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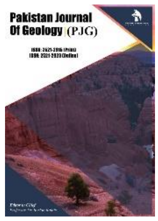

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RESEARCH ARTICLE

SEDIMENTARY DEPOSITIONAL SEQUENCE AND PETROPHYSICAL PROPERTY ANALYSIS FROMWELL LOGS OF 'WONDER' FIELD, COASTAL SWAMPDEPOBELT, NIGER DELTA

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ABSTRACT

In the Niger Delta's "WONDER" field, seven wells were thoroughly examined. The petrophysical characteristics of the sequences were determined using sequence stratigraphy, and the lithostratigraphic settings were modeled. Utilizing Schlumberger Petrel Software and Microsoft Excel, well logs and reservoir sands (RES A, RES B, and RES C) were analyzed, and petrophysical parameters were calculated. Biostratigraphic plots of the varieties of foraminifera in the reference well (WON 12-ST1) showed three sequences. These were found by matching log trends with depositional settings. There were three maximum flooding surfaces and four sequence boundaries. All of the sequences were classified as type-1, and there were three system tracts: transgressive (TST), highstand (HST), and lowstand (LST). In the HST and LST, prograding and aggrading sands with diminishing shale volume uphill were combined with retrograding shale and sand units. In the LST, TST, and HST, hydrocarbon buildups were discovered based on resistivity log data and calculated hydrocarbon saturation values. Average petrophysical parameters showing different shale volumes, total porosity, hydrocarbon saturation, and permeability ranges were calculated for RES A, RES B, and RES C over the seven wells. Examples of these ranges were found in Reservoir A, where the permeability measured 6978–8391 mD, the hydrocarbon saturation ranged from 51–59%, and the amount of shale ranged from 9–14%. This research provides crucial insights into the sedimentary patterns and hydrocarbon potential of the "WONDER" field in the Niger Delta.

KEYWORDS

Sequence Stratigraphy, Petrophysical Analysis, Lithostratigraphic Settings, Depositional Patterns, Reservoir Sands.

1. INTRODUCTION

Exploration activity has increased due to the growing worldwide demand for oil and gas, which is being driven by the industry's attractive earnings. As a result, oil exploration and production companies are extending their operations further offshore and into the flanks of the delta, uncovering new prospects but also facing increased risks. Traditionally, exploration focused on structural traps, but the evolving landscape has shifted emphasis toward stratigraphic traps. The offshore environment poses unique challenges, particularly the structural complexity of the geology, necessitating the development of accurate techniques for analyzing sediment depositional patterns and the petrophysical properties of the field. This research aims at addressing these challenges and related issues. It involves leveraging well-log data to evaluate reservoir properties and characteristics, understand depositional environments, and comprehend the implications of depositional sequences on hydrocarbon potential and productivity. The processes encompass determining reservoir dimensions, utilizing well log data to assess hydrocarbon-containing reservoirs and calculate petrophysical properties, and applying geological knowledge to study stratigraphic features.

This study relies heavily on sequence stratigraphy, which examines the links between genetically linked strata within a chronostratigraphic framework. According to Mitchum et al. (1977), a sequence is a genetically related series of conformable strata that are separated by either their correlative conformities or their unconformities. The sequence starts with a decline in relative sea level and ends with another decline. Sequence borders and maximum flooding surfaces further divide this sequence into Low stand, Transgressive, and High stand system tracts. Subunits of a sequence consist of parado sequences, which react to the interaction of sediment supply, subsidence, and eustatic variations.

For the purpose of identifying sequences, system tracts, and old cycles, biostratigraphy offers useful tools. Microfossils are used to help correlate stratigraphic sections and provide information about the dominant depositional environments. By examining stacking patterns, well log sequence stratigraphy proves useful in determining stratigraphic sequences. Tectonics, eustasy, and climate are reflected in the sedimentary record's patterns, with stratigraphic surfaces denoting variations in depositional environments.

Biostratigraphic data and log patterns are integrated during the interpretation phase. Sequence boundaries and maximum flooding surfaces can be determined with the aid of biostratigraphic data, especially foraminifera variety and abundance. Log patterns are varied and correspond to various depositional environments; they show how energy regimes change over time. The significance of petrophysics in

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hydrocarbon exploration has been highlighted by earlier studies, such as Olushola et al.2013) study on the 'Meri_T' field in the South Western Niger Delta. Kalu et al. (2020) generated a three-dimensional structural model and determined the petrophysical characteristics of the reservoirs as part of their reassessment of the Emerald Field located in the Niger Delta Basin. These studies underscore the critical role of carefully interpreted analyses in relating petrophysical data to deposition in the ever-evolving landscape of oil and gas exploration.

