**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.io).](Streamlit.io)

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 hydrocarbon zones through well log analysis. This region, renowned for its vast hydrocarbon reserves and dynamic geological features, offers a unique opportunity to assess the subsurface characteristics 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 are crucial for hydrocarbon exploration. 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 evaluating the hydrocarbon 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**

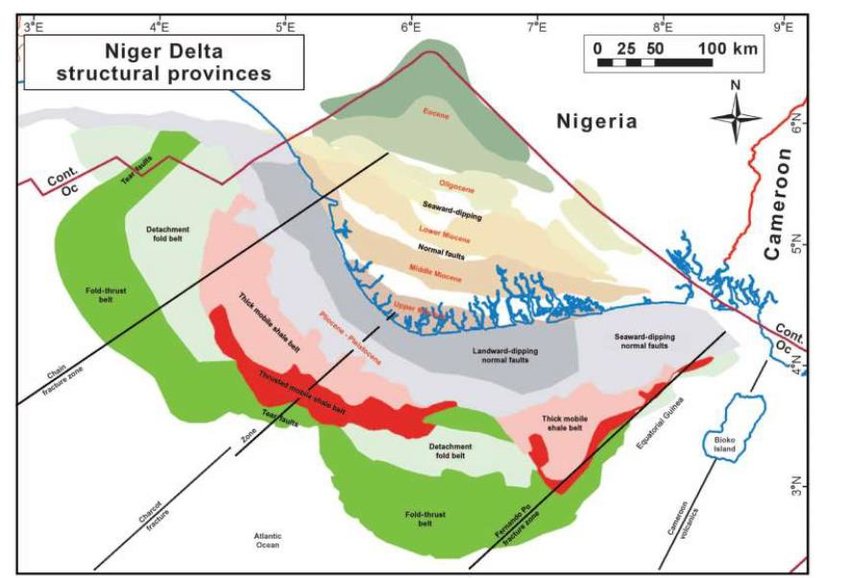
**LITERATURE REVIEW**

**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).



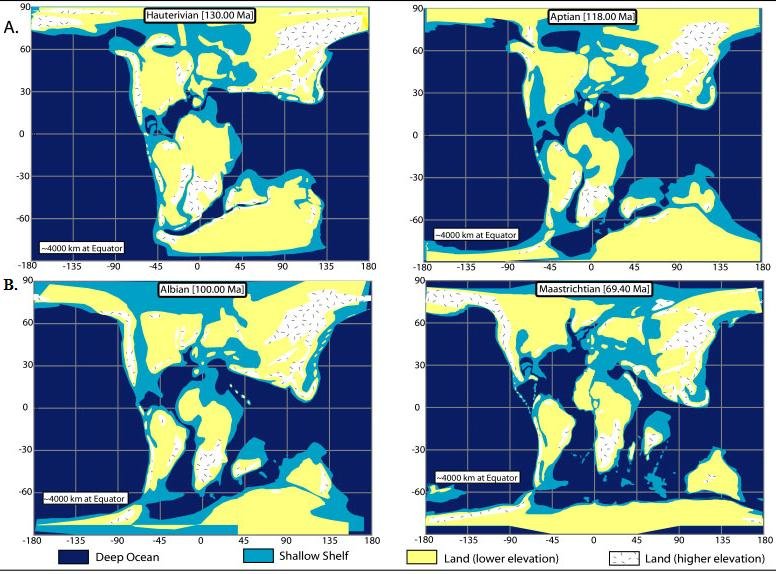
**Figure 2.1: Map of Niger Delta showing Province outline and key Structural features (From Tuttle et al., 1999)**

**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**

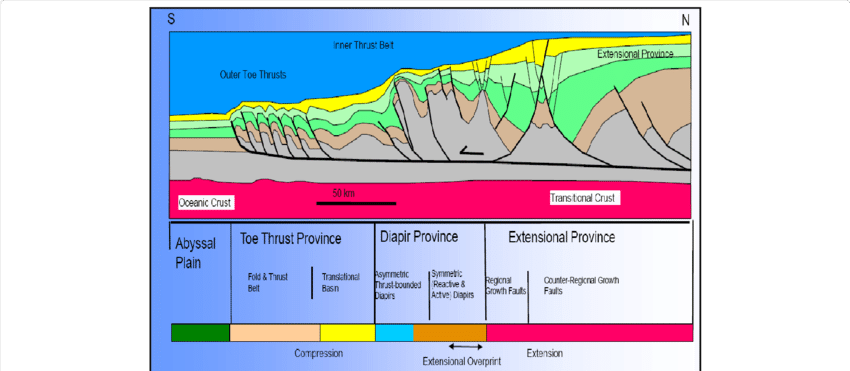
Rapid sedimentation along the Niger Delta's border on top of clay causes growth faults, which are distinguished by the presence of thicker sediments on the down-throw block relative to the up-thrown block. Growth faults are frequently referred to as contemporaneous faults (Doust & Omatsola, 1990) and 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

