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MID CRETACEOUS SUBSURFACE CARBONATE DEPOSIT AND RESERVOIR DEVELOPMENT OF THE MFAMOSING LIMESTONE CALABAR FLANK

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ABSTRACT

This research analyzed the reservoir quality of the Mfamosing Limestone with a view to classifying it as a potential reservoir rock within the Calabar Flank. Materials used in this research are processed seismic data acquired around the Calabar flank and well logs of three wells (A, B, C) drilled at different periods within the study area, core as well as mud log data. The procedure used involved prospect identification and mapping, structural and stratigraphic analysis, reservoir quality and classification of the carbonate rock in the study area. The results were analyzed and classified the Mfamosing Limestone using hydrocarbon storage capacity and deliverability potential. Wells A and B was drilled 0.8km apart and well C drilled 4.7km from well B which encountered the Mfamosing Limestone with logs indicating hydrocarbon in Well A which had a shallower sandstone lenses. The sandstone lens in Well A was tested for hydrocarbon and flowed briefly and stopped. Wells B and C were planned and drilled using Well A as reference amongst other parameters to evaluate the hydrocarbon potential of the Mfamosing Limestone. Wells B and C were found completely dry. Two conventional coring runs at depths 10,490ft-10,552.5ft and 10,552.5ft-10,614ft in Well B indicated that the cored intervals are light grey, moderate to very hard, and fossil rich limestone with no direct fluorescence. The core analysis results suggest that limestone is dry and highly indurated with no evidence of physical porosity. This suggest that the Mfamosing Limestone penetrated by all three wells though massive has no hydrocarbon storage capacity and deliverability potential typical of a reservoir rock. This research therefore suggests that the Mid Cretaceous subsurface Mfamosing Limestone is more of a mineral carbonate deposit than a hydrocarbon reservoir.

Keywords: Conventional Coring, Hydrocarbon Storage Capacity and Deliverability, Fluorescence, Hydrocarbon Reservoir

1. INTRODUCTION

This research takes into account two different phases of analysis in the development of this work – the pre drill analysis and the post drill analysis phases. The pre drill analysis considers all the historical backgrounds of the study area, the geologic and geophysical studies carried out as well as data from satellite fields and a reference well (well A) drilled in same area (Calabar Flank) in making some geologic inferences. The post drill analysis explains the findings from the outcome of the wells drilled (Well A and B) on the basis of the pre drill analysis earlier carried out. The reference well and all other wells drilled subsequently were all drilled, south central of the Calabar Flank which encountered the Mid Cretaceous Mfamosing Limestone. The structure is a stratigraphic play which was tested for hydrocarbon bearing shallow sand lense in Well A drilled at the flank of the structure down dip the carbonate platform, however Well B and C was drilled through the crest and updip of the same platform to appraise well A and the deeper end of the structure respectively did not encounter hydrocarbon Selema et al. (2022). This makes it geologically gratifying to classify the carbonate structure as either hydrocarbon reservoir or a carbonate mineral deposit using the information provided by the pre drill analysis and post drill (well data) analysis collated in this research work. Ekpo et al. (2013) for a better understanding of the hydrocarbon generation potential of the Calabar Flank, carried out a detailed geochemical and organic petrographic studies with the aim of reconstructing paleoenvironmental control on the deposition of organic-rich shales in the Calabar Flank. Previous studies on the Cretaceous sediments in outcrops of the Calabar Flank are mostly limited to geological descriptions Adeleye and Fayose (1978), Petters (1982), Reyment (1965), Petters et al. (1995). Other geochemical studies in the Calabar Flank include organic geochemical appraisal Essien and Ufot (2010), geochemical studies of subsurface limestone Ekwere (1993) and geochemistry and organic petrography Ekpo et al. (2012). The Calabar Flank is that part of the southern Nigerian sedimentary basin characterised by crustal block faulting and is bounded by the Oban Massif to the north and the Calabar Hinge Line delineating the Niger Delta Basin in the south Figure 2. It is also separated from the Ikpe Platform to the west by a NE–SW trending fault in the eastern part, extending up to the Cameroon Volcanic Ridge. The Cretaceous shales exposed in the Calabar Flank are unique in Upper Cretaceous sequence Ekpo et al. (2013). The study area is located Cross River State, within the southern part of the Benue Trough. The study area is one of the most folded and mineralized sediments in Nigeria. The area is low lying and appears physiographically well defined, relating perfectly with the Cross-river drainage area. Its eastern boundaries are the basement complex province of the Obudu Plateau and the Oban Hills both of which are extensions of the Cameroonian mountains about 1800m above sea level Figure 1.

Figure 1

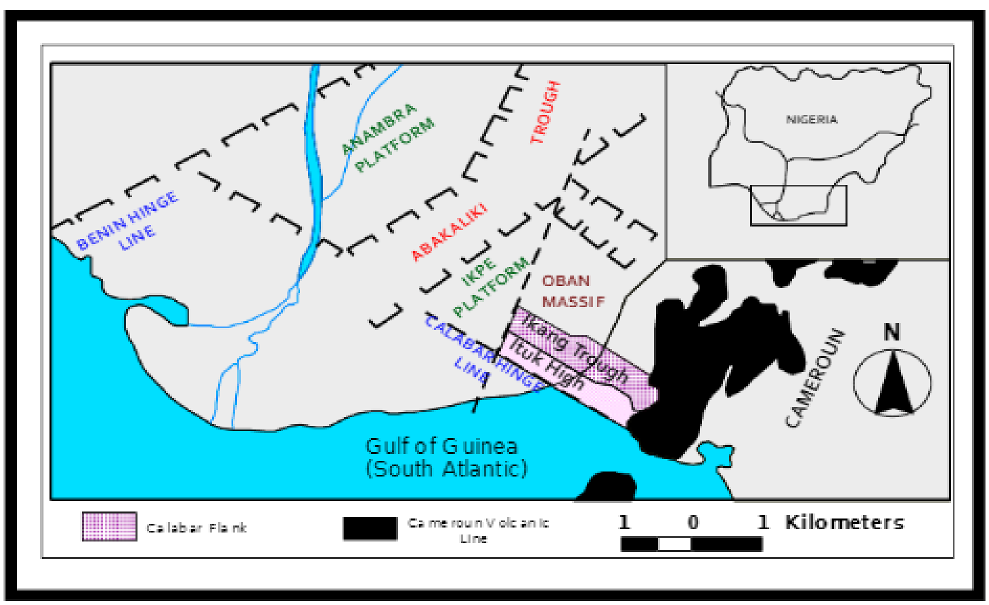

Figure 1 Map Showing Structural Elements of the Calabar Flank and Adjacent Areas (Redrawn from Nyong and Ramanathan (1985).

2. STRATIGRAPHY

The associated transgressive and regressive cycles, this region experienced made sediments of varying composition to be deposited Nyong and Ramanathan (1985). The sedimentary succession in this region comprises Cretaceous sequences - the Awi Formation, the overlying marine Odukpani Group and Nkporo Shale and Tertiary sediments – the Benin Formation (see Figure 2a). The main geologic and stratigraphic units that underlie this region includes the arkosic sandstones of the Awi Formation, Mfamosing Limestone, the Ekenkpon Shale (organic shale, calcareous mudstones, and oyster beds), New Netim Marlstones, Nkporo Shale (carbonaceous shales, mudstones and gypsum) and the Benin Formation Offiong and Edet (1998). The Cretaceous sedimentary rocks range from the Aptian to Campo-Maastrichtian whereas sedimentation began with the deposition of the Awi formation Sandstones interbedded with shales uncomformably overlain by fossilifereous Mfamosing Limestone which continued with the deposition of the Ekenkpon shale and New Netim Marlstone. A period of non-deposition was recorded during the Late Coniacian to Early Campanian such that sedimentation in the Cretaceous ended with the deposition of the Nkporo Shale - Late Campano-Mastrichtian Figure 2.

