Lithostratigraphic Characterization and Petroleum System Elements of the MI Well, Niger Delta Basin

Abstract ***This study presents a comprehensive lithostratigraphic characterization of the MI Well in the Niger Delta Basin through microscopic examination of ditch cutting samples. The aim was to identify the lithofacies units and assess the presence and distribution of petroleum system elements. A total of seventy-two samples ranging in depth from 4500ft-11460ft (1372m-3493m) were analyzed, revealing four lithofacies units: sandstone, shale, sandy shale, and shaly sand. Through interpretation of the lithological log, the cap/seal rock, reservoir rock, and probable source rock units were identified. The lithostratigraphic model generated from the study provides a comprehensive understanding of the depth intervals and lithological properties of the identified units. The cap/seal rock, with a thickness of approximately 460ft, was found to be the top-most shale facies. The reservoir rock, comprising sand, sandy shale, and shaly sand lithofacies, has a thickness of around 1920ft. The lowermost massive shale facies, approximately 3540ft thick, is interpreted as the probable source rock for the petroleum system. These findings have significant implications for hydrocarbon exploration and production in the Niger Delta Basin. The identification of lithofacies units and their respective roles as cap/seal, reservoir, and source rocks allows for a better assessment of the hydrocarbon potential in the MI Well. The lithostratigraphic model, along with the established lithozones, offers valuable insights for regional correlation and comparison with other wells in the basin.***

Keywords*: lithostratigraphy, petroleum system, Niger Delta Basin, microscopic examination, lithofacies units, reservoir characterization, hydrocarbon exploration*

1. Introduction

The Niger Delta is located in the Gulf of Guinea (fig. 1) and spans the Niger Delta Province, as defined by [1]. Over time, from the Eocene to the present, the delta has gradually extended southwestward, forming depobelts that represent its most active regions at each stage of development [2]. These depobelts make up one of the world's largest regressive deltas, covering an area of approximately 300,000 km2 [3], with a sediment volume of 500,000 km3 [4], and a sediment thickness exceeding 10 km in the basin depocenter [5].

Within the Niger Delta Province, there is a single identified petroleum system, referred to as the Tertiary Niger Delta (Akata-Agbada) Petroleum System[3;6]. The petroleum system extends throughout the province's boundaries (fig. 1) and encompasses known resources (cumulative production plus proved reserves) of 34.5 billion barrels of oil (BBO) and 93.8 trillion cubic feet of gas (TCFG) (equivalent to 14.9 billion barrels of oil equivalent, BBOE) [7]. Currently, most of the petroleum resources are located onshore or on the continental shelf in waters less than 200 meters deep (fig. 1), primarily within large, relatively uncomplicated structures. While a few giant fields exist in the delta, the largest field holds just over 1.0 BBO [7]. According to the U.S. Geological Survey's World Energy Assessment [1], the Niger Delta Province ranks as the twelfth richest in terms of petroleum resources, accounting for 2.2% of the world's discovered oil and 1.4% of the world's discovered gas [8].

The Niger Delta Basin, located in Nigeria, is globally recognized as a prolific hydrocarbon province, boasting substantial oil and gas reserves that have played a crucial role in the country's economic growth and energy production [9]. Exploration and production activities in the basin have been of paramount importance due to the significant economic benefits derived from the exploitation of its hydrocarbon resources[10]. To ensure effective resource assessment and extraction, a comprehensive understanding of the geological characteristics and petroleum system elements within individual wells is essential. The MI Well, situated in the Niger Delta Basin, represents a valuable target for hydrocarbon exploration. However, there is a need for a thorough lithostratigraphic characterization of this well to gain insights into its hydrocarbon potential.

Lithostratigraphic characterization plays a pivotal role in examining the lithological properties and deciphering the presence and distribution of petroleum system elements within a geological formation [11;12]. By conducting a detailed analysis of the lithofacies units and their spatial variations, valuable information can be obtained regarding reservoir quality, source rock potential, and sealing capacity [13; 14]. Extensive research has been conducted on the geology and hydrocarbon potential of the Niger Delta Basin. Previous studies have examined the depositional environments, stratigraphy, and lithological properties of various wells in the basin. For instance, [15] conducted a detailed lithostratigraphic analysis of the Ughelli Formation, highlighting the presence of sandstone and shale lithofacies. Similarly, [16] investigated the reservoir quality and source rock potential in the Niger Delta Basin, emphasizing the importance of lithological characteristics.

In the context of the MI Well, a comprehensive lithostratigraphic characterization is lacking, which hampers a comprehensive understanding of its hydrocarbon potential. Thus, this study aims to bridge this knowledge gap by conducting a detailed examination of ditch cutting samples from the MI Well and generating a lithostratigraphic model. The main objectives of this study are to identify and describe the lithofacies units present within the MI Well, including sandstone, shale, sandy shale, and shaly sand. By interpreting the lithological data and integrating it with well logs, a comprehensive lithostratigraphic model will be generated, providing insights into the presence and distribution of petroleum system elements such as cap/seal rocks, reservoir rocks, and probable source rocks.

The significance of this research lies in its contribution to the understanding of the geological characteristics and hydrocarbon potential of the MI Well in the Niger Delta Basin. The generated lithostratigraphic model will serve as a practical tool for assessing the hydrocarbon potential, optimizing drilling strategies, and guiding future exploration and production efforts [17; 18]. Furthermore, it will facilitate regional correlation and comparison with other wells in the basin, advancing the broader understanding of the geological framework and enhancing exploration success rates.

In conclusion, this study aims to conduct a comprehensive lithostratigraphic characterization of the MI Well in the Niger Delta Basin. By examining the lithofacies units and analyzing the presence and distribution of petroleum system elements, valuable insights will be gained into the hydrocarbon potential of the well. The findings will contribute to the overall understanding of the geological characteristics within the Niger Delta Basin and support informed decision-making in hydrocarbon exploration and production activities.

