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Masters of Engineering in Petroleum Engineering

***Identification of Upper Sandstone Reservoir Rocks, Properties and
Structural Mapping of the Abay Basin For Petroleum Exploration:***

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**Identification of Reservoir Rocks, Properties and Structural Mapping
of the Abay Basin in Viewing of Petroleum Exploration:**

*A project work Submitted to the Center for Ethio-Mines Development-
Addis Ababa Institute of Technology in partial fulfillment of the
requirements for the degree of Masters of Engineering.*

BY

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Abstract

The basins has unique geological characteristics and holds different types of sedimentary rocks, such as sandstones, shales, carbonates, and volcanic rocks.

The Abay (Blue Nile) Basin is located in the northwestern part of the country and covers an area of over 63,000 square kilometers. The Abay Basins covers a sizable area of the country. It includes Were Ilu, Mechale, and Legehida, which have notable oil seep exhibits.

The contribution of the Upper Sandstone reservoir rock data is gathered from prior researchers and written materials in order to develop a relevant relationship between the types of reservoir rocks and structural mapping of the study area.

In order to undertake the experimental tests for this study, samples are gathered from the field and sent to laboratory centers. In the laboratory, the chemical composition, porosity and permeability values of the reservoir rocks are determined using a representative sample that was collected from the study area.

Based on the results of the experiments, the reservoir rock for the Abay (Blue Nile) Basin formation is an Upper Sandstone reservoir rock with relatively good porosity and excellent permeability. The Upper Sandstone rocks in the Abay basin have porosity values that range from 32.31 to 34.35% and permeability values that range from 1766 to 2350 mD, which suggests that the reservoir quality is generally very good (porosity)and excellent (permeability).

During field work, it was discovered that the following fault systems were dominate in the study area. These includes; east-west (E-W) trending faults, northeast-southwest (NE-SW) trending faults, and northwest-southeast (NW-SE) trending faults. The oil and natural gas can be gathered and stored in reservoirs, the geological features called hydrocarbon traps.

The presence of a petroleum system in the Abay Basin is strongly supported by the oil seepage at Were Ilu. The study area is characterized by rough structures, so airborne geophysical surveys are advised rather than ground geophysical surveys; seismic lines are needed for the study of the Abay Basin in order to delineate structural traps, stratigraphic traps, and indicate active faulting in the areas where it is possible for seismic line surveys; the basin requires further study regarding the main hydrocarbon fluids reservoir rocks, the total organic carbon contents of the source rocks and the carbonate reservoir rocks.

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Acronyms

A	Area of the sample
cm	Centimeter
cm ³	Cubic centimeter
cm ²	Centimeter square
°C	Degree centigrade
DAT	Data analyzing technology
E-W	East- West
GSE	Geological Survey of Ethiopia
GPS	Geological positioning system
L	Length of the tube
K	Permeability of the sample
M ²	Meter squares
MER	Main Ethiopian rift
MARS	Main east Africa rift system
Mm	Millimeter
MoM	Minister of Mine
NNE	North north east
NNW	North north west
NW	Northwest
NE	Northeast
Pa	Pascal
P _o	Out let fluid pressure
P _i	The inlet fluid pressure
SE	Southeast
Sw	Southwest
USS ₁	Upper sandstone 1
USS ₂	Upper sandstone 2
USS ₃	Upper sandstone 3
USS ₄	Upper sandstone 4
μ	Dynamic viscosity of fluid
Φ	Porosity
Φ _t	Total Porosity
Φ _e	Effective porosity
Q	Flow rate
ASS	Atomic absorption Spectroscop
ASTM	Standard Test Methods of Apparent Porosity

Chapter One

1. Introduction

1.1 Background of the study area

The basins has unique geological characteristics and holds different types of sedimentary rocks, such as sandstones, shales, carbonates and volcanic rocks.

The Abay (Blue Nile) Basin is located in the northwestern part of the country and covers an area of over 63,000 square kilometers. It is primarily composed of sandstones, shales, and volcanic rocks that were deposited during the Mesozoic and Cenozoic eras. This basin also contains significant hydrocarbon reserves and several exploration companies are actively exploring the area.

Overall, the sedimentary basins of Ethiopia hold significant potential for the exploration and development of oil, gas, geothermal energy and other mineral resources. The government of Ethiopia has been actively promoting the development of these resources to drive economic development in the country (Barnes, 1976) and its hydrocarbon potential.

The source rock in the Abay Basin is predominantly composed of organic-rich shales of the Upper Jurassic-Lower Cretaceous deposits. These shales were deposited in a deep marine environment and have the potential to generate significant amounts of oil and gas. Geochemical analyses of the source rocks have shown that they have good to excellent oil-prone and gas-prone properties.

Besides the source rocks, the Abay Basin also contains several potential reservoir rocks such as sandstones and carbonate rocks of the Mesozoic and Cenozoic deposits. These reservoir rocks have good porosity and permeability properties, making them suitable for hydrocarbon accumulation.

Despite the potential for hydrocarbon exploration in the Abay Basin, they have been few exploration activities conducted in the area, primarily due to geopolitical instability and a lack of investment in the oil and gas sector. However, recent changes in the government's policies have led to increased interest from international oil companies and several exploration blocks have been awarded to companies for exploration activities.

In conclusion, while, the Abay Basin has not been extensively explored for hydrocarbons, preliminary studies suggest that it has significant potential for oil and gas exploration. Further exploration and evaluation activities are needed to confirm the hydrocarbon potential and identify commercial reserves in the basin (Wolela Ahmed, 2008). This study proposes to document some information about the source rocks characteristics which have their own contribution for the formation of hydrocarbon resources in the reservoir rocks to accumulate the oil and gas resources through it and economic potential of the central portion of the Abay sub- basin of Were Ilu area.

The current Upper Sandstone reservoir rocks identification and structural mapping of Abay Basin is proposed by the postgraduate petroleum engineering students sponsored by Ministry of Mine believing to conduct the detail study of the reservoir rocks properties and making the structural mapping of the area in the basin analysis. The program is designed by the Center of Ethio-Mine Development, after the analyses of hydrocarbon exploration methodologies and processes.

Reservoir rocks are porous and permeable rocks where hydrocarbon fluids accumulate and can be economically recovered. Traps are geological structures that prevent hydrocarbons from continuing their migration and hold them within the reservoir rock. These structures can take different forms such as anticlines, faults or stratigraphic traps. Seals are rock formations that form an impermeable barrier above the reservoir rock, preventing hydrocarbons from escaping.

In the context of the Abay Basin, the source rock for potential hydrocarbon reserves is the organic-rich shales of the Upper Jurassic-Lower Cretaceous deposits which have been shown to have good to excellent hydrocarbon-generating potential. The migration path for hydrocarbon fluids in the Abay Basin is thought to be through faults and fractures in the surrounding rocks.

Reservoir rocks in the Abay Basin may include sandstones and carbonate rocks of the Mesozoic and Cenozoic deposits. These rocks have good porosity and permeability properties, making them suitable for hydrocarbon accumulation.

Trap structures in the Abay Basin may include both structural and stratigraphic traps, such as anticlines and fault blocks. The Impermeable rock formations such as shale or evaporites act as seals preventing hydrocarbons from escaping.

In conclusion, the Abay Basin contains all the necessary geological components for the formation of a petroleum system, and preliminary studies indicate the presence of

significant hydrocarbon potential in the area. Further exploration and evaluation activities are needed to confirm the hydrocarbon potential and identify commercial reserves in the basin.

The Upper Sandstone rocks, the Antalo Formation, the Adigrat Sandstone and the Melka Jilo Formation are the most promising reservoir rocks in the Abay Basin. These formations have good porosity and permeability properties and are associated with potential sealing rocks, making them ideal for the formation of hydrocarbon accumulations. Further exploration and evaluation activities are needed to confirm the presence of commercial hydrocarbon reserves in these formations (Wolela Ahmed, 2008).

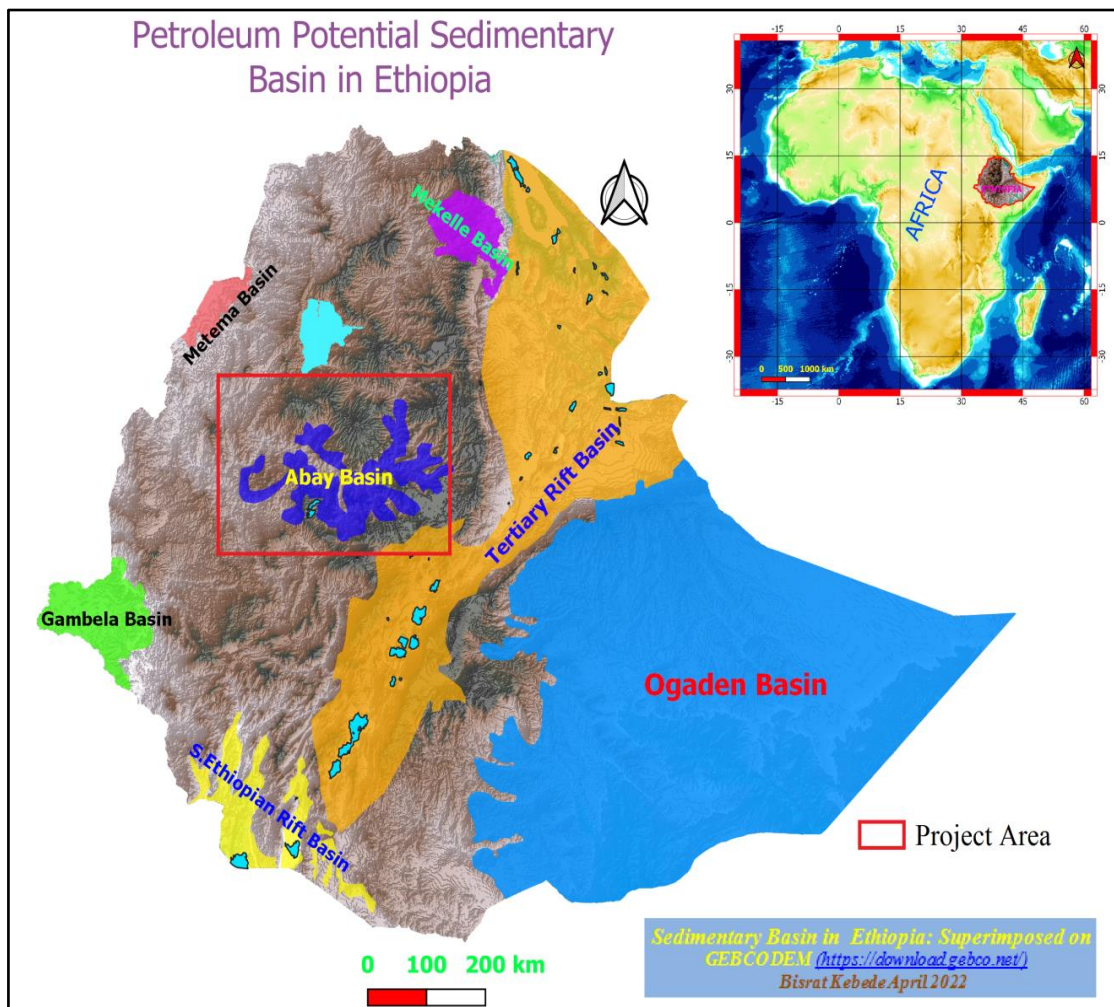


Fig. 1. 1. Prospective Sedimentary Basins of Ethiopia

1.2. Geographic setting of the study area

1.2.1 Location and Accessibility

In addition to the asphalt road, there are also several unpaved roads and tracks that provide access to remote areas within the study area. However, it is important to note that some areas may be difficult to access during the rainy season due to muddy and flooded conditions.

Researchers and exploration companies interested in conducting activities in the study area will need to obtain permits and permissions from the appropriate government agencies, including the Ministry of Mines and Petroleum and the Ethiopian Environmental Protection Authority. These agencies can provide guidance on the necessary steps to take to ensure that exploration activities are conducted in a safe and responsible manner, while minimizing environmental impact.