2. Location and Geology the Study Area

The Niger Delta Basin is situated in the Gulf of Guinea, at the tip of the continent of West Africa. The Niger Delta, which stretches 300 kilometers from its apex to its outlet, is one of the world's largest hydrocarbon regions. A coarsening upward-regressive association of tertiary strata approximately 12 km thick is seen in the Niger Delta (Whiteman, 1982).The research area is located in the Niger Delta's coastal marshland region (Figure 1 and 2). It spans the latitudes 4°N to 9°N and the longitudes 4°E to 9°E.It is composed of a clastics series that is regressive generally and has a maximum thickness of about 12 km. From the Eocene to the present, the delta has deteriorated southward, creating dipobelts that show the delta's most active region at each stage of its development. These depobelts make up one of the largest regressive deltas in the world, with a surface area of around 300,000 km^, a sediment volume of about 500,000 m^, and a sediment thickness of more than 10 km in at main basin depocenter. The Niger Delta province is known to have only one petroleum system, the tertiary Niger Delta (Akata – Agbada) system.

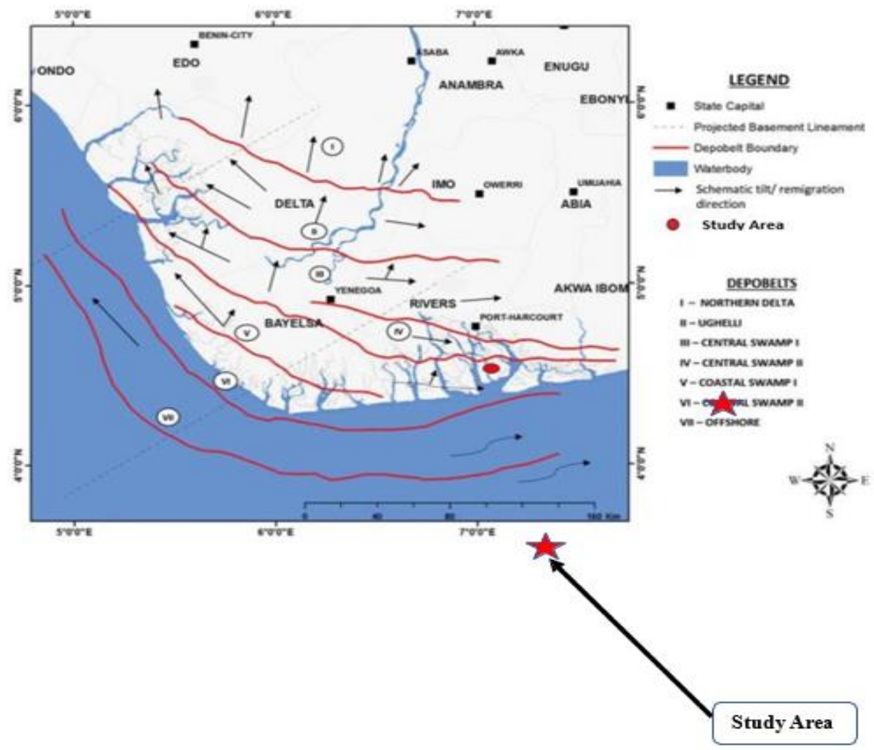

Figure 1: Location map of the study area.

