indicate more gas-prone kerogen), Tmax (the temperature at which S2 is released, which is an indicator of the thermal maturity of the rock), S1 (the amount of free hydrocarbons already generated and expelled from the rock), S2 (the amount of hydrocarbons that can be generated from cracking of kerogen in the rock), and S3 (the amount of carbon dioxide that can generated from cracking of kerogen and bitumen in the rock), and OI are some of the most important parameters(Tissot & Welte, 1984.)(Olatunde, 2016) (Agbor et al., 2023). The key advantage of this method: its ability to analyze samples swiftly and consumption of very small amounts of the sample during analysis.

The reflectance of incident light from vitrinite particles in the rock samples is measured using the vitrinite reflectance method. Vitrinite is a common organic substance found in coal and shale that is generated from woody plant debris. When sedimentary rocks are buried and heated, vitrinite's reflectance rises with temperature and pressure, serving as a trustworthy gauge of the rock's thermal maturity (Ombati et al., 2023)(Hackley P.C., 2021). The most popular method for figuring out maturity is this one. In addition to being a reliable method for determining thermal maturity, vitrinite reflectance testing is also affordable and simple to carry out. The majority of research aimed at determining the shale source rock's capability for petroleum

generation uses vitrinite reflectance as a proxy for thermal maturity. Thermal maturity-profiling of immature, oil-window mature, condensate wet gas mature, and dry-gas mature shales was provided by (Curtis et al., 2012; Hazra et al., 2015; Hackley and Cardott, 2016), with R0 values of less than 0.55 percent, 0.55-1.15 percent, 1.15-1.40 percent, and more than 1.40 percent, respectively. At reflectance values of less than 1.0 percent, gas is released from type III kerogen or as a result of secondary cracking (Hunt, 1996).

3.1.6. Core samples data and Sampling technique

A crucial aspect of the technique employed in this research study is the selection of core samples from a broader group of interest. Because it doesn't favor any certain segment of the group, it employed a technique known as simple random sampling. It used the formula sample size = (total group size* desired samples size)/total number of items in the group to get the number of samples required. The M95-12V8, M95-12V9, M95-13V1, M95-13V2, M95-14V1, M95-16V1, and M95-16V8 samples were chosen.

4. CHAPTER 4 RESULTS AND DISCUSSIONS

In this chapter the samples definition, location and the results obtained from the vitrinite reflectance and Rock-Eval pyrolysis are presented in scatter plots, tables and discussions.

4.1 Samples definitions, Results and Evaluations

Seven rock core samples collected from the Usisya-Mbamba basin using random sampling technique. The geochemical characteristics: Total organic carbon content (TOC) and Vitrinite reflectance (R_0) of samples natural gas source rocks were analyzed.

Table 2: sample location

Samples	Core length(cm)	Water depth(m)	REGION	ENVIRONMENT	LAT(°S)	Long (°E)
M95-12V8	524	660	Usisya-Mbamba Basin	relay ramp channel	10.97	34.2813
M95-12V9	524	660	Usisya-Mbamba Basin	relay ramp channel	10.97	34.2813
M95-13V1	528	660	Usisya-Mbamba Basin	relay ramp channel	10.977	34.308
M95-13V2	528	660	Usisya-Mbamba Basin	relay ramp channel	10.977	34.308
M95-14V1	556	671	Usisya-Mbamba Basin	abyssal plain	10.965	34.4175
M95-16V1	585	677	Usisya-Mbamba Basin	abyssal plain	11.079	34.3457
M95-16V8	585	677	Usisya-Mbamba Basin	abyssal plain	11.079	34.3457

Table 3: shows the names and definitions of the rocks samples that were collected from the study area. It shows the sample name, core length, water depth, region, environment, latitude and longitude and map reference for each sample. The samples were collected from various locations in the Usisya-Mbamba basin, ranging from shallow to deep water environments.

Table 3: Total organic carbon and Rock-Eval pyrolysis data of Usisya-Mbamba Basin

Samples	Water depth(m)	TOC (wt %)	S1(mgHCg^{-1})	S2(mgHCg^{-1})	S1+S2	R_0	HI	OI	Tmax °C	PI
M95-12V8	660	2.48	0.23	1.31	1.54	0.15	53	99	419	0.15
M95-12V9	660	1.6	0.42	3.57	3.99	0.11	223	269	418	0.11
M95-13V1	660	3.51	0.96	15.22	16.18	0.06	433	71	419	0.06
M95-13V2	660	1.68	0.32	3.59	3.91	0.08	213	245	423	0.08
M95-14V1	671	1.68	0.19	0.63	0.82	0.23	37	395	394	0.23
M95-16V1	677	1.78	0.52	2.89	3.41	0.15	160	251	422	0.15
M95-16V8	677	3.24	1.3	11.03	12.33	0.11	340	303	421	0.11
Average	**666.43**	**2.28**	**0.56**	**5.46**	**6.03**	**0.13**	**208.43**	**233.29**	**416.57**	**0.127**

