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# A Review of the Qualitative and Quantitative Hydrocarbon Potential of the Offshore Liberian Basin

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## Abstract

This report focuses on the assessment of potential for undiscovered, technically recoverable oil and gas resources within the Liberian offshore Basin. The 2D and 3D seismic reports were used to generate and evaluate the reservoir systems of the basin, and the syn-rift section. The results show that sediments were deposited during relative sea level fall along the shoreline. Pyrolysis results indicate a TOC of 2.6 wt% across the basin. However, Carmine Deep-1 has a TOC range of 1.3-2.55wt%, as well as Nighthawk-1 shows a TOC range of 0.52-3.6 8wt%. This is an indication of mature source rock. The vitrinite reflectance from predrill data analysis (Rock-Eval analysis) has a range of 0.77R% for Carmine Deep-1 and 0.97R% for Nighthawk-1 well. This also shows that the source rock is in the early Mature stage and the type of organic matter present in Carmine-1 formation is different compared to Nighthawk formation. Geochemical analysis from predrill and exploration data the biomarker shows the presence of an extended tricyclic terpanes in Carmine Deep-1 well, which indicates that marine upwelling took place during the Aptian-Upper Albian/Cenomanian-Turonian interval. This shows that the Aptian-upper Albian/Cenomanian-Turonian interval experienced favourable conditions for organic matter productivity and the development of a good hydrocarbon source rocks. The results imply that the basin has a good source rock quality and quantity with Nighthawk-1 and Carmine Deep-1 indicating good source potential, hence, has provided a framework for future prediction of good source rock performance.

**Keywords:** West African Transform Margin, Liberian Basin, Hydrocarbon Potential, Pyrolysis, Total Organic Carbon (TOC).

## Introduction

The Liberian Offshore Basin is connected to the opening of the Atlantic Ocean and it represents a rifted and subsided region that developed during the breakup of the supercontinent Pangaea. However, this study is driven with a focus on the assessment of potential for undiscovered, technically recoverable oil and gas resources in the Liberian Offshore Basin.

The Liberian Basin has long been thought to contain significant offshore oil target but only recently, because of increased in political stability, has been the site of new exploration drilling. The Liberian Basin forms part of the West African Transform Margin that extends from Sierra Leone to Benin (Frynas, 1998).

The West African Transform Margin, offshore west Africa is an emerging region for offshore oil and gas exploration, and greater political stability in the recent decades in a number of countries that comprise the region have encouraged oil and gas companies to engage in drilling activities in this region (Liu et al., 2008).

Hydrocarbon exploration has been active in this region since the 1970s when offshore seismic was acquired and shelfal wells were drilled. Early exploration was concentrated on the Albian-Aptian structural traps in wells drilled in shallow water above the continental shelf (Conn and Rodriguez, 2011). The location map of the basin is presented in Figure 1.