In addition to hydrocarbons and minerals, the study area also offers opportunities for research in other areas such as geothermal energy and groundwater resources.

The region has several hot springs and geothermal fields, which have the potential to be developed as sources of renewable energy.

The study area is also home to several important cultural and historical sites, including the ancient city of Gonder and the Blue Nile Falls which can provide additional opportunities for educational and tourism activities.

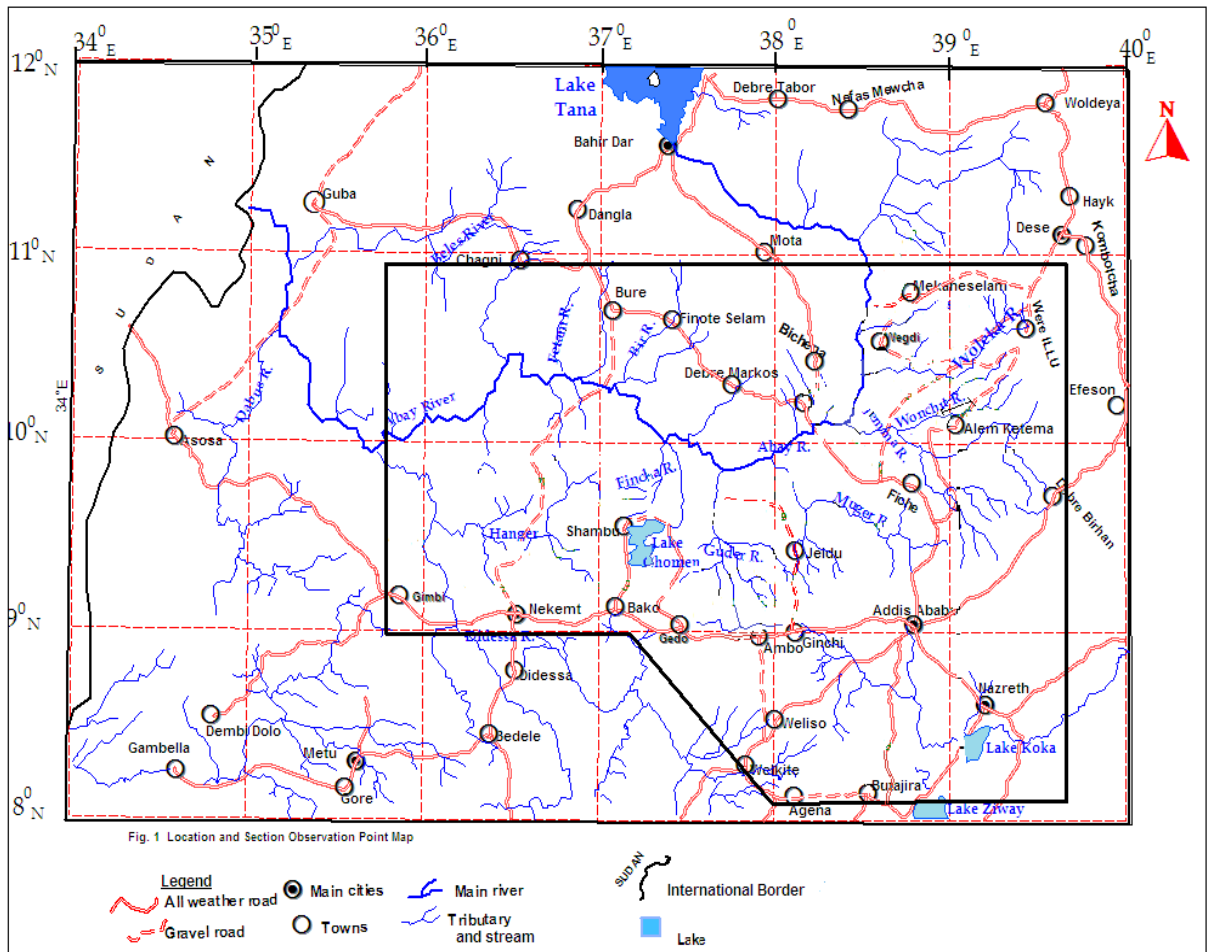


Figure 1.2. Location map of the project area with the network of the roads

1.3. Physiography and climate of the study area

1.3.1 Physiography

The physiographic nature of the proposed area is characterized by lowland and hills formed by sedimentary rocks. The Abay River was also known as the Blue Nile which flows through the western part of the study area. The river originates from Lake Tana in Ethiopia which, is situated at an elevation of approximately 1,800 meters above sea level. The river then flows through various highland and lowland areas before joining the White Nile in Khartoum, Sudan, to form the Nile River.

The total length of the Abay River varies from 1,460 to 1,600 kilometers, depending on different sources of information.

The river has a steep gradient and passes through rugged terrain as it descends from the Ethiopian highlands. It then flows into the lowlands and meanders through the proposed study area.

The Abay River and its tributaries have played a significant role in shaping the landscape and physiography of the region. The river has eroded the underlying sedimentary rocks created deep gorges and valleys. In some areas, the river has deposited sediment, forming alluvial plains.

The presence of the Abay River and its tributaries provides several benefits to the local communities. These including irrigation for agriculture, hydropower generation and transportation.

1.3.2 Climatic Condition

The climatic conditions in the study area are characterized by high temperatures and a semi-arid climate. The mean annual temperature in the area is 19.42 degrees centigrade, with the warmest months being from February to May and the coldest months being July and August. The area experiences two rainy seasons with the first rainy season from late May to late September and the possibility of continuation up to mid-October. The second rainy season occurs from mid-March to mid-April.

According to the Ethiopia Meteorological Authority, the mean annual rainfall in the study area is 732.438 millimeters per year. This relatively low amount of rainfall coupled with high temperatures makes the area prone to drought and water scarcity, particularly during the dry season.

1.4 Geological Setting of the basin

The study area is part of the Abay River basin which, is a semi-arid plateau area located in the remote northwestern part of Ethiopia. The Were Ilu area, where the study area is located, is mostly dominated by reservoir and source rocks. The area is characterized by low-lying hills and plains with the Abay River meandering through it. The rock formations in the area are mainly sedimentary with some volcanic activity in the past. The unique geological and climatic conditions of the area make it an important site for scientific research and exploration, particularly in the fields of geology, hydrology and ecology (Rabben et al., 1979) and (Beicip, 1985).

The Abay Basin has a long history of sedimentation with deposition occurring throughout the Paleozoic, Mesozoic and Cenozoic eras. The stratigraphy of the basin is complex with several rock formations of varying ages present in the region.

The crystalline basement of the basin dates back to the Precambrian era and is made up of ancient igneous and metamorphic rocks. Overlying the basement are Paleozoic sediments which consist of marine shale, sandstone and limestone formations.

During the Mesozoic era, the area was covered by a shallow sea and sedimentation continued with the deposition of the Adigrat sandstone, Gohatsion formation and Antalo limestone. The Gohatsion formation is composed of alternating limestone and shale layers while, the Antalo limestone is a thick formation characterized by well-developed reef structures.

The Upper Sandstone rocks of the basin, which are of particular interest for their source and reservoir potential date back to the Cretaceous era. The Amba Aradom sandstone, a formation within the Upper Sandstone rocks, is characterized by thick, cross-bedded sandstone, and is believed to have been deposited in a deltaic environment.

In addition to sedimentary rocks, the Abay Basin has also experienced volcanic activity and Tertiary volcanism has resulted in the deposition of extensive basaltic lava flows, which cover vast areas of the basin.

The sedimentary history of the Abay Basin is characterized by a combination of marine and terrestrial sedimentation with complex stratigraphy that reflects changes in sea level, tectonic activity and volcanic eruptions over millions of years ([Wolela Ahmed, 2004](#)).

The Ashangi formation is a rock formation within the Abay Basin that is known for its potential as a reservoir rock. In the Yeshum valley at Mekane Selam, the Ashangi formation is particularly thick reaching a sequence of about 550m. The rocks within the formation are highly weathered with minor tuff beds present.

In Were Ilu, the Ashangi formation is of particular importance due to its potential as a reservoir rock. The area surrounding the formation is made up of strongly weathered basalt, which has played a role in shaping the landscape over time.

Overall, the Ashangi formation in the Yeshum valley at Mekane Selam represents a significant sequence of reservoir rocks within the Abay Basin. The formation's thickness and proximity to the strongly weathered basalt in Were Ilu make it an important area of study for geologists and researchers interested in the history of sedimentation and the potential for hydrocarbon exploration in the region ([Tamrat and Tibebe, 1997](#)).

1.5 Statement of the problem

The Were Ilu oil seep is a natural oil spring that is located in the Abay Basin which provides evidence of the presence of hydrocarbons in the region. The seep is located in a low sedimentary basin which is one of the areas of focus for researchers interested in the oil potential of the Abay Basin.

Despite the existence of the Were Ilu oil seep, there has been relatively little research focused specifically on the source rocks and lithological characteristics of the Abay Basin. While these factors are important considerations when evaluating the quality of hydrocarbon deposition and geochemistry in the region, researchers have not yet studied the physical characteristics of the reservoir rocks in relation to hydrocarbon accumulation.

The porosity and permeability of reservoir rocks are key factors in the presence of hydrocarbons but in the study area, there are no corresponding structural maps or well data available to support the evaluation of these characteristics. As a result, further research is needed to better understand these physical characteristics and their relationship to the accumulation of hydrocarbon reserves in the Abay Basin..

The low-lying sedimentary region in the northwestern part of Ethiopia is known as the Abay Basin, where the hydrocarbons like oil and natural gas can gather. However, there is still a lack of quality study on the region's hydrocarbon deposition, geochemistry and physical tests including porosity, permeability and water absorption in comparison to the Ogaden basin.

The goal of this project is to further explore the potential for hydrocarbon exploration in the Abay Basin, specifically in the Were Ilu region. This will involve investigating the characteristics of reservoir rocks in the area with a focus on Upper Sandstone reservoir rocks.

In addition to studying the lithological and physical characteristics of these rocks, the project will also include local structural mapping of the area.

1.6 Hypothesis

The Upper Sandstone reservoir rocks in the Abay Basin are composed of sandstone which is a common reservoir rock type. The porosity of these sandstones ranges from low to high and is generally higher in the more porous layers of the formation.

Permeability is also an important factor in the accumulation and production of hydrocarbons. It refers to the ability of the rock to allow fluids to flow through it. The permeability of the Upper Sandstone rocks in the study area varies depending on the depositional environment and the degree of cementation, which affects the size and connectivity of the pores within the rock.

Saturation and wettability are other properties of reservoir rocks that are important in hydrocarbon exploration. Saturation refers to the proportion of the pore space that is filled with fluids while, wettability refers to the ability of the fluids to adhere to the rock surface. These factors affect the ability of the fluids to flow through the rock and can also impact the recovery of hydrocarbons.

Structural mapping of the study area can provide important information on the distribution and location of hydrocarbon reserves as well as the geological processes that have influenced their formation and accumulation.

Oil seeps are areas where oil and gas have migrated to the surface, can be useful indicators of the presence of hydrocarbons in the subsurface. Structural mapping can help to identify the faults, folds, and other geological features that influence the movement and accumulation of hydrocarbons.

Thus, the analysis of the reservoir rock properties and the structural mapping of the study area, associated with the oil seeps, can provide valuable insights into the potential for hydrocarbon reserves in the Abay Basin. Rocks with high porosity and permeability are considered good reservoir rocks and are more likely to accumulate and produce hydrocarbons in economic quantities.

1.7 Project Objectives

1.7.1 General objectives

The main objective of this project is to identify the Upper Sandstone reservoir rocks in the study area as well as to create a structural map of the area.

1.7.2 Specific Objectives

These are specific objectives for the project. To further elaborate:

- Measuring the porosity and permeability of the Upper Sandstone reservoir rocks
- Determining the physical properties of the Upper Sandstone rocks
- Studying the chemical composition of the Upper Sandstone rocks
- Preparing a structural map for the study area

1.8 Significance of the study

The formation, content, physical test, application and environmental impact of hydrocarbon exploration have not yet been researched in the Abay Basin.