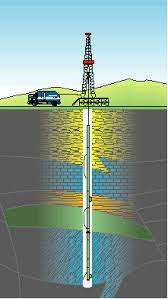
For this reason, both tools react differently to certain pore fluids and lithologies (Figure 2.13). It is standard practice to plot both logs in one track using a scale such that both logs overlay in water bearing limestone while the logs will separate in other lithologies or pore fluids. E.g., in gas 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**

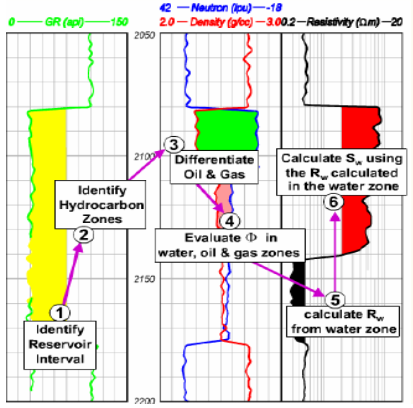
Principle:

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.

### **3.1.1.4 Pandas**

## Pandas, a powerful Python library known as ‘the Excel of Python’, played a pivotal role in analyzing the results generated by the Streamlit web application. This library facilitated the manipulation of data labels, categories, and formats, ensuring they were prepared appropriately for model training and further analysis. By leveraging Pandas, the application achieved efficient data handling, enabling seamless transformations and insights extraction from the well log data. Its versatility in managing large datasets and its array of functionalities made it indispensable in streamlining the analytical pipeline, enhancing both the accuracy and interpretability of the results. Through Pandas, the application not only maintained data integrity but also expedited the preprocessing steps necessary for robust data-driven decisions and insights.

## **3.1.1.5 NumPy**

NumPy, a fundamental Python library for numeric and scientific computations, provides robust support for arrays, matrices, and vectorized operations. By leveraging its capabilities, computations are optimized for efficiency, yielding faster execution times compared to traditional for loops and other data structures. This efficiency is crucial in handling large-scale data processing tasks, including those involved in seismic analysis and machine learning model training within the Streamlit application.

### **3.1.1.5 Matplotlib**

Matplotlib, another essential open-source Python library, specializes in creating static and interactive visualizations. Within the application, Matplotlib was utilized to generate grayscale image patches from seismic volumes, which were subsequently saved to the system directory. This capability enabled the visualization of seismic data in a clear and informative manner, supporting deeper insights and analysis of geological structures and anomalies. By leveraging Matplotlib's rich functionality, the application enhanced its ability to present complex data visually, aiding in both exploration and interpretation phases of seismic data analysis.

**3.1.2 Streamlit**

Streamlit is an open-source Python library designed for creating and sharing custom web applications for data science and machine learning projects. It allows data scientists and analysts to build interactive and visually appealing web apps with minimal effort, using pure Python scripts. By simply adding a few Streamlit commands, users can transform their data scripts into rich, interactive web applications that can include charts, data tables, maps, and other interactive widgets. This makes it easy to prototype, deploy, and share data insights and models with others without requiring extensive web development skills. Streamlit's intuitive design and powerful capabilities enable quick and effective data storytelling and decision-making.

**3.1.3. Data Set**

In this Streamlit web application project, the dataset comprises a well log in LAS format, utilized for visualization purposes and the calculation of key parameters crucial for understanding reservoir characteristics. The well log includes depth (DEPTH), gamma ray (GR), resistivity (ILD), bulk modulus (RHOB), neutron (NPHI), and sonic (DT) logs, providing a comprehensive view of the subsurface geological formations. The application allows users to visualize the well log data in various formats, such as log plots, cross-sections, and 3D models, facilitating the interpretation of geological features and petrophysical properties. Additionally, users can perform calculations to derive parameters like water saturation, permeability, and facies analysis, enhancing their understanding of reservoir dynamics. These visualization and analysis capabilities, seamlessly integrated into the Streamlit web application, empower users to explore and interrogate the well log data with ease. By providing interactive tools and intuitive interfaces, the application facilitates data-driven decision-making and fosters a deeper understanding of subsurface reservoirs.

