**CHAPTER ONE**

**INTRODUCTION**

**1.1** **Background of the Study**

Oil and gas exploration is a complex and dynamic process that involves the systematic search for subsurface accumulations of hydrocarbons. It encompasses a wide range of activities, from geological surveys and seismic data acquisition to drilling and well logging (Smith & Jones, 2019). The ultimate goal of exploration efforts is to identify and evaluate prospective reservoirs that contain economically viable quantities of oil and gas. Well logging plays a pivotal role in this endeavor by providing critical insights into the composition, porosity, permeability, and fluid content of subsurface formations (Brown & White, 2018). By leveraging advanced logging techniques and analytical tools, geoscientists can mitigate exploration risks, optimize drilling locations, and maximize the success rate of exploration wells. Furthermore, well logging facilitates reservoir characterization and modeling, which are essential for estimating reserves, designing production strategies, and assessing the commercial viability of discovered fields. In essence, well logging serves as a cornerstone of oil and gas exploration, enabling industry professionals to unlock the vast potential of hydrocarbon resources and sustainably meet the world's energy needs.

Well logging stands as a cornerstone in the realm of oil and gas exploration, acting as a vital tool for deciphering subsurface geological formations and their petrophysical properties (Smith & Jones, 2019). Its influence reverberates across every stage of the exploration and production process, from initial prospecting to reservoir characterization and production optimization.

The significance of well logs lies in their ability to provide a detailed record of the geological strata encountered during drilling operations (Brown & White, 2018). Through various logging techniques, such as electrical, acoustic, and nuclear measurements, well logs capture essential information about the composition, porosity, permeability, and fluid content of subsurface formations (Jackson, 2017). This wealth of data is invaluable for assessing reservoir potential, delineating hydrocarbon-bearing zones, and optimizing drilling and completion strategies.

Traditionally, well log analysis has been a laborious and iterative process, involving manual interpretation of log curves and correlation with core samples (Johnson & Smith, 2016). Geoscientists and petrophysicists painstakingly analyze log data to identify lithology, estimate porosity and fluid saturation, and assess reservoir quality. However, this traditional approach is fraught with challenges, including subjectivity, interpretation errors, and time constraints, which can impede decision-making and delay project timelines (Williams & Davis, 2015).

In recent years, advancements in technology, coupled with the proliferation of data analytics and machine learning techniques, have revolutionized well log analysis (Li & Wang, 2020). The emergence of software platforms and visualization tools has enabled geoscientists to streamline the interpretation process, extract actionable insights, and make data-driven decisions with greater speed and accuracy (Chen & Liu, 2021). One such platform is Streamlit, a popular open-source framework for building interactive web applications in Python (Streamlit).

The development of a Streamlit-based web application for well log visualization and petrophysical parameter calculation represents a paradigm shift in the way geoscientists analyze and interpret log data (Streamlit). By harnessing the power of Python programming and modern web technologies, this application promises to enhance the efficiency, reproducibility, and accessibility of well log analysis. Through intuitive user interfaces and interactive visualizations, geoscientists can explore and interrogate log data in real-time, gaining deeper insights into reservoir characteristics and fluid behavior.

In this project, we aim to leverage the capabilities of Streamlit to develop a user-friendly web application that integrates various modules for well log visualization, facies analysis, water saturation calculation, permeability estimation, and other petrophysical analyses. By consolidating these functionalities into a single platform, we seek to empower geoscientists with the tools they need to expedite decision-making, optimize reservoir development strategies, and maximize hydrocarbon recovery.

Through the amalgamation of cutting-edge technology, domain expertise, and collaborative innovation, we aspire to propel the field of well log analysis into a new era of efficiency, accuracy, and insight. By democratizing access to advanced analytical tools and fostering interdisciplinary collaboration, we aim to accelerate the pace of discovery and unlock new frontiers in the exploration and production of oil and gas resources.

#### **1.2 Problem Definition**

In traditional well log analysis, geoscientists and engineers encounter several challenges that hinder efficiency, accuracy, and decision-making. Manual interpretation of log data is time-consuming and prone to subjective biases, leading to inconsistencies in results (Johnson & Smith, 2016). Moreover, the complexity and volume of data make it difficult to extract actionable insights in a timely manner. Traditional software tools often lack user-friendly interfaces and interactive visualization capabilities, limiting the accessibility of log data to a broader audience (Williams & Davis, 2015). Furthermore, the siloed nature of data analysis workflows impedes collaboration and knowledge sharing among multidisciplinary teams. These challenges underscore the need for a more streamlined and integrated approach to well log analysis that leverages modern technologies and addresses the evolving demands of the industry.

1.3 **Study Location**

The Niger Delta, located in southern Nigeria, serves as the focal point of this study on the exploration and identification of potential geothermal zones. This region, renowned for its vast hydrocarbon reserves and dynamic geological features, offers a unique opportunity to assess the geothermal potential within a complex and diverse geological setting. Stretching over approximately 70,000 square kilometers, the Niger Delta encompasses a network of interconnected rivers, creeks, and mangrove swamps, forming one of the world's largest deltaic systems. The region is characterized by a series of sedimentary basins, including the Benin, Anambra, and Niger Delta basins, which have been shaped by millions of years of sediment deposition and tectonic activity.

The Niger Delta is situated within the broader context of the West African Rift System, a geologically active region characterized by rift valleys, fault lines, and volcanic activity. This geological setting, combined with the region's proximity to the Gulf of Guinea, contributes to the unique subsurface conditions that may harbor potential geothermal reservoirs. The study area within the Niger Delta will encompass strategically selected boreholes, distributed across different geological formations and tectonic structures. These boreholes will serve as key sampling points for collecting well log data, including gamma ray, resistivity, sonic, and other relevant parameters, essential for assessing the geothermal potential of the region.

#### **1.4 Aim and Objectives**

Develop an intuitive Streamlit-based web application for well log analysis in the oil and gas industry, aiming to streamline workflows, enhance data interpretation, and foster collaboration among multidisciplinary teams.

#### Objectives;

1. Create a user-friendly interface for visualizing well log data and conducting petrophysical analyses,
2. Implement advanced visualization tools to facilitate data interpretation and presentation,
3. Automate petrophysical parameter calculations to improve analysis efficiency,
4. Enable real-time collaboration features to promote knowledge sharing and teamwork, and to

#### Ensure scalability, performance, and accuracy through rigorous testing and validation processes.

#### **1.6 Justification**

The development of a Streamlit-based web application for well log analysis is justified by the need for modernizing and optimizing existing workflows in the oil and gas industry. Traditional approaches to well log analysis is often laborious, time-consuming, and prone to subjective interpretation errors. By leveraging Streamlit's capabilities, we aim to address these challenges and enhance the efficiency, accuracy, and accessibility of well log analysis. The web application will streamline workflows, automate repetitive tasks, and provide advanced visualization tools to aid in data interpretation.