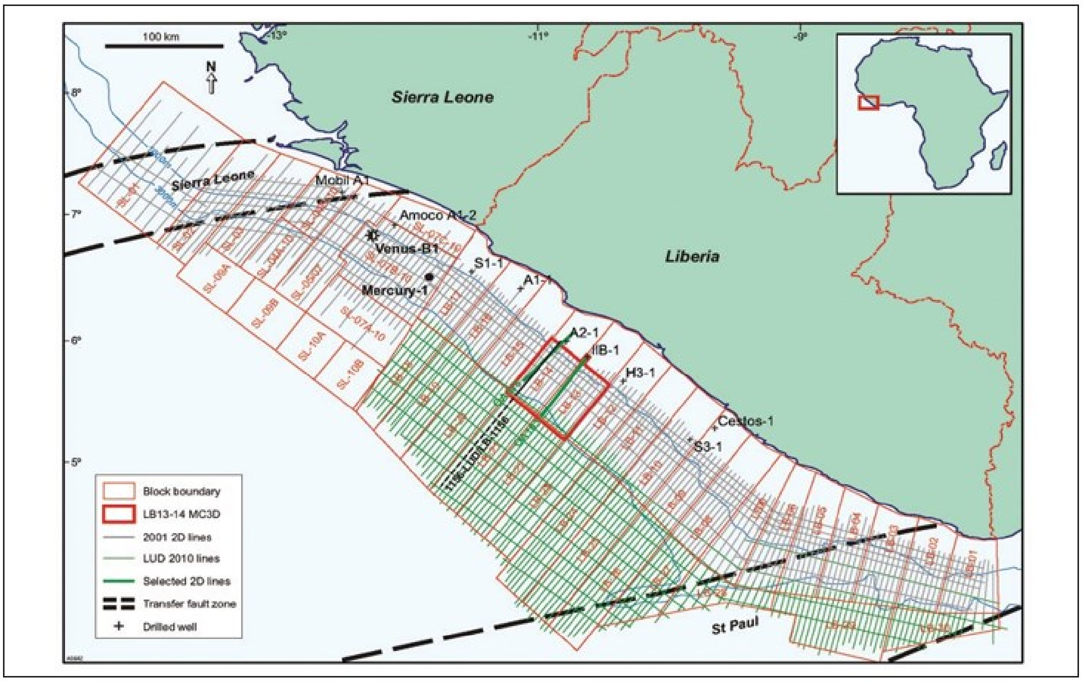


**Figure 1: Location Map of the Liberian Basin** (Conn & Rodriguez, 2011)

The Liberian Basin, which includes the continental shelf and edge of the Liberian coast, has attracted considerable attention in the past and the present, leading to a number of geological and geophysical researches that resulted in the drilling of multiple wells offshore along the coast. When Cretaceous or more recent sediments were deposited, block faulting happened simultaneously (Thorman, 1972). Petroleum exploration initially commenced in Liberia as early as 1948 when offshore seismic was acquired and shelfal wells were drilled and ceased in 1972 with four wells been drilled; two wells by Union Carbide while Chevron and Cestos drilled one well each (Temple and Desgranges, 2014). These wells were not commercially viable but a working petroleum system was identified which appears to have led to no additional or extensive drilling during these periods (Temple and Desgranges, 2014). Exploration activity started again in 1968 when the government commissioned an offshore/onshore aeromagnetic survey. The survey indicated the presence of a thick sedimentary section. Further in 1968, Conoco and Chevron acquired magnetic, seismic and gravity data from the government with Union Carbide also acquiring some offshore/onshore gravity data (Tarr, 2014). All exploratory wells drilled during these periods were proven to be non-commercial until during one of the intermittent periods of Liberian's civil wars in the year 2000, TGS-NOPEC Geophysical company, under the auspices of the then newly formed National Oil Company of Liberia (NOCAL), began the acquisition of seismic data offshore Liberia. Early exploration was concentrated on the Albian-Aptian structural traps in wells drilled in shallow water above the continental shelf (Doyle, 1982). Later in 2011, two exploration wells were drilled offshore Liberia, Apalis-1 and Montserrado-1. Apalis. These wells were found to have upper Cretaceous source rock and reservoir rock with oil shows. Montserrado-1 was drilled to a depth of 5400 m (17720 ft) and a non-commercial oil discovery in late Cretaceous reservoir sands. The well-drilled encountered a good quality, water-bearing sands. In a deeper secondary target, 8 m (26 ft) of hydrocarbon pay was intersected and a sample of light oil was recovered (Heller and Marcel, 2012).

**Research Problem**

The west African Transform Margin has numerous regions of hydrocarbon potential extending from Sierra Leone to the west and Benin to the East. The Liberian basin is comparable to the Sierra Leone Basin with comparable inland topography where huge gas prospect has been identified. However, the Liberian Basin has not experienced any commercial discovery of commercial hydrocarbon after a few exploration wells being penetrated. There's prove of gas column in a few of the wells drilled within the post Cretaceous. The need to investigate this phenomenon is relevant to the improvement of the Liberian Basin. It remains hazy why the Liberian Basin isn't demonstrating adequate hydrocarbon potential in spite of a working petroleum system. This research will explore the basin commercial practicality by assessing the hydrocarbon potential and determine the source rock and reservoir properties of the basin.

**Geological Background**

The Liberian Basin is situated offshore of Liberia between the southern Liberian-Harper Basin and Sierra Leone. Both the St. Paul transform system and the Sierra Leone transform system encircle its southern and northern margins. With the use of  magnetic and gravity measurements, (Schlee et al., 1974) the basin was identified on the continental edge of west coast Liberia. The transform systems play a significant role in the tectonic framework and evolution of the region. The presence of the transform faults influences the structural configuration and sedimentation patterns within the Liberian Basin (Ye et al., 2017).

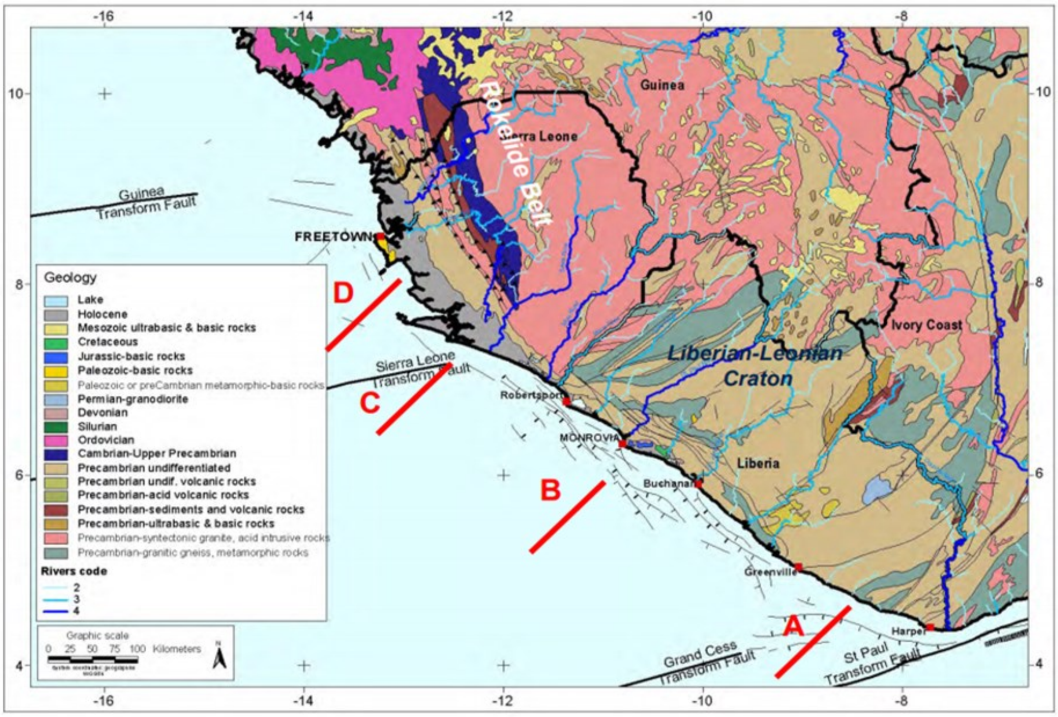


**Figure 2: A geological map illustrating the basins along the west African transform Margin, specifically highlighting the Liberian and Sierra Leone basins and their transform fault boundaries** (Bennett and Rusk, 2002)

A series of basins developed along the West African Transform Margin between major transform fault zones associated with the opening of the South Atlantic Ocean from the early Cretaceous onward. The Sierra Leone transform fault and St. Paul transform fault are regarded as forming the boundaries between the Sierra Leone Basin and Harper Basin of the Liberian Basin as seen in Figure 2.

A generalized stratigraphic chart for the sedimentary section of the Liberian Basin indicates the syn-transform stage was active from Aptian to Turonian. The Aptian to mid-Albian was the active rifting stage with fluvial/lacustrine conditions generally trending to shallow marine with the final breakup of Gondwanaland. From the mid-Albian unconformity to top Turonian, the seismic data indicate continuing transform movement in deep-water (at times anoxic) conditions. A significant uniformity occurs around the Santonian-Campanian with a passive margin stage from Late Campanian to Recent. Another major unconformity is seen in the Oligocene and has caused up to 1 km of erosion on the slope in places. The Miocene-to-Recent interval tends to be characterized by slumps and canyons created in a deep-water environment. Shelfal wells indicates that source rock is present in the Aptian-Albian interval (Figure 3) in lacustrine-shallow marine environments (Conn and Rodriguez, 2011).