Figure 2

AGE	LITHOLOGY		DESCRIPTION
Recent Eocene -	Benin Formation		Loose sands, pebbly and arkosic
Maastrichtian L. Campanian -	Nkporo Shale		Dark grey, very fissile carbonaceous shale with gypsum bands and some calcareous nodules
Santonian	Santonian Deformation		Santonian deformational episode characterized by period of folding of pre-existing rocks and erosion and/or non deposition.
Coniacian	ODUKPANI GROUP	New Netim Marl	Dark grey massive marls intercalating with flaggy, calcareous grey shale with thalassinoides structures
Turonian		Ekenkpon Shale	Grey fissile shale with thin bands of calcareous nodules, limestone and mudstone units. Abundant shell fragments, keeled ammonite, juvenile
Cenomanian		Un-named Shale	Dark gray shale, highly fissile and separated by the upper shale unit by a regressive mudstone
Mid - Albian		Mfamosing Limestone	White to light grey limestone, stromatolitic at the base, with abundant fossils (gastropods, corals, shell fragments)
Neocomian - Aptian	Awi Formation		Reddish brown, coarse to medium grained arkosic sandstone. Pebbly at the base and exhibit fining upward succession in cycles, graded bedding.
Precambrian	Precambrian Basement Complex		Southeastern Basement Complex – Oban Massif composed predominantly of granite gneisses, granites and granodiorites.

Figure 2 Stratigraphic Chart of the Calabar Flank (Modified after Petters et al., 2010).

3. PETROLEUM SYSTEM AND PLAY IN THE CALABAR FLANK

The late Albian to Cenomanian Shale is believed to be the possible source rocks within the Calabar Flank while the main reservoir rock is the Mfamosing Limestone deposited Mid Albian. The trapping mechanisms may be predominantly stratigraphic features. While the migration pathways are macrofractures which may have been enhanced by the Santonian orogeny. The Nkporo Shale may act as the seal to the reservoir rock - Mfamosing Limestone Figure 3 - Figure 4. According to Reijers and Petters (1997), Well A was drilled within the limestone sequence of the Mfamosing Limestone and coupled with observed oil seepages within the study area to the surface further confirms a functional petroleum system in place. Ekpo et al. (2013), showed from their work that the bulk geochemical data such as TOC and SOM, of most of the samples except those at the basement boundary have TOC contents higher than 0.5wt.% with high extractibility >500 ppm, the minimum requirements for source rocks. The TOC content of Mfamosing samples is < 0.5wt.% and the extractability is <125 ppm while the Ekenkpon Shale has TOC content > 0.5 wt.%, hence classified as non-source rocks.

Figure 3

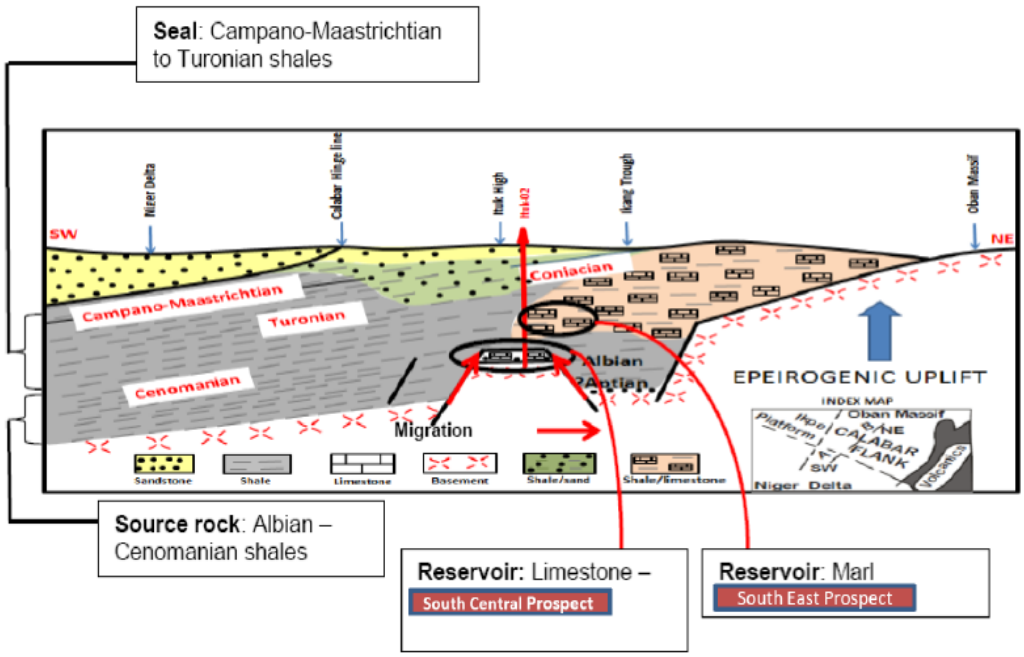

Figure 3 Possible Migration Pathway (Modified after Nyong, 1995, Reijers and Petters, 1997).

Figure 4

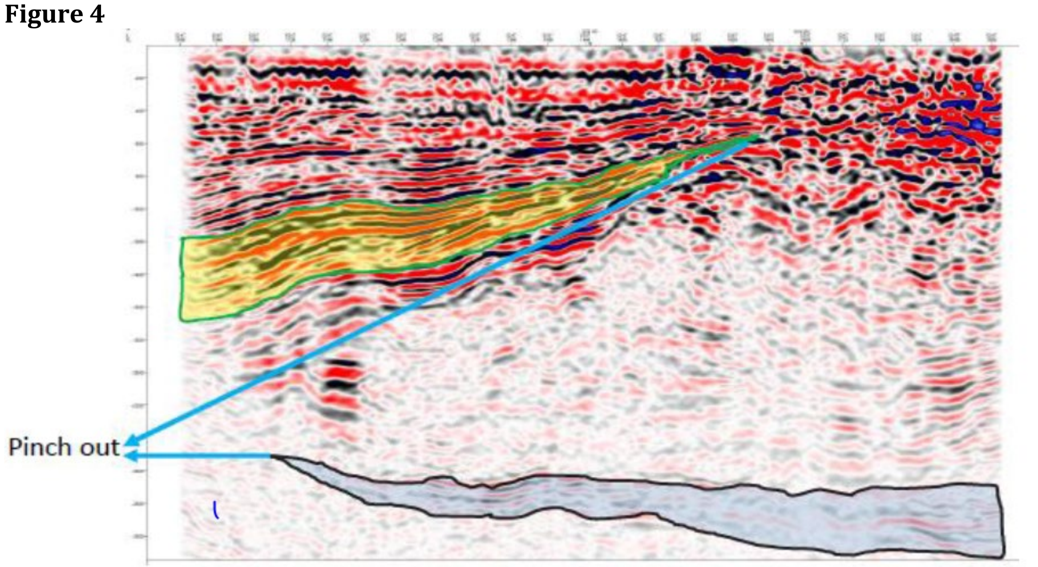

Figure 4 Typical Stratigraphic Traps in Study Area

4. MATERIALS AND METHODS

Materials used for this research includes:

1) Seismic
2) Amplitude data
3) Well logs
4) Location and structural Maps
5) Mud log data
6) Core data

Methods

The procedure adopted in carrying out this research involves prospect identification and mapping, structural and stratigraphic analysis, reservoir quality and classification of the carbonate structure in the study area.