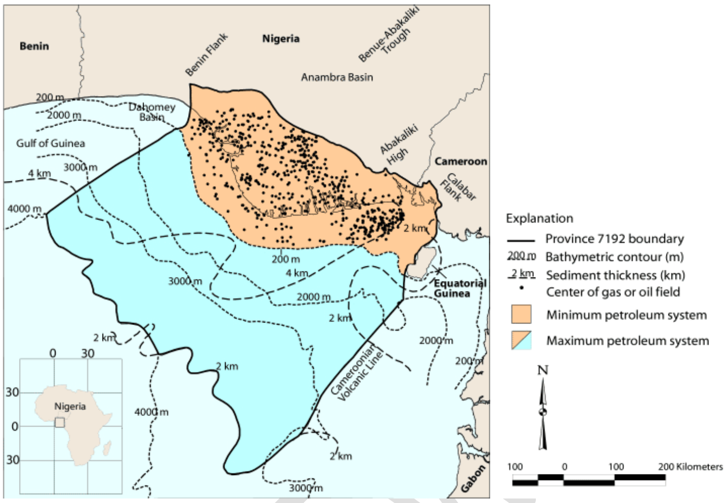


Figure 1.Index Mao of Nigeria and Cameroon. Map of the Niger Delta showing Province Outline [19]

1.1. Province Geology of the Niger Delta

The Niger Delta Province, encompassing southern Nigeria and southwestern Cameroon (figure 1), is a significant onshore and offshore geological region spanning approximately 300,000 km². It is characterized by complex geology and tectonic processes. The province is bounded by the Benin flank to the north, the Abakaliki High and Calabar flank to the northeast, the Cameroon volcanic line to the east, and the Dahomey basin and the 4000-meter bathymetric contour to the west, south, and southwest. The tectonic history of the Niger Delta Province involves the influence of Cretaceous fracture zones, which are expressed as trenches and ridges in the deep Atlantic. Rifting began in the Late Jurassic and continued into the Middle Cretaceous [20], associated with the opening of the South Atlantic. Rifting diminished by the Late Cretaceous, and gravity tectonics became the dominant deformational process. The lithology of the Cretaceous section beneath the Niger Delta Basin is not well-known since it has not been directly penetrated. However, information is extrapolated from the exposed Cretaceous section in the nearby Anambra basin. Sedimentation in the Cretaceous involved tide-dominated and river-dominated deltaic processes, along with the deposition of shallow marine clastics offshore. The Tertiary section of the Niger Delta is composed of three formations. The Akata Formation, located at the base of the delta, consists of thick shale sequences, turbidite sands, and minor clay and silt. It is considered a potential source rock and reservoir in deep-water areas. Above the Akata Formation is the Agbada Formation, which is the major petroleum-bearing unit consisting of paralic siliciclastics. The uppermost formation is the Benin Formation, which is a continental deposit of alluvial and upper coastal plain sands (figure 2). The Niger Delta is characterized by the presence of depobelts, which are separate units defined by synsedimentary faulting resulting from variable rates of subsidence and sediment supply. There are five major depobelts within the Niger Delta, each with its own sedimentation, deformation, and petroleum history. Overall, the Niger Delta Province exhibits a complex geologic history shaped by tectonic processes, gravity tectonics, and sedimentation patterns. It is an important region for petroleum exploration and production due to its petroleum-bearing formations and potential reservoirs.

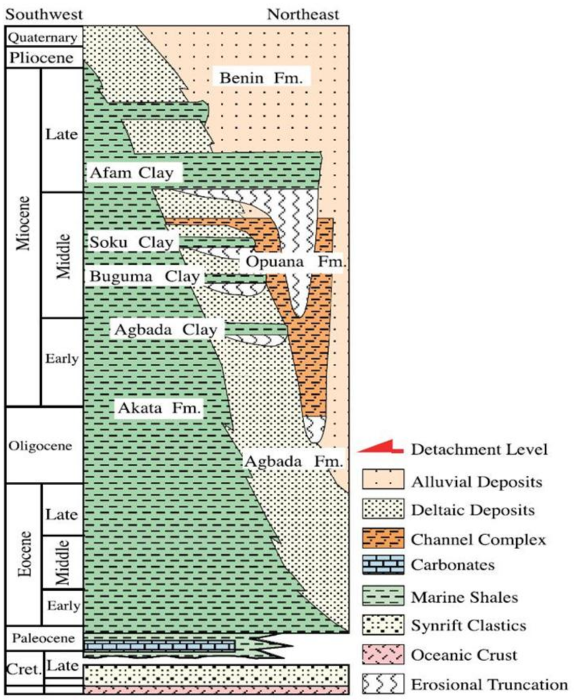


Figure 2. Schematic diagram of the regional stratigraphy of Niger Delta Basin. After [21]

1.2. Petroleum System

The Tertiary Niger Delta (Akata-Agbada) petroleum system has a history that spans from the Paleocene to the present. The main source of petroleum within the system is the Akata Formation, although smaller amounts are also generated from mature shale beds in the lower Agbada Formation. Deposition of overburden rocks began in the Middle Eocene and has continued to the present day. In the northern part of the basin, the Agbada and Benin Formations are present, transitioning to the Akata Formation in the deep-water areas where the Agbada and Benin Formations thin out and disappear seaward. Petroleum generation within the Niger Delta started in the Eocene and has been ongoing. The generation process proceeded from north to south as successively younger depobelts entered the oil window. Reservoirs for the discovered petroleum are primarily sandstones found throughout the Agbada Formation. For undiscovered petroleum, potential reservoirs exist below the currently producing intervals and in the distal portions of the delta system. These reservoirs may include turbidite sands within the Akata Formation. Trap and seal formation within the delta are influenced by gravity tectonics. Structural traps have been the main focus of exploration, but stratigraphic traps are expected to become increasingly important targets in the distal and deeper parts of the delta. Overall, the petroleum system of the Tertiary Niger Delta has a complex history of deposition, petroleum generation, and trap formation, with the potential for further exploration and discovery in both structural and stratigraphic traps.

1.3. Location of Study Area

Five regional depobelts are defined in the basin – (1) Northern Delta, (2) Greater Ughelli, (3) Central Swamp, (4) Coastal Swamp and (5) Offshore depobelts (Figure 1).

The study area is in the Greater Ughelli Depobelt of the Niger Delta basin of Nigeria. The study area, MI Well, lies within the Greater Ughelli Depobelt of the Niger Delta Basin in Southern Nigeria (figure 3). The Greater Ughelli Depobelt is a region of geological significance known for its sedimentary deposits and substantial hydrocarbon potential. The Niger Delta Basin is a vast sedimentary basin that spans a significant area in Nigeria. It is renowned for its abundant reserves of oil and gas, making it a highly active area for exploration and production activities in the country's petroleum industry. Within the Niger Delta Basin, the Greater Ughelli Depobelt represents a specific geological zone characterized by the progradation of deltaic sediments. Over time, sedimentary deposits have accumulated as the delta advanced southwestward within this depobelt. The MI Well, situated within the Greater Ughelli Depobelt, is likely a well that has been drilled for exploration or production purposes. Wells such as MI Well play a critical role in evaluating the presence, quality, and commercial viability of hydrocarbon resources within the Niger Delta Basin. The Greater Ughelli Depobelt, including the MI Well, is a region of significant interest for the oil and gas industry in Nigeria. It serves as a focal point for various activities related to the exploration, development, and production of hydrocarbons in the Niger Delta Basin.