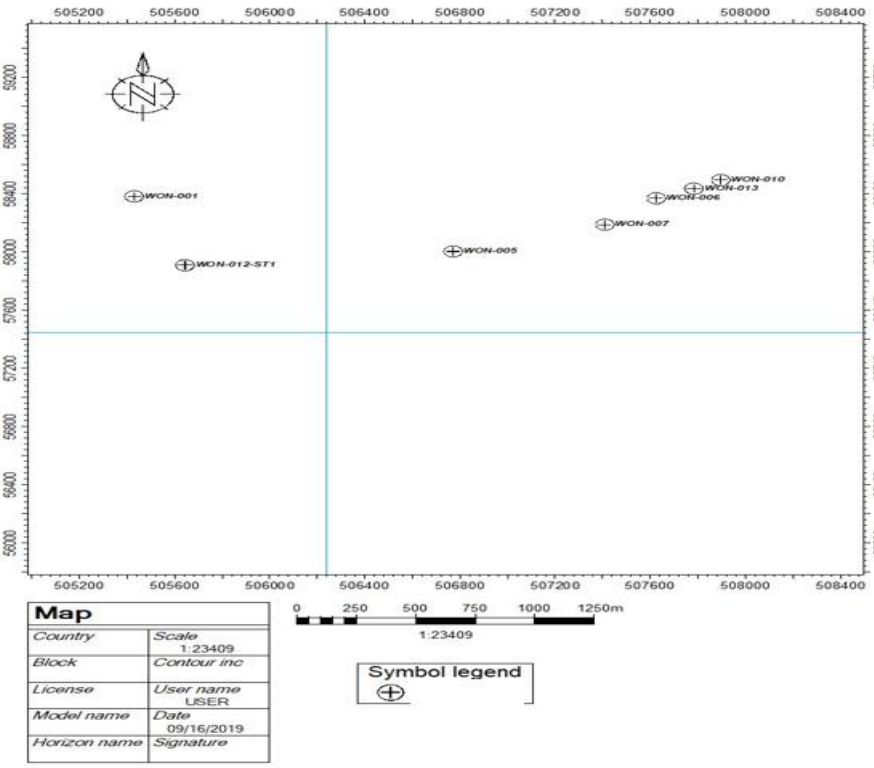

Figure 2: Base Map of the Study Area Showing Well locations.

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3. Research Methodology

Four well logs' worth of composite wireline log data were evaluated (see table 1).

The suites of well log data used for this work, which included bulk density logs, neutron porosity, resistivity, spontaneous potential (SP), and gamaray (GR), were obtained from Shell Petroleum Development Company (SPDC).The subsurface lithologies were mapped using the Gamma Ray Log after the well data was entered into the Petrel software, and the petroleum properties were then determined. The research area's base map was created once the wells were loaded. The logs were divided into non-reservoir zones and possible reservoir zones. Based on the findings from the deep resistivity reading instruments, hydrocarbon-bearing reservoirs were located. Hydrocarbon kinds, on the other hand, (oil and gas discrimination) were based on the overlay of density-neutron logs. Subsequently, the maximum flooding surfaces and sequence boundaries were identified in order to subdivide the geological succession (Loutitetal., 1988, Van Wagoneretal., 1990, Posamentier and George, 1994).To determine the maximum flooding surfaces and sequence boundaries, biostratigraphic data was employed. After looking for the highest peaks that would indicate flooding surfaces, maximum flooding surfaces, and sequence boundaries were found in the gammaray logs.

Many pattern stacking patterns (gradational, retrogradational, and progressive parameter sets) were examined in respect to the individual sequences below and above predetermined positional systems in order to comprehend the systems and fictitious elements. Lithology and resistivity logs were used to analyze the curve form in relation to the depositional circumstances. Furthermore, the log signatures of individual wells were compared with the systems tract interpretation methods suggested by Posamentier and George (1994) and Neal et al. (1993). (G) All of the wells had their lithology interpreted, and tracts for systems and parasequences were established by carefully examining the log patterns. Following a petrophysical investigation, many metrics pertaining to the reservoirs and sands were calculated, including the amount of shale, water saturation, porosity, and net pay etc. were computed and related to the reservoir sands.

Table 1: Logs Used in the Study Area

WELLS	LOGS			
	GR	NPHI	RHOB	LL9D
WON 1	✓	✓	✓	✓
WON 5	✓	✓	✓	✓
WON 6	✓	✓	✓	✓
WON 7	✓	✓	✓	✓
WON 10	✓	✓	✓	✓
WON 12-ST1	✓	✓	✓	✓
WON 13	✓	✓	✓	✓

✓ Present, GR – Gamma ray NPHI – Neutron log RHOB – Density log LL9D – Deep laterolog

3.1 Qualitative interpretation

3.1.1 Lithology Interpretation

The research area's lithology, or the sand and shale bodies, was defined using Gamma Ray (GR) 1 og. The GR log's leftward deflection indicated the presence of sand bodies, but the rightward deflection indicated shale, which is indicative of a high concentration of radioactive materials in the material.Typically, the separation of shale and sand lithologies is achieved using a central cutoff of 72 API units and a GRlogis scale of 0-150 API.