5. RESULTS AND DISCUSSIONS

The results of this research is presented in Figure 5, Figure 6, Figure 7, Figure 8, Figure 9, Figure 10, Figure 11, Figure 12, Figure 13, Figure 14, Figure 15, Figure 16 and Table 1, Table 2, Table 3, Table 4, Table 5, Table 6.

Figure 5

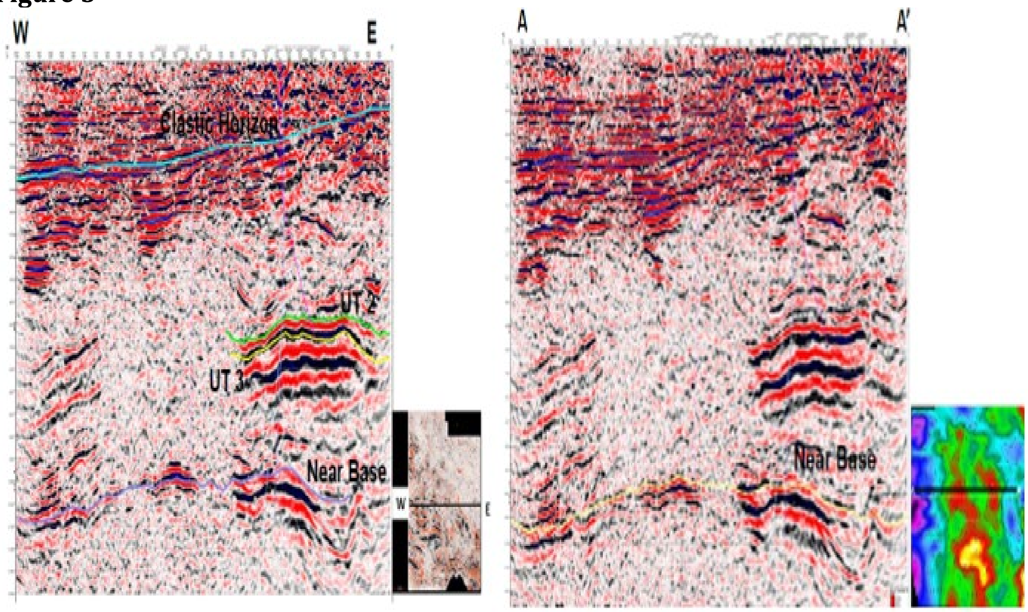

Figure 5 Cross line 1426 Through South Central Prospect Structure. UT1 – UT4 and Near Base

Figure 6

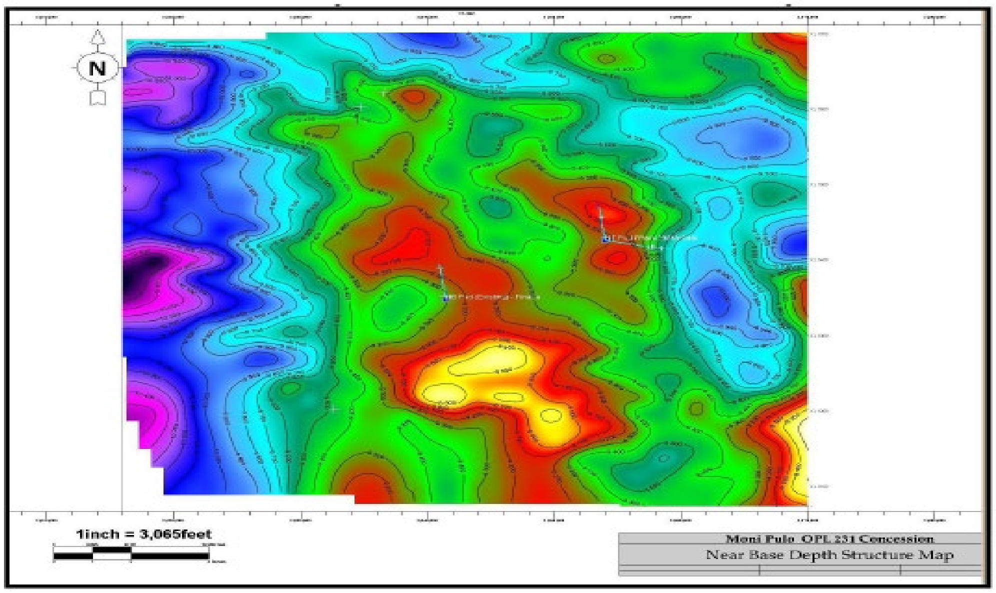

Figure 6 Near Base (Carbonate) Depth Structure Map

Figure 7

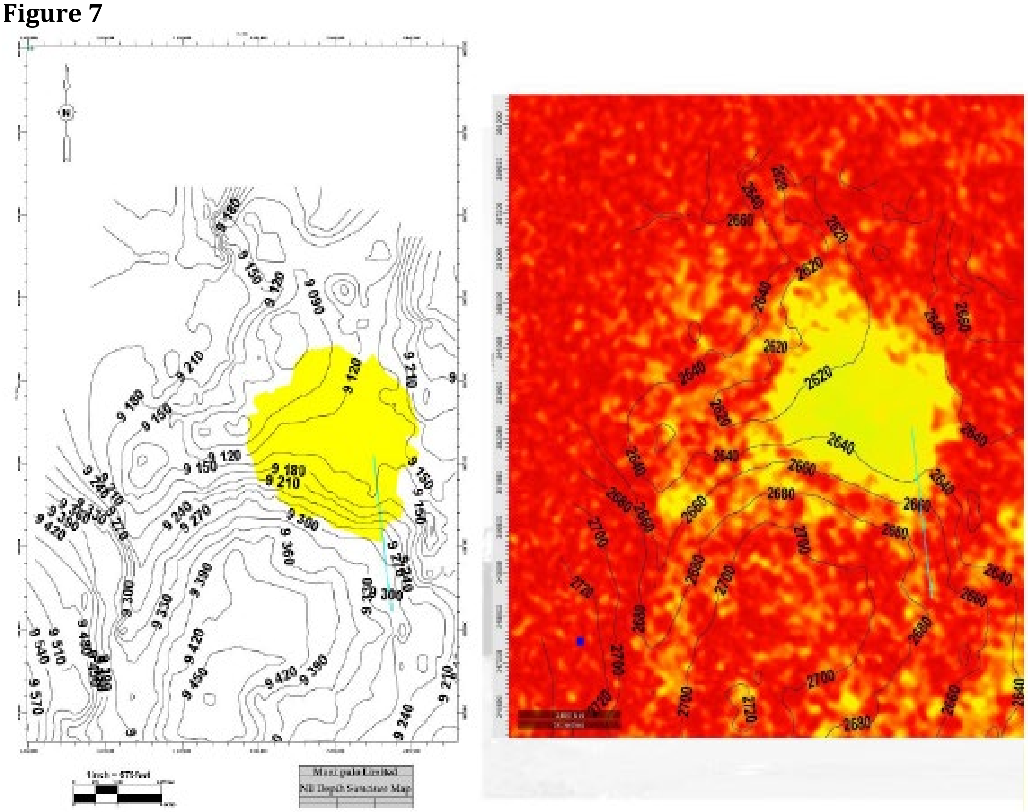

Figure 7 South Central Prospect Map and Sweetness Seismic Attribute Extract Highlighting the Stratigraphic Prospect Area