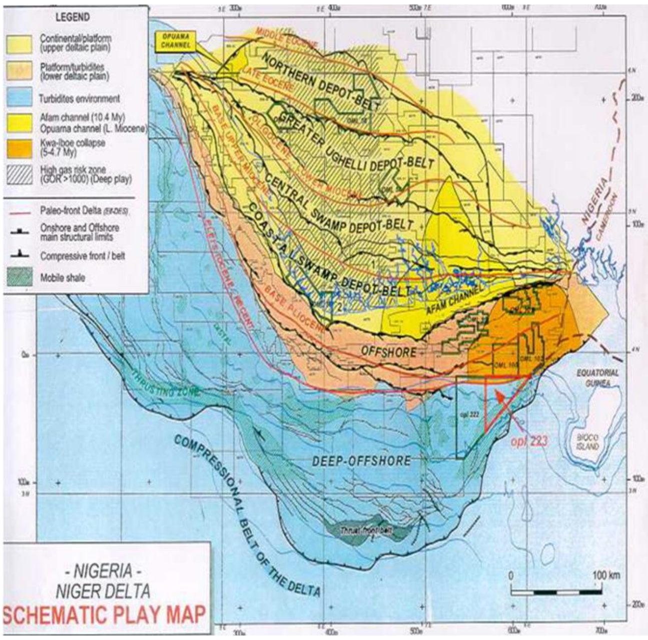


Figure 3. Map of Niger Delta Showing the Location of the Study Area [22]

2. Materials and Methods

The nature of subsurface exploration requires obtaining the downhole rock samples that provide a wealth of information, an unweathered and undisturbed, sequence of rock properties [23]

Ditch cutting samples from the MI Well, spanning a depth range of 4500ft-11460ft (1372m-3493m), were subjected to microscopic examination. Using a reflected light microscope, physical parameters such as color, grain size, fissility, shape, sorting, and rock type were analyzed. The samples were classified into lithofacies units based on their characteristics, and a lithostratigraphic model was generated to delineate the different zones and elements of the petroleum system. The lithofacies distribution and properties in the study area are important for understanding the reservoir characteristics and hydrocarbon potential of the different intervals [24].

2.1. Sample Collection:

Ditch cutting samples from the MI Well in the Niger Delta Basin were collected for microscopic examination. A total of seventy-two (72) samples were collected, covering a depth range from 4500ft to 11460ft (1372m to 3493m). The samples were carefully retrieved and stored in labeled sample bags to ensure their safety during transportation and subsequent analysis.

2.2. Microscopic Examination:

The microscopic examination of the ditch cutting samples was conducted to determine the lithological features and characterize the lithofacies units present within the MI Well. A reflected light microscope was utilized for the analysis, allowing for the observation of physical parameters such as color, grain size, fissility, shape, sorting, and rock type.

The microscopic examination of the ditch cutting samples was conducted using a reflected light microscope. This instrument allows for the observation of samples under reflected light, enabling the examination of their physical parameters and characteristics. The samples were prepared for microscopic analysis by carefully selecting representative portions and mounting them onto glass slides. Prior to mounting, the samples were cleaned and polished to remove any debris or impurities that could hinder accurate observation. The reflected light microscope was equipped with various magnification lenses, allowing for detailed examination of the samples at different scales. The microscope settings, such as brightness, contrast, and focus, were adjusted to optimize the visibility of the sample features. During the examination, the microscope was used to observe and record the physical properties of the samples, including color, grain size, fissility, shape, sorting, and rock type. These observations were documented through visual examination and image capture using a digital camera attached to the microscope. The reflected light microscope provided valuable information about the composition, texture, and structural characteristics of the samples. It allowed for the identification of different mineral phases, their arrangement within the samples, and the presence of any diagenetic features or sedimentary structures. The use of a reflected light microscope in this study ensured a detailed and accurate analysis of the ditch cutting samples. The instrument's ability to provide high-resolution images and precise observations contributed to the reliable characterization of the lithofacies units and the generation of the lithostratigraphic model.

2.3 Lithofacies Identification:

Based on the microscopic examination and petrographic analysis, the identified lithofacies units were classified and described. The lithofacies units included sandstone, shale, sandy shale, and shaly sand. The criteria for lithofacies identification were based on the observed physical and textural properties of the samples.

2.4 Lithostratigraphic Modeling:

The lithostratigraphic model was generated based on the lithofacies identification and their depth intervals. The model included information on lithology, lithofacies, lithozones, shale/sand percentage, homogenetic zone, heterogenetic zone, reservoir zone, and source rock zone. The lithostratigraphic model provided a comprehensive representation of the lithological variations and the distribution of petroleum system elements within the MI Well.

2.5 Data Analysis:

Data analysis was performed to interpret the results and derive meaningful conclusions. The lithostratigraphic model was analyzed to determine the depth intervals of the cap/seal rock, reservoir rock, and probable source rock units within the MI Well.

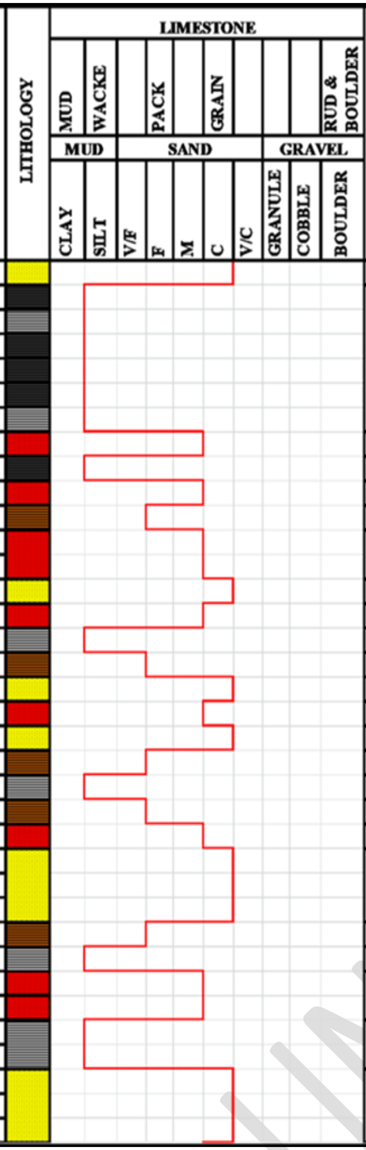
2.6 Reagents and Materials:

The reagents and materials used in the study included sample bags, thin section slides, mounting media, and microscope slides. Sample bags were sourced from a reputable supplier, while the thin section slides, mounting media, and microscope slides were obtained from a specialized laboratory equipment supplier.