**Efficiency Enhancement:** Traditional well log analysis methods often involve manual interpretation and analysis, which can be time-consuming and prone to errors. The development of a Streamlit-based web application will automate repetitive tasks, streamline workflows, and accelerate the analysis process, thus improving overall efficiency.

**Data Accessibility:** Access to well log data is often restricted to specialized software and trained personnel, limiting its accessibility to a broader audience within the organization. By deploying a web-based platform, well log data can be made easily accessible to geoscientists, engineers, and decision-makers across different departments, facilitating data-driven decision-making and collaboration.

**Advanced Visualization:** Visualization plays a crucial role in data interpretation and communication of findings. The web application will incorporate advanced visualization tools, such as interactive log plots, cross-sections, and 3D models, to enhance the presentation of well log data and aid in the interpretation of complex geological structures.

**Collaborative Work Environment:** In the oil and gas industry, well log analysis often involves multidisciplinary teams comprising geoscientists, petrophysicists, reservoir engineers, and geologists. The web application will enable real-time collaboration features, such as shared dashboards, annotation tools, and commenting capabilities, to promote knowledge sharing and teamwork among team members.

**Scalability and Flexibility:** With the growing volume and complexity of well log data, scalability and flexibility are essential considerations. The web application will be designed to scale seamlessly with increasing data volumes and accommodate diverse analysis requirements, ensuring that it remains adaptable to the evolving needs of the organization.

**CHAPTER TWO**

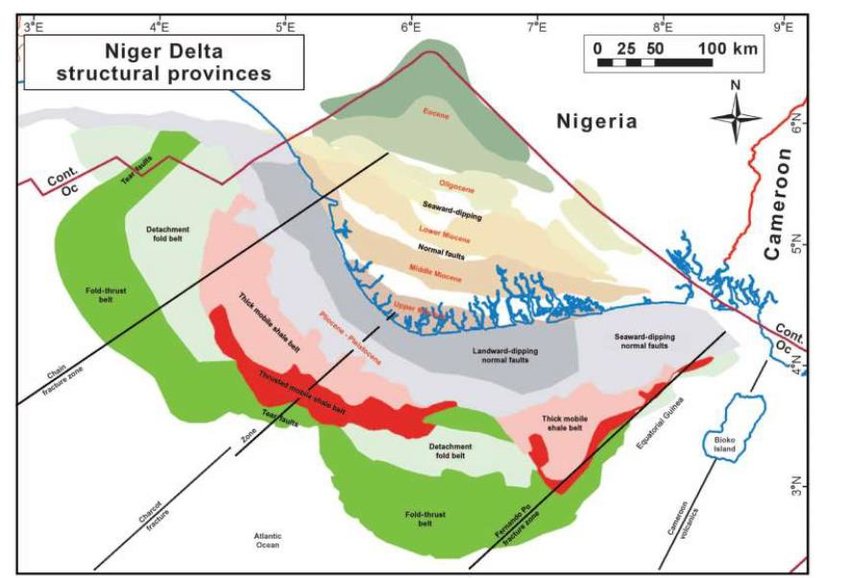
**LITERATURE REVIEW**

**2.1 Geology of Niger Delta**

According to Klett et al. (1997), the Niger Delta is located in the Gulf of Guinea and encompasses the whole Niger Delta Province (Figure 2.1). The delta has prograde southwestward from the Eocene to the present, creating depobelts that represent the majority of the delta at each stage of its formation (Doust and Omolola, 1990). With a surface area of 300,000 km2, a sediment volume of 500,000 km2, and a sediment thickness of more than 10 km in the basin depocenter, these depobelts constitute one of the greatest regressive deltas in the world, (Hospers, 1965). Only one petroleum system was found in the Niger Delta Province during this assessment. The Tertiary Niger Delta (Akata-Agbada) Petroleum System is the term used to describe this system. (Doust and Omolola, 1990). The extent of the maximum petroleum system coincides with the boundaries of the province.

**2.2 Province Geology**

One of the greatest Tertiary delta systems in the world and a province with an abundance of hydrocarbons is the Niger Delta. According to Dust and Omatsola (1990), the delta has prograded south-westward since the Eocene, generating depobelts that characterize the delta's most active region at each stage of its history. A region of around 256,000 km2 is covered by the Niger Delta. The large transgressive marine Akata Shales, the prolific paralic Agbada Formation, and the continental Benin Sands are the subsurface lithostratigraphic units. About 40 billion barrels of oil and more than 40 trillion cubic feet of gas are in reserve. Traps are mainly dip closures (rollover anticlines in growth faults) and relatively rare stratigraphic traps. (Adegoke, Oyebamiji. Edel. Osterloff, Ulu, 2017).



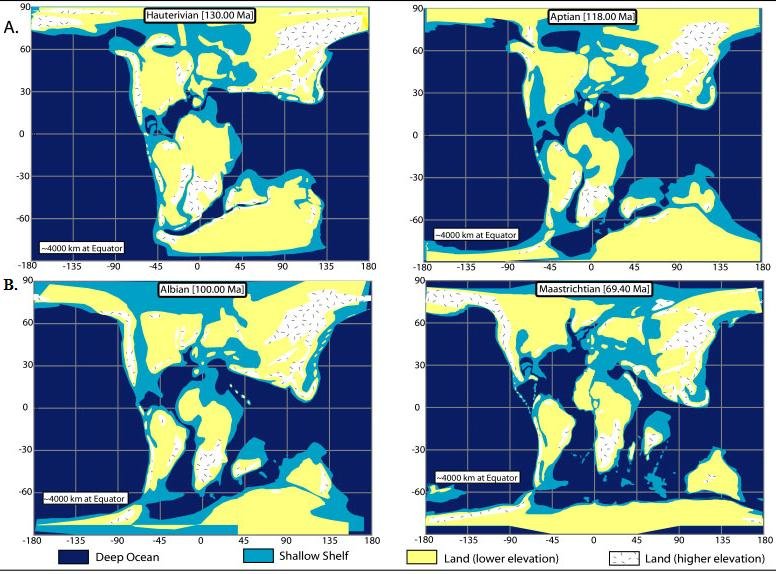
**Figure 2.1: Map of Niger Delta showing Province outline and key Structural features (From Tuttle et al., 1999)**

**2.3 Tectonics**

Cretaceous fracture zones that produce trenches and ridges in the deep Atlantic have an impact on how the continental margin is arranged on Equatorial Africa's west coast. These ridges create the border faults of the Cretaceous Benue-Abakaliki depression in Nigeria, which penetrates far into the West African shield, and divide the margin into distinct basins. The rift triple junction linked with the opening of the South Atlantic produced the trough as a failed arm. The basic paleogeography of the region is depicted in Figure 2.2, along with the relative placements of the African and South American plates over the course of the rifting. Gravity tectonism replaced rifting as the main process of deformation. Shale's mobility, which was caused by two processes, caused this deformation. First, shale diapirs developed as a result of the denser delta-front sands (Agbada Formation) loading the less compacted, over-pressured prodelta and delta-slope clays (Akata Formation). Second, the under-compacted delta-slope clays (Akata Formation) in the basin-ward direction lacked lateral support, resulting in slope instability. Before the Benin Formation was deposited, gravity tectonics was completed for each deposit, producing intricate structures such shale diapirs, roll-over anticlines, collapsed growth fault crests, back-to-back features, and steeply dipping, closely spaced flank faults. (Evanmy et al, 1978; Xiao and Suppe, 1992). These faults mostly offset different parts of the Agbada Formation and flatten into detachment planes near the top of the Akata Formation.