Figure 7a

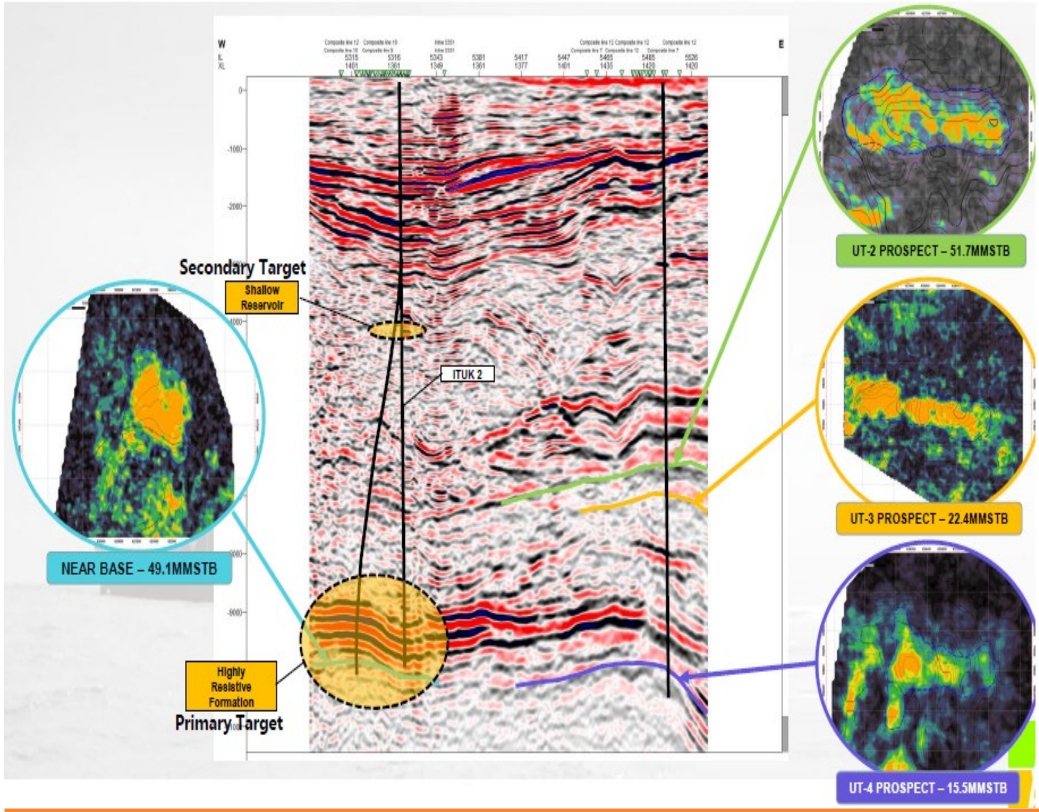

Figure 7a Amplitude Supported Prospect Identification and Mapping

Figure 7b

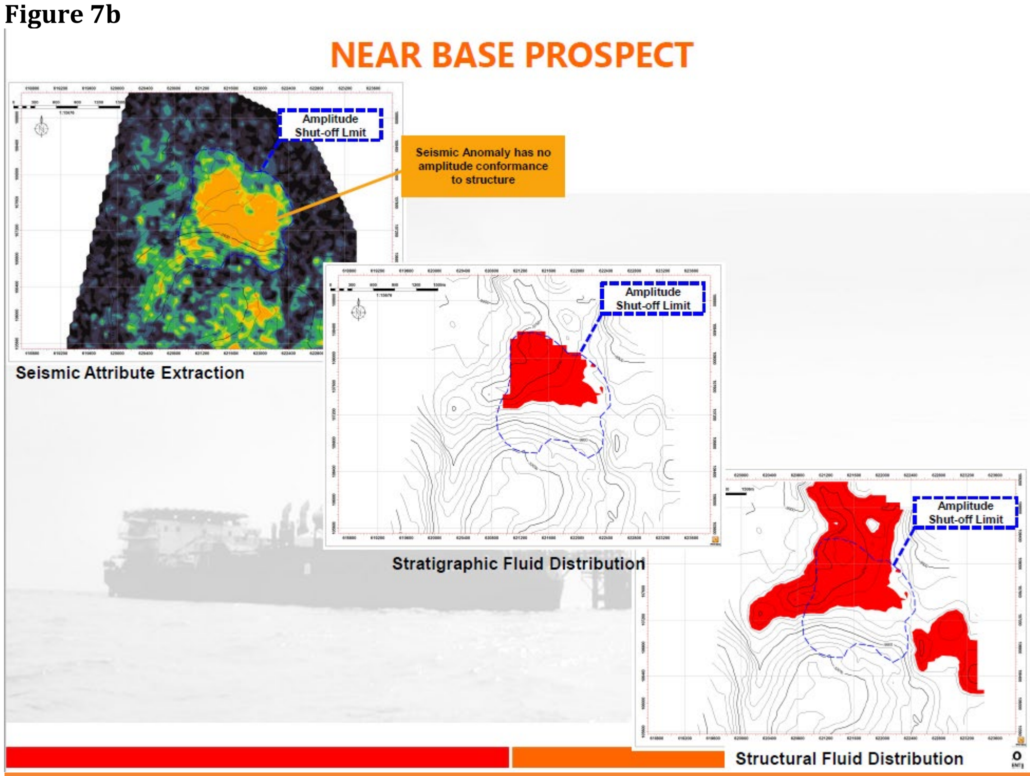

Figure 7b Near Base (Carbonate) Prospect

Figure 8

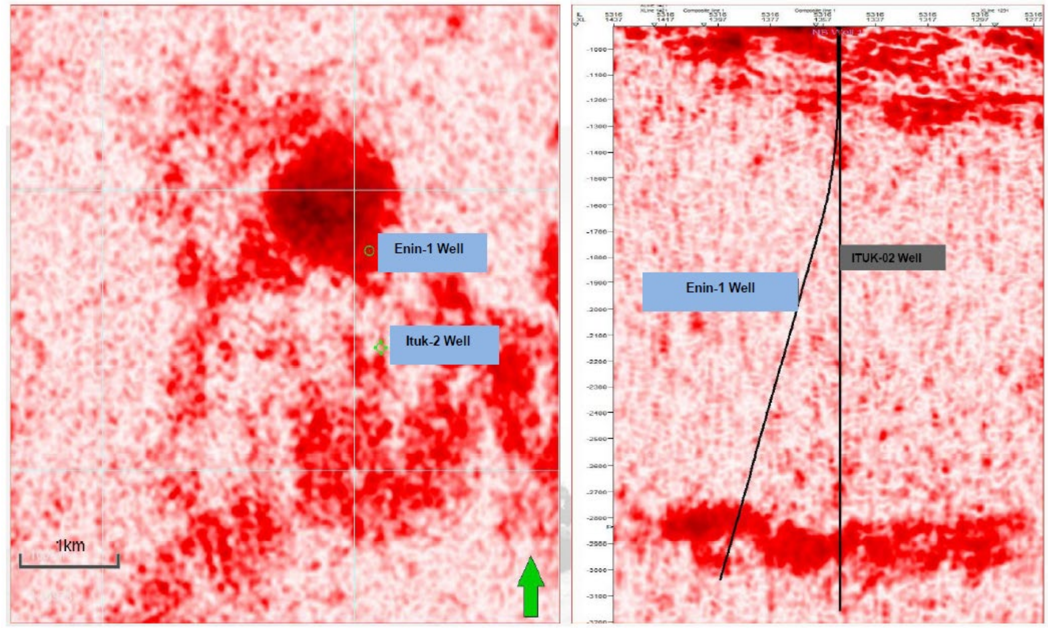

Figure 8 Time Slice at 2834ms and Inline 5316 Showing RMS Amplitude Extraction at South Central Prospect Location.