3.1.2 HydrocarbonReservoir Delineation

Resistivity log, a fluid identification method, was used to identify hydrocarbon containing reservoirs qualitatively. High resistivity readings are commonly seen in hydrocarbon-bearing sand, whereas low resistivity is important in water-bearing sand. Using the Neutron-Density crossover, the fluid content of the hydrocarbon-bearing sands was further identified.

3.1.3 Fluid Contact Identification

Neutron-Density crossover and the resistivity log were used to identify the fluid contact. A high crossover value suggests gas, while a low crossover value suggests oil. The fluid contact is seen at a depth of 8780 feet, marking a transition zone inside the reservoir from an oil-bearing zone to a water-saturated region.

3.1.4 Well Log Correlation

By mapping major stratigraphic surfaces (SBs and MFSs) using biostratigraphic data, well correlation was obtained in Petrel window. The optimal datum on which to hang the correlation cross sections was found to be the maximum flooding surface. Aiding reservoir investigations in the field, correlation was used to determine a continuity or discontinuity of facies.

3.1.5 Log Sequence Analysis

Three major steps were employed in log sequence analysis. These steps are basically qualitative

They are,

i) Understanding the lithology ii) Electrosequence analysis for log-based sequences, facies, and depositional environment; iii) Electrofacies annotation.

Grain size and depositional contexts of the various rock units in the wellfield were determined with the aid of Gamma Ray Log values and Signals (fining and coarsening ascending signals).

3.2 Quantitative Interpretation

The application of mathematical models and relations—which yield the same values for the log responses to the formation parameters—is a component of the quantitative interpretation.

In order to determine the amount of hydrocarbon existing in a reservoir, the pace at which hydrocarbon can be produced to the earth's surface through well bores, and the fluid movement in rocks, reservoir models are developed upon the measurement and derivation of petrophysical parameters. The following are a few of the crucial petrophysical factors for reserve appraisal: porosity, lithology, shale volume, netto gross, thickness of the sand, hydrocarbon saturation, water saturation, hydrocarbon reserves, etc.

3.2.1 Volumeof Shale (Vsh) analysis

This was derived from the gamma ray log first by determining the gamma ray index IGR:

$$IGR = \frac{(GRlog - GRmin)}{(GRmax - GRmin)} \qquad (1)$$

Where IGR = gamma ray index; GR log = gamma ray reading of the formation; GR min= minimum gamma ray reading (Sand baseline); GR max = maximum gamma ray reading (shale baseline).

For the purpose of this research work, Larionov's volume of shale formula for tertiary rocks was used:

$$Vsh = 0.0083\ (23.7Igr-1) \qquad (2)$$

Where Vsh=Volume of shale; IGR = gamma ray index

3.2.2 Porosity (Φ) analysis

It is the portion of the sample's total volume that is made up of holes or voids. It is possible to obtain porosity from a neutron orsonance log. The calculated total and effective porosity

3.2.2.1 Using Density log

$$\phi = \frac{(\rho ma - \rho b)}{(\rho ma - \rho f)} \qquad (3)$$

Where ρma=rock matrix density;ρb =measured density (from the log);ρf = fluid density(flushed zone). In water zone, ρf =ρmfwhich is approximately 1.1gm/cc. while in hydro carbon zone,

$$\rho fl = 0.7\ \rho mf + 0.3\ \rho hc \qquad (4)$$

ρflisapproximately 0.9foroil, 0.74 for gasand 1forwater.

For the purpose of this research work, the porosity derived from density log was used.

3.2.2.2 Using sonic log

Porosity from sonic log is estimated using the why llie's time average equation:

$$\phi = \frac{(\Delta tlog - \Delta tma)}{(\Delta tf - \Delta tma)} \quad (5)$$

WhereΔtlog = Sonic log reading; Δtf= interval transit time of the saturating fluid; Δtma=interval transit time of the matrix material.