3. Results

The microscopic examination of the MI Well samples in the Niger Delta Basin revealed important findings regarding the lithological characteristics and petroleum system elements within the well. A total of seventy-two (72) samples were analyzed using a reflected light microscope, focusing on physical parameters such as color, grain size, fissility, shape, sorting, rock type, minerals, and sand/shale percentage. The examination provided valuable insights into the geological properties of the well. Based on the microscopic examination, four main lithofacies units were identified: sandstone, shale, sandy shale, and shaly sand. These lithofacies units were distinguished by their distinct visual features observed under the microscope. Light and dark grey shale, shaly sand, sandy shale, and sand were the specific lithologies identified within the MI Well samples. Furthermore, the examination allowed for the identification of potential source rocks, reservoir rocks, and cap rocks within the MI Well. The presence of these elements has significant implications for the hydrocarbon potential of the well. The lithostratigraphic model generated from the results provided a comprehensive overview of the depth, lithology, lithofacies, lithozones, shale/sand percentage, homogenetic zone, heterogenetic zone, reservoir zone, and source rock zone within the well

Table 1: Lithostratigraphic Description of MI Succession



S/N	DEPTH[FEET]	DEPTH[METER]	LITHOLOGY	LITHOFACIES	SHALE/SAND PERCENTAGE	LITHOZONES	HETEROGENETIC ZONE	HOMOGENETIC ZONE	RESERVOIR UNIT	SOURCE ROCK UNIT	CAPROCK UNIT
1	4500	1372	Sandstone	Whitish -colourless,coarse,sub rounded,well sorted sand	100% sandstone	Zone 49		1			
2	4740	1445	Shale	Dark grey shale	100% shale	Zone 48		2			1
3	4820	1469		Light -dark grey shale		Zone 47					
4	4860	1481		Dark grey shale		Zone 46					
5	4980	1518									
6	5100	1554									
7	5220	1591		Light grey shale		Zone 45					
8	5340	1628	Shaly sand	Whitish-dark grey,fine-coarse,sub rounded,poorly sorted shaly sand	90% sandstone, 10% shale	Zone 44	1		1		
9	5460	1664	Shale	Dark grey shale	100% shale	Zone 43		3			
10	5580	1701	Shaly sand	Whitish-dark grey,fine-coarse,sub rounded,poorly sorted shaly sand	60% sandstone, 40% shale	Zone 42	2				
11	5700	1737	Sandy shale	Whitish-dark grey,fine-coarse,sub rounded,poorly sorted sandy shale	60% shale, 40% sandstone						
12	5820	1774	Shaly sand	Whitish-dark grey,fine-coarse,sub rounded,poorly sorted shaly sand	60% sandstone, 40% shale						
13	5880	1792			70% sandstone, 30% shale						
14	5940	1811	Sandstone	Whitish-dark grey,coarse,sub rounded-sub angular,well sorted sand	100% sandstone	Zone 41		4			
15	6000	1829	Shaly sand	Whitish-dark grey,fine-coarse,sub angular,poorly sorted shaly sand	80% sandstone, 20% shale	Zone 40	3				
16	6060	1847	Shale	Light-dark grey shale	100% shale	Zone 39		5			
17	6120	1865	Sandy shale	Whitish-dark grey,fine-coarse,sub rounded,poorly sorted sandy shale	60% shale, 40% sandstone	Zone 38	4				
18	6180	1884	Sandstone	Whitish-dark grey,coarse,angular,well sorted sand	100% sandstone	Zone 37		6			
19	6240	1902	Shaly sand	Whitish-dark grey,fine-coarse,sub angular,poorly sorted shaly sand	80% sandstone, 20% shale	Zone 36	5				
20	6300	1920	Sandstone	Whitish-colourless,coarse,angular,well sorted sand	100% sandstone	Zone 35		7			
21	6360	1939	Sandy shale	Dark grey shale	80% shale, 20% sandstone	Zone 34	6				
22	6420	1957	Shale	Light grey shale	100% shale	Zone 33		8			
23	6480	1975	Sandy shale	Light-dark grey,fine-coarse,sub rounded,poorly sorted, sandy shale	90% shale, 10% sandstone	Zone 32	7				
24	6540	1993	Shaly sand	Light grey,fine-coarse,sub rounded,poorly sorted,shaly sand	90% sandstone, 10% shale	Zone 31					
25	6600	2012	Sandstone	White-colourless,coarse,sub rounded,well sorted sand	100% sandstone	Zone 30		9			
26	6660	2030		White-colourless,coarse,sub angular,well sorted sand							
27	6720	2048		Whitish-colourless,coarse,angular-sub angular,well sorted sand							
28	6780	2067	Sandy shale	Whitish-dark grey,fine-coarse,sub rounded,poorly sorted sandy shale	60% shale, 40% sandstone	Zone 29	8				
29	6840	2085	Shale	Light grey shale	100% shale	Zone 28		10			
30	6900	2103	Shaly sand	Whitish-light grey,fine-coarse,sub angular,poorly sorted,shaly sand	90% sandstone, 10% shale	Zone 27	9				
31	6960	2121		Whitish-dark grey,fine-coarse,sub rounded,poorly sorted,shaly sand	70% sandstone, 30% shale						
32	7020	2140	Shale	Light grey shale	100% shale	Zone 26		11			
33	7080	2158									
34	7140	2176	Sandstone	Light grey.coarse,sub rounded,well sorted sandstone	100% sandstone	Zone 25		12			
35	7200	2195									
36	7260	2213		Dark grey,coarse,angular-sub rounded,well sorted sand		Zone 24					

37	7320	2231	Shaly sand	Whitish-dark grey,fine-coarse,sub angular,poorly sorted shaly sand	70% sandstone, 30% shale	Zone 23	10			
38	7380	2249		Dark grey shale	100% shale	Zone 22		13		
39	7500	2286	Shale	Brownish grey shale		Zone 21				
40	7620	2323			80% shale, 20% sandstone		11			
41	7740	2359	Shaly sand	Light grey,fine-coarse,angular,poorly sorted,shaly sand	90% sandstone, 10% shale	Zone 20				
42	7860	2396		Brownish grey shale		Zone 19				
43	7980	2432								
44	8040	2451		Light grey shale		Zone 18				
45	8100	2469								
46	8220	2505		Light -dark grey shale		Zone 17				
47	8340	2542		Brownish grey shale		Zone 16				
48	8460	2579								
49	8580	2615								
50	8700	2652								
51	8820	2688		Light grey shale		Zone 15				
52	9060	2761		Dark grey shale		Zone 14				
53	9180	2798								
54	9300	2835								
55	9420	2871		Light grey shale		Zone 13				
56	9540	2908		Brownish grey shale		Zone 12				
57	9660	2944	Shale	Light grey shale	100% shale	Zone 11		14		1
58	9780	2981								
59	9900	3018		Brownish grey shale		Zone 10				
60	10020	3054		Light grey shale		Zone 9				
61	10140	3091								
62	10260	3127								
63	10380	3164		Brownish grey shale		Zone 8				
64	10500	3200		Dark grey shale		Zone 7				
65	10620	3237		Brownish grey shale		Zone 6				
66	10740	3274		Dark grey shale		Zone 5				
67	10860	3310		Light grey shale		Zone 4				
68	10980	3347								
69	11100	3383		Light -dark grey shale		Zone 3				
70	11220	3420		Dark grey shale		Zone 2				
71	11340	3456		Light grey shale		Zone 1				
72	11460	3493								

KEY

SANDSTONE | DARK/BROWNISH GREY SHALE | LIGHT GREY SHALE | SHALY SAND | SANDY SHALE

3.1. Description of Lithozones

The lithostratigraphic model generated for the MI Well includes a description of the lithozones, which are presented here in a bottom-to-top sequence based on their depth.