Due to a lack of researchers who could examine it, the economic uses of well-developed reservoir rocks such Upper Sandstone and Limestone are not known in this basin.

The basin play an important role for the formation of oil and natural gas. However, the output of the proposed project may be provide the basic reservoir information about the area.

Few researchers in the Abay Basin have done in-depth research on the lithological features of the basin as well as the characteristics of the source rocks, which is one of the fundamental building blocks for the accumulation of hydrocarbons.

However, there is no information on the Upper Sandstone reservoir rocks, which play a role in the formation of oil seeps.

The project study may have the following contributions and outcomes:

- ✓ Increased knowledge and understanding of the characteristics and properties of Upper Sandstone rocks in the Abay Basin.
- ✓ A better understanding of the chemical composition of Upper Sandstone rocks.
- ✓ Accurate measurements of porosity and permeability values in Upper Sandstone reservoir rocks.
- ✓ The production of a detailed structural map of the study area, which will provide important information on subsurface geological features that can influence hydrocarbon accumulation.
- ✓ The potential for further research and exploration efforts in the Abay Basin

1.9 Scope of Work

Tasks which involve to meet the project objectives are described in the Statement of the project and includes clarification and review of the project plan, initial technology assessment, collection and consolidation of published advanced reservoir rock data. Measurements to be performed on these selected samples comprise:- types of reservoir rocks, the layer of reservoir rocks and construct the structural mapping of the basin as well as the study area in detail. This project is study the contribution of the Upper Sandstone reservoir rocks for the accumulation of the hydrocarbon in the basin and delineate the structural mapping of the study area.

Chapter Two

2. Literature review

The numerous investigations were conducted in the Abay Basin like geological structure, geomorphology and geological set up have been made (Kazmin, 1980; Getaneh Assefa, 1981) and estimation of the source rocks were also made in the basin (Wolela Ahmed, 2008). Some research indicates that the Precambrian crystalline basement, Palaeozoic and Mesozoic sedimentary successions and Tertiary continental flood basalts which are the fundamental components for the presence of hydrocarbons in the basin, characterize the source rocks of central Ethiopia. The several researches were conducted based on their stratigraphic and structural development of the northwest plateau of the Abay Basin (Gani et al., 2007).

According to the scientists, the Mesozoic rift basins of eastern and central Africa are related to the Abay basin (Bosellini, 1989., Bosellini, 1992) due to the Abay basin had similar stratigraphic correlation to that of the Sudan basin, which extends across the northeast-trending Main Ethiopian Rift to join the Ogaden Basin in southeast Ethiopia, and its own contribution to the occurrence of hydrocarbons through it with the help of the reservoir rocks (Bosellini, 1989; Russo et al., 1994).

The physical characteristics of reservoir rocks such as porosity and permeability enable the displacement of oil and gas from the reservoir and the amount of oil recovery is constrained by the extent to which the displacing gas or liquid accumulates (Bosellini, 1989., Bosellini, 1992).

Estimating the potential hydrocarbon concentration in a given petroleum system is a key component of their scientific research, the porosity and the permeability value can be measured both the uses of direct and indirect methods.

The direct techniques of acquiring porosity data involve laboratory measurements on core samples of the relevant reservoir rock while, the indirect methods applied on the relationships between the reservoir rocks (Koesomadinata, 1980).

2.1 The Petroleum Reservoir

A geological formation known as a petroleum trap occurs where petroleum gathers within a layer of sedimentary rock. The layers of rock geometry and characteristics are essential to prevent hydrocarbon fluids from moving freely.

When petroleum migrates into the limestone layer from its source far below the surface and it replaces the water that had previously filled the layer.

Considering that petroleum has a lower density than water which collects near the top of the structure (Amyx, J.W., 1960).

2.2 Significance of Rock Properties

The characteristics of the trap rock and the fluids contains play a major effect in determining the amount of recoverable hydrocarbon in a trap and the rate at which it may be produced.

As a result, certain characteristics set a ceiling on the amount of petroleum that may be collected from the trap and determine its overall volume. The physical factors such as compaction, cementation, dissolution and recrystallization are the basic rock properties that determine the reservoir quality of a trap. These mechanisms are influenced by the detrital composition of the rock, burial depth, burial time, burial temperature, pore fluids and pore fluid pressure (Amyx, J.W., 1960).

2.3 Concept of Physical Properties of Reservoir Rock

Porosity refers to the amount of empty space (pore space) within a rock. It is expressed as a percentage of the total volume of the rock and ranges from 0% (no pore space) to 100% (all empty space). Porosity can be influenced by several factors; including the size, shape and packing arrangement of the grains that make up the rock as well as the presence of natural fractures or other features that provide additional pore space.

Permeability, on the other hand, refers to the ability of a rock to allow fluids to flow through it. It is related to the size and connectivity of the pore spaces within the rock as well as the viscosity of the fluid and the pressure gradient driving the flow. Rocks with high permeability are able to transmit fluids quickly and easily while, those with low permeability may impede flow or require artificial stimulation (such as hydraulic fracturing) to enable production.

Both porosity and permeability are critical factors in determining the commercial viability of a reservoir. A rock with high porosity but low permeability may hold significant amounts of hydrocarbons but if those hydrocarbons cannot be economically produced due to slow flow rates or other obstacles. Similarly, a rock with high permeability but low porosity may allow for rapid production but may not contain enough hydrocarbons to be commercially viable. Successful reservoir exploration and development requires a careful understanding of both of these key characteristics of the rock formation.

Although the effectiveness of reservoir rock depends on a number of significant characteristics, the paper's major subjects may be centered on the rocks porosity and permeability (Douglas, W., 1982).

2.3.1 Porosity

The storage capacity (pore volume) that can hold fluids is determined by a rock's porosity. It can also be described as an evaluation of the fluid-holding capacity of reservoir rocks.

Porosity is a feature that describes a rock ability to serve as a reservoir for fluid store. A petroleum reservoir rock composition might be made of anything from very soft and unconsolidated sand to a very hard and compact Sandstone (Miah, 2014). Analyzing and assessing the performance of a particular reservoir requires an understanding of the physical characteristics of the rock and the interaction that already exists between the hydrocarbon system and formation (Ahmed, T., 2010).

The important rock property is determined mathematically by the following generalized relationship:

$$\Phi = \frac{\text{Pore volume}}{\text{Bulk volume}}$$

Where ; Φ = porosity

2.3.1.1 Porosity Quality ranges

The quality of porosity is generally classified based on its values were as follows:

Porosity range (%)	Porosity quality
0 - 5	Negligible
5 - 10	Poor
10 - 15	Fair
15 - 20	Good
20 - 25	Very good (maximum carbonate reservoir rocks)
10 - 40	Very good (in sandstone reservoir rocks)

Table 2.1. Porosity quality based on porosity range (Miah, 2014)

2.3.1.2 Engineering Classification of Porosity

Porosity can be separated into three groups in terms of engineering classification, such as total, effective and ineffective.

Total porosity (Φ_t) is equal to the ratio of the rocks total pore volume to its bulk volume. The interconnected pore volume is divided by the bulk volume to determine **effective porosity (Φ_e)** and **ineffective porosity (Φ_i)** is calculated as the isolated pore volume of the rocks divided by the bulk volume.

Due to their relative homogeneity, sandstones typically have total porosity values that are equivalent to their effective porosity values.

$$\text{That means: } \Phi_t = \Phi_e$$

where as Φ_t is total porosity and Φ_e is effective porosity

As petroleum engineers we are mainly interested in the effective porosity the formation of hydrocarbons fluids could be only flow through connected pores.

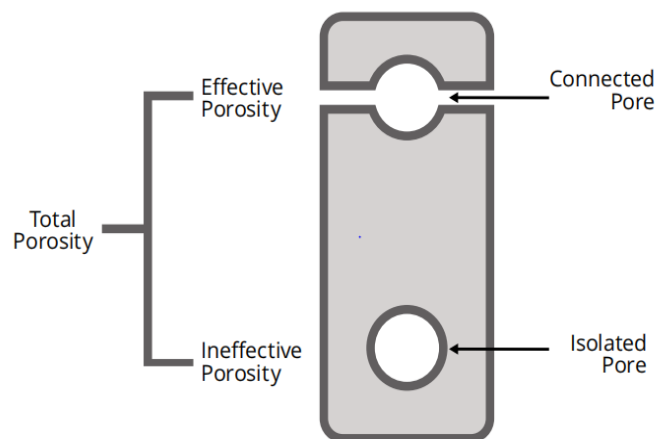


Fig. 2.1. The difference between porosity subdivisions

2.3.2 Permeability

Some reservoirs may have much higher permeability while, others may have much lower permeability.

Darcy's law is an equation that describes the flow of fluids through porous media, such as groundwater through soil or oil through rock. The law relates the flow rate of a fluid through a porous medium to the pressure gradient driving the flow.

The Darcy's law provides a useful tool for predicting the behavior of fluids within a porous medium and can aid in reservoir management and production optimization.

A parameter that describes the flow in porous media is permeability and calculate the production flow rate from the reservoir to the surface using Darcy's law.

This can be achieved by measuring the reservoir's permeability using laboratory tests on core samples taken from the same reservoir rock. Darcy's law can be used to calculate the results of all the parameters connected to the core.

However, it is important to note that permeability values can vary widely depending on the specific reservoir geology and geological setting.

Reservoirs with higher permeabilities (greater than 500 mD) tend to have larger pore spaces and greater connectivity between pores, allowing for more rapid flow rates and higher production potential. However, these reservoirs can also be more susceptible to water influx and aquifer drive which can reduce oil production and recovery.

Reservoirs with lower permeabilities (less than 100 mD) may have smaller, less connected pores and often require specialized recovery techniques such as hydraulic fracturing ("fracking") to create additional flow paths and improve production rates.

It is important to carefully characterize and understand the permeability and other properties of the reservoir rock to optimize production and recovery as well as to minimize the risk of formation damage or premature water breakthrough.

This requires a combination of laboratory measurements and field observations as well as sophisticated modeling and simulation techniques to predict fluid flow and recovery over time.

Darcy's formula can be also expressed as:

$$Q = \frac{KA(P_i - P_o)}{\mu L} \quad \text{and} \quad K = \frac{Q\mu L}{A(P_i - P_o)}$$

Where, Q = the flow rate (cm^3/s or m^3/s), P_o = the outlet fluid pressure (Pa), P_i = the inlet fluid pressure (Pa), μ = the dynamic viscosity of the fluid (Pa.s), L = the length of the tube (cm or m), K = the permeability of the sample (Darcy or m^2) and A = the area of the sample (cm^2 or m^2).

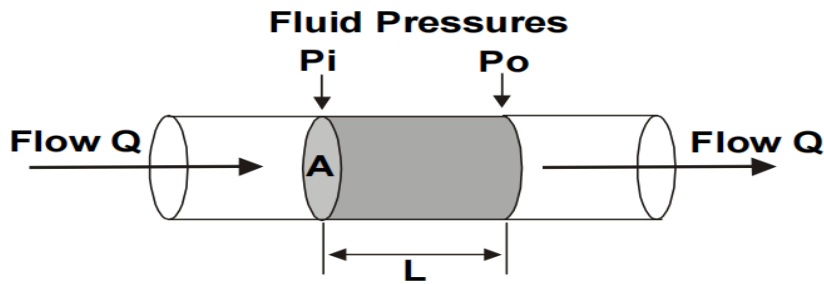


Fig. 2.2. Permeability definition

2.3.2.1 Controls and range of Permeability values in nature

2.3.2.1.1 Controls on Permeability

Porosity and pore connectivity are primary factors determining permeability. Porosity refers to the percentage of total rock volume that is comprised of pore spaces and it is a key indicator of the available space for fluids to flow within the rock. Higher porosity generally indicates a greater amount of interconnected pore spaces which allows for more fluid flow and higher permeability.