**2.4 Regional Lithostratigraphy of the Niger Delta**

The Niger Delta Basin, the youngest and southernmost sub-basin in the Benue-Abakaliki trough, has not pierced the Cretaceous portion (Reijers et al. 1997). Only the exposed Cretaceous section in the nearby Anambra basin may be used to predict the lithologies of the Cretaceous rocks in this area. The shoreline was concave into the Anambra basin during the Campanian through the



**Figure 2.2: Cretaceous Paleontology of the opening of South Atlantic and Development of the Region among Niger Delta (130 – 69 ma). Cenozoic Paleontology (50.3 to present Plots)**

Paleocene, resulting in convergent longshore drift cells that produced river- and tide-dominated sedimentation during regressions and transgressions, respectively. The Anambra basin has a number of shales that reflect shallow marine clastics that were deposited farther offshore, including the Albian to Cenomanian Asu River shale, the Cenomanian to Santonian Eze-Uku and Awgu shales, and the Campanian/Maastrichtian Nkporo shale.

Paleocene Late Cretaceous shale distribution beneath the Niger-Delta is uncertain. The Imo shale, on the other hand, was deposited in the Anambra Basin to the northeast and the Akata shale in the Niger Delta Basin region to the southwest during the great transgression known as the Sokoto Transgression, which started in the Paleocene. Wave-dominated sedimentation resulted from the Eocene's convexly curved coastline form and divergent longshore drift cells. The Niger Delta Basin proper began to accumulate paralic sediments at this time, and as the sediments moved southward, the shoreline became increasingly convex toward the sea. The longshore drift cells are diverging, and waves nevertheless dominate delta sedimentation in the Niger Delta Basin today (Reijers et al., 1997). Short and Stauble (1967) explain the type sections of these formations, and several studies provide summaries of their findings. (e.g., Avbobvo, 1978, Doust and Omatsola, 1990). The formations are:

**Benin Formation:** The Niger Delta's youngest formation, the Benin formation, can be found between Benin-Onitsha in the north to farther inland than the current coastline. The formation is made up of thick, locally interbedded shale that is thought to be the top bed of braided stream origin and enormous, very porous, fresh water carrying sandstone. In general, the sands and sandstone of the Benin formation are poorly sorted and range in size from coarse to medium to fine. It is an alluvial and upper coastal plain sand deposit that dates from the later Eocene to recent periods and is up to 2000 meters thick. (Avbovbo, 1978).

**Agbada Formation**: The main petroleum-bearing unit started in the Eocene and is still going strong now. The formation, which comprises the real deltaic component of the series, is made up of paralic siliciclastic that is almost 4000 meters thick. Delta-front, delta-topset, and fluvio-deltaic settings are where the clastic collected. Shale and sandstone beds were equally distributed throughout the lower Agbada Formation, but the higher part is primarily composed of sand with only a few interbeds of small shale. Short and Stauble (1967)

**Akata Formation:** The main petroleum-bearing unit dates back to the Eocene and continues today. The formation, which is almost 4,000 meters thick and represents the sequence's real deltaic part, is made up of paralic siliciclastic. Clastic collected in fluvial-deltaic, delta-front, and delta-topset settings. Shale and sandstone layers were deposited in equal amounts in the lower Agbada Formation, although the top part is largely made of sand with just a few interbeds of modest amounts of shale.

**2.5 Structural Features of Niger Delta**

One of the most noticeable geological features in the Niger Delta is the growing fault pattern. Syn-sedimentary faults and folds that trend East-West (E-W) are known as growth faults, and they frequently coexist with anticlines and mud dips. These formations appear to be independent of the three major tectonic stages outlined earlier and are most likely the result of internal energy within the sediments rather than orogenic pressures from without. (Doust and Omatsola, 1990). These faults are thought to be gravity faults that began as a result of differential loading on the underlying, mobile, under-compacted Akata Shales and occurred concurrently with fast sedimentation. This simultaneous sedimentation and gravity faulting caused the down-thrown block to accumulate heavier sediment than the up-thrown block. The strata have also been inclined toward the basin as a result of the heavy sediment load deposited in the delta front and the associated subsidence. In rollover anticline structures that trap oil in dip closures or up against a synthetic or antithetic fault, the majority of the oil in the Niger Delta is to be discovered.

**2.5.1 Faulting of The Niger Delta**

Faulting generally exists in the Niger delta are the growth faults. The different types of faults associated with the growth faults also include rollover anticline major counter regional faults, antithetic faults and crystal faults (Figure 2.3).

**2.5.1.1 Growth Faults**

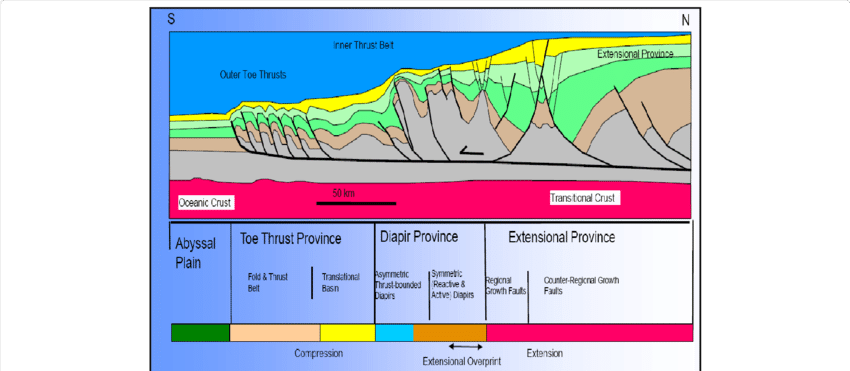
Rapid sedimentation along the Niger Delta's border on top of clay causes growth faults, which are distinguished by the presence of thicker sediments on the down-throw block relative to the up-thrown block. Growth faults are frequently referred to as contemporaneous faults (Doust & Omatsola, 1990) and are significant in interpretation because they act as the main pathway for hydrocarbons moving from maritime shale of the Akata formation to reservoir sand of the Agbada formation of the Delta.