**3.2 Methodology**

**3.2.1 Data Acquisition**

This section provides a comprehensive overview of the process involved in acquiring well log data in LAS format. It begins by discussing the various sources from which the data was obtained, including both public repositories and proprietary databases. The selection of specific well(s) for analysis is then detailed, highlighting the rationale behind the choices made. This includes criteria such as geographical location, ensuring a representative spread across different regions, and the depth of the wells, which was considered to capture a range of subsurface conditions. Additionally, the availability and completeness of data played a crucial role in the selection process. Wells with the most comprehensive and high-quality data sets were prioritized to ensure the reliability and robustness of the analysis. The section also touches on any challenges faced during data acquisition, such as data gaps or inconsistencies, and how these were addressed. By providing this detailed context, the section sets the stage for the subsequent analysis and interpretation of the well log data.

**3.2.2 Data Preprocessing**

This section describes the preprocessing steps applied to the well log data prior to analysis. The preprocessing process begins with data cleaning, which involves identifying and removing inconsistencies or outliers in the dataset. This step is crucial to ensure the integrity and accuracy of the data, as it helps to eliminate errors that could skew the analysis results.

Following data cleaning, filtering is applied to focus on relevant data ranges. This involves selecting specific intervals or depths that are pertinent to the analysis objectives, thereby narrowing down the dataset to the most critical information. Filtering helps to enhance the clarity and relevance of the analysis by excluding extraneous data that could dilute the findings.

Normalization is another key preprocessing step, aimed at standardizing the data format or units. This is particularly important when dealing with data from multiple sources or different measurement systems. By converting all data to a common scale or unit of measurement, normalization ensures consistency and comparability across the dataset, facilitating more accurate and meaningful analysis.

The rationale behind each preprocessing step is rooted in the need to enhance data quality and reliability. Data cleaning addresses potential inaccuracies, filtering refines the focus of the analysis, and normalization ensures uniformity. Collectively, these preprocessing steps play a pivotal role in improving the robustness and validity of the analysis results. Their impact is reflected in the enhanced accuracy, clarity, and comparability of the insights derived from the well log data.

**3.2.3 Streamlit Development**

This section covers the development process of the Streamlit web application. The initial phase involves setting up the development environment, selecting the appropriate programming languages, frameworks, and tools. Python is chosen as the primary programming language due to its extensive libraries and support for data science and web development. Streamlit, a Python-based framework, is selected for building the web application due to its simplicity and efficiency in creating interactive web interfaces.

The structure of the application is carefully outlined, comprising its main components, modules, and user interface elements. The application is organized into distinct modules, each responsible for specific functionalities such as data loading, preprocessing, analysis, and visualization. The user interface is designed to be intuitive and user-friendly, featuring interactive elements like file upload buttons, sliders, and dropdown menus to facilitate user interaction and customization.

Integration of necessary libraries and dependencies is a critical aspect of the development process. Essential libraries such as Pandas for data manipulation, Matplotlib and Seaborn for data visualization, and LASIO for reading well log data are incorporated to support the desired functionality. Dependencies are managed using tools like pip or conda to ensure compatibility and ease of installation.

Throughout the development process, emphasis is placed on creating a robust, scalable, and maintainable codebase. Code is written following best practices and principles such as modularity, reusability, and readability. Testing is conducted at various stages to identify and fix bugs, ensuring the application performs as expected.

By meticulously planning and executing each phase of the development process, the Streamlit web application is crafted to meet the needs of users, providing a powerful tool for analyzing well log data efficiently and effectively.

**3.2.4 User Interface Design**

This section elaborates on the design principles and considerations underlying the development of an intuitive and user-friendly interface for the Streamlit web application. The interface layout was meticulously planned to ensure a logical and efficient arrangement of elements, promoting a seamless navigation flow for users. Key components, such as the sidebar for file uploads and parameter selection, were strategically positioned for easy access and interaction. The design aimed to minimize clutter and provide a clear visual hierarchy, guiding users naturally through the analysis process.