In addition to porosity, the size and shape of the rock grains also play a significant role in determining permeability. Smaller grains typically result in smaller pore spaces which can limit fluid flow and reduce permeability. Conversely, larger grains may have larger interconnected spaces that allow for more fluid flow and higher permeability.

The shape of the grains can also affect how closely they pack together and how interconnected their pore spaces are, further influencing permeability. For example, well-rounded grains with smooth surfaces may pack together more closely and have less interconnected pore spaces, whereas, angular or irregular grains may have more open pore space and better connectivity leading to higher permeability.

Other secondary factors such as the presence of natural fractures, faults or other structural features in the rock can also affect permeability by providing additional pathways for fluid flow.

Overall, understanding the relationship between porosity, grain size and shape and other rock properties is essential in evaluating reservoir potential and designing effective recovery strategies.

2.3.2.1.2 The range of Permeability values

The range of the permeability values in an oil reservoirs are generally classified in the following rates (Miah, 2014):

Permeability Value (mD)	Classification
1 - 10	Poor
10 - 100	Fair
100 - 1000	Good
> 1000	Excellent

Table 2.2. Reservoir permeability classification (Miah, 2014)

2.3.3 Significance of Porosity and Permeability on petroleum system

Porosity and permeability play a significant role in determining the potential amount of hydrocarbons that may be present in scientific studies on a certain petroleum system (Ahmed, T., 2010).

The reservoir rocks may still have sufficient porosity and permeability to allow for oil and gas to flow but they are not the primary targets for exploration and production.

Minor reservoir rocks may occur within the same geological formations as the major reservoir rocks or they may occur in separate units above or below them. In some cases, minor reservoir rocks may even act as seals, preventing hydrocarbons from escaping from the major reservoir rocks.

While minor reservoir rocks may not be the primary targets for exploration and production, they can still play an important role in the petroleum system. For example, they may act as reservoirs for associated gas, which can be produced along side oil from the major reservoir rocks. Additionally, the presence of minor reservoir rocks can be an indicator of potential for additional exploration targets in the area (Douglas, W., 1982).

2.3.4 Factors affecting the volume of the reservoir rocks

The following list of factors are an explanation of how reservoir rock volume in hydrocarbon formation is affected:

- **Pattern arrangement and grain size:-** The actual size of the grains has no bearing on the permeability of a reservoir rock or its porosity aside from the arrangement pattern of the grain sizes which impacts the attributes of the rock (Miah, 2014).
- **Shape of the grains:-** Grains with high sphericity tend to pack tightly to provide a minimum amount of pore space which increases angularity and therefore, increases pore space volume.
- **Sorting the grains by size:-** Grain size affects reservoir characteristics. The total amount of empty space tends to be reduced when different grain sized are mixed together.
- **Increased grain compaction:-** results in a reduction in the volume of empty spaces (Ahmed, T., 2010).

Chapter Three

3. Methodology

3.1 Materials, Data and Sampling

3.1.1 Materials

The materials and the equipment that are require to conduct the project works during and after the field works includes; Geographic Position System (GPS), digital camera, stationary materials, sleeping bag, pen, geologic hammer and sample bag etc.

3.1.2 Data

The data on the Upper Sandstone reservoir rock could be gathered from previous researchers and written materials in order to build a relevant relationship between the types of reservoir rocks and structural mapping of the study area. The following is a list of the many data sections found in data analyzing technology (DAT) files:

- 1.** Measurements of porosity and permeability of the reservoir rock
- 2.** Reservoir rock descriptions
- 3.** Physical and chemical properties of reservoir rocks
- 4.** Structural maps of the study area

3.1.3 Sample Collection

The Ministry of Mines (MoM) of Ethiopia was not provided the reservoir rock samples for the basin from Were Ilu area of various locations used in this study. It took a small number of reservoir rocks (Upper Sandstone samples) to collect and analyze the representative units of the research area in the laboratory. The samples were prepared for three different analyses: a large number of samples were used to measure the rocks porosity and permeability while, the remainder were used to assess its chemical composition.

From the many species in the study area, representative samples of the Upper Sandstone reservoir rocks of the Basin were collected. Based on location, samples were taken from the study area and the Geographic Positioning System (GPS) readings are reported in the table below:

No	Samples Code	Reading					
		Easting	Northing	Strike	Dip	Altitude	Depth
1	USS ₁	0547392	1214515	N15E	N65	2044	2
2	USS ₂	0547230	1211261	N10E	50	1860	2
3	USS ₃	0547160	1226551	N5E	60	2150	1
4	USS ₄	0547090	1276725	N50E	N20	1860	1

Table 3.1. The measurement locations of collected samples, measuring of dykes, strike and dip direction of the study area during field work

Chapter Four

4. Results and Discussion

4.1 Results

4.1.1 Field description of the reservoir rocks of the Basin

The Upper Sandstone reservoir rocks in the Abay Basin have the potential to contain significant hydrocarbon resources that could be economically extracted. However, in order to successfully explore and develop these resources, it is necessary to understand their characteristics and properties.

The project work will focus on studying the chemical composition of the Upper Sandstone reservoir rocks; including the presence of organic matter and hydrocarbon-bearing fluids. This will provide important information on the potential for hydrocarbon formation and accumulation.

In addition, the physical properties of the reservoir rocks, including their porosity and permeability values will be measured. Porosity refers to the amount of open space within the rock that can hold fluids such as oil and gas while, permeability refers to the ability of fluids to flow through the rock. These measurements will provide important data on the suitability of the Upper Sandstone reservoir rocks for hydrocarbon exploration and production.

The project work will contribute to a greater understanding of the potential for hydrocarbon resources in the Abay Basin and could help to inform future exploration and development efforts in the region.

4.1.1.1 The Upper Sandstone reservoir

The Upper Sandstone rock in the Abay Basin is considered to be a good type of reservoir rock for hydrocarbon accumulation due to its physical properties. Within the Upper Sandstone formation, there are two types of rocks. These includes; Mugher mudstone and Debre Libanoes sandstone.

The Cretaceous Sandstone rock within the Upper Sandstone formation is characterized by medium to coarse grained and moderately to well sorted sandstones which are associated with thin beds of conglomerates. These sandstones are expected to have good reservoir potential due to their favorable texture which is characterized by packaging of similar sized grains rather than a combination of coarse and fine grained composition.

The performance of the Sandstone as a reservoir rock is described by its combination of porosity and permeability which depends on the degree to which sand dominates the rock. The best Sandstone reservoirs are those that are composed mainly of quartz grains of sand size of nearly equal sizes or silica cement with minimal fragmented particles. This indicates that the Upper Sandstone rock in the Abay Basin has the potential to be an excellent reservoir rock for hydrocarbon accumulation.

The project work focused on studying the chemical composition and physical properties of the Upper Sandstone reservoir rocks will provide valuable insights into the potential for hydrocarbon resources in the region.



Fig. 4.1. The Upper Sandstone, light grey, fine to medium grained sandstone

4.1.1.1.1 Physical properties of Upper Sandstone rocks

The Upper Sandstone reservoir rocks in the Abay Basin are expected to have a moderate to high porosity due to the presence of well-packaged quartz grains and minimal fragmented particles. The porosity can range from 32.31-34.35% or even higher depending on the lithology.

The Upper Sandstone reservoir rocks in the Abay Basin are expected to have moderate to high permeability due to their well-sorted grains and good porosity. The permeability values can range from 1766-2350 mD.

However, it should be noted that these physical properties need to be measured using laboratory tests to obtain accurate values. The project work was conducted such tests in the Geochemical Laboratory of the Geological Survey of Ethiopia and the Ethiopian Construction Design and Supervision Works Corporation.

In addition to their physical properties, the Upper Sandstone reservoir rocks in the Abay Basin are characterized by their lithology which gives rise to unique structures such as caves and mountains. The Upper Sandstone formation in the Northwestern part of Ethiopia is typically light grey in color while, in the study area it is dominated by light white in color. The grain size can range from fine to medium to coarse depending on the location within the formation.

The texture of the Upper Sandstone rocks in the Abay Basin is characterized by the size and shape of the grains as well as the arrangement of the framework grains of detrital components. The texture also includes the presence of non-clastic and fragmental material which can affect the porosity and permeability of the rock.

The grain size of the Upper Sandstone rocks in the Abay Basin can range from fine to coarse with a relatively uniform size distribution. The grains are usually angular to sub-angular in shape and may exhibit some surface features such as pits or grooves.

The arrangement of the framework grains is also an important aspect of the texture of the Upper Sandstone rocks.

In general, the texture of the Upper Sandstone rocks in the Abay Basin plays a critical role in determining the physical and mechanical properties of the rock, including its porosity, permeability and strength.

The Upper Sandstone rocks in the Abay Basin can have a variety of colors depending on the presence of different impurities within the minerals. The most common colors are includes; yellow, reddish, grey, white and light white.

The project work was also consider the color of the Upper Sandstone rocks in the Abay Basin in its analysis and characterization of the rock.

The shape and roundness properties of the Upper Sandstone rock grains are important characteristics for understanding the effectiveness of the rock as a hydrocarbon reservoir. These properties are important because they can affect the porosity and permeability of the rock which in turn can impact the flow of hydrocarbon fluids through it. For example, more angular and irregular grains may have lower porosity and permeability due to the presence of void spaces between grains, whereas, more rounded grains may be able to pack more tightly and have higher porosity and permeability.

Overall, understanding the shape and roundness properties of the Upper Sandstone rocks in the Abay Basin is important for understanding the distribution and behavior of hydrocarbon fluids in the region.



Fig. 4.2. The Coarse Upper Sandstone rock of the basin



Fig. 4.3. The white sandstone reservoir rocks of the Basin

4.1.1.1.2 Samplings

The representative samples of the reservoir rocks are collected and take from selected sites of the study area and want to determine the chemical composition, measure the porosity and permeability values are analyzed in the laboratory.

The representative samples of the Upper Sandstones are collected from the road cutting areas due to the absence of drilling wells in the Abay Basin. The lack of the drilling well data in the Abay Basin has its own effects on the laboratory results and difficult to know the accurate values of the porosity and permeability values of the reservoir rocks.

The four Upper Sandstone rock samples collected from different outcrops in the Abay Basin are considered representative of the entire basin based on three factors:

- **Widely distributed localities:-** The samples were collected from outcrops located in various places around the basin margin which indicating that they are likely to be representative of the different areas within the basin.
- **Paleozoic to Mesozoic strata:-** The rocks from which the samples were collected represent a wide range of geological time periods and covering the Paleozoic to the Mesozoic era. This suggests that the samples are representative of the different geological formations within the basin.
- **Oil seep areas:-** The sampled material covers the oil seep areas, suggesting that it is likely to represent the conditions and properties of the rocks that contain hydrocarbon reserves.

The factors mentioned above support the conclusion that the four Upper Sandstone rock samples collected from different outcrops in the Abay Basin are representative of the entire basin and can be used for further analysis and characterization of the rocks.

Incorporating and integrating the Easting and Northing reading coordination values and other collected data related to the representative samples during fieldwork are important for the construction of a location map of the study area.

The Easting and Northing coordinates are used to locate and map the exact position of the sample collection sites within the study area which helps to identify the spatial distribution of the Upper Sandstone rocks.

The other collected data such as lithology, grain size, mineral composition and porosity are also important for constructing a location map as they provide information on the physical and chemical properties of the rock.

By integrating these data into a location map, it becomes possible to visualize the geological features and characteristics of the study area, including the distribution of the Upper Sandstone rocks and potential hydrocarbon reservoirs.

The combining of the Easting and Northing coordinates and other collected data related to the representative samples is an essential step in constructing a comprehensive location map of the study area.

The project work was utilize these data to create a detailed location map that will aid in the interpretation and analysis of the Upper Sandstone rocks in the Abay Basin.