Lithozone 1:

Depth: 11460-11340ft (3493-3456m)

This lithozone is characterized by light grey shale with a thickness of 120ft (37m). It exhibits fissility, indicating its ability to split along parallel planes. The shale is non-calcareous and moderately hard, suggesting a certain level of compaction. The dominant mineral present in this lithozone is quartz.

Lithozone 2:

Depth: 11220ft (3420m)

This lithozone consists of dark grey shale. It also displays fissility, indicating its propensity to fracture along parallel planes. The shale is non-calcareous and moderately hard. The dominant mineral observed within this lithozone is quartz.

Lithozone 3:

Depth: 11100ft (3383m)

The lithozone is characterized by a mixture of light to dark grey shale. Similar to the previous lithozones, it exhibits fissility, indicating its ability to split along parallel planes. In contrast to the previous lithozones, this one is calcareous, containing calcium carbonate. The shale is moderately hard, and quartz is the dominant mineral present.

Lithozone 4:

Depth: 10980-10860ft (3347-3310m)

This lithozone comprises light to dark grey shale with a thickness of 120ft (37m). Like the preceding lithozones, it displays fissility, indicating its propensity for fracturing along parallel planes. The shale is non-calcareous and moderately hard. Quartz is the primary mineral observed within this lithozone.

Lithozone 5:
Depth: 10740ft (3274m)
This lithozone is characterized by dark grey shale. It exhibits fissility, indicating its ability to split along parallel planes. The shale is non-calcareous and moderately hard, suggesting a certain level of compaction. The dominant mineral present in this lithozone is quartz.

Lithozone 6:
Depth: 10620ft (3237m)
At a depth of 10620ft (3237m), this lithozone is characterized by brownish grey shale. Similar to the previous lithozones, it displays fissility, indicating its propensity to fracture along parallel planes. The shale is non-calcareous and moderately hard. Quartz is the dominant mineral observed within this lithozone.

Lithozone 7:
Depth: 10500ft (3200m)
The lithozone at 10500ft (3200m) is characterized by dark grey shale. It exhibits fissility, indicating its ability to split along parallel planes. The shale is non-calcareous and moderately hard. Quartz is the dominant mineral present.

Lithozone 8:
Depth: 10380ft (3464m)
This lithozone is characterized by brownish grey shale. Similar to the previous lithozones, it displays fissility, indicating its propensity for fracturing along parallel planes. The shale is non-calcareous and moderately hard. Quartz is the dominant mineral observed within this lithozone.

Lithozone 9:
Depth: 10260-10020ft (3127-3054m)
With a thickness of 240ft (73m), this lithozone consists of light to dark grey shale. It displays fissility, indicating its ability to split along parallel planes. The shale is non-calcareous and moderately hard. Quartz is the primary mineral observed within this lithozone.

Lithozone 10:
Depth: 9900ft (3018m)
This lithozone is characterized by brownish grey shale. It displays fissility, indicating its ability to fracture along parallel planes. The shale is non-calcareous and moderately hard, suggesting a certain degree of compaction. Quartz is the dominant mineral observed within this lithozone.

Lithozone 11:
Depth: 9780-9660ft (2981-2944m)
With a thickness of 120ft (37m), this lithozone consists of light to dark grey shale. Similar to the previous lithozones, it exhibits fissility, indicating its propensity for fracturing along parallel planes. The shale is non-calcareous and moderately hard. Quartz is the dominant mineral present within this lithozone.

Lithozone 12:
Depth: 9540ft (2908m)
At a depth of 9540ft (2908m), this lithozone is characterized by brownish grey shale. It displays fissility,

indicating its ability to split along parallel planes. The shale is non-calcareous and moderately hard. Quartz is the dominant mineral observed within this lithozone.

Lithozone 13:
Depth: 9420ft (2871m)
The lithozone at 9420ft (2871m) is characterized by light to dark grey shale. It exhibits fissility, indicating its propensity for fracturing along parallel planes. The shale is non-calcareous and moderately hard. Quartz is the dominant mineral present.

Lithozone 14:
Depth: 9300-9060ft (2835-2761m)
With a thickness of 240ft (74m), this lithozone consists of dark grey shale. Similar to the previous lithozones, it displays fissility, indicating its ability to split along parallel planes. The shale is non-calcareous and moderately hard. Quartz is the dominant mineral observed within this lithozone.

Lithozone 15:
Depth: 8820ft (2688m)
This lithozone is characterized by light grey shale. It displays fissility, indicating its ability to fracture along parallel planes. The shale is non-calcareous and moderately hard, suggesting a certain degree of compaction. Quartz is the dominant mineral observed within this lithozone.

Lithozone 16:
Depth: 8700-8340ft (2652-2542m)
With a thickness of 360ft (110m), this lithozone consists of brownish grey shale. It exhibits fissility, indicating its propensity for fracturing along parallel planes. The shale is non-calcareous and moderately hard. Quartz is the dominant mineral present within this lithozone.

Lithozone 17:
Depth: 8220ft (2505m)
The lithozone at 8220ft (2505m) is characterized by light to dark grey shale. It displays fissility, indicating its propensity for fracturing along parallel planes. The shale is non-calcareous and moderately hard. Quartz is the dominant mineral observed within this lithozone.

Lithozone 18:
Depth: 8100-8040ft (2469-2451m)
With a thickness of 60ft (18m), this lithozone consists of light to dark grey shale. It exhibits fissility, indicating its propensity for fracturing along parallel planes. The shale is non-calcareous and moderately hard. Quartz is the dominant mineral present within this lithozone.

Lithozone 19:
Depth: 7980-7860ft (2432-2396m)
This lithozone is characterized by brownish grey shale with a thickness of 120ft (36m). It displays fissility, indicating its ability to split along parallel planes. The shale is non-calcareous and moderately hard. Quartz is the dominant mineral observed within this lithozone.

Lithozone 20:
Depth: 7740ft (2359m)
This lithozone is characterized by poorly sorted light grey shaly sand. It is predominantly composed of 90% sandstone and 10% shale. The shale within this lithozone is fissile, non-calcareous, and moderately hard. The sand component is coarse and angular. Quartz is the dominant mineral present within this lithozone.

Lithozone 21:
Depth: 7620-7500ft (2323-2286m)
With a thickness of 120ft (37m), this lithozone comprises brownish grey sandy shale and brownish grey shale. The sandy shale consists of 80% shale and 20% sand. Similar to other lithozones, the shale within this lithozone is fissile, non-calcareous, and moderately hard. The minerals observed include quartz and feldspar.

Lithozone 22:
Depth: 7380ft (2249m)
Characterized by dark grey shale, this lithozone exhibits fissility, non-calcareous nature, and moderate hardness. The minerals quartz and mica are present within this lithozone.