Interactive features were incorporated to enhance user engagement and experience. For instance, dynamic plots and real-time updates provide immediate feedback and insights, fostering a more interactive and exploratory environment. The interface was designed to be responsive and adaptable, ensuring a consistent user experience across different devices and screen sizes. Accessibility and usability considerations were paramount, with efforts made to ensure that the application is accessible to users with varying levels of technical proficiency and those with disabilities. This includes implementing keyboard navigation, screen reader compatibility, and clear, descriptive labels for all interactive elements.

**3.2.5 Visualization Techniques**

In this section, the visualization techniques and tools employed to effectively present well log data are explored. Various types of visualizations, such as log plots, cross-sections, histograms, and 3D models, were utilized to facilitate comprehensive data interpretation and analysis. Log plots were instrumental in displaying continuous measurements of well properties, allowing for a clear comparison of multiple parameters across the same depth intervals. Cross-sections provided a detailed view of the subsurface structures, aiding in the identification of geological features and stratigraphic relationships.

Histograms were used to represent the distribution of specific well log parameters, enabling the detection of trends and anomalies within the dataset. These visualizations helped in recognizing patterns, such as the prevalence of certain lithologies or fluid types at different depths. 3D models offered a more immersive view of the well log data, allowing for spatial visualization of geological formations and enhancing the understanding of reservoir characteristics. Each visualization technique was selected for its ability to highlight specific aspects of the data, making it easier to interpret complex information and derive meaningful insights. Examples include identifying hydrocarbon-bearing zones through cross-sectional analysis, detecting anomalies in porosity and permeability distributions using histograms, and visualizing the spatial extent of different facies with 3D models. These visualizations collectively contributed to a more thorough and nuanced understanding of the well log data, supporting effective decision-making in subsurface exploration and development.

**3.2.6 Analytical Algorithms**

This section provides a detailed account of the algorithms and methodologies employed to calculate key petrophysical parameters from well log data. Each algorithm is explained step-by-step, highlighting the mathematical formulas and computational procedures used. The calculation of water saturation, for instance, involves the application of Archie's equation, which relates resistivity measurements to water saturation levels through specific parameters like formation resistivity factor and water resistivity. This process requires the manipulation of well log resistivity data to derive accurate estimates of water content in the reservoir.

Permeability calculations are performed using empirical correlations such as the Timur-Coates or Kozeny-Carman equations. These correlations use porosity and irreducible water saturation data to estimate permeability, providing insights into the ease with which fluids can move through the reservoir rock. The methodologies involve integrating well log measurements with established petrophysical models to generate reliable permeability values. Facies analysis is conducted using classification algorithms that leverage gamma-ray, density, and neutron porosity logs to distinguish between different lithologies. The algorithms classify the rock types based on predefined thresholds and criteria, aiding in the identification of sand, shale, and other facies.

Each algorithm is tailored to quantify specific parameters critical for reservoir characterization. The significance of these calculations lies in their ability to provide a comprehensive understanding of the reservoir's properties. Water saturation estimates help in evaluating hydrocarbon potential and determining the movable hydrocarbon volumes. Permeability assessments are crucial for predicting fluid flow behavior and planning efficient extraction strategies. Facies analysis aids in geological modeling and reservoir delineation, providing a clear picture of the subsurface environment. Collectively, these methodologies form the backbone of petrophysical analysis, transforming raw well log data into actionable insights for reservoir evaluation and development.

**3.2.7 Integration of External Tools**

This section outlines the integration of external libraries, APIs, and software tools into the Streamlit web application. Each external tool serves a specific purpose to enhance functionality and access to additional resources. For example, the use of the lasio library facilitates the reading and processing of LAS files, crucial for handling well log data. The matplotlib and seaborn libraries are employed for creating detailed visualizations, such as log plots and histograms, aiding in data interpretation. APIs like Google Maps or custom geospatial APIs might be integrated to provide geographical context to the well locations, enhancing the spatial analysis capabilities of the application. These integrations not only extend the application's capabilities but also significantly improve the user experience by offering robust data processing, visualization, and interactive features, making the analysis process more intuitive and comprehensive.

**3.2.8 Testing and Validation**

This section outlines the testing procedures and validation methods implemented to ensure the accuracy, reliability, and performance of the Streamlit web application and the analytical results it produces. Various types of tests were conducted, including unit tests to verify the functionality of individual components, integration tests to ensure seamless interaction between different modules, and user acceptance tests to evaluate the overall user experience and satisfaction. Validation benchmarks and standards, such as comparing computed results with industry-standard software or known datasets, were employed to assess the quality of the application's outputs. Performance testing was also carried out to measure the responsiveness and stability of the application under different conditions and loads. These rigorous testing and validation processes ensured that the application met high standards of accuracy and reliability, providing users with confidence in its analytical capabilities.