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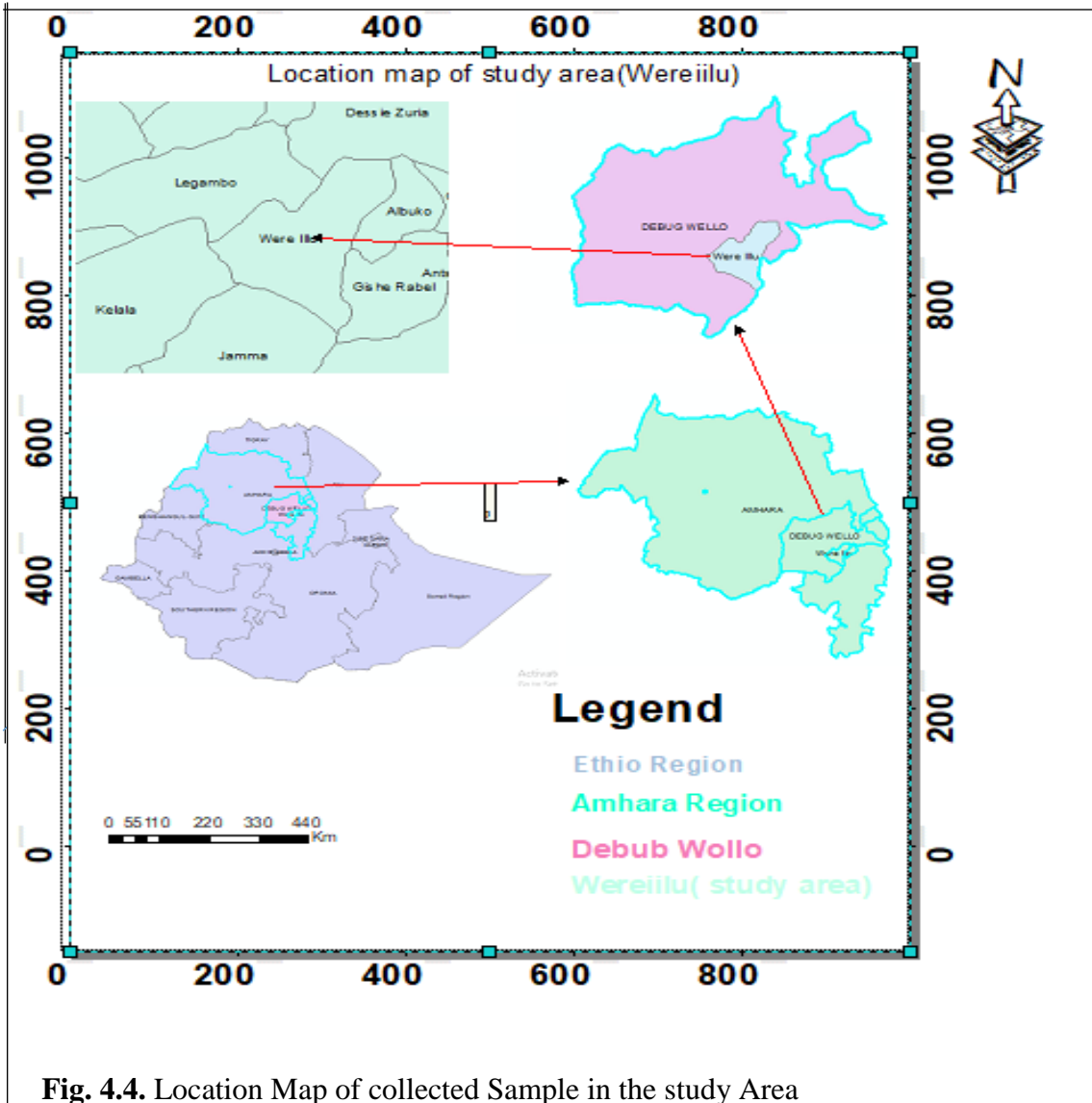


Fig. 4.4. Location Map of collected Sample in the study Area

4.1.1.1.3 Experimental Analysis Methods

The method used to measure the value of the porosity and permeability of the Upper Sandstone reservoir rocks as well as the chemical composition analysis, is essential in characterizing the rocks and understanding their potential as hydrocarbon reservoirs in the Abay Basin.

After collecting the rock samples from the field, they are crushed into fine powder in the laboratory to enable the experimental tests.

The experimental tests are grouped into two main categories. These includes; the determination of the chemical composition of the rocks and the measurement of the porosity and permeability of the Upper Sandstone reservoir rocks in the basin.

The porosity and permeability values vary slightly between the samples but overall they suggest that the Upper Sandstone reservoir rocks in the Abay Basin have good reservoir potential. The chemical composition analysis shows that the rocks are primarily composed of silica (SiO₂) with smaller amounts of aluminum oxide (Al₂O₃) and iron oxide (Fe₂O₃). These results will be considered in conjunction with other data and analysis to evaluate the potential for hydrocarbon production from the Upper Sandstone rocks in the basin.

No.	Description	Sample codes			
		USS ₁	USS ₂	USS ₃	USS ₄
1	Unit weight rock (g/cc)	1.62	1.70	1.65	1.71
2	Specific gravity	1.90	1.89	1.85	1.88
3	Water absorption (%)	20.98	23.02	21.85	22.10
4	Porosity (%)	32.31	34.35	33.25	32.60

Table 4.1. The physical properties of Upper Sandstone reservoir rocks

Figure 4.1. The physical properties of Upper Sandstone reservoir rocks. The figure shows a series of plots for each property (Unit weight, Specific gravity, Water absorption, and Porosity) across the four sample codes (USS1, USS2, USS3, USS4). The plots show the values for each property, with USS1 generally having the highest values and USS4 the lowest. The y-axis for all plots ranges from 0 to 40. The x-axis for all plots is labeled 'Sample codes'.

1	1
2	2
3	3
4	4
5	5
6	6
7	7
8	8
9	9
10	10
11	11
12	12
13	13
14	14
15	15
16	16
17	17
18	18
19	19
20	20
21	21
22	22
23	23
24	24
25	25
26	26
27	27
28	28
29	29
30	30

4.1.1.1.3.1 Chemical composition of the Upper Sandstone rocks

Determining the chemical composition of the reservoir rocks in the Abay Basin is important as it helps to identify the types and proportions of minerals and elements present. This information can provide insight into the origin and evolution of the rocks, as well as their potential as hydrocarbon reservoirs.

To determine the chemical composition of the reservoir rocks, representative samples were collected from the study area and sent to the Geological Survey of Ethiopia (GSE) for laboratory analysis. The GSE uses various techniques such as X-ray fluorescence (XRF) and inductively coupled plasma mass spectrometry (ICP-MS) are important to determine the chemical composition of the samples.

For the determination of the chemical composition of the Upper Sandstone reservoir rocks, the representative samples of the Upper Sandstone rocks were sent to the GSE. From the results, the primary mineral composition of the rocks can be determined, which helps to identify potential porosity and permeability characteristics that can lead to hydrocarbon accumulation.

In general, the chemical composition analysis of the reservoir rocks in the Abay Basin is an important component in evaluating their potential as hydrocarbon reservoirs.

4.1.1.1.3.2 Methods

The laboratory analysis of the chemical composition of rocks can involve a range of analytical methods and techniques. The methods used was depend on the type of rock being studied and the specific elements or minerals of interest.

In the case of the Upper Sandstone reservoir rocks in the Abay Basin, the chemical composition analysis was likely conducted using a combination of analytical techniques. Some commonly used methods for this type of analysis include:

- **X-ray fluorescence (XRF):-** This technique involves analyzing the energy emitted by the sample after being bombarded with X-ray which is commonly used for non-destructive, rapid elemental analysis.

- **Inductively coupled plasma mass spectrometry (ICP-MS):-** ICP-MS is a highly sensitive technique used for trace element analysis. It involves ionizing a sample using an inductively coupled plasma source and then analyzing the resulting ions using mass spectrometry.
- **Lithium borate (LiBO₂) fusion:-** This method involves fusing the sample with lithium borate to create a homogeneous glass bead which can then be analyzed using X-ray fluorescence or ICP-MS.
- **Hydrofluoric acid (HF) attack:-** HF is a strong acid that can be used to dissolve silicate minerals, allowing for the analysis of elements such as silicon, aluminum and iron.
- **Gravimetric analysis:-** This method involves measuring the mass of a precipitate formed by reacting the sample with a known reagent.
- **Colorimetric analysis:-** Colorimetric methods involve measuring the absorbance or reflectance of light by a sample which can provide information about the presence and concentration of certain elements.
- **Atomic absorption spectros (AAS):-** AAS involves measuring the absorption of light by atomic vapor to determine the concentration of a particular element in a sample.

Based on these techniques, the specific procedures used to examine the chemical composition of the Upper Sandstone reservoir rocks in the Abay Basin would likely involve a combination of sample preparation, analytical techniques and data analysis to determine the concentrations and types of elements and minerals present in the rock samples.

Step 1. Field sample collections

Step 2. Laboratory sample preparation

Step 3. Laboratory intervention

Step 4. Laboratory testing

Step 5. Do the calculations

Step 6. Presenting the Results

For the analytical result to be accurate, the aforementioned procedures must be correctly carried out and followed.

The following table provides a summary of the laboratory analysis findings about the chemical composition of representative samples of reservoir rocks from the Upper Sandstone that were collected from the GSE:

No.	Sample Code	Chemical Composition of Upper Sandstone										
		SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	Na ₂ O	K ₂ O	MnO	P ₃ O ₅	TiO ₂	H ₂ O
1	USS ₃	65.40	15.58	4.12	1.52	0.60	1.76	2.20	0.08	0.14	0.21	1.57
2	Weight of Sample	1.3 Kilograms										

Table 4.2. Chemical composition of the upper sandstone rock

The chemical analysis of Upper Sandstone rocks typically reveals varying proportions of major and minor elements, including SiO₂, Al₂O₃, Fe₂O₃, MgO, CaO, Na₂O, MnO, K₂O, P₃O₅, TiO₂, and H₂O.

Based on the average chemical composition we provided, the Upper Sandstone reservoir rocks in the Abay Basin can be classified as arkose sandstone, which is a type of sandstone that contains more than 65% silica (SiO₂). This high silica content is a defining characteristic of arkose sandstone and can have implications for the physical and mechanical properties of the rock such as its porosity and permeability.

4.1.1.1.4 Determination of Porosity and Permeability of the Rocks

Porosity and permeability are important physical properties of reservoir rocks like Upper Sandstone that can influence the amount and flow of fluids (such as oil, gas, or water) that can be produced from them.

Porosity is a measure of the amount of empty space (or pores) within a rock, expressed as a percentage of the total volume. It can be determined by various methods, including core analysis, image analysis, and fluid displacement techniques.

Permeability, on the other hand, is a measure of how easily fluids can flow through a rock determined by the size of the pore spaces and their connectivity. It can also be measured using various methods, including core analysis, fluid flow through porous media and well tests. These properties are essential for understanding the potential

reservoirs as well as developing effective drilling and production strategies in the petroleum industry.

4.1.1.1.4.1 Porosity (Φ) Determination

The porosity of the reservoir rock is the property that tells how porous a rock is and also defined as a measure of the capacity of a reservoir rocks to contain or store fluids. The porosity value of the sandstone reservoir rocks may be between 10 and 40%.

Estimates of the reservoir porosity can be obtained from several sources both direct and indirect methods but in this project the porosity value is calculated by using direct method.

4.1.1.1.4.1.1 Determination Methods

The experiments of this study were aimed to determine the porosity values of the Upper Sandstone reservoir rocks.

1. Sample preparation

Direct methods of determining porosity involve physically measuring the volume of void spaces (or pores) within a rock sample. One common direct method is the fluid saturation technique in which the sample is first weighed and then completely saturated with a fluid (such as water) under controlled conditions. The saturated sample is then re-weighed to determine the amount of fluid that was added which represents the volume of the void spaces. The porosity can then be calculated as the ratio of the volume of void spaces to the total volume of the rock sample.