Table 4: presents the results of the Rock-Eval pyrolysis and Vitrinite reflectance analysis of rock samples collected from the Usisya-Mbamba Basin. It shows the sample name, water depth, total organic carbon (TOC), free hydrocarbons (S_1), remaining hydrocarbon potential (S_2), temperature of maximum hydrocarbon generation (T_{max}), hydrogen index (HI), and oxygen index (OI) for each sample. The table also shows the average values of these parameters for all samples. These results indicate that the samples have moderate to high organic matter content and thermal maturity, suggesting a fair to good natural gas source rock potential in the basin.

4.2 Interpretation of the results

4.2.1 Total organic matter

Table 4 shows the average of TOC values for all samples of Usisya-Mbamba basin. According to the examined datasets, the organic matter had an average TOC of **2.28wt%** which indicates a good organic richness and a good source rock (refer to **Table 1**) and is indicative of type III kerogen, which is a poor to fair source rock of natural gas. The minimum TOC value of the area is **1.6wt%** which indicates a fair organic richness and suggests that some of samples in the basin may not even be considered source rocks, while the maximum TOC value of the area is **3.51wt%** which indicates a good organic richness and indicates that there is some potential for natural gas generation in localized areas.

Overall, the TOC values in the Usisya-Mbamba basin are relatively low, suggesting that it is not a particularly favourable basin for natural gas exploration. However, further exploration may be warranted in areas where the TOC values are higher, such as those areas where TOC values are greater than **3wt%**.

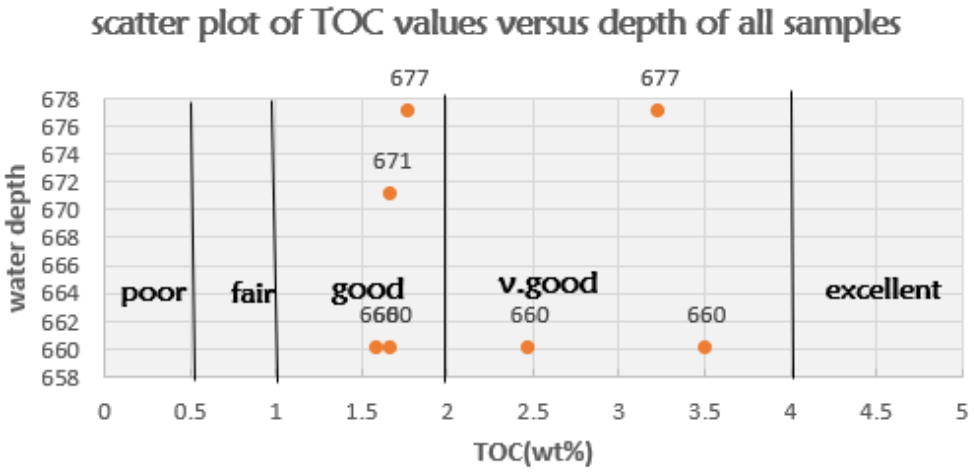


Figure 6: plot showing the TOC versus depth

According to the cross plots, all samples are of fair to good organic-rich source rock with only three samples have very good organic richness (**Table 4**).

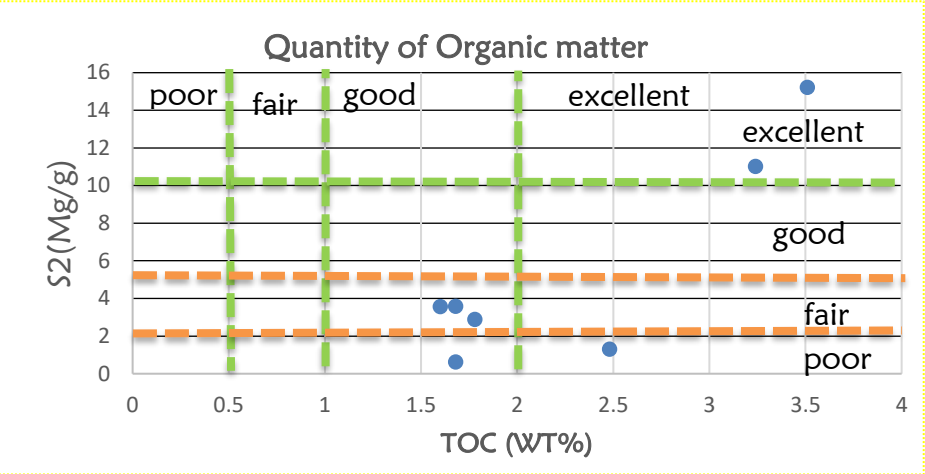


Figure 7: plot showing the quantity of organic matter

Figure 7 shows 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 meet the accepted standard of a source rock with an outstanding level of organic matter quantity and has confirmed by S2, which falls within the fair to excellent region. Therefore, we can say that the source rock has an adequate quantity of organic matter which has been preserved