3.2.3 Formation water resistivity factor estimation (F)

Formation There are several ways to evaluate water resistivity. This study's methodology involves the estimation of formation water resistivity from resistivity logs. The formation's resistivity at 100% water saturation (where Sw=1) is proportional to the water's resistivity inside its pores. This is expressed mathematically in clean formations as;

$$F = Ro / Rw \quad (6)$$

WhereRw = formation water resistivity; Ro = resistivityat100% water saturation; F=formation factor. Ro is read from the resistivity log. Porosity(ϕ) is calculated from porosity log.

The relationship between normation factor (F) and porosity (ϕ) as proposed by Archie (1942) is;

$$F = \frac{a}{\phi m} \quad (7)$$

Where a=tortuosity constant which usually lies between 0.6and 1; m= cementation factor;

ϕ=porosity; F=formation factor. For carbonates

$$F = \frac{1}{\phi 2} \quad (8)$$

For unconsolidated sands (humble formula);

$$F = \frac{0.62}{\phi 2.15} \quad (9)$$

For consolidated sands (humble formula);

$$F = 0.81 \quad (10)$$

3.2.4 Water / Hydrocarbon saturation analysis

Given that a pore space may hold either water or hydrocarbon, the hydrocarbon occupies the fraction of the residual pore space after the water saturation (Sw) is determined. The calculation of water saturation from resistivity and porosity logs can be used to infer hydrocarbon saturation, which cannot be tested directly.

Fraction of pore space occupied by hydrocarbons is represented by Sh, and by water by Sw.

$$Sh = 1 - Sw \quad (11)$$

The Archie's equation for estimating water saturation is;

$$Sw = (a^* Rw / \phi m^* Rt)1/n \quad (12)$$

Where a = tortuosity constant which usually lies between 0.6 and 1; m= cementation factor; n= saturation exponent; Rw= formation water resistivity; Rt= true resistivity.

3.2.5 Irreducible water Saturation (Swirr)

Whether or not information is soluble in water relies on the bulk volume of water. A zone has irreducible water saturation when the bulk volume of water in the formation remains constant, and vice versa.

Mathematically;

$$Swirr = (F / 2000)1/2 \quad (13)$$

4. DISCUSSION OF RESULTS

Analysis of petro physical parameters and sequence stratigraphy were carried out in order to evaluate hydrocarbon potential and sediment depositional patterns. The results obtained were presented in form of logs, tables and charts in order to aid reasonable inferences.

4.1 Lithology Identification

To identify the lithology, the gamma-ray log of the seven (7) wells (Figure 2) under study was evaluated. The lithology of the studied intervals is dominated by alternating sand and shale, with sand occurring more frequently near the top of the log and shale happening more frequently as the logging gets deeper. In order to reduce ambiguity in interpretation, the lithology type has been reduced to three distinct types: sand, sandy-shale, and shale (Figure 3).

4.2 Lithostratigraphic Correlation Panel

In lithostratigraphic correlation, several lithologic units penetrated by the well are identified. The lateral and geometric distribution of distinct sand and shingle strata passed by the well were studied using the gamma-ray log. The field of study's reservoirs ands were disclosed by the lithostratigraphic correlation panels (Figure 4 and 5). One correlation panel moved in the NW-SE direction, while the other moved in the NE-SW direction.