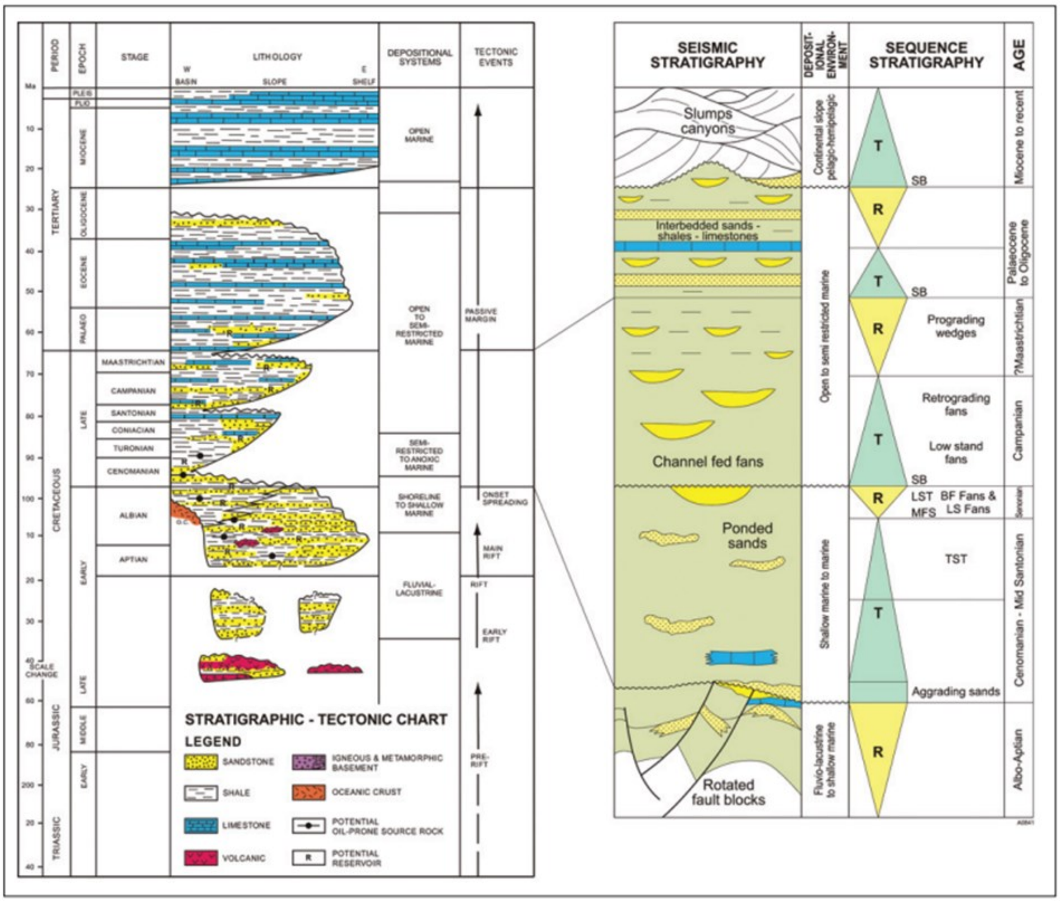


**Figure 3: A generalized stratigraphic and tectonic chart of the Liberian Basin, illustrating depositional environments and seismic stratigraphy in relation to tectonic events** (Charpentier et al., 2008)

## Objectives

### General Objective

To qualitatively and quantitatively assess the Hydrocarbon potential of the Liberian Basin.

### Specific Objectives

- Using predrill data to explain and quantify the Total organic carbon, Biomarker, API, and maturity level of the Liberian basin.
- Using wells and exploration reports to study the reservoir, syn-rift system, and the environment of deposition of the Liberian Basin.
- Evaluate the Hydrocarbon potential of the offshore Liberian Basin.

### Research Questions

1. What are the key factors affecting the offshore hydrocarbon potential of the Liberian basin, and how can they be evaluated effectively?

2. How do well logs and exploration reports inform the understanding of the reservoir characteristics, syn-rift systems, and the depositional environment of the Liberian Basin?
3. What is the total organic carbon, biomarker, API gravity, and maturity level of hydrocarbons in the Liberian Basin based on Pre-drill data?

## Literature Review

### The Geology of Liberia

Liberia is located on the West African shield, an ancient geological formation composed of rocks that are between 2.7-3.4 billion years old. The shield consists predominantly of stone, schist, and gneiss formations. Over its long geological history, the West African shield has undergone significant rifting and faulting and faulting processes, shaping its current landscape (Hadden, 2006). One notable feature of the West African shield is the presence of iron-bearing formations called itabirites. These formations are significant as they often contain economically valuable iron ore deposits. The West African Shield is characterized by ancient rocks that have been highly metamorphosed and deformed over billions of years. It includes a variety of rocks types, such as granite, gneiss, and schist, as well as greenstone belts that contain volcanic and sedimentary rocks. Monrovia, the capital of Liberia, is situated on an outcrop of diabase, which is a dark-colored, fine grained rock. In terms of the broader geological context of Liberia, the majority of crystalline rocks in the country are of Precambrian age.

The western region of Liberia is characterized by ancient Precambrian basements rocks, such as granite and gneiss, which are some of the oldest rocks on earth. These rocks formed over billions of years through processes like metamorphism and magmatism. Liberia sits on the West African Craton, a stable part of the African continental that dates back to the Archean Eon (4-2.5 billion years ago). This craton is composed of various rock types, including granite-greenstone belts and sedimentary basins (Gunn et al., 2018).

Sandbars that are deposited by rivers, lagoons, and mangrove swamps define the shoreline along the Atlantic Ocean. The grassy plateau inland sustains a small amount of Archean-era agriculture and there are lenses of Proterozoic greenstone belts throughout the eastern part of the nation.

### Formation and Tectonic setting of the Liberian Basin

The Liberian Basin formed during the breakup of the supercontinent Pangaea during the Mesozoic time, around 200 million a long time back. This breakup come about within the division of Africa from south America and started the opening of the Atlantic Ocean. The basin is situated inside the biggest West African Craton, a steady continental crust piece that has experienced generally small structural action since the Precambrian time. Be that as it may, during the Mesozoic and Cenozoic times, the region experienced critical structural events, counting rifting and basin formation (Dirks et al., 2009).