The generated seismic attributes shows the relationship between the encountered hydrocarbon interval in Well A at the flank of the stratigraphic play structure and Well B updip of the carbonate platform identified by bright amplitude anomaly - direct hydrocarbon indicator Figure 8. The reservoir levels were interactively inferred from descriptions of the ditch cuttings and log signatures Figure 9, Figure 10, Figure 11, Figure 12. Well B was drilled as a deviated exploration/appraisal well to target the Near Base prospect structure. The well was drilled to a total depth of 11277ftMD in 2018. The well was drilled from a two well cellar where well A (drilled earlier) currently exists. The hole was however, plugged as analysis of evaluation logs showed no indication of hydrocarbon. The objective was to penetrate and appraise the near base carbonate at the crest and also appraise the updip section of the structure. However, when penetrated the Mfamosing Limestone (carbonate rock) was found completely dry and highly indurated. Well C was drilled with the objective of penetrating the Mfamosing Limestone (carbonate rock) at the flank updip to investigate the near deep of the structure was found completely dry with highly indurated carbonate as observed in Well C, two (2) conventional coring runs was carried out - Core 1: 10,490ft–10,552.5ft and Core 2: 10,552.5–10,614.25ft respectively. See Figure 13 – Figure 14 and Table 1 - Table 2. Lithologic descriptions of the cored sections showed that the cored interval within the primary target showed a light grey, moderate to very hard, and fossil rich limestone with no direct hydrocarbon fluorescence. However, some oil stains with direct fluorescence were observed in the secondary target (shallow reservoir - sandstone), further confirming the presence of hydrocarbon and validating the submission of Well B – Ekpo et al. (2013) classified the Mfamosing Limestone as a non-reservoir rock.

Figure 9

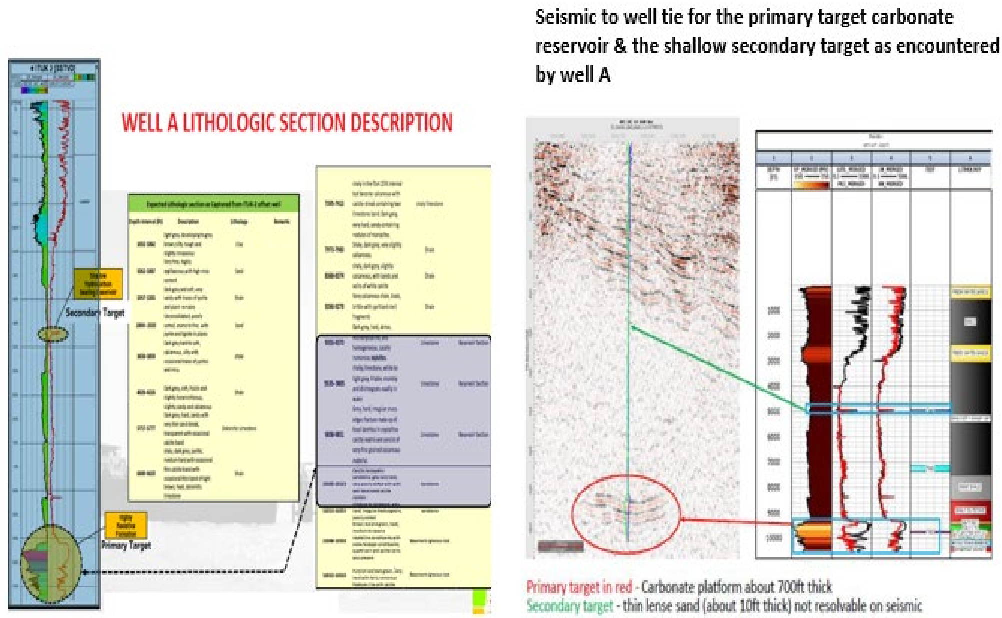

Figure 9 Seismic Section Showing the Seismic to Well tie for the Primary Carbonate Platform Target Near Base (NB) Reservoir and the Shallow Secondary Target as Encountered by Well A.

Figure 10

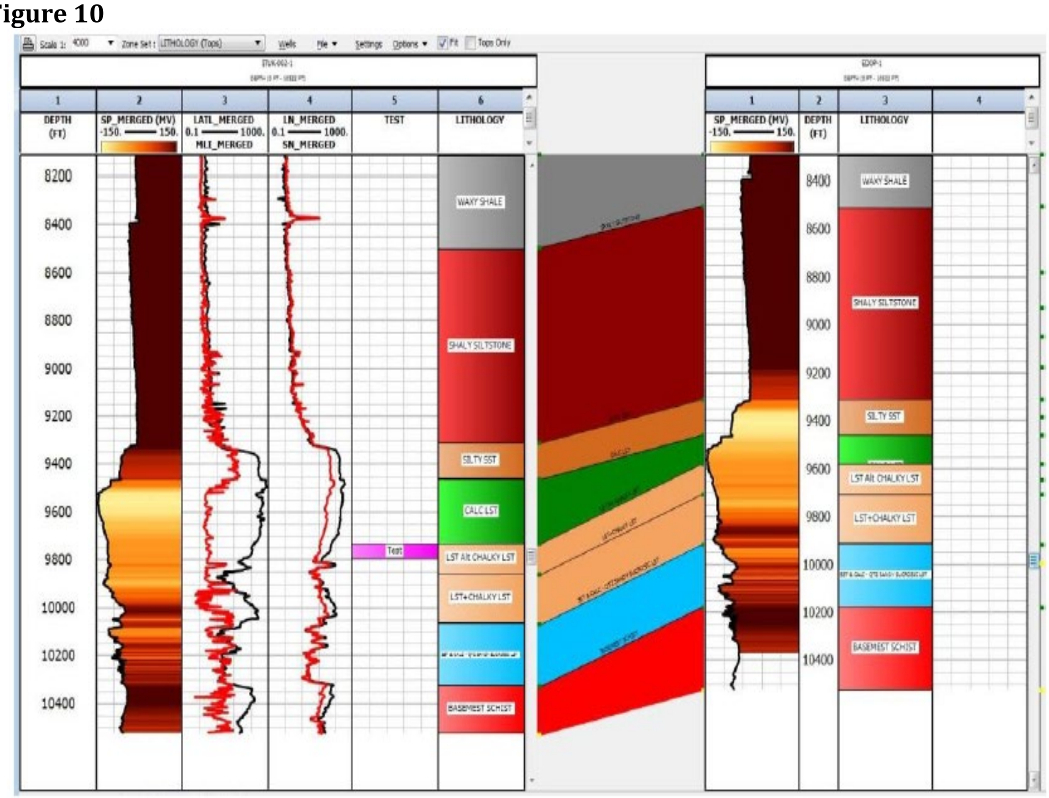

Figure 10 Lithostratigraphic Correlation Between Well A and Prognosed Well B Highlighting Near Base Reservoir Level.