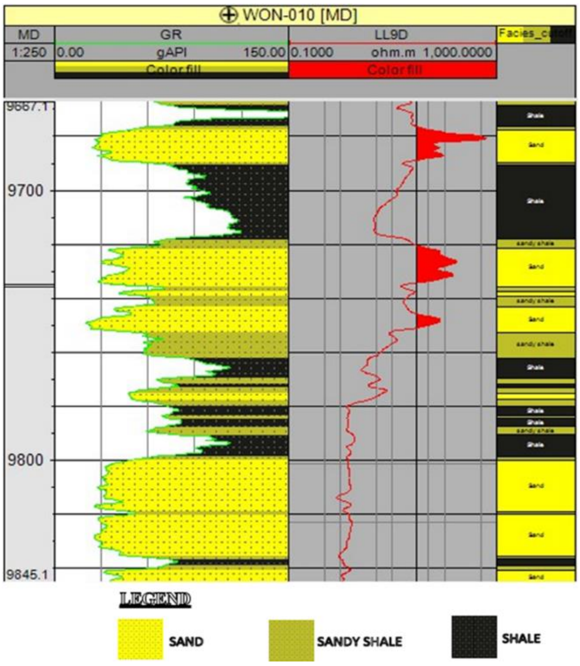

Figure 3: Lithologic Identification Used in the Study

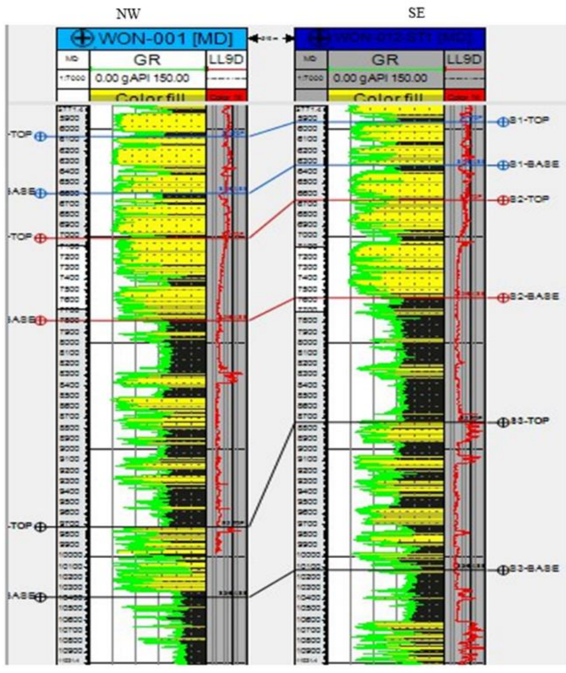

Figure 4: Lithostratigraphic Correlation Panel Across the Wells in the NW-SE Direction

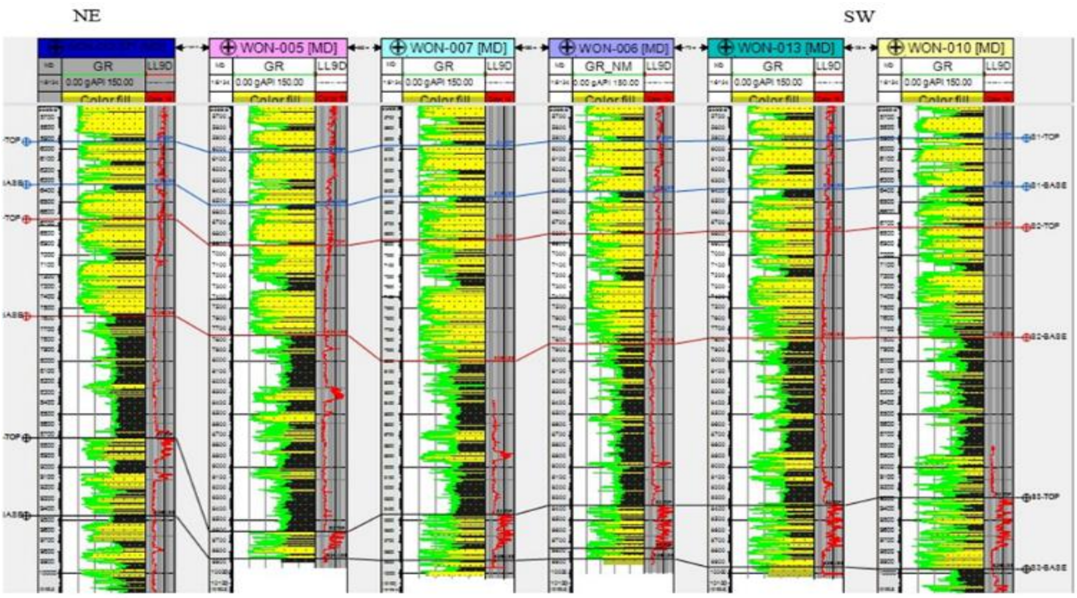

Figure 5: Lithostratigraphic Correlation Panel Across the Wells in the NE-SW Direction

5. Sequence Stratigraphic Interpretation of Thelogs

In the "WONDER Field" (Figure 6, 7, 8, 9, 10, and 11), three (3) depositional sequences (SEQ1, SEQ2, and SEQ3) and the corresponding systems tracts are interpreted and mapped based on the biostratigraphic data of the difference well (WON12-ST1) and the spatial distribution of the recognized constrained surfaces (MFSs and SBs).