**3.2.9 Deployment Strategy**

This section details the deployment strategy for the Streamlit web application, encompassing key considerations from hosting to maintenance. It starts by exploring the selection of a hosting provider based on criteria such as performance, reliability, and scalability, ensuring optimal server configuration to support anticipated user traffic and application demands. Security measures are discussed in depth, focusing on safeguarding sensitive data through encryption protocols, access controls, and compliance with relevant privacy regulations. Maintenance procedures are outlined to ensure ongoing functionality and performance, including regular updates to incorporate new features, patches for security vulnerabilities, and monitoring to promptly address any issues that may arise. This comprehensive deployment strategy aims to provide a secure, scalable, and reliable platform for users to access and utilize the Streamlit web application effectively.

**3.2.10 Documentation and User Guide**

In this final section, the methodology, code, and functionality of the Streamlit web application are meticulously documented to enhance usability and accessibility. A comprehensive user guide is crafted to provide detailed instructions on navigating the application, interpreting analysis results, and troubleshooting potential issues. This documentation ensures that end-users can effectively utilize the application, leveraging its features for data analysis and decision-making processes. Clear explanations and visual aids are integrated into the guide to simplify complex concepts and empower users to maximize the application's capabilities. By prioritizing robust documentation, the Streamlit web application aims to foster user confidence and facilitate seamless interactions, promoting enhanced usability and overall user satisfaction.

**CHAPTER FOUR**

**RESULT AND DISCUSSION**

**4.1 Introduction**

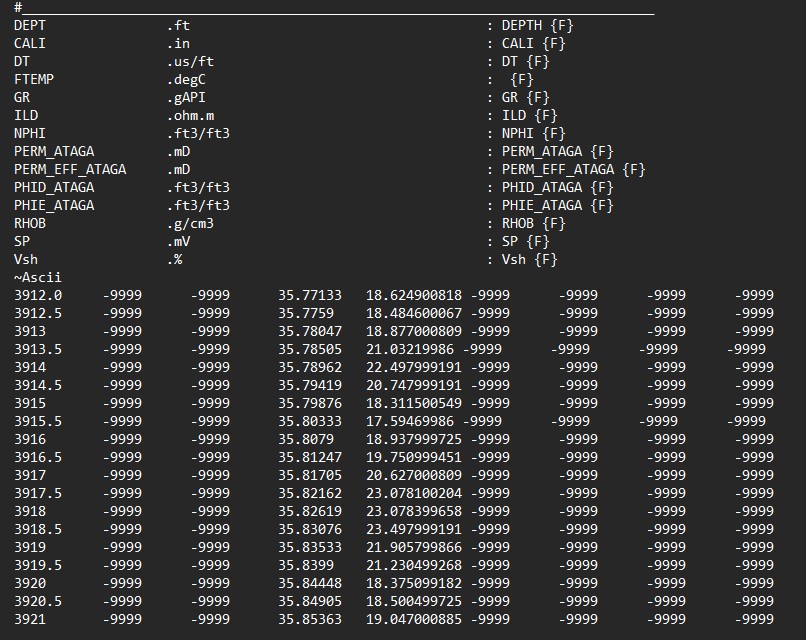
This project focuses on the analysis of well log data to assess the petrophysical properties of subsurface formations. Key findings include the determination of lithology based on gamma-ray logs, calculation of porosity, evaluation of water saturation, permeability assessment, and identification of shale content. The results provide valuable insights into the geological characteristics of the reservoir, essential for understanding its potential for hydrocarbon extraction.