Figure 11

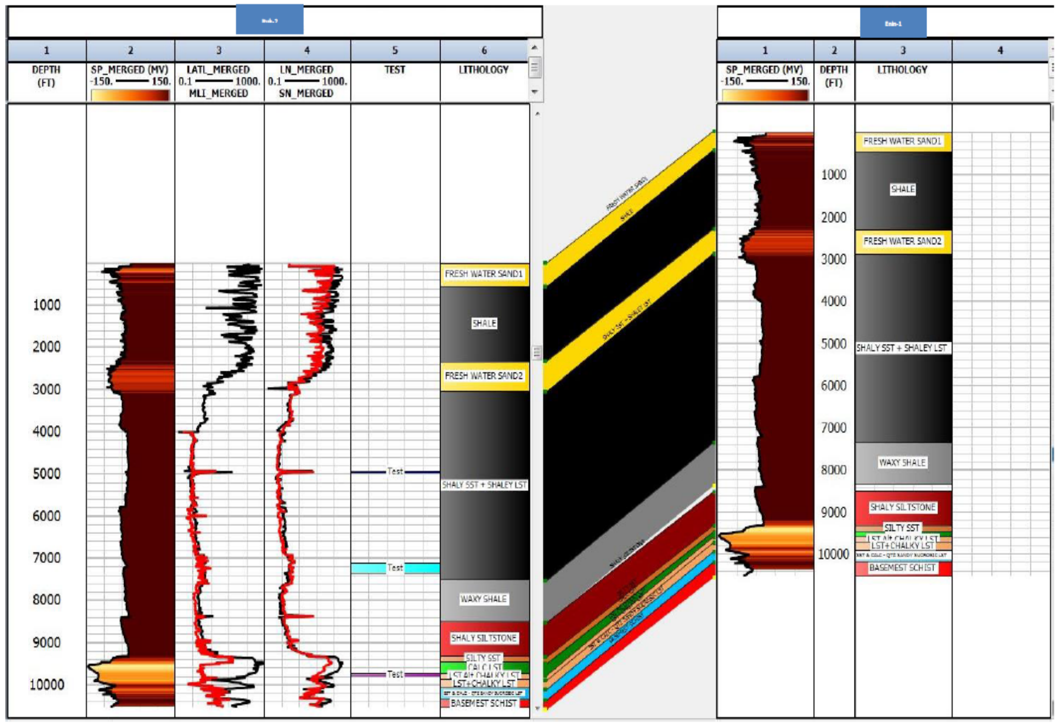

Figure 11 Lithostratigraphic Correlation Between Well a and well b. well a was Drilled to Target the Flank of the Near Base Reservoir Encountered Gas/Condensate**.**

Figure 12

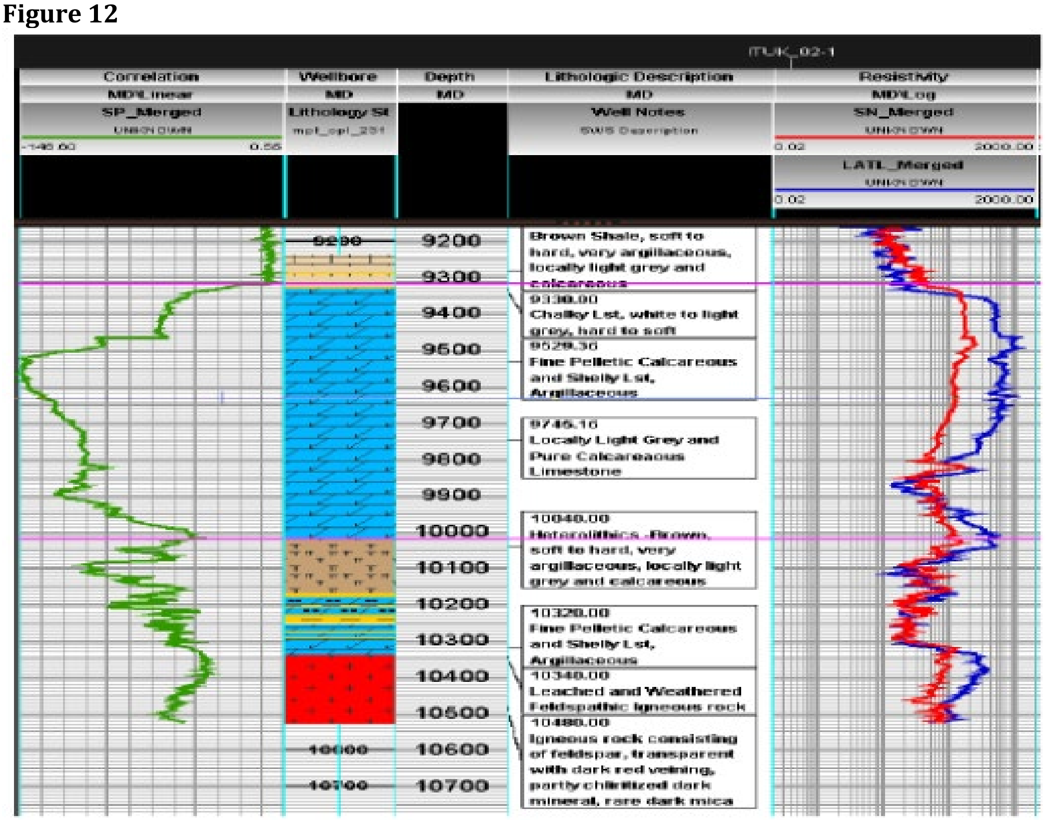

Figure 12 Lithological Description of Ditch Cuttings in Well A – the Carbonate Platform

Geologic Chance of Success

The geologic chances of success for development of the study area was analyzed and based on this, the two planned wells (Well A and B) were drilled and tested for hydrocarbon. Table 1, Table 2, Table 3, Table 4.