**Paynesville Sandstone**

The Paynesville Sandstone (White, 1972) is as a rule found underneath white or brown unconsolidated sand stores, forming low, rounded, brownish handles in wide savannahs. It may be a gneiss formation. Jurassic diabase sills and barriers barge in it, and it looks to be overlain by an amygdaloidal basalt stream.

A potential thickness of generally 1,000 meters is proposed by gravity and aeromagnetic data near to the Sugar Shoreline (Thorman, 1972). It is tentatively believed that the Paynesville sandstone is Devonian. It bears a striking resemblance to the Devonian cross bedded orthoquartzite that contains spores and is found stratigraphically beneath Jurassic basalts and Cretaceous sedimentary rocks in a number of offshore drill sites.

**Farmington River Formation**

The Farmington River Formation (White, 1972) consists of two interbedded facies, a "polymict conglomerate" (Kfc) that is most abundant near the base and to the northeast and becomes less abundant upward and seaward, and a "wacke" sandstone (Kf) that makes up the bulk of the formation and becomes finer grained upward with increase of the thin shale interbeds. The sandstone ranges from arkose to graywacke. A thickness of about 1.5 kilometers is estimated for the onshore part of the formation on the basis of gravity data (Behrendt et al., 1974). An Early Cretaceous age is based on pollen and spores from several localities. Correlative marine rocks have been found in several offshore drill holes.

## Materials and Methods

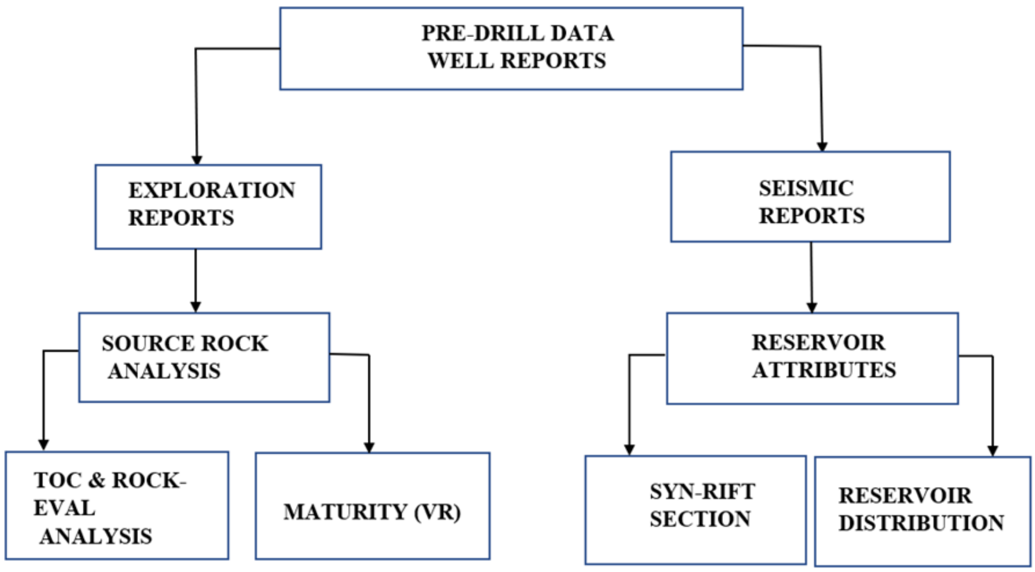


**Figure 4: A flowchart detailing the methodology to analyze the hydrocarbon Potential of the Liberian Basin.**

The study combines both qualitative and quantitative approaches to describe and explain the reservoir units and source rock properties. Qualitative analysis involves describing the lithological characteristics, depositional environments, and stratigraphic relationships of the reservoir units and source rocks. Quantitative analysis involves numerical assessments, such as calculating the total organic carbon content, thermal maturity, and hydrocarbon generation potential of the source rock.

The materials used for this study includes; predrill data analysis and desktop studies carry out on the basin, end of well reports, research papers and available exploration reports, Isojars, flame ionization Dector (FID), Mass Spectrometry (MS) and Isotubes. Special attention was being paid to two wells from the Basin (Carmine Deep Well and Nighthark).

Drill cuttings and SWC (Side Wall Core) representative samples were collected at a regular interval and from different depths to capture the variations in the rock formation. Samples were cleaned to remove any drilling mud or contaminations and crushed at typically less than 2 mm for analysis. 4 samples for the hotshot analysis and 75 samples for the regular analysis and 2 shales in Cenomanian-Turonian (CT) and 8 sandstones for extracts and Gas Chromatography (GC) and Gas Chromatography Spectrometry (GC-MS) for Nighthawk-1 well, while 21 samples for hotshot analysis and 65 samples for regular analysis and 16 shales in CT for extracts and GC, and GC-MS for Carmine-1 well.

Total Organic carbon was analyzed using pyrolysis method. Pyrolysis method is one of the widely used techniques for determining the organic carbon content (TOC) in rock samples. This method involves subjecting the sample to high temperatures in an inert atmosphere, causing the organic matter to decompose and release volatile compounds. The compounds are then analyzed to quantify the organic content of the rock sample (Hazra et al., 2017).

Fluid inclusion analysis using isojars (headspace gas) and isotubes (mud gas) was a method used to study the composition and characteristics of fluids trapped within rock samples. This analysis provides valuable information about the history of fluid migration, temperature, and pressure condition.

Isojars are small containers that are used to capture and analyze the gases released from fluid inclusions. The grinded samples were placed into an isojar and sealed tightly, then the isojar was heated to a temperature of 150°C to allow the trapped gases to be released into the headspace. The headspace gas was then analyzed using the GC (Gas Chromatography) to identify and quantify the different gases present. The composition of headspace provides information about the type of fluids trapped in the inclusions and their potential sources.

Isotubes are sampling devices that collect gases directly from the drilling mud during the drilling process. An Isotubes was connected to the drilling mud circulation system to collect gases that are released during drilling. The gases collected were representative of the fluids encountered during the drilling process, including those from fluid inclusions and were analyzed using the GC to determine their composition. The Isotubes analysis provides information about the fluids encountered while drilling and was used to compared with the isojar analysis to validate the earlier results.