In this study, the direct method was used to determine the porosity values of the Upper Sandstone reservoir rocks. The rock samples were prepared using unconsolidation with a weight of one (1) kilogram and were saturated with water for 24 hours to ensure complete saturation of the pore spaces. The wet shaping method was used to uniformly distribute the wet content in the dry sandstone and the samples were deposited in layers with increasing density from the bottom to the top of the tool, resulting in more uniform samples and repeatable test results.

The saturated samples were then weighed before and after immersion in water to determine the volume of void spaces and the porosity values were calculated as the ratio of the volume of the void spaces to the total volume of the rock sample. These direct measurements provide an accurate assessment of the porosity values of the Upper

Sandstone reservoir rocks which can inform further analyses and production strategies in the petroleum industry.

2. Direct methods

On the samples of the reservoir rocks collected in the study area, direct measurements are made. These samples are known as representative samples of the basin that are gathered during field study may consist of rock fragments and fractured boulders that are brought from the surface.

The ASTM D7263 (Standard Test Method for Apparent Porosity D7263) which measures the bulk unit weight values of the Upper Sandstone rocks, is the Standard Test Method that is used to measure the physical attributes of the Upper Sandstone reservoir rocks in the laboratory analysis and the fundamental standard test method for determining the water absorption and porosity values of rocks is ASTM C128 (Standard Test Method for Apparent Porosity C128).

This test method is crucial for determining the values of the physical characteristics of Upper Sandstone reservoir rocks, including the rock's unit weight, specific gravity, water absorption and porosity.

The Ethiopian Construction Design and Supervision Works Corporation Laboratory conducted measurements of the porosity of the reservoir rocks using the direct approach in the study. The results are presented in the following tables:

No.	Sample Code	Porosity Value (%)
1	USS ₁	32.31
2	USS ₂	34.35
3	USS ₃	33.25
4	USS ₄	32.60

Table 4.3. The Porosity value of the Upper Sandstone reservoir rock

4.1.1.1.4.2 Permeability (K) Determination

Another direct method for determining the permeability of reservoir rocks is through laboratory tests using a device called a **permeameter**. Unlike indirect methods that

utilize well tests or production data, a permeameter provides a direct measurement of the rock's ability to transmit fluids such as oil, gas or water.

A permeameter typically consists of a core holder that allows a cylindrical rock sample (core) to be placed under controlled pressure conditions. A fluid (such as oil or water) is then allowed to flow through the sample and the flow rate is measured and used to calculate the permeability of the rock.

The permeability test can be performed using core samples collected from a reservoir or by using oil samples obtained through oil extraction processes. This test may take less time to complete and produces reliable results in comparison to indirect methods.

By measuring the permeability of the reservoir rock, the flow characteristics of the fluids through the rock can be estimated and numerical simulation models can be developed to predict the fluid flow behavior in the reservoir. This information is essential in developing effective reservoir production strategies, selecting drilling locations and maximizing hydrocarbon recovery from the reservoir.

Due to a lack of Permeameter in the laboratory, we were unable to measure the permeability of the Upper Sandstone reservoir rocks in the representative samples that were brought from the study area. As a result, we had to estimate the permeability of the reservoir rocks using an indirect method.

1. Indirect Methods

Different empirical equations and values have been proposed for different types of rock formations. However, the accuracy of the permeability estimations based on such empirical correlations largely depends on the validity of the assumptions and the limitations of the correlation being used.

In the absence of permeability data obtained through direct or laboratory methods, the use of empirical correlations can provide quick estimates of permeability for preliminary analysis. However, it is important to note that these estimations should be considered as initial approximations and verified with laboratory measurements and field data to ensure their accuracy for practical applications.

Reference	Correlation
(17)	$K = 19.17 * e^{0.14 * \Phi} \dots\dots\dots (1)$ <p>Where K is Permeability and Φ is Porosity of the reservoir rocks</p>

Table 4.4. Correlation between Porosity and Permeability (Gersson F.B. et al., 2019)

Based on the information provided above, we can estimate the permeability of the Upper Sandstone reservoir rocks and present the results in the table below.

Correlation

No	Sample Codes	$K = 19.17 * e^{0.14 * \Phi}$ (Correlation)	
		Porosity Value (%)	Permeability Value(mD)
1	USS ₁	32.31	1766
2	USS ₂	34.35	2350
3	USS ₃	33.25	2015
4	USS ₄	32.60	1840

Table 4.5. The permeability values of the Upper Sandstone rocks (correlation)

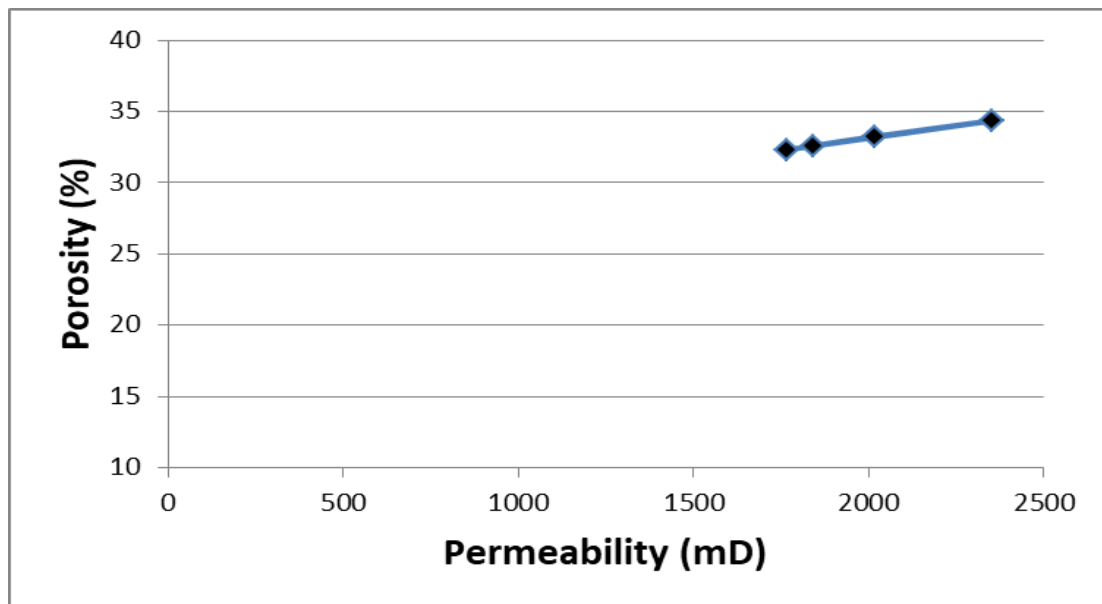


Fig. 4.5. Porosity vs Permeability graph (Correlation)

4.1.2 Structural Faults of the Study Area

The shear displacement of faults can create pathways for hydrocarbons to move from source rocks to reservoir rocks.

When a fault occurs, it can juxtapose rocks with different permeabilities and porosities creating pathways for fluids to migrate and accumulate in reservoirs.

In addition, the deformation caused by faulting can create fractures and other types of permeability enhancing features in the rock. These can improve the flow characteristics of the reservoir and enhance the recovery of hydrocarbons.

However, faults can also have a negative impact on hydrocarbon reservoirs by creating traps that prevent the movement and accumulation of fluids. For example, a fault can create a barrier that seals off a reservoir, trapping hydrocarbons and limiting their recoverability.

Furthermore, faults can also act as conduits for water, leading to the potential for water breakthrough in hydrocarbon reservoirs. This can result in decreased overall recovery of hydrocarbons and reduced productivity of wells.

Therefore, by understanding the role of faults and their effects on reservoir rocks, it is essential for effective hydrocarbon exploration and production in the Abay Basin and other geological systems.

Normal Faults: These are faults where the displacement occurs vertically along the fault plane. Normal faults are associated with extensional tectonic environments where rocks are being pulled apart by tensional stresses.

Reverse Faults: These are faults where the displacement occurs in a vertical direction but in the opposite direction to that of normal faults. Reverse faults are associated with compressional tectonic environments where rocks are being pushed together by compressional stresses.

Strike-slip Faults: These are faults where the displacement occurs horizontally along the fault plane. Strike-slip faults are associated with transpressional tectonic environments where rocks are being pushed together by lateral forces.

The presence of these fault systems in the Abay Basin suggests that the area has been subjected to diverse tectonic regimes. The different types of fault systems exhibit different characteristics and therefore have different implications for hydrocarbon exploration and production.

For example, normal faults can create pathways for hydrocarbons to migrate and accumulate in reservoirs, while reverse faults can create barriers that trap hydrocarbons. Strike-slip faults can also have varying effects on hydrocarbon reservoirs depending on the orientation and magnitude of displacement.

Therefore, it is important to understand the geometry, orientation, and behavior of faults in the Abay Basin to effectively assess their impact on hydrocarbon reservoirs and develop appropriate exploration and production strategies.

4.1.2.1 Northwest-Southeast trending faults

In addition to their impact on the geological history and landscape of the region, the NW-SE trending faults also have important implications for hydrocarbon exploration and production in the Abay Basin. These faults can act as conduits for the migration of hydrocarbons and creating pathways for the fluids to move from source rocks to reservoir rocks. The displacement caused by the faults can also create traps and barriers that can prevent the movement and accumulation of hydrocarbons affecting the overall productivity of wells in the area.

Understanding the geometry, orientation and behavior of these faults is therefore crucial for effective hydrocarbon exploration and production in the Abay Basin.

By taking into account the effects of these faults on the hydrocarbon reservoirs, operators can optimize recovery and maximize the potential of the Abay Basin as a hydrocarbon resource.

4.1.2.2 Northeast-Southwest trending faults

These faults and border fault segments are active and have been responsible for the uplift and formation of mountainous areas in the Ethiopian highlands. They have also created localized zones of extension and compression, leading to the development of graben structures and basins in the region. In addition, these faults have been responsible for the formation of important mineral deposits, including gold, copper, and silver.

The NE-SW trending faults in the region are also important for hydrocarbon exploration and production. They can act as conduits for hydrocarbon migration and accumulation, and their activity can create traps and barriers for hydrocarbon reservoirs. As a result, understanding the behavior and geometry of these faults is critical for effective hydrocarbon exploration and production in the Abay Basin.

In addition, studying their surface expressions can provide valuable information on the timing and nature of their activity. By integrating this information with geological and geophysical data, operators can optimize their exploration and production strategies and maximize the potential of the Abay Basin as a hydrocarbon resource.

4.1.2.3 East-West (E-W) trending faults

In the Mehal Meda town area, the Ambo trending fault intersects another significant geological feature (Blue Nile river). The intersection of the fault and the river has resulted in the formation of the Blue Nile Gorge is one of the largest and most impressive canyons in the world.

The Ambo trending fault and its associated geological features have important implications for hydrocarbon exploration and production in the Abay Basin. The fault acts as a barrier that separates different rock units and can create traps for hydrocarbons to accumulate. In addition, its activity can create pathways for hydrocarbon migration, resulting in the formation of productive reservoirs.

Generally, the complex tectonic environment in the region is characterized by intersecting fault systems has played a significant role in shaping the landscape, geological history, and hydrocarbon potential of the Abay Basin.

4.1.3 Field Structural Mapping of the Study Area

One way that faults can be identified in the field is by looking for observable displacements in rock formations such as abrupt changes in thickness or orientation. Faults can also manifest as areas of discordance between different rock layers known as fault planes, where, one side of the fault has moved relative to the other.

Joints are another type of geological structure that can be observed and recorded in the field. These are fractures in rocks that do not involve significant movement but are important in influencing the behavior of rocks under stress. Joints can be identified by their linear or curvilinear shapes and can be seen as zones of weakness in rock formations.

In addition to mapping and plotting faults and joints, a range of other geological fieldwork techniques can be used to gather information about the subsurface geology and structure of a region.

By combining geological fieldwork observations with data from other sources such as laboratory analyses of rock samples, geologists can build a more complete understanding of the tectonic activity and geological history of a given region.