Lithozone 23:
Depth: 7320ft (2231m)
This lithozone is characterized by poorly sorted whitish to dark grey shaly sand. It comprises approximately 70% sandstone and 30% shale. The sand component is coarse and sub-angular in shape. The minerals quartz and mica are observed within this lithozone.

Lithozone 24:
Depth: 7260ft (2231m)
Consisting of dark grey sandstone, this lithozone exhibits coarse, angular to sub-rounded grains that are well sorted. The minerals quartz and mica are present within this lithozone.

Lithozone 25:
Depth: 7200-7140ft (2195-2176m)
This lithozone is characterized by well-sorted light grey sandstone. The sandstone is coarse and sub-rounded in texture. The primary mineral observed within this lithozone is quartz. It has a thickness of 60ft (19m).

Lithozone 26:
Depth: 7080-7020ft (2158-2140m)
Comprising light grey shale, this lithozone exhibits fissility, non-calcareous composition, and moderate hardness. The dominant mineral present is quartz. It has a thickness of 60ft (18m).

Lithozone 27:
Depth: 6960-6900ft (2121-2103m)
This lithozone is characterized by poorly sorted shaly sand. It consists of two sub-lithozones: whitish to light grey shaly sand and whitish to dark grey shaly sand. The former is composed of approximately 70% sandstone and

30% shale, with coarse and sub-angular sand grains. The latter is composed of 90% sandstone and 10% shale, with coarse and sub-rounded sand grains. The shale within both sub-lithozones exhibits fissility, is non-calcareous, and has moderate hardness. The primary mineral observed is quartz. The lithozone has a thickness of 60ft (18m).

Lithozone 28:
Depth: 6840ft (2085m)
This lithozone consists of light grey shale. It displays fissility, a non-calcareous composition, and moderate hardness. The dominant mineral present is quartz.

Lithozone 29:
Depth: 6780ft (2067m)
This lithozone consists of poorly sorted whitish to dark grey sandy shale. It is composed of 60% shale and 40% sandstone. The sand grains are coarse and sub-rounded, while the shale is fissile and moderately hard. The primary mineral present is quartz.

Lithozone 30:
Depth: 6720-6600ft (2048-2012m)
Characterized by whitish to colorless sandstone, this lithozone displays coarse sand grains that are angular to sub-angular and sub-rounded. The dominant mineral observed is quartz. It has a thickness of 120ft (36m).

Lithozone 31:
Depth: 6540ft (1993m)
This lithozone comprises poorly sorted light grey shaly sand. It is predominantly composed of 90% sandstone and 10% shale. The shale exhibits fissility, is non-calcareous, and moderately hard, while the sand grains are coarse and sub-rounded. The primary mineral present is quartz.

Lithozone 32:
Depth: 6480ft (1975m)
This lithozone consists of poorly sorted light to dark grey sandy shale. It is composed of 90% shale and 10% sandstone. The shale exhibits fissility, is non-calcareous, and moderately hard. The sand grains are coarse and sub-rounded. The primary mineral observed is quartz.

Lithozone 33:
Depth: 6420ft (1957m)
Comprising light grey shale, this lithozone displays fissility, a non-calcareous composition, and moderate hardness. The dominant mineral present is quartz.

Lithozone 34:
Depth: 6360ft (1939m)
This lithozone is characterized by dark grey sandy shale. It consists of 80% shale and 20% sandstone. The shale exhibits fissility, is non-calcareous, and moderately hard. The primary mineral present is quartz.

Lithozone 35:
Depth: 6300ft (1920m)
Characterized by whitish to colorless sandstone, this lithozone displays coarse, angular, and well-sorted sand grains. The dominant mineral observed is quartz.

Lithozone 36:
Depth: 6240ft (1902m)
This lithozone comprises poorly sorted whitish to dark grey shaly sand. The sand grains are coarse and sub-angular. It is predominantly composed of 80% sandstone and 20% shale. The primary minerals present are quartz and mica.

Lithozone 37:
Depth: 6180ft (1884m)
This lithozone is characterized by well-sorted whitish to dark grey sandstone. The sand grains are coarse and angular. The primary minerals present are quartz and mica.

Lithozone 38:
Depth: 6120ft (1865m)
Comprising poorly sorted whitish to dark grey sandy shale, this lithozone is composed of 60% shale and 40% sandstone. The sand grains are coarse and sub-rounded, while the shale exhibits fissility, is non-calcareous, and moderately hard. The primary minerals observed are quartz and mica.

Lithozone 39:
Depth: 6065ft (1847m)
This lithozone is characterized by light to dark grey shale. The shale exhibits fissility, is non-calcareous, and moderately hard. The primary minerals present are quartz and mica.

Lithozone 40:
Depth: 6000ft (1829m)
This lithozone is characterized by poorly sorted whitish to dark grey shaly sand. The sand grains are coarse and sub-rounded. It is composed of 80% sandstone and 20% shale. The primary minerals present are quartz and mica.

Lithozone 41:
Depth: 5940ft (1811m)
Characterized by whitish to dark grey sand, this lithozone displays coarse, sub-rounded to sub-angular, and well-sorted sand grains. The primary minerals present are quartz and mica.

Lithozone 42:
Depth: 5880-5580ft (1792-1701m)
This lithozone consists of poorly sorted whitish to dark grey shaly sands and sandy shale. The sand grains are coarse and sub-rounded, while the shales are fissile and moderately hard. The primary minerals present are quartz and mica. The lithozone has a thickness of 300ft (91m).

Lithozone 43:
Depth: 5460ft (1664m)

Characterized by dark grey shale, this lithozone exhibits fissility, is non-calcareous, and moderately hard. The primary minerals present are quartz and mica.

Lithozone 44:
Depth: 5340ft (1628m)
This lithozone is characterized by poorly sorted, whitish to dark grey shaly sand. The shale is fissile, non-calcareous, and moderately hard, while the sand is coarse and sub-rounded. It is composed of 90% sandstone and 10% shale. The primary minerals present are quartz and mica.

Lithozone 45:
Depth: 5220ft (1591m)
This lithozone is characterized by light grey shale. The shale exhibits fissility, is non-calcareous, and moderately hard. The primary mineral present is quartz.

Lithozone 46:
Depth: 5100-4860ft (1554-1481m)
This lithozone consists of dark grey shale with a thickness of 360ft (109m). The shale is fissile, non-calcareous, and moderately hard. The primary mineral present is quartz.

Lithozone 47:
Depth: 4820ft (1469m)
This lithozone is characterized by light to dark grey shale. The shale exhibits fissility and is moderately hard. The primary mineral present is quartz.

Lithozone 48:
Depth: 4740ft (1445m)
This lithozone is characterized by dark grey shale. The shale is fissile, non-calcareous, and moderately hard. The primary mineral present is quartz.