Table 1

Table 1 Volumetrics for Target Reservoir

Geologic Factor	Probability (0.1)	Comment/Reasoning
Source Rock Presence and Maturity	0.1	Source Rock seen by Well A
Migration from Mature Kitchen/Preservation	0.8	Well A found condensate
Presence of Reservoir Facies	0.85	Stratigraphic trap – Carbonate platform with a higher relief target
Seal Integrity	0.2	Prospect overlain by Netim Marl/Nkporo Shale
Geologic Chance of Success	0.61/61%	

Table 2

Table 2 Oil Case Volume

		Percentile Forecast Values (MMBbl)		
Prospect	Reservoir horizon	P10	P50	P90
South Central Prospect	Near Base	20.2	45.6	83.6

Table 3

Table 3 Gas Case Volume

Reservoir Horizon	Prospect	Cases (ft)	GRV (MMCF)	GRV (MMCF) Base Case	GIIP (MMCF)	GIIP (MMCF) Base Case
NEAR BASE	South Central Prospect	High D-1-9310	5257.9	5217.2	444.0	440.7
		High D-2-9310	4744.2		400.9	
		Low -9170	433.2		36.5	

Table 4

Table 4 Petrophysical Parameters

NTG (V/V)	Porosity (V/V)	Hydrocarbon Saturation (V/V)
0.65	0.2	0.65

Figure 13a

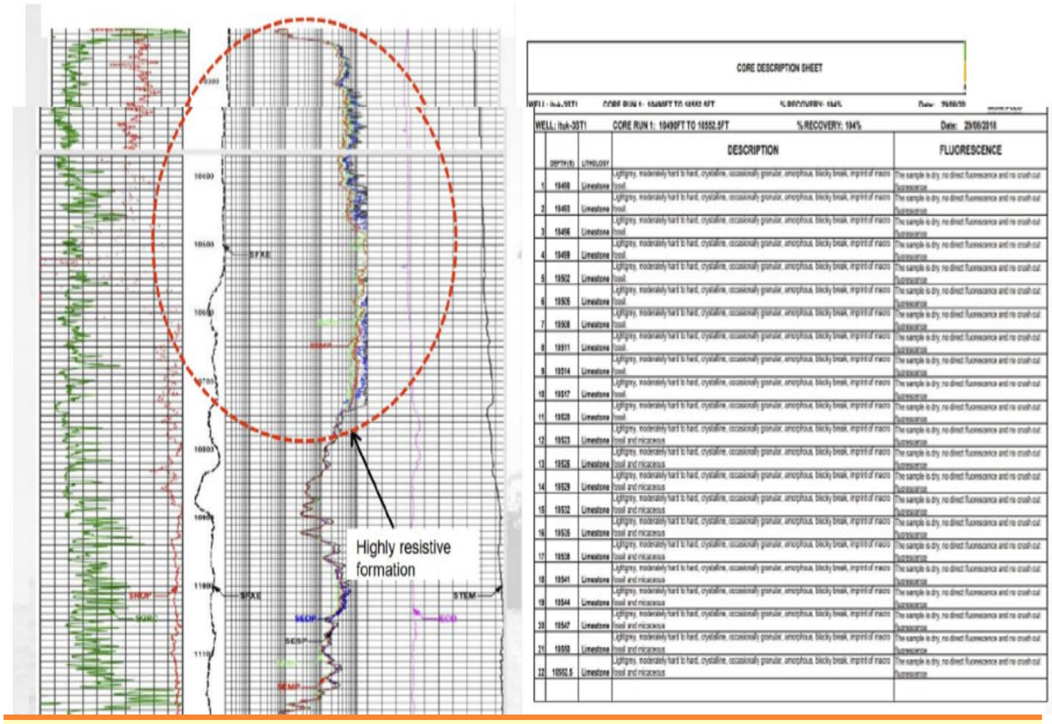

Figure 13 a Well B Cored and lithologic Interval Description

Figure 13b

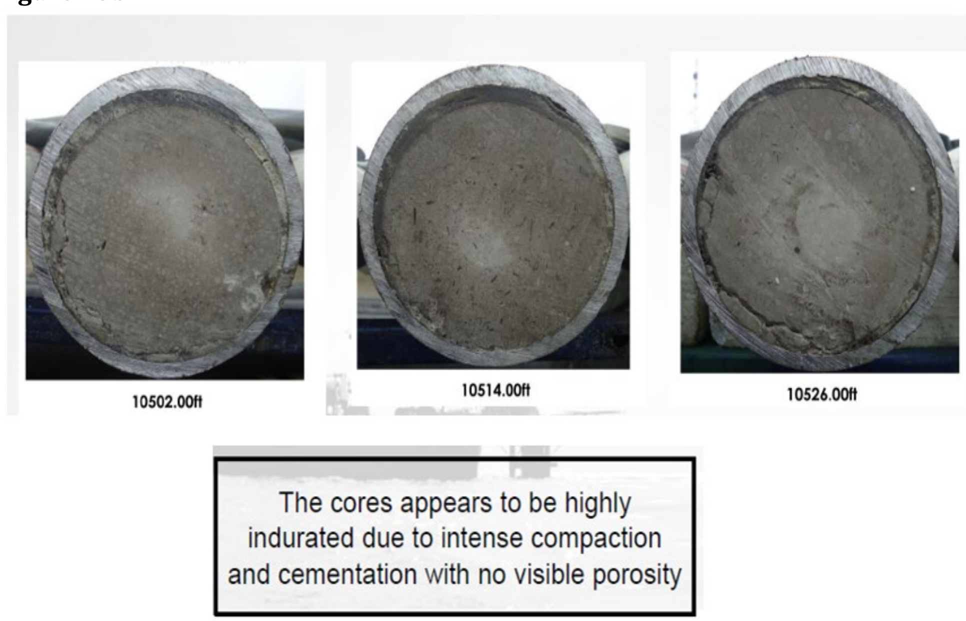

Figure 13 b Well B Core Photos of Carbonate Target Reservoir

Figure 14

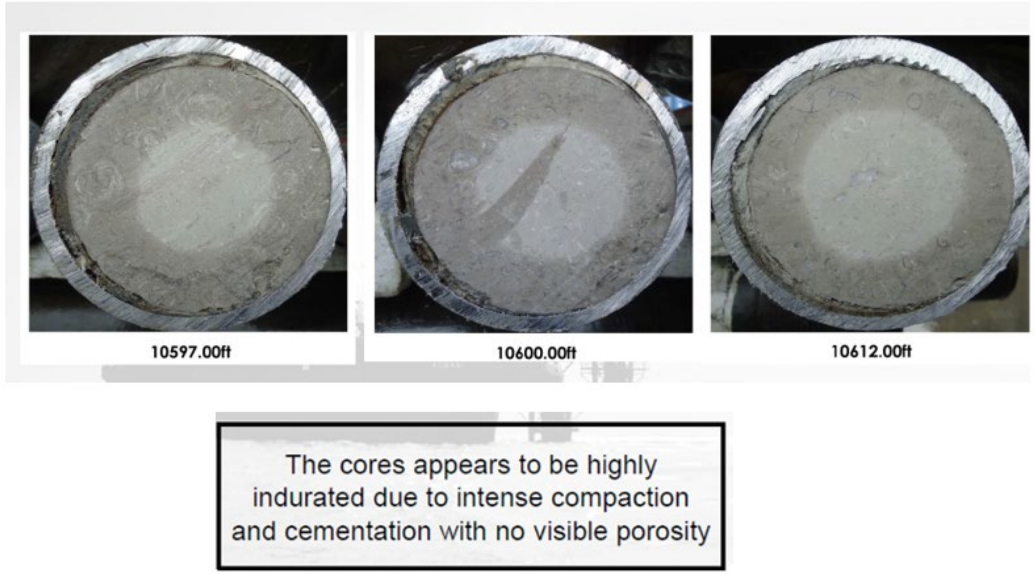

Figure 14 Well A Core Photos of Carbonate Target Reservoir

Figure 15

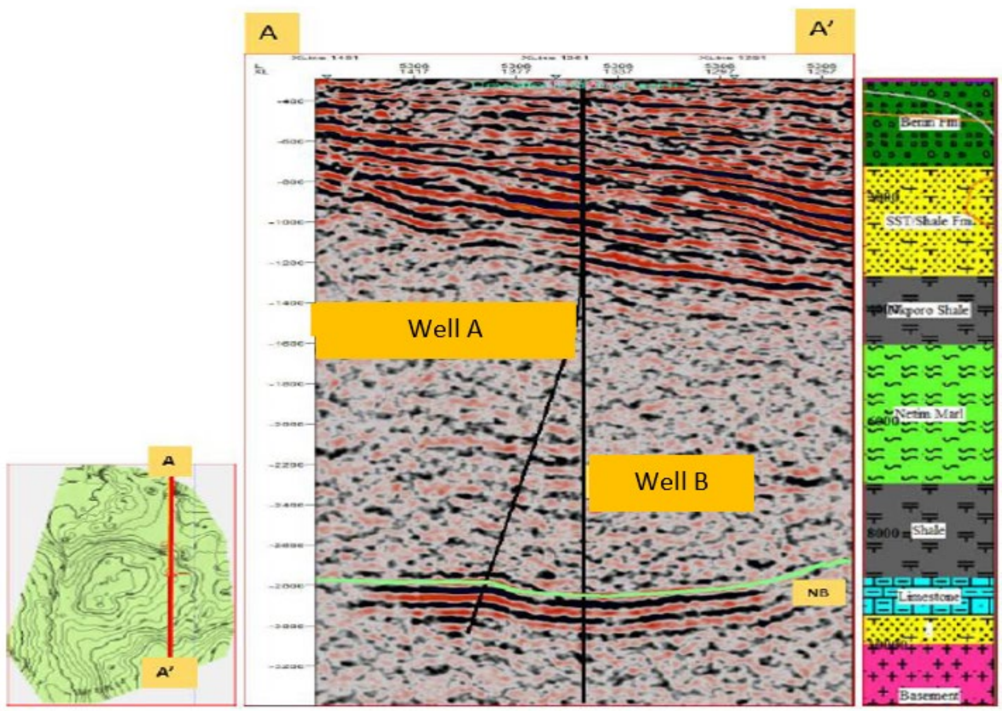

Figure 15 Seismic Section Through South Central Prospect Structure Showing the Position of Well A and Well B.

Table 5

Table 5 Stratigraphic and Lithologic Sequence of the Calabar Flank with Wells that Penetrated Each Section.

Age	**Formation**	**Depositional Environment**	**Wells That Penetrate Formations**
Campanian-Maastrichtian	Nkporo Shale	Shallow - Marine	Wells A, B, C penetrated this formation
Santonian	Santonian Episode	No Deposition	No Record
Coniacian	New Netim Marl	Marine	Only Well C penetrated
Cenomanian - Turonian	Ekenkpon Shale	Marine	Wells A, B. C penetrated this formation
Albian	Mfamosing	Marine	A, B, C penetrated Formation
Aptian	Awi Formation	Fluvio-Deltaic	A, B, C penetrated Formation
Precambrian	Oban Basement		

Figure 16

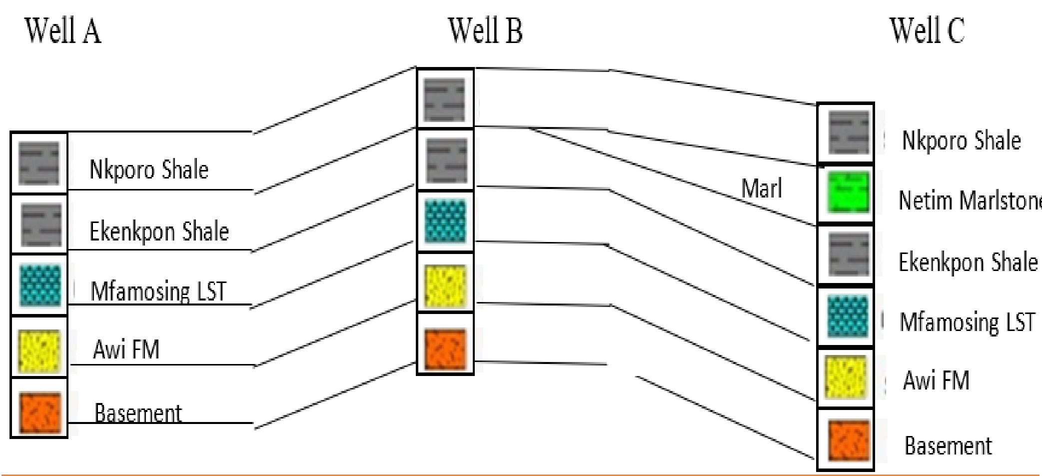

Figure 16 Correlation of Stratigraphic Units Penetrated by Three Wells in This Work

Table 6

Table 6 Wells that Penetrated the Mfamosing Limestone in the Calabar Flank.

WELL A	**WELL B**	**WELL C**
▪ Encountered Mfamosing Limestone.	Encountered Mfamosing Limestone.	Encountered Mfamosing Limestone.
▪ Logs indicate presence of HC – shallow sandstone reservoir.	Logs indicating no presence of HC of the Mfamosing Limestone.	Logs indicating no presence of HC of the Mfamosing Limestone.