There may also be other structures and features related to the tectonic activity in the region that are not readily apparent from surface observations alone.

Geological fieldwork such as mapping and surveying, can provide valuable insights into the regional geology and tectonic activity.

By combining these different sources of data, geologists can develop more accurate models of the geological history and tectonic processes in a given region. This information can be used for a wide range of applications, including; hydrocarbon resource exploration .

Moreover, the relationship between the different fault systems can be complex and can play a significant role in the formation of geological structures and the distribution of mineral resources. For example, the interaction between the NE-SW and NW-SE faults can create complex patterns of faulting and fracturing that can influence the trapping and migration of hydrocarbons.

Additionally, the fault system may provide useful information for identifying potential sites for resource exploration, such as hydrocarbons and minerals, which can have significant economic benefits for the region.

No	Samples Code	Reading					
		Easting	Northing	Strike	Dip	Altitude	Depth
1	USS ₁	0547392	1214515	N15E	N65	2044	2
2	USS ₂	0547230	1211261	N10E	50	1860	2
3	USS ₃	0547160	1226551	N5E	60	2150	1
4	USS ₄	0547090	1276725	N50E	N20	1860	1

Table 4.6. The measurement locations of collected samples, measuring of dykes, strike and dip direction of the study area during field work

Moreover, the presence of joint sets in the Upper Sandstone rocks can also impact the hydrogeology of the region. Fractures and joints can act as pathways for groundwater flow and their orientation and spacing can affect the permeability of the rock and the rates of water movement. Therefore, understanding the distribution and characteristics of joint sets in the Upper Sandstone is important for evaluating the hydrocarbon resources and developing effective management strategies.

Fieldwork in the Abay river basin has also revealed the presence of faults in the basaltic rocks. These faults are believed to have formed as a result of tectonic activity and their orientation and displacement can have implications for hydrocarbon resources exploration, hazard mitigation and environmental management.

In conclusion, the study of joint sets and faults in the Abay river basin is a critical component of understanding the geology and hydrogeology of the region.

The joint sets in the Upper Sandstone rocks can play a significant role in the propagation of fractures and faults into the overlying basaltic rocks and they can impact the structural integrity of the rock formations in the area. Therefore, understanding the nature and distribution of these joint sets is an important component of the geological studies in the Abay river basin.

4.1.3.1 Data and Methods

Field studies may also involve collecting rock samples and conducting laboratory analyses in order to better understand the composition, texture and mineralogy of the rocks. This can provide important insights into the geological processes that formed the rocks and the history of the Earth's tectonic activity.

The field studies are a crucial component of geological research, providing valuable information for understanding the history and processes of the Earth's geology. Through careful mapping, sampling and analysis, geologists can develop models that provide insights into the formation and evolution of the Earth's surface as well as identify areas that may be rich in hydrocarbon resources.

In the case of the Blue Nile SE-flowing stretch close to Lake Tana, the field studies have focused on examining the structural and geological information within the quaternary volcanic rocks.

Field investigation and data analysis are essential tools used in geological research to provide detailed structural maps of specific areas. In the case of the Were Ilu area, geological researchers would have conducted fieldwork, including detailed geological mapping, surveys and measurements.

The detailed structural mapping can help identify potential natural resources in the area such as mineral deposits and hydrocarbon reservoirs.

Understanding the geological structures and formations present in the area is essential for identifying areas that are likely to contain these resources and developing strategies for their exploration and extraction.

In general, the fieldwork plays a critical role in geological research, providing valuable data and insights that can support a wide range of applications from resource exploration to hazard mitigation to environmental management.

By creating a comprehensive structural style for the Abay (Blue Nile) Basin, researchers can better understand the geological processes that have shaped the basin over time. This can include identifying the types of rocks, structures and formations present in the basin as well as their relationships and interactions with each other.

Analyzing the structural inclinations of the basin within the regional tectonic framework can provide insights into the broader geological context of the area. This can involve identifying how the basin fits into the larger tectonic framework of the region, including the presence of faults, folds and other geological features that may influence the behavior of the basin over time.

Finally, building a structural map model for the basin can provide a visual representation of the geology of the area, highlighting the major structural features and geological formations present in the basin. This can help researchers and decision-makers better understand the risks and opportunities associated with the area, including the potential for hydrocarbon resource extraction.

The final engineering structural maps that are produced after the post-fieldwork research contain a wealth of information that is useful for a variety of applications. They can also be used to identify potential areas for development such as areas with suitable soil conditions for building or areas with hydrocarbon water resources that could be extracted. In addition, engineering structural maps can be used for hydrocarbon resource exploration and extraction activities. For example, they can be used to identify potential

areas for oil and gas exploration or to plan the construction of dams or other hydroelectric projects.

The scale allows for a detailed representation of the geology and structures present in the study area, while still providing a broad enough view to see the larger patterns and relationships between the different geologic features.

The resulting structural map is a crucial tool for understanding the geological context of the region, identifying potential hazards and opportunities and informing decision-making and planning activities. From identifying potential oil or gas reserves to assessing the risk of landslides or earthquakes and the engineering structural map provides a wealth of information that is essential for a wide range of applications in engineering, geology and resource management.

The following processes are used to generate the structural map of the study area:

Step 1. Take the (x,y) coordinate reading of the area by using GPS

Step 2. Measure the strike and the dip direction and obtain the values of the structures

Step 3. Measure the joint space values of the structures

Step 4. Insert all the known and collected values into the system and analysis by using **ArcGIS version 10** application

Step 5. Label the structures such as faults, lineaments, lakes, towns, dykes and water bodies by different color in the system

Step 6. Finally by using the ArcGIS system we can prepare the structural map at a scale of 1:50,000.

For analysis and the creation of the map layout, the Geographic Information System (ArcGIS® version 10) of the ESRI was used.

The areas of engineering structural map is created by ArcGIS 10 ® which is used to create the maps at a scale of 1:50,000.

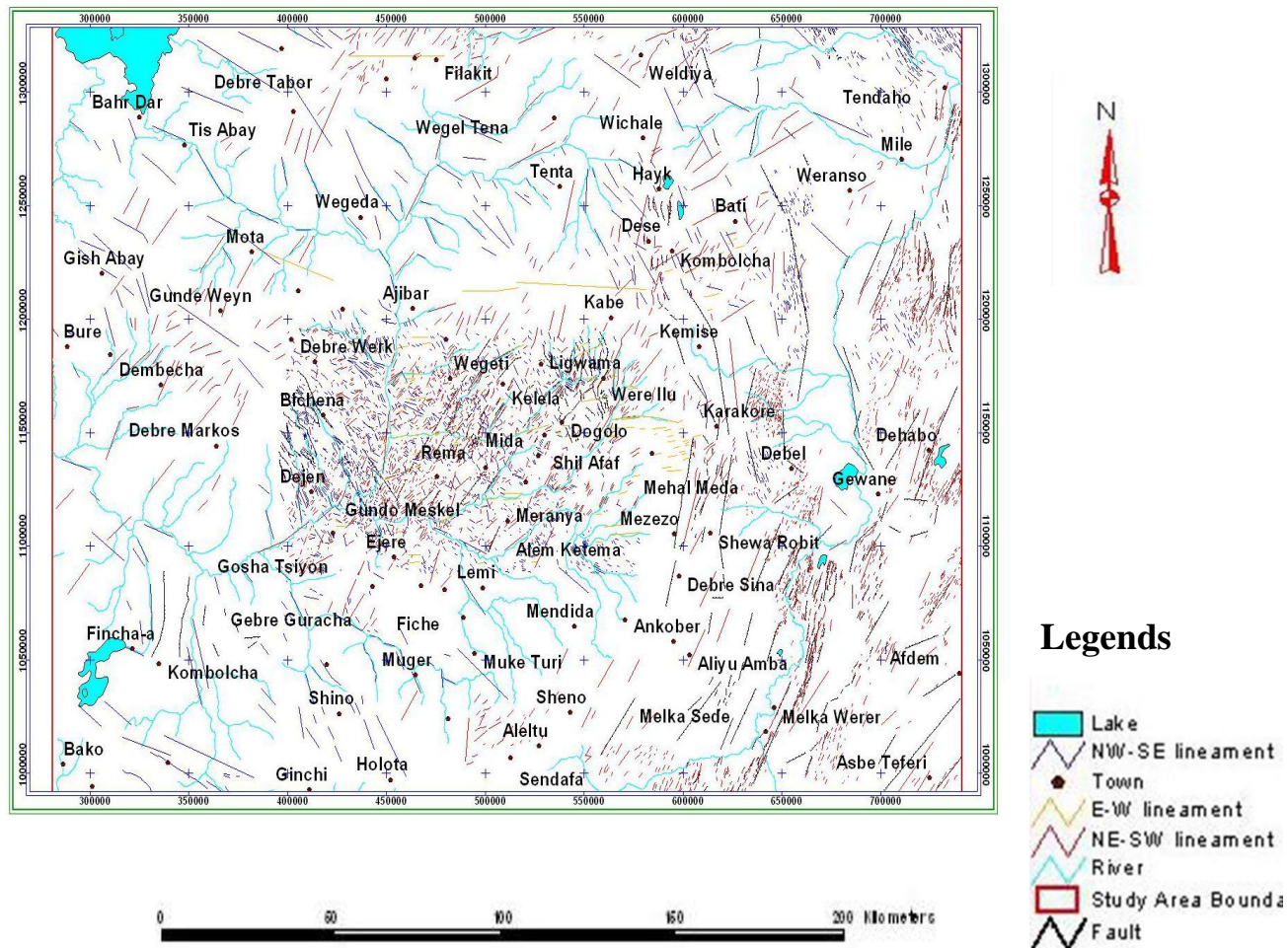


Table 4.6. Structural Map of the study Area

4.1.4 Possible trapping Mechanism in the basin

The structural characteristics of an anticline can be important in identifying potential oil and gas reserves. Anticlines are formed by the folding of rock layers, resulting in a dome-shaped structure with the oldest rocks at the center. Hydrocarbons trapped within the porous and permeable rocks of the reservoir can accumulate at the crest of the anticline allowing for the potential for economic extraction.

However, it should be noted that not all anticlines are suitable for hydrocarbon accumulation, and other geological factors must be considered as well such as the presence of source rocks and migration pathways.

The concept of traps and the identification of favorable geological structures such as anticlines are important tools in the exploration and development of oil and gas reserves. By understanding the geological context of an area and the potential for hydrocarbon

accumulation, explorers can focus their efforts on promising targets and ultimately leading to successful resource development and economic benefits.

Hydrocarbon traps are geological structures that allow for the accumulation and retention of hydrocarbons, such as oil and natural gas in the reservoirs. These traps are created when permeable reservoir rocks such as sandstones or carbonates are covered by less permeable rocks known as **cap rocks**. The cap rocks act as barriers to preventing the hydrocarbons from escaping and allowing them to accumulate in the reservoirs.

There are various types of traps that can be categorized based on their geological characteristics. Structure-based traps such as anticlines and fault traps are formed by tectonic forces that deform the rock layers and create structural traps for hydrocarbons. Anticlines, as mentioned earlier are upward folding structures that can form trapping structures for hydrocarbons.

Fault traps, on the other hand, are formed when faults create impermeable barriers or channels that allow for the accumulation of hydrocarbons.

Stratigraphic traps, on the other hand, are formed by variations in the rock layers themselves. In these traps, the hydrocarbons are trapped by changes in the rock properties such as porosity, permeability or lithology. These changes can create barriers or reservoirs that are conducive to the accumulation and retention of hydrocarbons.

While, the presence of hydrocarbons is crucial for economic development focus on the exploration efforts which is often identifying and locating these traps that have the potential to contain hydrocarbons. By studying the geology and understanding the various types of traps and explorers can target areas with a higher likelihood of finding economic hydrocarbon reservoirs.

In the Abay Basin, the Jurassic source rocks have the potential to supply hydrocarbons to reservoirs that are trapped by a mix of stratigraphic and structural traps.