**2.5.1.2 Rollover Anticline**

The rollover anticline is formed as a result of dip sections such as producer by rotation of a block resulting from sliding along a curve fault plane usually associated with gravity faulting coinciding with deposition of sediments.

**2.5.1.3 Major Counter Regional Fault**

These are faults located at the southern end of regional flanks. They are basically secondary structures derived from extensional phenomenon characterizing the delta migratory pathways from extensional phenomenon.



**Figure 2.3: Schematic of a Seismic Section from Niger Delta continental slope rise for the results of internal gravity tectonics on the sediments at the distal portion of the Depobelts. (Modified from Lehner and De Ruiter, 1997, Doust and Omosola, 1990).**

**2.5.1.4 Antithetic Faults**

Secondary geological faults known as "antithetic faults" travel in the opposite direction from the main synthetic fault to which they are connected. These faults are distinguished by their opposing displacement with respect to the main fault, which causes opposing fault movements within the same structure.

**2.5.1.5 Crestal Faults**

One or more crestal faults that run parallel to the rollover structure define rollover structures as geological features. These structures frequently develop in conjunction with processes involving diapirism and crestal collapse. Diapirism is the process by which salt or other buoyant minerals travel upward through the Earth's crust, causing the development of anticlines and related faulting.

**2.6 Depobelts**

The Niger Delta consists of five siliciclastic sedimentation cycles, with each cycle containing three formations. These cycles, also known as depobelts, are 30-60 kilometers wide and prograde southwestward over 250 kilometers into the Gulf of Guinea. They are defined by syn-sedimentary faulting resulting from variable rates of subsidence and sediment supply (Doust and Omatsola, 1990). The deposition of each depobelt is due to the interplay of subsidence and supply rates, forming discrete units. When further subsidence could no longer be accommodated, the focus of sediment deposition shifted seaward, creating a new depobelt. Each depobelt corresponds to a break in regional dip and is bounded by growth faults on the landward side and large counter-regional faults or the growth fault of the next seaward belt on the seaward side. Doust and Omatsola (1990) categorize the delta into three depobelt provinces based on structure. The Northern delta province, which overlies relatively shallow basement, has the oldest growth faults that are generally rotational, evenly spaced, and increase in steepness seaward. The central delta province has depobelts with well-defined structures, such as successively deeper rollover crests that shift seaward for any given growth fault. The distal delta province is the most structurally complex due to internal gravity tectonics on the modern continental slope as shown in figure 2.3.

**2.7 Petroleum and its Occurrence**

Petroleum occurs throughout the Agbada formation of the Niger-Delta, however, several directional trends form an 'oil-rich belt having the largest field and lowest gas: oil ratio (Ejedawe, 1981; Doust and Omatsola, 1990). The belt extends from the northwest offshore area to the southeast offshore and along a number of north-south trends in the area of Port Harcourt. It roughly corresponds to the transition between oceanic crusts, and is within the axis of maximum sedimentary thickness. This hydrocarbon distribution was originally at attributed to timing of trap formation relative to petroleum migration (earlier landward structures trapped earlier migrating oil). However, showed that in many rollovers, movement on the structure-building fault and resulting growth continued and was relayed progressively southward into the younger part of the section by successive crustal faults, concluding that there was no relation between growth along a fault and distribution of petroleum.

Weber, (1987) indicates that the oil-rich belt 'golden lane coincides with a concentration of Rollover structures across Depobelts having short southern flanks and little paralic sequence to the south. Doust and Omatsola, (1990), suggest that the distribution of petroleum is likely related to heterogeneity of Source Rock type (greater contribution from paralic sequences in the West) and/or Segregation due to Remigration. Hack et al. (1997) relate the position of the oil-rich belt to oil-prone marine Source rock was controlled by pre-tertiary structural sub-basins related to basement structures: Outside of the oil rich belt (central, easternmost and northernmost parts of the delta). The Gas-Oil Ratios (GOR) are high. The GOR within each depobelt increases seaward and along strike away from depositional centers, causes for the distribution of GOR's are speculative and includes, Remigration induced by tilting during the latter history of depositing within the down dip portion of the depobelt, Up-Dip flushing of accumulation by gas generated at higher maturity and/or Heterogeneity of source rock type (Doust and Omatsola, 1990).

**2.7.1 Source Rock**

There are has been much discussion about the Source rock for petroleum in the Niger-Delta (e.g., Ekweozor et al. 1979; Ekweozor et al 1980; Lambert-Aikhionbare and Ibe, 1984; Doust and Omatsola, 1990). Possibilities include variable contributions from the Marine interbedded shale in the Agbada formation, the Marine Akata shale, Cretaceous shale (Daukoru et al, 1975, Ejedawe al 1979; Ekweozor et al, 1979, Ekweozor et al 1980; Lambert-Aikhionbare and Ibe, 1984; Doust and Omatsola, 1990).

**2.7.2 Agbada-Akata**

The Agbada formation has intervals that contain organic carbon contents sufficient to be considered good reservoir rocks (see data in Ekweozor et al, 1980; Nwachukwu and Chukwura, 1986). The intervals, however, rarely reach thickness sufficient to produce a world-class oil province and are immature in various parts of the delta. The Akata shale is present in large volume beneath the Agbada Formation and is at least volumetrically sufficient to generate enough oil for a world class oil province such as the Niger-Delta.

(Figure 2.4). Based on organic-matter content and type proposed that both the marine shale (Akata formation) and the shale interbedded with paralic sandstone (lower Agbada formation were the source rock for the Niger Delta oils. (Ekweozor et al 1979) used aβ-hopanes and oleananes to finger print crude with respect to their source, the shale of paralic Agbada Formation on the Eastern side of the delta and the Akata marine- paralic source on the western side of the delta. (Ekweozor et al, 1980) further constrained this hypothesis using geochemical maturity indicators, including vitrinite reflectance data that showed rocks younger than the deeply buried lower parts of the paralic sequence to be immature. Lambert- Aikhionbare and Ibe (1984) argued that the migration efficiency from the over-pressure Akata shale would be less than 20%, indicating that little fluid would have been released from the formation. They derived a different thermal maturity profit showing that shale within the Agbada formation is nature enough to generate hydrocarbon.