Seismic data were acquired and processed from a seismic section, a survey recorded in water depth approximately 3000 to 4500 meters, comprising of in-lines and cross-lines were analyzed to determine the reservoir distribution and syn-rift section of the Liberian Basin. The data was analyzed using the petrel software to determine, major fault blocks, reservoir distribution and the syn-rift section of the Basin.
Horizon interpretation, which involves identifying and picking key seismic events, such as the top and base of reservoir units and syn-rift structures was carried out. This helps in mapping the distribution and geometry of the reservoirs and syn-rift features within the seismic section, such as the basin floor fan and rifting that created the basin.
Amplitude analysis was done using the amplitude versus offset technique to examine variations in seismic amplitudes to identify potential reservoirs and syn-rift structures. Seismic inversion was done using the pre-stack inversion to estimate the rock properties of the subsurface; it helps in determining the distribution of the reservoir and identifying the syn-rift structures.
In the syn-rift analysis, seismic data was used to create cross-sections that highlighted the structural and stratigraphic features associated with the syn-rift phase.

## Results and Discussions

The results obtained from predrill and end of wells reports (EOW), seismic survey reports, as well as geochemical analyses were carried out to technically review and evaluate the hydrocarbon potential of offshore Liberian Basin.
These data were carefully analyzed in terms of source rock properties, correlation and attribute extraction were utilize to generate: source rock analysis, reservoir attributes (reservoir sand and distribution) as well seismic section that describes the reservoir and syn-rift unit of the Basin.
The data were processed from a seismic section and well test data that included a regional 2-D and 3-D ultradeep seismic survey recorded in water depth 300-4500 m. The source rock interpretation was carried from results obtained from cuttings and SWC data specifically for the two wells in the Basin, Carmine Deep-1 and Nighthark-1.
The interpreted and analyzed predrill and end of wells reports was used to delineate the geochemical properties of the Basin in terms of source rock evaluation with special emphasis on two wells from the Basin (Carmine Deep-1 and Nighthawk-1). The Geochemical data was used to determine source rock quality, biomarkers indication and TOC across each well in the Basin.

### Carmine Deep-1

Carmine Deep-1 contains a regular sample of 65 cuttings for TOC and Rock-eval analysis and 16 shales samples of SWC for TOC and Rock-Eval analysis and 5 shales samples for extracts used in GC and GC-MS analysis.

Abundant oil inclusions observed at 11050', 11160' and 12050' in Carmine with the highest abundance at 11160'. API gravities from fluid inclusions showed two populations: 30-35 and 38-41, probably indicating multiple charge episodes. Hydrogen Index (HI) from Carmine Deep Well in the Turonian-Cenomanian -Upper Albian from Hotshot sample varies between 40-181, low hydrogen index values are typically due to presence of oxidized organic matter and/or high maturity of the source rock. Total Organic Carbon value varies between 1.3-2.5 wt% in the Turonian- Cenomanian –Upper Albian from hotshot samples (Figure 5).

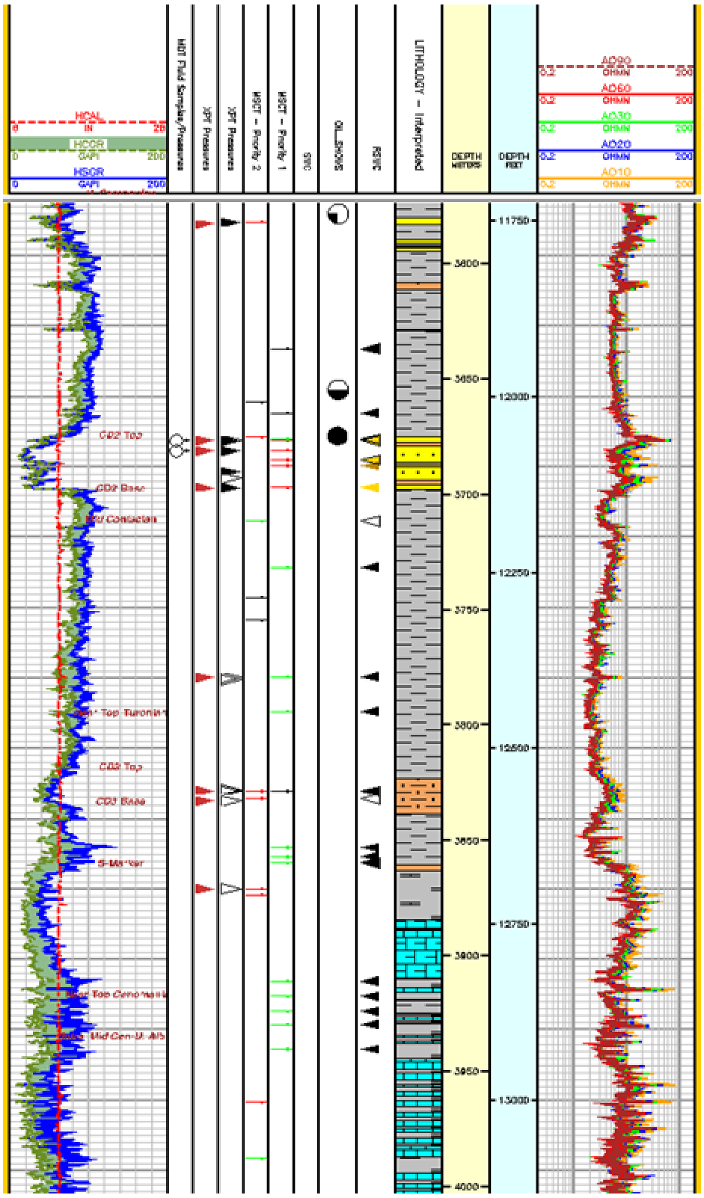

**Figure 5: Well Log section of Carmine Deep-1 Well: Chevron Liberia Ltd, 2012**

**Table 1: Geological and Geochemical characteristics of Carmine Deep-1 well.**

| CARMINE DEEP-1 | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Data** | Depth (ft) | AGE | TOC w% | HYDROGEN INDEX | Tmax | %S | API GRAVIT |
| **Hotshot** | 11050, 11160, and 12050 | | | | | | 30-35 ar 38-41 |
| **Hotshot** | 12400-13600 | Turonian-Cenomanian -Upper. Albian | 1.3-2.5 | | | | |
| **Hotshot** | 12400-13600 | Turonian-Cenomanian -Upper. Albian | | 40-181 | | N/A | |
| **Hotshot** | 12400-13600 | | | | 438-446 | | |