Nevertheless, understanding the geological context of the area and potential trap types can still provide valuable information for exploration efforts and the identification of promising targets for future development.

4.1.5 The Petroleum Potential of the Abay (Blue Nile) Basin

The Upper Sandstone rocks in the Abay Basin appear to have ideal reservoir qualities for the accumulation of hydrocarbons. The basaltic flows intercalated with late Cretaceous strata may also serve as an excellent reservoir. The formation of numerous structural

traps, including fault blocks, horsts, and grabens, may offer potential locations for the accumulation of hydrocarbons. However, detailed geophysical data such as seismic surveys, would be necessary to properly identify and map these traps and determine their potential for economic resource development.

Regarding to the indicators of oil seeps in the Abay Basin, the areas of Were Ilu, Mechale, Legehida, and Denge Ber all show signs of oil seeps. Were Ilu has been specifically selected as the area of focus for this project work. It is important to study these oil seeps as they can be a valuable tool in hydrocarbon exploration, helping to indicate the presence of potential reservoirs and suggesting areas for further investigation. However, exploring the economic viability of these oil seeps will require further investigation.

4.1.5.1 Were Ilu Oil Seep Site

The presence of a petroleum system in the Abay Basin is strongly supported by the oil seepage at Were Ilu. Due to the lack of drilled wells throughout the basin and the availability of rock samples from the research region, the location of the Were Ilu oil seep site is identified using Ministry of Mine (MoM) documented data and pseudo well sites.

Were Ilu Oil Seep Site is the location to demonstrate the existence of a petroleum system in the Abay Basin within the Ethiopian Plateau due to the above reservoir rocks.

The Were Ilu area, which contains Mount Amba Ferit.

A portion of the petroleum that is escaping from the subsurface and leaking on areas of deep fractures is represented by the oil seeps. Therefore, the existence of an oil seep provides indirect information about deeper subsurface hydrocarbon deposits that may drive exploration efforts in the basin. The basin can also be evaluated, and a thorough explanation of where these oil seeps originate will be obtained.

The development of the Upper Sandstone reservoir rocks demonstrates the presence of hydrocarbon seeps in the basin. However, because to technological limitations, study was first limited to identifying the fundamental geochemical properties of the oil seeps in the basin.

In order to better understand the formation and provide information for the development of the oil and gas in the basin, this study presents geochemical data from four reservoir rock samples collected from four separate outcrop locations inside the Abay Basin.



Fig. 4.7. Were Ilu oil seep site of the Abay Basin

The geochemical data offer crucial information on the origins of the seeps, the geochemical properties of the reservoir rocks and the chemical make up of rocks that could be used as a guide for upcoming studies and sophisticated exploration for finding hydrocarbons in the Were Ilu region.

4.1.5.1.1 Pseudo Well in Were Ilu Area

Since no wells have been drilled in the Abay Basin, we chose to simulate the situation using fictitious wells. It is challenging to assume the input parameters because the Abay Basin lacks well data.

We need to know the age, thickness, lithology of the sediments, subsurface temperature were carry out a trustworthy maturity calibration and make a realistic approximation regarding hydrocarbon formation.

Unfortunately, the Abay Basin lacks any wells that have been drilled, which is how these data are often gathered. Furthermore, we were unable to locate any trustworthy data on heat transport or subsurface temperature.

In conclusion, the simulation's creation of oil and gas was altered or made easier by the existence of very thick basalts which also increased the burial depth and geothermal temperature.

As a result of the capacity of geological data on the Abay Basin, further research on its geology is required in order to evaluate the basin and conduct petroleum exploration.

4.1.5.2 Depth, temperature and thermal history of the area

The geothermal temperature, which is an integration of geothermal temperature throughout geological history, was calculated from the heat flow and thermal conductivity, according to a study by the Ethiopian Ministry of Mine.

Were Ilu oil seep site's geothermal gradient is 3.10C/100m and 3.20C/100m, respectively, despite variances in the thermal history examined by Ethiopia's Ministry of Mine and Geological Survey.

The depth of the basin is extremely shallow throughout the Gohatsion and Antalo formations, deep to 200 meters at the Antalo source rock and then shallows again during the Mugher and Debre-Libanos formations. The elevating starts at zero deposition before to the trap series and continues today, with a current altitude of 3500m.

Up until the intertrappen shale deposition, the speed of the uplifting was modest, After the intertrappen sandstone deposition, the speed increased till the present 3.20C/100m, correspondingly.

4.1.6 Petroleum Exploration of Abay Basin

Oil exploration in rift basins is getting more and more alluring. This is due to the fact that they may be found on all passive continental edges, where there are rich geological records, making it simple to reconstruct past history and where many significant petroleum discoveries have been found to be connected to rift basins. As a result, the Abay basin has a significant potential for petroleum resources because it is a separate rift basin.

The basins was impacted by a northwest-southeast trending rift in terms of tectonic activity. The extension of this structure into the Abay Basin has been validated by the project's noble intentions.

The Ministry of Mine reports that the later superimposition of a northeast-southwest trending rift for the accumulation of Jurassic marine sediments has increased interest in petroleum exploration.

As a result, the northeastern portion of the basin has the highest potential area. The Abay Basin's oil seeps could typically be found atop buildings for accumulating petroleum on

land. The hydrocarbon fluids may leak from an outcrop of oil-bearing rock, along geological layers and across them through rock fissures (fig. 13 and fig. 14).



Fig. 4.8. Oil seep reference area of the Abay Basin (take from Were Ilu area)



Fig. 4.9. Oil seep reference area of the Abay Basin (take from Mechala area)

At various stratigraphic layers, there are organic-rich sediments and good reservoir rocks which are linked to numerous unconformity surfaces and repetitive faulting with the northeast ward thickness increment of the marine deposits.

This increases the importance of this location for the exploration of hydrocarbons. An oil seep is a location on the surface of the earth where naturally occurring liquid hydrocarbons can escape under conditions of low pressure or flow.

4.2 Discussion

The Abay Basin's potential reservoir is the Upper Cretaceous Amba Aradam deposit (Upper Sandstone). Depending on how much sand predominates, the combination of porosity and permeability in sandstone describes how well it performs as a reservoir rock.

When compared to the Adigrat sandstone rocks, the Upper Sandstone reservoir rocks in the region are generally covered in a large area. The physical characteristics of the Upper Sandstone rocks are described as texture, color, grain size, form and roundness. In general, the Upper Sandstone rock that is found in the study area is usually characterized by light white in color, fine grains and medium to coarse grains.

The chemical analysis of Upper Sandstone rocks typically reveals varying proportions of major and minor elements, including SiO_2 , Al_2O_3 , Fe_2O_3 , MgO , CaO , Na_2O , MnO , K_2O , P_3O_5 , TiO_2 , and H_2O .

The Upper Sandstone reservoir rocks of the Abay (Blue Nile) Basin formation exhibit exceptional permeability and moderately good porosity, according to experimental results.

According to the results of the laboratory analysis, the Upper Sandstone reservoir rocks in the Abay basin have porosity values that range from 32.31 to 34.35% (Table 4.3), suggesting that they may be a good reservoir for the buildup of hydrocarbons.

The permeability of the Upper Sandstone reservoir rock values are similarly discovered in the range of 1766 and 2350mD, and the reservoir rocks have practically good porosity values (Table 4.5). This outcome suggests that the permeability values are rather excellent for the reservoir quality.

The computed values of the permeability of the Upper Sandstone reservoir rocks of the Abay Basin are shown in figure 4.5 by taking into account the results of the laboratory tests for porosity acquired from the experimental laboratory center.

The Upper Sandstone rocks, which have average values of 33.13% porosity and 1993mD permeability, are generally good reservoir rocks for the accumulation of hydrocarbons in the basin.

In many locations around the Abay Basin, there are signs that oil leaks are present. Were Ilu, Mechale, Legehida, and Dengle Ber are some of these regions.

The Abay Basin's oil seeps could typically be found atop buildings for accumulating petroleum on land. The hydrocarbon fluids could leak through geological layers and the area is more important for hydrocarbon exploration across them through rock fractures or directly from an outcrop of oil-bearing rock because it has good reservoir rocks and organic rich sediments at various stratigraphic levels, connected with multiple unconformity surfaces and repeated faulting with northeast ward thickness increment of the marine sediments.

4.3 Limitations

To identify the reservoir rocks and map the research area's structural makeup, there is a significant knowledge gap at this time. Around 520 kilometers separate the study region from Addis Ababa and 120 kilometers separate it from Dessie which is a town of South Wollo zone.

The political issue, the basin's structural layout, the lack of drilled wells, the existence of resources related to the basin that have been documented and other difficulties that I encountered while on the field made it difficult for me to complete my job in the basin.

Generally speaking, the following factors were constraints for my responsibilities when I prepared this project work:

- The accuracy levels of the results may be limited by the absence of a laboratory measurement of the total organic carbon content and the permeability of the reservoir rocks based on correlation for the measure isotherm parameters.
- The production-performance of Upper Sandstone reservoirs is recognized to be influenced by the geochemical impacts on the porosity and permeability.
- The structural features of the basin cannot be precisely expressed because to a lack of seismic and other geophysical data.
- There hasn't been any geochemical analysis done on the oil leaks from the Were Ilu and Dengel Ber graben in the northeastern half of the basin to determine whether there are mature oil source rocks there.
- It is challenging to acquire core samples during field observation in the Abay Basin since no wells have been drilled there and there is no well data.

Chapter Five

5. Conclusions and Recommendations

5.1 Conclusions

The basins has unique geological characteristics and holds different types of sedimentary rocks, such as sandstones, shales, carbonates and volcanic rocks.

This study focuses on the briefly exposed sub-basin of the deep section of the Were Ilu oil seep reservoir rocks in northwest Ethiopia.

The sedimentary basins of Ethiopia hold significant potential for the exploration and development of oil, gas, geothermal energy and other mineral resources

The goal of this research is to provide an understanding of the Upper Sandstone reservoir rocks and the structural mapping of the study region for the role that petroleum resources creation had in the formation of the Abay Basin's geology.

As for the absence of research on the reservoir rocks in the Abay Basin, this lack of information may pose a challenge for hydrocarbon exploration in the area. Understanding the physical and chemical features of the reservoir rocks is crucial for determining their potential for hydrocarbon accumulation, evaluating their economic value and designing appropriate development plans.

The Upper Sandstone reservoir rocks have the potential to be a good reservoir in the Abay Basin for the accumulation of petroleum resources. Additionally, the Upper Sandstone reservoir rocks have a high degree of permeability, indicating that they have good to excellent permeability and can easily transmit liquids.

During fieldwork, it was discovered that the following fault systems dominate the study area: faults with a northwest-southeast trend, faults with a northeast-southwest trend, and faults with an east-west (E-W) trend.

Hydrocarbons such as oil and natural gas, can gather and be stored in reservoirs thanks to geological features known as hydrocarbon traps. The presence of a petroleum system in the Abay Basin is strongly supported by the oil seepage at Were Ilu.

The Upper Sandstone rocks, which have average values of 33.13% porosity and 1993mD permeability are ideal reservoir rocks for the accumulation of hydrocarbons in the basin.

The Abay Basin is more crucial for hydrocarbon development since it crosses them via rock cracks or straight from an outcrop of rock that contains oil.

5.2 Recommendation

In the northeastern portion of the research region, the Abay Basin is thought to feature an excellent reservoir rock.

Finally, the following recommendations are suggested:

- Regarding the choice of geophysical survey methods, airborne surveys may indeed be a viable option for the Abay Basin, given its rugged terrain and rough buildings.
- Seismic lines are needed for the study of the Abay Basin in order to delineate structural traps, stratigraphic traps and indicate active faulting in the areas where it is possible for seismic line surveys.
- The basin has the existence of oil seeps which is potentially economic value hydrocarbon resources like the Ogaden Basin, so it also needs detailed studies about its hydrocarbon fluids accumulation elements.
- Based on the laboratory analysis results the basin has relatively good porosity and permeability values which may contains good reservoir rocks for the formation of petroleum resources.

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