(Ejedawe et al 1984) use maturation models to conclude that in the central part of the delta, the Agbada shale sources the oil while the Akata shale sources the gas. In other parts of the delta, they believe that both shales source of oil. Doust and Omatsola (1990) conclude that the source organic matter is in the deltaic off-lap sequences and in the sediments of the lower-coastal plain. Their hypothesis implies that both the Agbada and Akata formations likely have disseminated source rock levels, but the bulk will be in the Agbada formation. In deep water, they favour delta slope and deep turbidite fans of the Akata formation as source rocks. The Organic Matter in theses environments still maintains a terrestrial signature; however, it may be enriched in amorphous, hydrogen- rick matter from bacterial degradation. Stacher (1995) proposed that the Akata formation is the only source rock volumetrically significant and whose depth of burial is consistent with the depth of the oil window,

**2.7.3 Cretaceous**

According to Frost (1997), some experts have proposed that the marine Cretaceous shale underneath the Niger-Delta could potentially serve as a viable source rock, such as the pre-Albian super rock. However, due to its significant depth, this section has never been drilled, and there is no data available on its source-rock potential. While some have suggested that oil may migrate from the Cretaceous shale into the Agbada shale reservoirs, there is no data to support such a network. Additionally, the chemical composition of the oils presents conflicting evidence for the hypothesis of a Cretaceous source rock, particularly for an early Cretaceous one. Nwachukwu et al. (1995) reported low V: V+ Ni ratios in Niger-Delta crude (0.12), a ratio significantly smaller than that in Cretaceous oils in onshore seeps in the northern part of the province. However, according to Geomark Research Inc., the chemical signatures of the Niger- Delta crude are similar to those found in Cretaceous oils, and significant oleanane, a compound related to angiosperms that only became widespread in the late Cretaceous- Tertiary, is present in Niger-Delta crude. Haack et al. (1997) suggested that oil in hypothetical deep-water of the Niger-Delta may be partially sourced by upper Cretaceous rocks, based on the Northern Gulf of Mexico Basin model of older rocks sourcing oils in deeper water. However, since these oils are in hypothetical plays, there is currently no geochemical data available to test this hypothesis in the Niger Delta.

**2.7.4 Reservoir Rock**

Petroleum in the Niger Delta is produced from sandstone and unconsolidated sands predominantly in the Agbada Formation. Characteristics of the reservoirs in the Agbada Formation are controlled by depositional environment and by the depth of burial. Known reservoir rocks are Eocene to Pliocene in age, and are often stacked, ranging in thickness from less than 15 meters to 10% having greater than 45 meters thickness. The thicker reservoirs likely represent composite bodies of stacked channels (Doust and Omatsola, 1990). Based on reservoir geometry and quality, (Kulke, 1995) describes the most important reservoir types as point bars of distributary channels and coastal barrier bars intermittently cut by sand-filled channels. Edwards and santogrossi (1990) describe the primary Niger Delta reservoirs as Miocene paralic sandstones with 40% porosity, 2 darcies permeability, and a thickness of 100 meters, In the outer portion of the delta complex, deep-sea channel sands, low-stand sand bodies, and proximal turbidities create potential reservoirs. Burke, 1972 describes three deep-water fans that have likely been active through much of the delta's history, the fans are smaller than those associated with other large deltas because much of the sand of the Niger-Benue system is deposited on top of the delta, and buried along with the proximal parts of the fans as the position of the successive depobelts moves seaward (Burke, 1972). The distribution, thickness, shaliness, and porosity/permeability characteristic of these fans are poorly understood.

**2.7.5 Traps and Seals**

Most known Traps in Niger-Delta fields are structural although stratigraphic are not uncommon. The structural traps developed during syn-sedimentary formation of the Agbada paralic sequence. As discussed earlier, structural complexity increases from the north (earlier formed depobelts) of the south (later formed depobelts) in response to increasing instability of the under (compacted over pressured shale), Doust and Omatsola (1990) described a variety of structural trapping elements, including those associated with simple Rollover structures, Clay filled channels, structures with multiple Growth Faults structures with antithetic faults, and collapsed crest structures.

On the flanks of the delta, stratigraphic traps are likely as important as structural traps. In this region pockets of sand stones occur between diapiric structures, towards the delta toe (base of distal slope). this alternating sequence of sandstone and shale gradually grades to essentially sandstone. The primary source rock in the Niger Delta is the interbedded shale within the Agbada formation. The shale provides three types of seals Clay smears along faults, interbedded sealing units against which reservoir sand are juxtaposed due to faulting, and vertical seals (Doust and Omosola, 1990) on the flanks of the delta, major erosional events of early to middle Miocene age formation canyons that are now clay-filled. These clays formation the top seals for some important offshore fields.

**2.7.6 Petroleum Generation and Migration**

Evamy et al, 1978 set the top of the present oil window in the Niger Delta at the 240°F (115°C) isotherm. In the north western portion of the delta, the oil window (active source rock interval) lies in the upper Akata Formation and the lower Agbada Formation. To the South-East, the top of the oil window is strati graphically + lower (up to 4000m below the upper Akata/lower Agbada sequence.

Some researchers (Nwachukuwu and Chukwura, 1986; Doust and Omatsola. 1990) attribute the distribution of the top of the oil window to the thickness and sand/shale ratio of the over burden rock (Benin Formation and variable proportions of the Agbada formation). The sandy continental sediment (Benin Formation) has the lowest thermal gradient (1.3 to 1/8°C/100m); the paralic Agbada Formation has on intermediate gradient (2.7°C/100m); and the marine, over-pressured Akata Formation has the highest (5.5°C/100m) (Ejedawe et al, 1984). Therefore, within any depobelt, the depth to any temperature is dependent on the gross distribution of sand and shale. If sand/shale ratios were the only variable, the distal offshore subsurface temperatures would be elevated because sand percentages are lower. To the contrary, the depth of the hydrocarbon kitchen is expected to be deeper than in the delta proper, because the depth of oil generation is a combination of factors (temperature, time and deformation related to tectonic effects).

In the late Eocene, the Akata/Agbada formational boundary in the vicinity of this well entered the oil window at approximately 0.6 Ro argue that generation and migration processes occurred sequentially in each depobelt and only after the entire belt was structurally deformed, implying that deformation in the Northern Belt would have been completed in the late Eocene. The lowermost part of the Agbada formation here entered the oil window sometime in the late Oligocene.

The Northern Belt's shows the Akata source rock first entering the oil window in the Oligocene after reservoir rock deposition, Stacher assumes migration overlaps in time with the burial and structure development of overlying reservoir sequence and occurs primarily across and up faults. Migration pathways were short as evidenced from the wax content, API gravity, and the chemistry of oils (Short and Stauble, 1967).

Migration from mature, over-pressured shales in the distal portion of the delta may be similar to that described from over-pressured shales in the Gulf of Mexico. Hunt (1990) relates episodic expulsion of petroleum from abnormally pressured, mature source rocks to fracturing and resealing of the top of the over-pressured interval. In rapidly sinking basins, such as the Gulf of Mexico, the fracturing/resealing cycle occurs in internals of thousands of years. This type cyclic expulsion is certainly plausible in the Niger-Delta basin where the Akata formation is over-pressured. Belt and Oti (1995) predict a bias towards lighter hydrocarbons (gas and condensate) from the over- pressured shale as a result of down- slope dilution of organic matter as well as differentiation associated from over-pressured.