***Hint:*** *the above table provides detailed information about the geological and geochemical properties observed at various depths in the Carmine Deep-1 well. It includes depth intervals, geological ages, total organic carbon content, HI values, Tmax values, sulfur content and API gravity for the formations encountered. The Carmine deep-1 well exhibits excellent petroleum potential due to the very high TOC, indicating a rich source rock capable of generating large amounts of hydrocarbons. The varying HI suggests a complex mixture of organic material, capable of generating both oil and gas. The HI values indicate that while the source rock is primarily gas-prone (Type III kerogen), there is a substantial component of oil-prone kerogen (Type II) in some parts of the rock*

**Nighthawk-1**

Nighthawk contains regular samples of 75 cuttings for TOC and Rock-Eval analysis with 28 samples SWC for TOC and Rock-Eval analysis and extracts for GC and GC-MS analysis while 8 sandstones were used for hotshot samples analysis using GC and GC-MS.

Abundant oil inclusions were observed in the sand at 13610 ft in Nighthawk (from hotshot samples). API gravities measured on fluid inclusions show several populations: 19-21, 31-35, 29-31 and 36-38, probably indicating multiple charge episodes. Hydrogen index from Nighthawk-1 cuttings in the Turonian-Cenomanian-Upper Albian at 13940'-14570' varies between 40-181, low hydrogen index values are typically due to presence of oxidized organic matter and/or high maturity of the source rock in both Carmine and Nighthawk Wells. Vitrinite reflectance at measurements between 13760'-14879' in Nighthawk-1 indicate maturities between 0.77-0.97%Ro. This indicates a potential source rock in this interval which is within the late oil generation window. However, vitrinite reflectance was potentially impacted by presence of more mature terrigenous organic material from the shelf. %S from hotshot samples at 13970' and 14275' in Nighthawk-1 are 2.42 and 1.92% respectively. Source rocks containing elevated Sulphur values tend to generate hydrocarbon earlier than low %S source rocks (Figure 6).

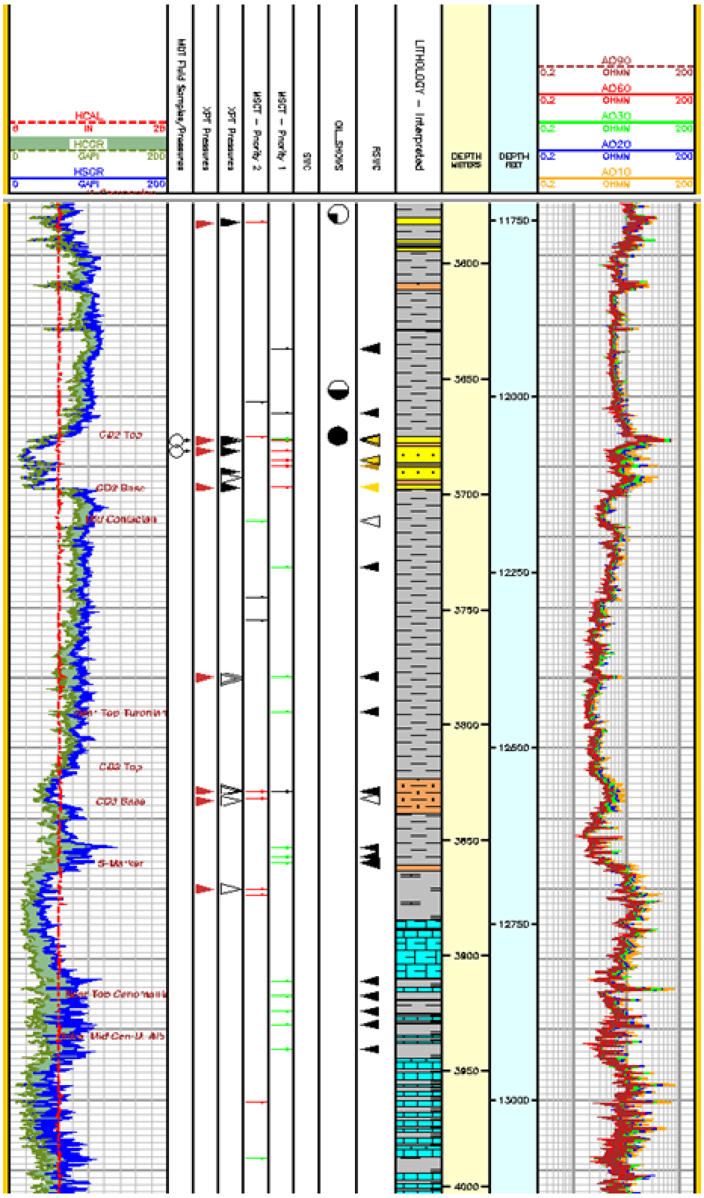

**Figure 6: Comprehensive Well Log analysis of the Nighthawk -1 well, Liberian Basin: Detailed stratigraphic and petrophysical characterization,** Chevron Liberia Ltd, 2012

**Table 2: Geological and Geochemical characteristics of Nighthawk-1 well.**

| NIGHTHAWK | | | | | | | |
|---|---|---|---|---|---|---|---|
| **DATA** | DEPTH (ft) | AGE | API GRAVITY % | TOC w% | HYDROGEN INDEX | VITRINITE REFLECTANCE %RO | %S |
| **Hotshot** | 13610 | | 19-21, 31-35, 29-31 and 36-38 | | | | |
| **Cuttings** | 13940, 14570 | Turonian Cenomanian -Upper. Albian | | 1.2-3.7% | | | |
| **Cuttings** | 13940-14570 | Turonian Cenomanian -Upper. Albian | | | 40-181 | | |
| **Cuttings** | 13760-14879 | | | | | 0.77-0.97 | |
| **Hotshot** | 13970-14275 | | | | | | 2.42 and 1.92% |