Lithozone 49:
Depth: 4500ft (1372m)
This lithozone is characterized by well-sorted whitish to colorless sandstone. The sandstone is coarse and sub-rounded. The primary mineral present is quartz.

These descriptions provide additional information about the lithological composition of the MI Well at various depths. The presence of shale, shaly sand, and sandstone layers with different characteristics suggests variations in the sedimentary processes and depositional environments. [25]. The identification of quartz and mica minerals helps in understanding the lithostratigraphy and potential reservoir properties of the formations. These details contribute to a more comprehensive understanding of the subsurface geology and assist in the evaluation of hydrocarbon prospects within the Niger Delta Basin.

4. Discussion

The results obtained from the microscopic examination and the subsequent lithostratigraphic analysis provide a foundation for discussion regarding the geological and hydrocarbon potential of the MI Well in the Niger Delta Basin. The identified lithofacies units and lithologies indicate a complex sedimentary environment within the well, with the presence of both shale and sandstone indicating potential source rocks and reservoir rocks, respectively. The lithostratigraphic model generated from the examination results enables a comprehensive understanding of the lithological variations and their distribution within the well. This information can aid in determining the potential for hydrocarbon accumulation and the presence of favorable reservoirs within the MI Well.

4.1. Hydrocarbon Play Elements

In the context of the petroleum system, the lithostratigraphic information provided suggests the presence of essential hydrocarbon play elements. The sands identified within the lithozones have the potential to serve as reservoir rocks. Reservoir rocks are characterized by sufficient porosity and permeability to allow the migration and accumulation of hydrocarbons. In this case, the sandstones within the interpreted lithozones can act as potential reservoirs.

Additionally, the shales identified within the lithozones can be regarded as potential source rocks and seal/cap rocks. Source rocks contain organic matter that has undergone thermal maturation, leading to the generation or potential generation of hydrocarbons. These source rocks host the processes involved in hydrocarbon formation and serve as the origin of oil and gas. The shales' properties, such as organic content, thermal history, and time, influence the generation and migration of hydrocarbons. The presence of shales in the lithozones suggests the potential for hydrocarbon generation within the system.

4.2. Reservoir Rocks:

Reservoir rocks are sub-surface rock units with adequate porosity and permeability for the migration and accumulation of petroleum. Sandstones and carbonate rocks are commonly identified as reservoir rocks. Based on the lithostratigraphic model provided, one reservoir rock unit is interpreted between the depths of 5340ft and 7260ft. This unit likely consists of sandstones that exhibit suitable porosity and permeability for hydrocarbon storage and flow.

4.3. Source Rock:

Source rocks are subsurface sedimentary rock units, primarily composed of shale or limestone that contains the precursor materials for hydrocarbon formation. These rocks contain organic matter derived from ancient biological species. Through geological processes involving high temperatures and extended periods, this organic matter undergoes transformation, leading to the generation of hydrocarbons. The lithostratigraphic model indicates the presence of one source rock unit between the depths of 7860ft and 11400ft. This unit likely contains the necessary organic matter and thermal conditions for hydrocarbon generation.

4.4. Cap Rock or Seal Rock:

Cap rock or seal rock refers to impermeable rock units that act as barriers to prevent the migration of hydrocarbon fluids. Common types of cap or seal rocks include shale, evaporites, and carbonates. The lithostratigraphic model suggests the presence of one probable cap rock unit between the depths of 4740ft and 5200ft. This unit likely consists of shale or similar impermeable rocks that can act as an effective seal, preventing hydrocarbons from escaping and allowing for the formation of a trapped accumulation.

These interpretations of the lithostratigraphic data provide insights into the hydrocarbon play elements within the studied area. The identification of potential reservoir rocks, source rocks, and cap/seal rocks is crucial in understanding the presence and potential for hydrocarbon accumulation in the subsurface. Further exploration and analysis can help refine these interpretations and guide hydrocarbon exploration and production efforts in the region.

The findings of this study are consistent with previous research conducted in the Niger Delta Basin, which has established the presence of source rocks, reservoir rocks, and cap rocks within the sedimentary sequence.[25; 26, 27; 28; 29]. However, the detailed characterization provided by the microscopic examination enhances our understanding of the specific lithofacies units and their potential as hydrocarbon-bearing formations.

The results and discussions presented in this study contribute to the overall understanding of the petroleum system elements in the MI Well. The comprehensive analysis of the lithological characteristics and the identification of potential source rocks and reservoir rocks provide valuable insights for future exploration and production activities in the Niger Delta Basin.

4. Conclusion

In conclusion, this lithostratigraphic study provides valuable insights into the geological characteristics of the subsurface in the studied area. The identification and interpretation of lithozones have allowed for the recognition of key hydrocarbon play elements, including potential reservoir rocks, source rocks, and cap/seal rocks. These findings have implications for understanding the potential for hydrocarbon accumulation and the overall petroleum system in the area.

By delineating the lithozones and their corresponding lithologies, we have established a framework for further exploration and research. The presence of sandstone units with suitable porosity and permeability suggests the possibility of viable reservoir rocks for hydrocarbon storage and production. The identification of shale units as potential source rocks indicates the presence of organic matter capable of generating hydrocarbons. Additionally, the recognition of cap/seal rocks highlights the importance of impermeable layers in trapping hydrocarbons within the subsurface.

However, it is important to acknowledge the remaining gaps in knowledge and areas for further research. While the lithostratigraphic model provides a valuable initial understanding of the subsurface geology, more detailed studies, such as core analysis and well log data integration, would enhance our understanding of the reservoir properties and connectivity. Additionally, geochemical analysis of the source rocks would provide insights into the hydrocarbon generation potential and maturity levels.

Lastly, this study provides a foundational understanding of the subsurface geology and hydrocarbon play elements in the studied area. It serves as a basis for future research and exploration activities, highlighting the need for more detailed investigations to refine our understanding of reservoir properties, source rock characteristics, and the overall petroleum system.

References

[1] Klett, T.R., Ahlbrandt, T.S., Schmoker, J.W., and Dolton, J.L. "Ranking of the world's oil and gas provinces by known petroleum volumes." U.S. Geological Survey Open-file Report-97-463. CD-ROM. 1997.

[2] Doust, H., and Omatsola, E. "Niger Delta." In Divergent/Passive Margin Basins, edited by J. D. Edwards and P. A. Santogrossi, 239-248. AAPG Memoir 48. Tulsa: American Association of Petroleum Geologists, 1990.

[3] Kulke, H. "Nigeria." In Regional Petroleum Geology of the World. Part II: Africa, America, Australia and Antarctica, edited by H. Kulke, 143-172. Berlin: Gebrüder Borntraeger, 1995.

[4] Hospers, J. "Gravity field and structure of the Niger Delta, Nigeria, West Africa." Geological Society of American Bulletin, vol. 76, pp. 407-422, 1965.

[5] Kaplan, A., Lusser, C.U., Norton, I.O. "Tectonic map of the world, panel 10." Tulsa: American Association of Petroleum Geologists, scale 1:10,000,000, 1994.