**2.7.7 Overview of A Reservoir**

Belt and Oti (1995). There are essential requirements/factors that lead to the accumulation of oil and gas in commercial quantities in the subsurface. These have been broken down into five essential requirements which are sometimes referred to informally as the 'magic five'.

**Source**: Generally, a shale or very fine-grained limestone with a minimum of 0.5% of the type of organic matter that will give rise to petroleum.

**Heat**: obtained from the earth by burial of the source rock and required in order to generate petroleum from the organic matter. A temperature of approximately 150°F is needed for oil to be generated, above about 350°F only gas is produced beyond 450°F even that is destroyed.

**Reservoir**: A layer or formation of rock that is both porous and permeable; usually sandstone and a carbonate.

**Cap rock or seal**: An impervious layer above the reservoir to retain the petroleum within it, usually shale or evaporate Sometimes the source rock itself may act as the seal if it directly overlies the reservoir.

**Trap**: A subsurface environment, formed by structural or stratigraphic control, where the petroleum in the reservoir is barred from further migration and therefore accumulates.

For these requirements to be met, there must be a sedimentary basin with a thickness of at least 2,000m-2,500m. This would ensure that source rocks, if only at the base of the sequence, are nature to the oil generation threshold. The basic approach in exploration therefore is to consider separately and together each and every member of the 'magic five and ensure that they have been satisfied in the area of study. If so, the cost of drilling and exploration well is justified.

**2.8 Geophysical Well Logging Method**

**2.8.1 Introduction**

Telford et al, 1976. The study of the properties of rocks by petrophysical techniques using electric, nuclear, and acoustical sources is referred to as geophysical well logging. The petrophysical log interpretation is one of the most useful and important tools available to a petroleum geologist. Besides their traditional use in exploration to correlate zones and to assist with structure and isopach mapping, logs help define physical rock characteristics such as lithology, porosity, pore geometry, and permeability. Logging data is used to identify productive zones, to determine depth and thickness of zones, to distinguish between oil, gas, or water in a reservoir, and to estimate hydrocarbon

reserves. Also, geologic maps developed from log interpretation help with determining facies relationships and drilling locations.

Of the various types of logs, the ones used most frequently in hydrocarbon exploration are called open hole logs. The name open hole is applied because these logs are recorded in the uncased portion of the well bore. The two primary parameters determined from well logs measurements are porosity, and the fraction of pore space filled with hydrocarbons. The parameters of log interpretation are determined both directly or inferred indirectly, and are measured by one of three general types of logs:

* Electrical
* Nuclear, and
* Acoustic or Sonic

The names refer to the sources used to obtain the measurements. The different sources create records (logs) which contain one or more curves related to some property in the rock surrounding the well bore

**2.8.2 Open-Hole Wireline Logging**

This is the technique of valuable data acquisition and the most important source of information of well evaluation whereby after a well has been drilled; measuring sensors (sondes) are lowered into the open well at the end of an electrical cable (Figure 2.12). Whilst pulling the tools out of the well, various properties of the formations are measured continuously as a function of depth. These physical properties can then be interpreted in terms of lithology, porosity, hydrocarbon saturation, fluid type, fluid volume etc.

**2.8.2.1 Gamma Ray Log**

The gamma ray (GR) (Figure 2.13), is the most commonly used reservoir thickness log. It measures the natural gamma radioactivity of the formation. This property can be used to discriminate between reservoir and non-reservoir rock. The natural radiation spectrum can also be analyzed, from which conclusions can be drawn about the detailed mineralogy of the rock.

**Principles**:

Some elements in nature emit radiation (Gamma Rays). Examples of such elements common in the earth's crust are potassium (K), thorium (Th) and Uranium (U). Most reservoir rocks (eg. Sandstone, Limestone, Dolomite) contain none or only small amounts of these elements and therefore have a low GR radiation level.

Evaluation Objective:

* Discriminate between reservoir and non-reservoir. (Net/Gross).
* Estimate shaliness of reservoir rock

**2.8.2.2 Density Log**

The density log is the most commonly used porosity log because it gives the most accurate measurement of porosity (Figure 2.13). It is based on the principle whereby, a strong gamma ray source bombards the rock with medium energy level gamma rays. These GR collide with electrons in the formation and in the process the GR are attenuated (Compton scattering). The count rate of these scattered GR at a fixed distance from the source is inversely proportional to the electron density of the formation from which the bulk density can be calculated.

Reservoir rocks consist of rock Matrix (e.g., quartz, calcite, dolomite) and pore fluid (e.g., water, oil, gas). The bulk density (p) of a reservoir rock is the weighted average density of the present pore fluid(s) (pa) and its rock matrix (pa).

**ρb= Փ x ρm +(1-Փ) x** **ρma** ---------------------------------------------------------------------------- (2.4)

Evaluation Objectives:

* Calculate the porosity (O) in layers of known Lithology
* Evaluate lithologies of formation in combinations with the neutron tool (see "Density/Neutron combination")
* Check consistency of the lithologies as seen by the mud log and the GPL

**2.8.2.3 Neutron Log**

Evaluation Objectives:

Calculate the porosity in layers of known porosity

* Evaluate lithologies of formations in combination with the Density tool
* Detection of gas bearing reservoir in clean formations.
* Check consistency of the lithologies as seen by the mudlog, GR and Density,

In neutron log (Figure 2.13), a neutron source is used to bombard the formation with high energy Neutrons. Most collisions of the neutrons with heavy atoms of the formation are near elastic. As a result, hardly any energy is lost. A collision with hydrogen atom (H) lowers the speed (energy level) of the neutron significantly, as both have the same mass. The distance over which the neutrons travel before they reach a lower (thermal) energy level is therefore related to the amount of hydrogen atoms present in the formation.

**2.8.2.4 Density/Neutron Combination**

Evaluation Objectives:

* Evaluate lithologies of formations
* Detection of gas bearing reservoir.

Principle:

The Density and the Neutron tool both determine the porosity of a reservoir, they do this by measuring different quantities:

* The Density tool measures the bulk density.
* The Neutron measures the hydrogen density

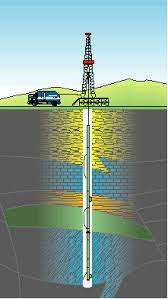
For this reason, both tools react differently to certain pore fluids and lithologies (Figure 2.13). It is standard practice to plot both logs in one track using a scale such that both logs overlay in water bearing limestone while the logs will separate in other lithologies or pore fluids. E.g., in gas bearing reservoir the recorded neutron porosity is lower and the bulk density is reduced, compared with the responses in a similar water oil bearing Formation. These effects can be significant (depending on the gas saturation in the invaded zone). The resulting separation with Neutron on the right and Density on the left is called gas separation. It is worthy to also note that shales have an inverted effect (shale separation - see Figure 2.13). Due to the clay-bound water, which is chemically attached to the clay particles, the neutron tool records high porosity, where in reality no effective porosity is present by Telford et al, 1976.