**4.2 Petrophysical Result**

#### **4.2.1 Dataset and Its Parameters**

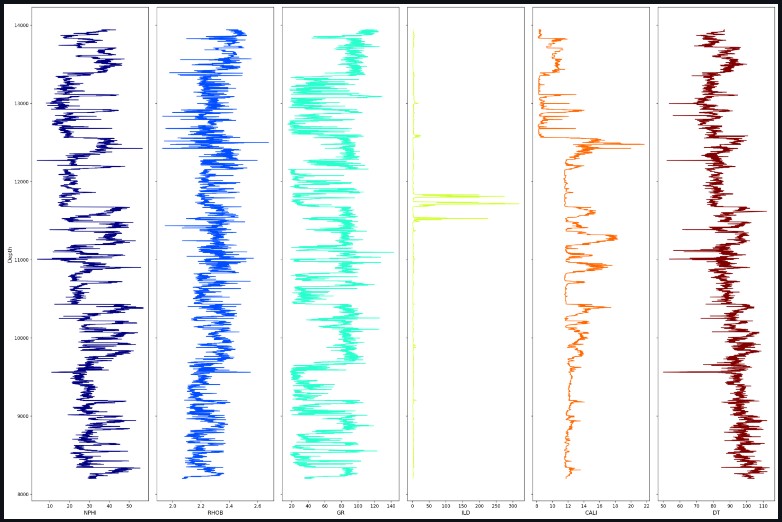
The dataset used in this study consists of well log data (Table 4.1). It includes critical parameters such as gamma-ray (GR), neutron porosity (NPHI), bulk density (RHOB), resistivity (ILD), acoustic travel time (DT), and caliper (CALI). These logs are essential for detailed reservoir characterization, providing insights into lithological composition, porosity variations, fluid content, and rock properties across different reservoir intervals. The data's comprehensive coverage enables a thorough analysis of subsurface geology, aiding in the identification of potential hydrocarbon-bearing zones and reservoir quality assessment.

**Table 4.1: Well log viewed on Notepad**



#### **4.2.2 Well Log Plot**

Detailed well log plots offer visual interpretations of individual parameters across depth intervals. Plots of gamma-ray, neutron porosity, bulk density, resistivity, acoustic travel time, and caliper reveal intricate variations and trends within the subsurface formations (figure 4.1). These visualizations not only highlight geological boundaries and stratigraphic features but also assist in identifying lithological changes, fluid contacts, and structural complexities. Such insights are crucial for reservoir characterization and play a significant role in optimizing well placement, field development strategies, and production enhancement plans based on detailed subsurface data.



**Figure 4.1: General Well Log Plot**

#### **4.2.3 Petrophysical Analysis Plot**

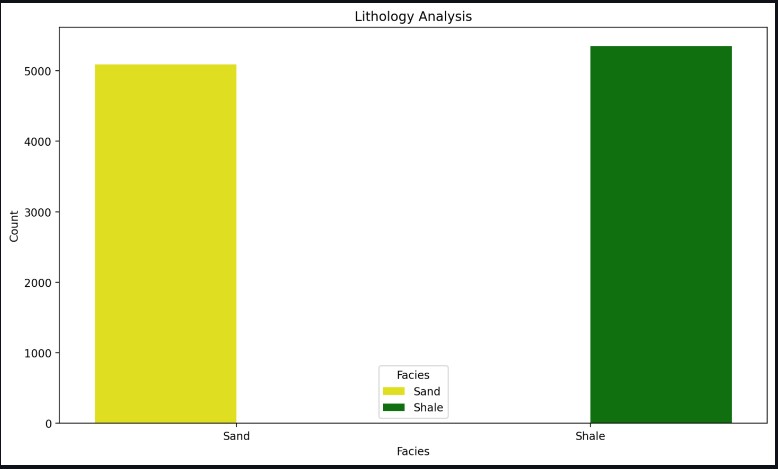
Comprehensive petrophysical analysis plots integrate multiple parameters to illustrate their spatial distribution and interrelationships within the reservoir (figure 4.2). Plots include logarithmic-scale resistivity profiles, overlaid bulk density and neutron porosity with shaded areas indicating differences, water saturation distributions, permeability trends, volume of shale variations, and porosity changes throughout reservoir depths. These visualizations provide a holistic view of reservoir heterogeneity, facilitating the identification of productive zones, reservoir compartmentalization, and potential flow barriers. They are instrumental in supporting reservoir management decisions, reservoir modeling efforts, and reservoir simulation studies aimed at optimizing hydrocarbon recovery and field performance.

#### **4.2.4 Facies Analysis Plot**

A violin plot visually represents the distribution of lithological facies (Sand vs. Shale) based on gamma-ray data (figure 4.3). This plot effectively illustrates facies variations and their spatial extent within the reservoir. It provides critical insights into sedimentological settings, depositional environments, and reservoir architecture, influencing interpretations of reservoir quality and connectivity. By identifying facies-controlled petrophysical properties such as porosity, permeability, and fluid saturation, this visualization supports robust geological modeling and enhances understanding of reservoir behavior under varying production scenarios.