[6] Ekweozor, C. M., and Daukoru, E. M. "Northern Delta Depobelt Portion of the Akata-Agbada(!) Petroleum System, Niger Delta, Nigeria." In The Petroleum System—From Source to Trap, edited by L. B. Magoon and W. G. Dow, 599-614. AAPG Memoir 60. Tulsa: American Association of Petroleum Geologists, 1994.

[7] Petroconsultants. "Petroleum exploration and production database." Houston, Texas: Petroconsultants, Inc., 1996. [Database available from Petroconsultants, Inc., P.O. Box 740619, Houston, TX 77274-0619].

[8] Frost, B.R. "A Cretaceous Niger Delta Petroleum System." In Extended Abstracts, AAPG/ABGP Hedberg Research Symposium, Petroleum Systems of the South Atlantic Margin, November 16-19, 1997, Rio de Janeiro, Brazil.

[9] Nwajide, C. S. "Lithofacies and depositional environments of sedimentary basins in Nigeria." In Lithofacies and sedimentary environments of sedimentary basins, edited by S. J. J. Gabbott, 333-363. IntechOpen, 2013.

[10] Adediran, S. A., Olabode, S. O., and Adepoju, M. O. "An appraisal of the Niger Delta Basin exploration and production: a road map for sustainable economic growth in Nigeria." Journal of Environmental Science, Toxicology and Food Technology 11, no. 6 (2017): 23-30.

[11] Adeoti, L., Ahmed, A., and Oyedele, K. "Depositional facies, lithofacies association and petroleum system of the Cretaceous

Ibom and Qua Iboe fields, Eastern Niger Delta Basin." Arabian Journal of Geosciences 11, no. 9 (2018): 201.

[12] Maju-Oyovwikowhe, G.E., and Ehika Ighodaro. "Determination of Rock Properties for Reservoir Evaluation and Environment of Deposition of XY-Well Using Side Wall Samples." FUW Trends in Science & Technology Journal 8, no. 1 (April 2023): 341-348.

[13] Nwankwoala, H.O., E.N. Onuigbo, C.O. Ofoegbu, et al. "Lithofacies and Depositional Environment of Paralic Successions in the Niger Delta Basin, Nigeria: A Case Study of the Cretaceous Amasiri Sandstone." Journal of African Earth Sciences 116 (2016): 34-47.

[14] Nton, M.E., A.E. Akpan, I.U. Udoh. "Lithofacies, Depositional Environments and Hydrocarbon Potentials of the Deep-Water Sediments in the Eastern Offshore Niger Delta, Nigeria." Journal of African Earth Sciences 139 (2018): 114-128.

[15] Ejedawe, J.E., Coker, S.J.L., Lambert-Aikhionbare, D.O., Alofe, K.B., and Adoh, F.O. "Evolution of oil-generative window and oil and gas occurrence in Tertiary Niger Delta Basin." American Association of Petroleum Geologists 68 (1984): 1744-1751.

[16] Efemena, O.O., and Maju-Oyovwikowhe, G.E. "Geological Description of the Majuefe-01 Well, Niger Delta, Using Cores and Wireline Logs Data." FUW Trends in Science & Technology Journal 7, no. 3 (December 2022): 121-127.

[17] Maju-Oyovwikowhe, G.E., and Lucas, F.A. "Depositional facies analysis using core samples from greater Ughelli Depobelt, Niger Delta Basin Nigeria." Journal of Applied Sciences and Environmental Management (2019).

[18] Olatinsu, O., O.O. Olobayo, A.O. Adisa, et al. "Integrated Lithostratigraphic, Petrographic, and Petrophysical Evaluation of the Pabot-1 Well, Central Swamp Depobelt, Niger Delta Basin." Journal of African Earth Sciences 176 (2021): 104180.

[19] Petroconsultants. "Petroleum Exploration and Production Database." Houston, Texas: Petroconsultants, Inc., 1996. Database available from Petroconsultants, Inc., P.O. Box 740619, Houston, TX 77274-0619.

[20] Lehner, P., and De Ruiter, P.A.C. "Structural History of Atlantic Margin of Africa." American Association of Petroleum Geologists Bulletin 61, no. 7 (1977): 961-981.

[21] Lucas, F., and Odedede, O. "Lithofacies Characterization of Sedimentary Succession from Late Cretaceous-Tertiary Age in Benin West-1, Northern Depobelt, Anambra Basin, Nigeria." World Journal of Engineering 9, no. 6 (2013): 513-518.

[22] wozor, K. K., Okosun, E. A., Adedapo, O. T., & Egboka, B. C. "Quantitative Evidence of Secondary Mechanisms of Overpressure Generation: Insights from Parts of Onshore Niger Delta, Nigeria." Petroleum Technology Development Journal 3, no. 1 (2013): 64-83.

[23] Maju-Oyovwikowhe, G. E., and Lucas, F. A. "Sedimentological Analysis of Core Samples to Decipher Depositional Environments: A Case Study of 'Valz-01' Well Niger-Delta Basin, Nigeria." Current Journal of Applied Science and Technology 36, no. 3 (2019): 1–16. https://doi.org/10.9734/cjast/2019/v36i330237.

[24] Maju-Oyovwikowhe, E.G. and Ukpebor, Osahon (2019). "Lithofacies Interpretation Using Core Photos from Different Wells in the Niger Delta: Insights for Reservoir Characterization and Exploration." FUW Trends in Science & Technology Journal, 4(2), 639-651, August 2019.

[25] Ighodaro, E. J., F. A. Lucas, O. I. Imasuen, and H. E. Omodolor. "Sedimentological Resolution of Hydrocarbon Play Elements of OGE-# 1 Well, Greater Ughelli Depo-Belt, Niger Delta Basin." Inter. J. Sci. Tech. Res 5, no. 06 (2016): 173-183.

[26] Lucas F.A, and Omodolor Hope E, "Lithofacies Characterization of Sedimentary Succession from Oligocene to Early Miocene Age in X2 Well, Greater Ughelli Depo Belt, Niger Delta, Nigeria." Journal of Geosciences and Geomatics, vol. 6, no. 2 (2018): 77-84. doi: 10.12691/jgg-6-2-5.

[27] Maju-Oyovwikowhe G. E and Okudibie E. J "Sedimentological and Petrographic Analysis of Side Wall Samples from the Niger Delta Basin, Nigeria: Implications for Depositional Environments and Reservoir Quality." Journal of Energy Technology and Environment.Vol.5,no2(2023). https://doi.org/10.5281/zenodo.8026291

[28] Maju-Oyovwikowhe, G.E. and Ighodaro, Ehika. "Determination of Rock Properties for Reservoir Evaluation and Environment of Deposition of XY-Well Using Side Wall Samples." FUW Trends in Science & Technology Journal 8, no. 1 (2023/4): 341-348.