**2.8.2.5 Resistivity Log**

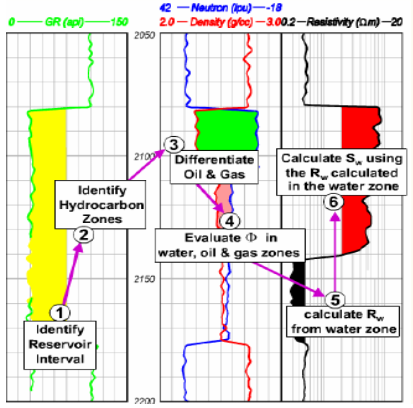
Principle:

Resistivity logging is a well logging technique used to measure the electrical resistivity of subsurface formations (Figure 2.13). The principle of resistivity logging is based on the fact that different rock types have varying electrical conductivity and resistivity properties. By measuring the electrical resistance of a formation, it is possible to estimate the rock type, porosity, and fluid saturation. The resistivity measurement is made by introducing a current into the formation through a pair of electrodes placed in the borehole and measuring the resulting voltage. The current is typically introduced into the formation by a current electrode placed on the surface or in the borehole, while the voltage is measured by a set of potential electrodes placed at different distances from the current electrode. The spacing between the electrodes determines the depth of Investigation

The resistivity measurement can be affected by the presence of conductive fluids, such as water or hydrocarbons, in the formation. The resistivity of the formation decreases, as the fluid saturation increases, and the resistivity logging tool can be used to estimate the number of fluids present in the formation.



**Figure 2. 12: Open Hole Wireline Logging.**



**Figure 2.13: Hydrocarbon effect and oil/gas differentiation**

**CHAPTER THREE**

**MATERIALS AND METHODS OF STUDY**

# **3.1. Materials**

## **3.1.1. Open-Source Software**

Several open-source software was used. Open-source software refers to software, codes that are

available for use with no restriction and limitations.

### **3.1.1.1. Python 3.8**

Python is a high-level programming language used for a wide variety of purposes ranging from machine learning and data science to web and development, scientific computing etc. “Python was created in the early 1990s by Guido van Rossum at Stichting Mathematisch Centrum (CWI, see <https://www.cwi.nl/>) in the Netherlands as a successor of a language called ABC” ([https://python.org](https://python.org/) ). The Python version 3.8. was for this project. The Python software and documentation is licensed under the Python Software Foundation (PSF) license.

### **3.1.1.2 OS**

This module provides a portable way of using operating system dependent functionality. The os library is used for working with system paths. “The design of all built-in operating system dependent modules of Python is such that as long as the same functionality is available, it uses the same interface” (docs.python.org). The module provides functions for creating, modifying,

deleting directories, fetching files from a directory or adding files to a directory.

**3.1.1.3 Lasio**

Lasio is a Python package designed to facilitate the reading, writing, and manipulation of Log ASCII Standard (LAS) files, which are widely used in the oil and gas industry for storing well log data. With Lasio, users can easily import LAS files into Python environments, allowing for seamless integration of well log data with data analysis and visualization workflows. Lasio provides a simple and intuitive interface for accessing log data stored in LAS files, enabling users to extract, manipulate, and analyze well log data with ease. Additionally, Lasio supports the writing of well log data back to LAS files, making it a versatile tool for both data retrieval and storage. Overall, Lasio simplifies the process of working with LAS files in Python, empowering users to leverage the rich and valuable information contained within well log data for various geoscientific and engineering applications.

### **3.1.1.4 Pandas**

Pandas is a python library developed for data analysis. It was used for making analysis of the

results; the labels and categories as well as preparing the files for training the models.

## **3.1.1.5 NumPy**

NumPy is a python library used for numeric and scientific computations. It supports arrays and matrix operations and vectorizations which leads to faster run times compared to for loops and

other data structures.

**3.1.1.5 Missingno**

Missingno is a Python library that provides tools for visualizing and analyzing missing data in datasets. It offers a variety of visualizations, such as bar charts, heatmaps, and dendrograms, to help users identify patterns and understand the extent of missingness in their data. Missingno also provides statistical summaries and matrix plots, allowing users to explore relationships between missing values and other variables in the dataset. By visualizing missing data, Missingno enables users to make informed decisions about data imputation, cleaning, and analysis, ultimately improving the quality and reliability of their analyses and insights.

### **3.1.1.6 Matplotlib**

Matplotlib is an open-source python library developed for rendering and making static and interactive visualizations. It was used for creating the grayscale image patches from the seismic volume and saved to the system directory.

**3.1.2 Techlog**

Techlog is a comprehensive software suite developed by Schlumberger, specifically tailored for petrophysical and geophysical analysis in the oil and gas industry. It provides a wide range of tools and functionalities for processing, interpreting, and visualizing well log and seismic data. Techlog offers modules for various petrophysical analyses, including formation evaluation, reservoir characterization, and geomechanics. It supports the integration of different data types, such as well logs, core data, and production data, allowing for holistic reservoir characterization and modeling. The software features advanced visualization capabilities, enabling users to create interactive plots, cross-sections, and 3D models to analyze subsurface formations. Additionally, Techlog provides tools for data quality control, statistical analysis, and uncertainty quantification, empowering geoscientists and engineers to make informed decisions during exploration and production operations.

## **3.1.3. Data Set**

In this study, the dataset comprises two well logs in LAS format, utilized for the calculation of key parameters crucial to understanding geothermal reservoir characteristics. Each of these logs include depth (DEPTH), gamma ray (GR), resistivity (ILD), bulk modulus (RHOB), neutron (NPHI), and sonic (DT) logs. The comprehensive dataset captures a spectrum of geological features essential for in-depth analysis.

Two specific wells, X1 and X2, were singled out for pore pressure analysis, conducted both using Python and Techlog. These wells were strategically chosen to deepen the investigation into the intricacies of pore pressure dynamics within the geothermal reservoir.

The calculations within the project are guided by specific formulas tailored to quantify relevant parameters:

Pore Pressure Gradient (PPG); signifies the change in pore pressure concerning depth intervals, elucidating variations in pressure levels across depths

PPG =

Pore Pressure Gradient with Sonic (PPG\_DT); Integrates Sonic (DT) data to refine the understanding of pressure gradients concerning acoustic properties, offering a more nuanced perspective on pressure dynamics.