*Hint: The above table summarizes the geological and geochemical data collected from the Nighthawk-1 well, specifically focusing on depth, age, API gravity, TOC content HI, Vitrinite reflectance, and Sulfur content from hotspot and Cuttings data. It provides a comprehensive overview of the depth intervals and respective geochemical parameters, allowing for a detailed analysis of the subsurface characteristics at different stratigraphic levels within the Nighthawk well. The TOC values indicate good to excellent source rock quality, capable of generating hydrocarbons, while the HI values suggest a potential for mixed oil and gas generation, with a tendency towards oil in the higher HI range. On the other hand, the vitrinite reflectance values indicate that the source rock is in the oil-generating window, which is favorable for petroleum potential and the API gravity range suggests a mix of heavy to medium-light crude oil to be present, with medium-light being more economically favorable. However, the high sulfur content could present challenges in future productions. Overall, the well shows a good potential for petroleum generation, particularly for oil, with some gas potential.*

**Source Rock Quality Offshore Liberian Basin**

Source rock varies rapidly from gas prone to mixed gas and oil prone between relatively closely spaced wells in Albian to Aptian and Cenomanian to Turonian. Variability in source

quality is related to organic matter oxidation due to high oxygen levels in shallow water depth and/or incoming sediments/current from the continent.
Source rock system in the Liberian Basin includes, late Cretaceous marine Cenomanian to Turonian Shales and early Lacustrine syn-rift Shales extending in age from Aptian to Albian. The hydrocarbon in the basin is mainly of Type II and III, gas to oil prone source rock or oil-prone to gas prone source rock. With the exception of Cestos well, most source rocks in the Liberian Basin are Type II. The Cretaceous system is the important source rock formed in the Cenomanian to Turonian organic rich Type II marine shale deposited during global anoxic event.
The early Cretaceous contain three or more oil-prone to marine and Lacustrine Type II/III source rock from Aptian to Albian age.
Maturity window in Nighthawk and Carmine Deep-1 are identical due to the results of the vitrinite reflectance. Carmine Deep-1 maturity increases faster with depth below 0.7% vitrinite reflectance (VR). This is because the composition and type of organic matter present in Carmine-Deep 1 formation is different compared to Nighthawk formation. Different types of organic matter have varying thermal stability, which affects their transformation into hydrocarbons at different rates. It is possible that the organic matter in Carmine Deep-1 is more thermally labile, meaning it is more easily converted into hydrocarbons as temperature and pressure increase, leading to a faster increase in maturity.
Higher maturity in Carmine Deep-1 is related to less conductive rock, there is more shale in Carmine-Deep 1 than Nighthawk. When organic matter undergoes thermal maturation, the higher temperatures facilitated by the lower thermal conductivity of shale can accelerate the conversion of organic material into hydrocarbons (Siskin and Katritzky, 1991). This might be reason for the higher maturity in Carmine-Deep1 Formation compared to the Nighthawk formation.

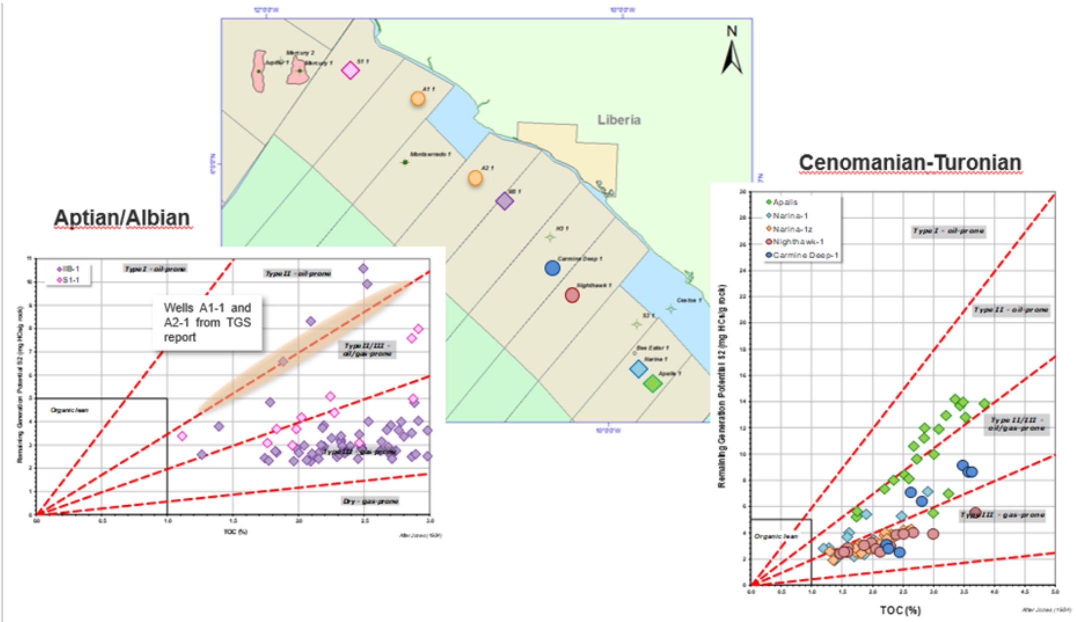


**Figure 7: Delineation of source rock quality across offshore Liberian Basin: Data and analysis are derived from a report by Chevron Liberia limited, 2012**

*Hint: the above figure provides a comprehensive analysis of the source rock quality within the offshore Liberian Basin. the central part of the figure displays a geological map of the offshore Liberian Basin. The Map highlights different geological blocks and wells locations (from TGS reports). The left graph showcases data related to the source rock quality from the Aptian to Albian age (it includes a diagonal line marking the threshold for hydrocarbon potential with data points scattered across indicating varying quality levels of source rock), the majority of data points lie below the threshold line, indicating moderate to poor source rock quality. However, some samples exhibit higher TOC and HI values, suggesting localized areas of better quality.*
*The right graph presents similar data for the Cenomanian to Turonian age rocks, plotting TOC against HI providing a comparative analysis with Aptian-Albian data. It shows a wider distribution of data points, with several samples surpassing the hydrocarbon potential threshold. This indicates a more heterogenous distribution of source rock quality, with some areas showing significantly better potential for hydrocarbon generation.*

### Syn-rift Section Offshore Liberian Basin

In the syn-rift section of the Liberian Basin, the reservoir sandstone units were deposited in Aptian-middle Albian continental (lacustrine-deltaic) and upper Albian marginal shoreline. During the phase which occurred in Aptian to middle Albian ages of the Cretaceous period, the depositional environments in the syn-rift of the Liberian Basin were predominantly continental, within lacustrine and deltaic settings. Lacustrine environments define sediments deposition in freshwater lakes, while deltaic environments involve accumulation of sediment at the mouth of river. In this phase, the reservoir sandstones units were

primarily formed by the deposition of sediments in these lacustrine and deltaic environments. The sandstones within these units typically exhibit characteristics such as moderate to high porosity and permeability, making them favourable reservoir rocks for hydrocarbon.
In the upper Albian age, the depositional environment in the syn-rift section of the Liberian Basin shifted to a marginal shoreline setting. Marginal shorelines are transitional areas between terrestrial and marine environments. During this phase, sediments were deposited along the shoreline as a result of various processes, including wave action and tidal currents.