▪ Shallow sandstone lenses of Well A tested for flow.	Cores shows Mfamosing Limestone highly indurated with no visible porosity.	Cores shows Mfamosing Limestone highly indurated with no visible porosity.

6. PRE-DRILL INTERPRETED SEISMIC SECTIONS/ATTRIBUTES

A block-wide seismic horizon interpretation was carried out for the near basement Carbonate platform (Mfamosing Limestone) (Figure 4and Figure 4b). Structural maps were generated based on the results of the interpreted horizons which revealed prospective locations (see Figure 5 - Figure 6). Seismic horizon interpretations of the study area carried out with amplitude anomaly support produced series of prospects which were selected for exploration. UT-2, UT-3, UT-4 and the near base carbonate prospects were identified and mapped based on their structural configuration (see Figure 7a and Figure 7b). Seismic attributes indicated that UT-2 exhibited a moderate degree of conformity to the structural configuration while UT-3 and Ut-4 showed poor conformity to structure suggesting that the lithological imprint could provide some enablement for hydrocarbon accumulation. The near base carbonate prospect was identified and selected for exploration due to its monoclinal structural configuration Figure 7b. Additionally, Well A that penetrated same region encountered some hydrocarbon in the sand lenses. This prospective structure is not a fault dependent closure and it is conformable to seismic attribute extract. The South Central prospect stratigraphic play exists at seismic time window of about 2700ms to 3000ms delineated by series of stacked bright amplitude anomaly (see Figure 8). Based on the identified, selected and mapped near the base carbonate platform, Wells B and C) were planned for development. The primary target for this well was the Near Base carbonate platform which occurred at 9186.3 ft. TVDSS. The target structure was tested by well A and traces of hydrocarbon found at the flank of the structure down dip of the play. Well B was to encounter the structure near the crest NW of the existing Well A identified by the bright seismic amplitude anomalies that conformed to the identified structure for possible hydrocarbon accumulations. Well C was drilled to encounter the structure updip to investigate the near deep structure Figure 7b.

7. CONCLUSION

The Mfamosing Limestone in the subsurface is a massive carbonate rock with no hydrocarbon storage capacity and deliverability potential typical of a reservoir rock. This research therefore suggests that the Mid Cretaceous subsurface Mfamosing limestone is more of a carbonate mineral deposit than a reservoir. It is one of the largest carbonate rock subsurface.

CONFLICT OF INTERESTS

None.

ACKNOWLEDGMENTS

None.

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