#### 

**Figure 4.2: Petrophysics Well Log Plot**



**Figure 4.3: Facie plot of lithology.**

#### **4.2.5 Average values across the Reservoir**

A detailed summary table presents the average values of key parameters across the reservoir, including gamma-ray, volume of shale, water saturation, permeability, porosity, and resistivity. (Table 4.2). This quantitative analysis provides a comprehensive overview of the reservoir's petrophysical characteristics and variability. By summarizing central tendencies and spatial distributions, the table facilitates comparative analysis across different well locations or field areas. Such insights are invaluable for reservoir engineers, geoscientists, and stakeholders involved in reservoir management, aiding in reservoir characterization, resource estimation, and strategic decision-making for optimal hydrocarbon recovery and asset development.

#### **New Data Columns**

The petrophysical analysis introduced additional computed columns to enhance reservoir characterization and analysis (Table 4.3). These include:

**Water Saturation (Sw)**: Calculated using resistivity and density logs, indicating fluid content within the reservoir.

**Permeability (Perm)**: Estimated from core data or empirical correlations, providing insights into fluid flow potential.

**Volume of Shale (Vsh)**: Derived from gamma-ray logs, offering insights into lithological composition and reservoir quality.

**Porosity**: Computed from bulk density logs, indicating pore space within the rock matrix. These columns play a crucial role in understanding reservoir dynamics, fluid behavior, and production potential, aiding in reservoir management and decision-making processes.

**Table 4.2: Average values across the Reservoir**

#### 

**Table 4.3: Data Set after petrophysics calculation vied on Excel**

#### 

#### **4.2.7 Save Plots and Tables**

All visualizations, including individual well logs, comprehensive petrophysical analysis plots, facies analysis plots, and summary tables, are saved (by clicking a button on the app) for further analysis and documentation. The saved outputs include:

* **Individual Well Log Plots**: Detailed visualizations of various well log parameters across depth intervals.
* **Petrophysical Analysis Plots**: Integrated plots showcasing the spatial distribution and interrelationships of key reservoir parameters.
* **Facies Analysis Plot**: Count plot illustrating the distribution of lithological facies based on gamma-ray data.
* **Average value across the Reservoir**: Summary table presenting average values of critical parameters across the reservoir. These saved outputs serve as references for reservoir modeling, simulation studies, and decision support, ensuring comprehensive data documentation and accessibility for future analyses and evaluations.

### **4.3 General Discussion**

The results presented in this study provide valuable insights into the petrophysical characteristics and lithological composition of the studied reservoir. Through a combination of well log analysis and petrophysical computations, key parameters such as gamma-ray intensity, volume of shale, water saturation, permeability, porosity, and resistivity were evaluated to characterize reservoir quality and fluid behavior.

#### **4.3.1 Reservoir Characterization and Interpretation**

The dataset utilized in this study comprised comprehensive well log data, enabling detailed analysis of subsurface properties. Key findings include:

**Lithological Variation**: The facies analysis revealed distinct lithological units characterized by varying gamma-ray signatures, crucial for identifying sand and shale intervals.

**Petrophysical Properties**: Calculated parameters such as porosity and permeability provided quantitative measures of reservoir quality, highlighting zones of high porosity conducive to fluid storage and zones with elevated permeability facilitating fluid flow.

#### **4.3.2 Insights into Reservoir Dynamics**

The integration of petrophysical analysis with geological interpretations yielded significant insights into reservoir dynamics:

**Fluid Saturation and Distribution**: Water saturation profiles depicted variations in fluid content across different reservoir depths, influencing hydrocarbon recovery strategies.

**Permeability Variability**: Effective permeability assessments highlighted zones of enhanced fluid flow potential, crucial for optimizing well placement and production strategies.

**Volume of Shale Impact**: Volume of shale computations identified intervals with higher shale content, impacting reservoir performance through porosity reduction and permeability barriers.

#### **4.3.3 Implications for Reservoir Management**

The findings have direct implications for reservoir management and development strategies:

**Optimized Production Strategies**: Insights into reservoir heterogeneity and fluid distribution guide enhanced well completion designs and production optimization techniques.

**Risk Mitigation**: Identification of low-porosity or high-shale zones informs risk management strategies, minimizing drilling uncertainties and optimizing economic returns.

**Future Directions**: Continued integration of advanced modeling techniques and additional data sources could further refine reservoir characterization, supporting sustainable reservoir development and management practices.