4.2.2 Thermal maturity

Table 4 show the average of Tmax values for all samples of the basin. The average was **416.57°C** which indicates the source rock is immature which means that the organic matter in the basin has not been heated to high enough temperatures to generate hydrocarbon. The minimum Tmax value is **394°C** which indicates that the source is immature while the maximum Tmax value is **423°C** which indicates an immature source rock (refer to figure 2). The figure 8 below shows the relationship between maximum temperature and production index which supports the fact that the stage of thermal maturity of a source rock lies in the immature stage since all samples are less than 430°C. The overall interpretation of **Table 4** is that the source rock in the Usisya-Mbamba basin is immature. This means that the organic matter in the basin has not been heated to high enough temperatures to generate hydrocarbon.

The average Tmax value of **416.57°C** is below the threshold for hydrocarbon generation, which is typically around **430°C**. The minimum and maximum Tmax values also fall below this threshold. However, the basin is still in development and it is possible that the source rock will mature in future.

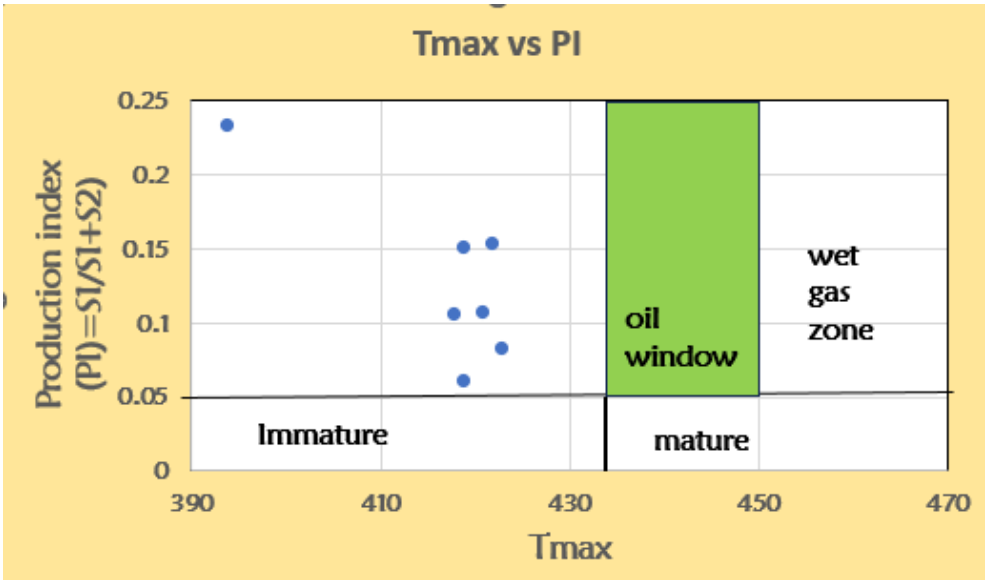


Figure 8: The plot of Tmax versus PI showing the thermal maturity of the source rock

4.2.3 Vitrinite Reflectance

Table 4 shows the average of vitrinite reflectance value for all samples of Usisya-Mbamba basin. The average was 0.13% which indicates that the source rock is immature. The minimum vitrinite reflectance is 0.06% indicates that the source rocks are still very immature and have not yet begun to generate hydrocarbons. The maximum vitrinite reflectance value of 0.23% suggests that some of the source rocks in the basin are approaching the early mature stage. Based on the results the vitrinite reflectance is less than 1.3% which indicates that the source rock is immature (refer figure 9).