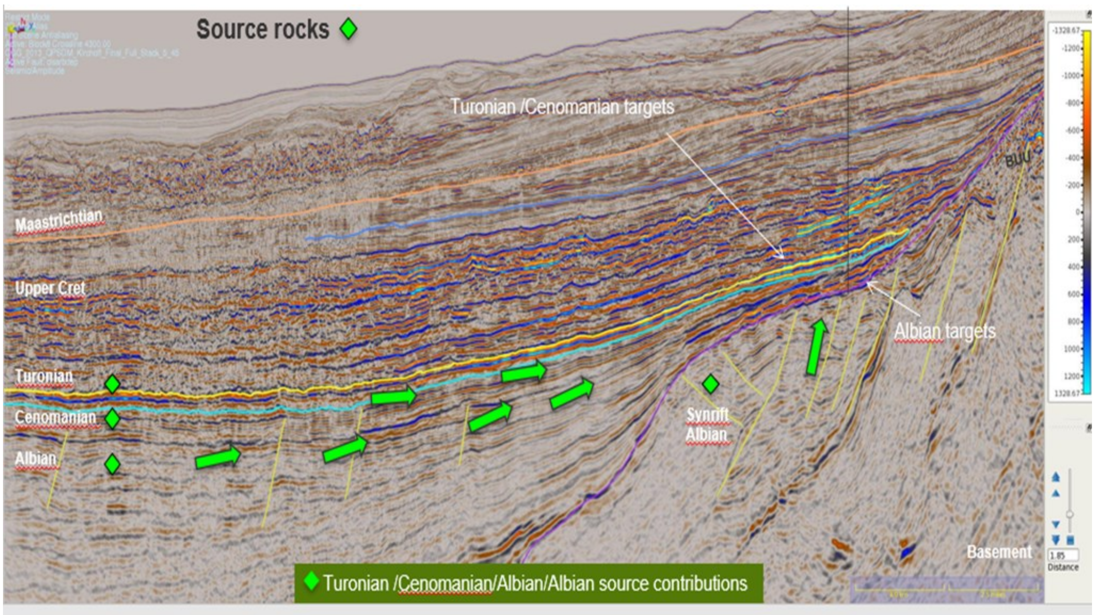


**Figure 8: Seismic section illustrating the stratigraphic and structural representation of the syn-rift offshore Liberian Basin**, Chevron Liberia Ltd, 2012

*Hint: the seismic section above showcases stratigraphic layers from the Albian at the base to the Maastrichtian at the top. The Turonian, Cenomanian, and Albian layers are highlighted for their significance in hydrocarbon exploration. The syn-rift nature of the basin is evident, suggesting a history of extensional tectonics, which likely contains normal faults, characteristic of rift basins. Potential hydrocarbon targets are marked within the Turonian and Cenomanian layers, with green arrows suggesting possible migration pathways or hydrocarbon accumulations.*
*The section highlights a potentially rich hydrocarbon system within a syn-rift setting.*

**Basin Prospectivity**
Previous exploration in the Liberia Basin has proven the existence of two distinct hydrocarbon systems (Early and Late Cretaceous). Initial exploration demonstrated the potential for an early Cretaceous petroleum system consisting Aptian-Albian Marine and Lacustrine Shales.

Overall, the Liberian Basin has a high prospectivity for hydrocarbon, but further exploration and drilling activities are needed to fully assess its hydrocarbon potential.
Technological advancements in exploration techniques from different partners, such as seismic surveys and well logging, will improve the understanding of the subsurface geology in the Liberia Basin. These advancements will provide better insights into the presence and characteristics of the late Cretaceous marine shales in the Liberian Basin, making them more attractive for exploration and development. This sequence is characteristically organic rich throughout offshore of West Africa.
Reservoir sandstones units formed here are characterized by their proximity to the shoreline and the influence of marine process. These sandstones exhibit different properties compared to those deposited during the earlier continental phase.

## Conclusion

In conclusion, the Liberian Basin has shown promising hydrocarbon potential. The presence of a working petroleum system with the presence of two source rocks; Marine Cenomanian/Turonian and Lacustrine syn-rift Aptian/Albian, geological structures, including fault systems, grabens, and horsts provide a favourable condition for hydrocarbon accumulation. The positive results from seismic surveys indicate the likelihood of significant hydrocarbon resources in the basin.
This study underscores the potential impact of source rock presence and source rock quality is highly variable in the basin and fluctuates from gas prone to mixed gas/oil prone in relatively short distances, highlighting the need for further instigation and potential avenues for future research. The basin's proximity to other oil rich regions in West Africa further supports the notion of its potential, reinforcing the importance of continued investigation and development efforts.

### Recommendations

Based on geological studies and exploration activities, the Liberian Basin is believed to have significant hydrocarbon potential. However, the following points are essential for the comprehensive analysis of the basin:

- Conduct a reservoir characterization: evaluate the potential reservoir rocks within the Liberian Basin. This can include studying the sedimentary facies, porosity, permeability and rock properties to assess the quality and productivity of potential hydrocarbon reservoirs.
- Conduct a structural analysis: analyze the structural framework of the basin, including faults systems, folds, and traps, to identity potential areas of hydrocarbon accumulation. This can be done through a comprehensive seismic interpretation, subsurface mapping, and structural modeling.
- Conduct a play fairway to identify areas with the highest hydrocarbon potential within the Liberian basin. This analysis should consider all the elements necessary

for hydrocarbon accumulation, including comprehensive source rock analysis, reservoir, seals, and traps.

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