PPG =

Hydrostatic Pressure (HP) computations aid in assessing the pressure exerted by the fluid column with depth, contributing to the overall understanding of the subsurface pressure regime.

HP = Fluid Density \* Gravity \* Depth

Porosity (N); a measure of the void spaces within a rock formation, is pivotal in the oil and gas industry as it denotes the capacity of a reservoir to hold hydrocarbons. This property, categorized as either primary (inherent pore spaces) or secondary (resulting from fractures or faults), determines the storage potential of fluids like oil and natural gas

N =

Where:

N is Porosity

is Bulk Density of dry specimen

is Particle Density

Permeability (K), on the other hand, signifies the rock's ability to transmit these fluids through connected pores. Rocks with high permeability facilitate efficient fluid movement, aiding in extraction.

By, using Darcy’s law to compute for Permeability. Brown and Smith (2005) show that permeability can be determined by the following relationship:

K =

Where:

K is Permeability

Q is Net air flow

is Applied Pressure

A is the inlet area

is viscosity

These formulas, meticulously applied to the X1 and X2 wells, serve as the backbone of the project's analytical framework. The precision of these calculations, derived from the well logs and meticulously chosen parameters, contributes to a nuanced and thorough understanding of the geothermal reservoir dynamics in the study area.

# **3.2. Methodology**

## **3.2.1. Machine Learning**

Machine learning (ML) is a branch of Artificial Intelligence (AI) whereby computers are designed to perform intelligent tasks without being explicitly programmed to do so. With the aid of algorithms, computers are trained to learn from data, identify existing patterns and use these patterns in making future predictions. This branch of AI is heavily dependent on data as it is required by the machines to learn from data and make inferences on new and unseen data.

Machine learning is largely divided into two types of learning; the supervised learning and the unsupervised learning.

### **3.2.1.1. Supervised Learning**

In supervised learning, the computers are trained with labels. This refers to a system of learning where the algorithm is provided with both input(s) and output to establish and identify patterns in the data. It is a ML technique whereby the ML algorithms are fed with labelled data. The chosen algorithm is trained on a labelled dataset that uses the provided labels(target) to control and evaluate the training process. Examples of algorithms used for supervised learning tasks are linear regression, random forest, support vector machines, KNN, gradient boosting algorithms, Artificial and Convolutional Neural Networks (ANNs, CNNs), etc. In supervised machine learning, we have two main types of problem/tasks;

1. **Regression**: This is a task where the training data is provided with a continuous target as the label. In this case, both input labels and predicted values are continuous or real values. A typical example of a regression task is the prediction of lithology values of the subsurface from well logs.
2. **Classification**: This is a machine learning task where the target labels are categorical. Here, prediction is done into different categories. A classification task could be binary or multi class. A typical example of supervised learning is the lithofacies prediction of the subsurface from well logs.

### **3.2.1.2. Unsupervised Learning**

In unsupervised learning, the machine learning algorithms are provided with unlabelled data. The algorithms extract patterns, determine and establish patterns present within the dataset. Deep belief networks (DBNs) and sparse coding are the two well-known techniques of unsupervised learning models. (Khanam M. 2015). The most common approach to unsupervised learning is cluster analysis of provided data. Basic models in unsupervised learning include; including factor analysis, state-space models, some mixtures of Gaussian, hidden Markov models, ICA, PCA. (Khanam M., 2015) Other examples of unsupervised learning algorithms are K-Means for clustering, Apriori algorithm for association rule learning problems, unsupervised deep learning algorithms like Self Organizing Maps for seismic facies mapping.

## **3.2.2. Machine Learning Algorithms**

Machine learning algorithms are a set of instructions or procedures, usually developed mathematical and logical operations to solve a particular task. Several machine learning algorithms have been developed and improved upon to have better prediction performance. Machine learning algorithms are largely grouped into the linear algorithms, tree-based algorithms, clustering algorithms and neural networks. Neural networks are used for this work.

### **3.2.3 Evaluation Metrics**

These are used to determine and measure the quality of machine learning predictions. They act as a guide in deciding what makes a good machine learning model. Different evaluation metrics are used for different purposes; classification or regression. Evaluation metrics are particularly useful for supervised machine learning workflows as labels which could be evaluated on exists. However, it is quite difficult to evaluate the quality of unsupervised machine learning models due to the absence of ground truth labels. Examples of common evaluation metrics include accuracy, F1 Score, Precision, Recall, Mean Intersection Over Union (Mean IoU), Root Mean Square Error (RMSE), coefficient of determination, etc.

**Reference**

Brown, R., & White, S. (2018). Introduction to Well Logging Techniques. Elsevier.

Chen, Z., & Liu, Q. (2021). Modern Approaches to Well Log Interpretation. Geophysical Prospecting, 30(4), 421-435.

Doust, H., & Omatsola, E. (1990). Niger Delta. In Edwards, J. D., & Santogrossi, P. A. (Eds.), Divergent/Passive Margin Basins (Vol. 48, pp. 201-238). AAPG Memoir.

Hospers, J. (1965). Gravity Field and Structure of the Niger Delta, Nigeria, West Africa. Geological Society of America Bulletin, 76(4), 407-422.

Jackson, M. (2017). Formation Evaluation: The Importance of Well Logging in Reservoir Characterization. Society of Petroleum Engineers Journal, 10(2), 89-104.

Johnson, D., & Smith, K. (2016). Challenges in Traditional Well Log Analysis. Oil & Gas Journal, 38(4), 321-335.

Jolliffe, I. T., & Cadima, J. (2016). Principal Component Analysis: A Review and Recent Developments. Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences, 374(2065).

Klett, T. R., Ahlbrandt, T. S., Schmoker, J. W., & Dolton, J. L. (1997). Ranking of the World's Oil and Gas Provinces by Known Petroleum Volumes: U.S. Geological Survey Open-File Report 97-463.

Li, X., & Wang, Y. (2020). Advancements in Well Log Analysis Technologies. Journal of Petroleum Science and Engineering, 75(2), 134-149.

MacQueen, J. (1967). Some Methods for Classification and Analysis of Multivariate Observations. In Proceedings of the Fifth Berkeley Symposium on Mathematical Statistics and Probability, Volume 1: Statistics.

Smith, J., & Jones, A. (2019). The Role of Well Logging in Oil and Gas Exploration. Journal of Petroleum Geology, 42(3), 211-225.

Streamlit. (n.d.). Retrieved from https://streamlit.io/

Van Rossum, G., & Drake, F. L. (2009). Python 3 Reference Manual. CreateSpace.

Williams, L., & Davis, P. (2015). Limitations of Traditional Well Log Interpretation Methods. Petroleum Technology Quarterly, 20(1), 45-58.