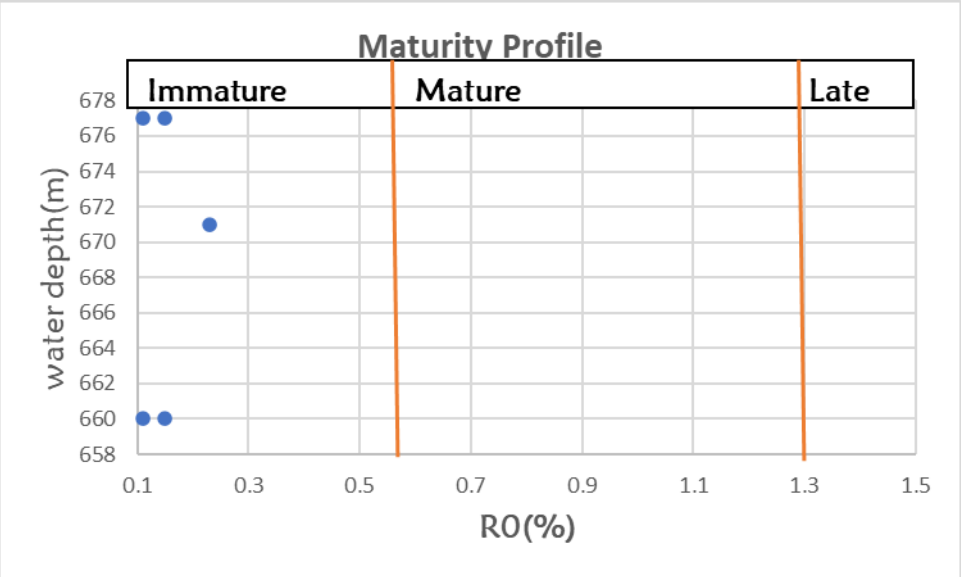


Figure 9: Plot of water depth against R0 showing maturity profile

Figure 9 shows the maturity profile of the source rock where all samples have fallen in the immature region, which means that it has not been subjected to sufficient heat and pressure to generate hydrocarbon based on vitrinite reflectance and the burial rate that has taken place over geologic time has not been sufficient enough to increase the temperature to initiate formation of natural gas in the source rock.

5 CHAPTER 5: CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The thorough evaluation of the Usisya-Mbamba Basin's natural gas source rock potential has produced encouraging information on the area's hydrocarbon potential. Numerous methods were used in the analysis, such as the measurement of vitrinite reflectance, thermal maturity, and organic matter content. The findings suggest that the organic richness of the source rock in the basin is favorable, placing it in the fair to outstanding category. It is important to remember that the source rock is still immature.

These conclusions have a strong foundation thanks to the combination of vitrinite reflectance, rock eval pyrolysis, and geochemical secondary data. Based on the available evidence, it is highly probable that the Usisya-Mbamba Basin might be an important hydrocarbon source rock. However, this evaluation also emphasizes the need for additional research and validation of this possibility.

This work has important ramifications for the development of petroleum reservoirs and the field of hydrocarbon exploration. It highlights how important it is to measure source rock potential in the larger framework of evaluating hydrocarbon resources. It's possible that the Usisya-Mbamba Basin will be important for future energy production, but more research and funding for exploratory efforts are needed to realize the basin's full potential. The knowledge gathered from this research can help develop hydrocarbon deposits in the Usisya-Mbamba Basin and other similar places responsibly and sustainably, promoting economic growth and energy security as the world's need for energy resources grows.

5.2 Recommendations

Based on the findings of this study, I recommend the following actions to further explore and utilize the natural gas potential in the Usisya-Mbamba Basin:

1. Further Exploratory: To validate the existence and size of natural gas deposits in the Usisya-Mbamba Basin, carry out additional exploration activities such as drilling test wells and conducting geological surveys. More specific information regarding the amount and caliber of the gas resources may be obtained through these initiatives.

2. Advanced Research: Invest in cutting-edge research methods and tools to comprehend the geological formations in the basin on a deeper level. This entails using state-of-the-art techniques to assess thermal maturity, organic content, and other pertinent variables. Further investigation can improve on current information and yield more precise evaluations of the natural gas potential of the basin.

3. Environmental Impact Assessment: To comprehend the possible ecological effects of gas exploration in the Usisya-Mbamba Basin, carry out a full environmental impact assessment before beginning any drilling or extraction operations. Put the appropriate procedures in place to guarantee sustainable activities and reduce the impact on the environment.

Ultimately, it is highly advised to carry out an extensive petrophysical data assessment in order to improve the precision and comprehension of the natural gas potential of the Usisya-Mbamba Basin. Data on the characteristics of the rock, as well as the porosity, permeability, and fluid content of the geological formations in the basin, should be systematically gathered and analyzed.

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APPENDICES

Appendix A

Table 4: showing the location and description of samples used in the study.

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Appendix B

Table 5: Total organic carbon and Rock-Eval pyrolysis data of Usisya-Mbamba Basin.

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