In conclusion, the combined use of well log analysis and petrophysical computations has provided a comprehensive understanding of reservoir characteristics and behavior. The insights gained are instrumental in guiding effective reservoir management decisions and formulating strategies for sustainable hydrocarbon extraction. Future research endeavors should focus on refining predictive models and leveraging emerging technologies to enhance reservoir characterization and management practices. This study underscores the importance of integrated approaches in reservoir evaluation, ensuring informed decision-making and optimizing resource recovery in complex subsurface environments.

**CHAPTER FIVE**

**CONCLUSION, LIMITATION AND RECOMMENDATION**

### **5.1 Conclusion**

In conclusion, the comprehensive analysis of well log data and advanced petrophysical computations has yielded invaluable insights into the geological and reservoir engineering aspects of the study area. Through the utilization of gamma-ray logs for lithological classification, we have effectively delineated distinct facies zones, providing critical information for reservoir characterization and understanding reservoir heterogeneity. This classification not only enhances our understanding of the geological setting but also supports targeted reservoir management strategies.

The derived petrophysical parameters, including porosity, permeability, water saturation, and resistivity, serve as fundamental metrics for assessing reservoir quality and productivity potential. These parameters play a pivotal role in guiding reservoir development decisions, optimizing well placement strategies, and designing effective stimulation programs. By integrating these insights into a cohesive reservoir model, we have achieved a comprehensive understanding of subsurface conditions, facilitating accurate reservoir performance predictions and informed decision-making.

Moreover, the integration of advanced analytical techniques and computational methods has enabled a holistic approach to reservoir characterization and management. The application of and data-driven analytics has further enhanced our predictive capabilities and model accuracy, setting a precedent for future reservoir studies and exploration efforts.

Moving forward, continuous advancements in data acquisition technologies, model validation techniques, and sustainable reservoir management practices will be crucial. By embracing innovation and collaboration across disciplines, we can further refine our understanding of subsurface dynamics, optimize production efficiencies, and ensure responsible resource development.

### **5.2 Limitations**

Despite the significant strides made, this study encounters several limitations that warrant acknowledgment. Variations in data quality and availability across different wells and depths may introduce uncertainties in the interpretation and application of results. Moreover, the inherent complexities of subsurface geology, including heterogeneity, anisotropy, and diagenetic effects, pose challenges in accurately characterizing reservoir properties.

Furthermore, while advanced petrophysical calculations provide valuable insights, inherent assumptions and empirical correlations used in these computations may introduce biases and inaccuracies. Addressing these limitations requires continuous advancements in data acquisition technologies, improved calibration techniques, and enhanced integration of multidisciplinary data sets.

### **5.3 Recommendations**

Based on the insights gained from this study, several recommendations are proposed to enhance future reservoir exploration and management efforts:

**Integrated Data Acquisition:** Expand the integration of diverse well log data sets, including advanced petrophysical measurements and real-time monitoring technologies, to capture a comprehensive range of geological and reservoir engineering parameters.

**Advanced Reservoir Modeling:** Implement integrated reservoir modeling approaches that incorporate machine learning algorithms and data-driven analytics. This will enhance predictive capabilities, facilitate more accurate reservoir characterization, and optimize development strategies.

**Risk Mitigation Strategies:** Develop robust risk assessment frameworks to quantify uncertainties associated with data interpretation and modeling outputs. Incorporate sensitivity analyses and Monte Carlo simulations to assess the impact of parameter variability on reservoir performance predictions.

**Continual Validation and Calibration:** Establish rigorous validation protocols to verify the accuracy and reliability of reservoir models against historical production data and well performance. Incorporate feedback loops to iteratively refine models and improve predictive accuracy over time.

**Sustainable Development Practices:** Embrace sustainable reservoir management practices that prioritize environmental stewardship, regulatory compliance, and community engagement. Implement measures to minimize environmental impacts, conserve natural resources, and promote responsible hydrocarbon development.

**Investment in Innovation:** Foster collaboration between academia, industry, and research institutions to advance technological innovations in reservoir characterization, monitoring, and management. Invest in emerging technologies such as digital twins, AI-driven analytics, and enhanced imaging techniques to unlock new insights and efficiencies in reservoir operations.

By implementing these recommendations, stakeholders can enhance their ability to make informed decisions, optimize reservoir performance, and achieve sustainable development goals in the oil and gas industry.

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