5.1 Identification of Stratigraphic Sequences and Systems Tracts boundaries

From log patterns and par sequence stacking patterns, boundaries of sequences and system tracts were found (Figure 9, 10, 11and Table2).The field's detailed sequence stratigraphy was completed by combining the resistivity log and gamaray log patterns with the foraminifera abundance and diversity of the reference well (WON12-ST1).

Units with well-developed shells and low resistivity values are identified as having the largest flooding surface, whereas units with maximal variety and aminiferal abundance peaks are identified as the boundary between retro gradational and progressive sequence sets.

The first notable flooding surface in a series is known as the Transgressive Surface of Erosion (TSE).It typically takes place at the foot of the Transgressive Systems Tracts' retrogradational parasequence stacks. Sequence Boundaries (SBs) were identified in regions with little biodiversity and abundance of fauna, or in the lack of documented biological events, indicative of low gamam and high resistivity responses. The base of a Sequence Boundary (SB) was likewise defined by a progradation-least stacking arrangement. The oldest and youngest sequences were formed by sequences 1 and 3, respectively

Table 2: Key Stratigraphic Surfaces Recognized from Log Data in the Wells

KEY SURFACES	WELLS WITH DEPTH TO TOP OF RECOGNIZED SURFACES						
	WON 1 (ft)	WON 5 (ft)	WON6 (ft)	WON7 (ft)	WON10 (ft)	WON 12-ST1 (ft)	WON 13 (ft)
SB-3/4	5800	5983	5875	5920	5845	5885	5870
MFS-3	6610	6540	6440	6480	6370	6370	6400
TS-3	6693	6615	6485	6535	6445	6482	6470
SB-2/3	7430	7252	7180	7215	7090	7035	7150
MFS-2	8030	7822	7930	8100	7880	8136	7915
TS-2	8275	8222	8160	8290	8095	8710	8135
SB-1/2	9072	8755	8455	8490	8420	9420	8415
MFS-1	9385	8915	8820	8810	8780	9745	8800
TS-1	9592	9455	9230	9325	9125	10416	9200
SB-1	10315	9960	9870	9940	9970	11345	9980

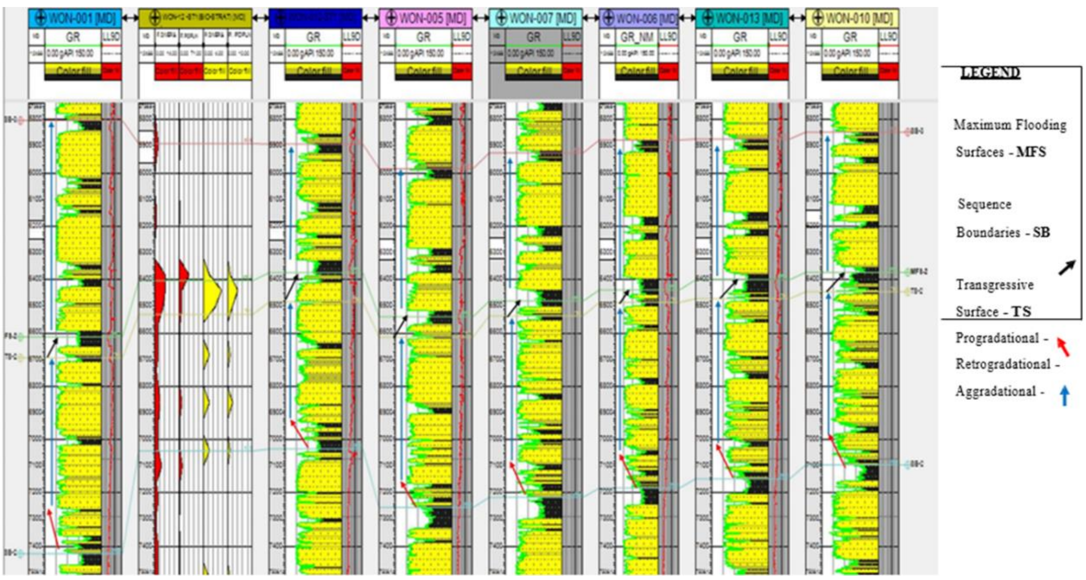

Figure 6: Stratigraphic Surfaces and Parasequence Sets Identification Across the Wells

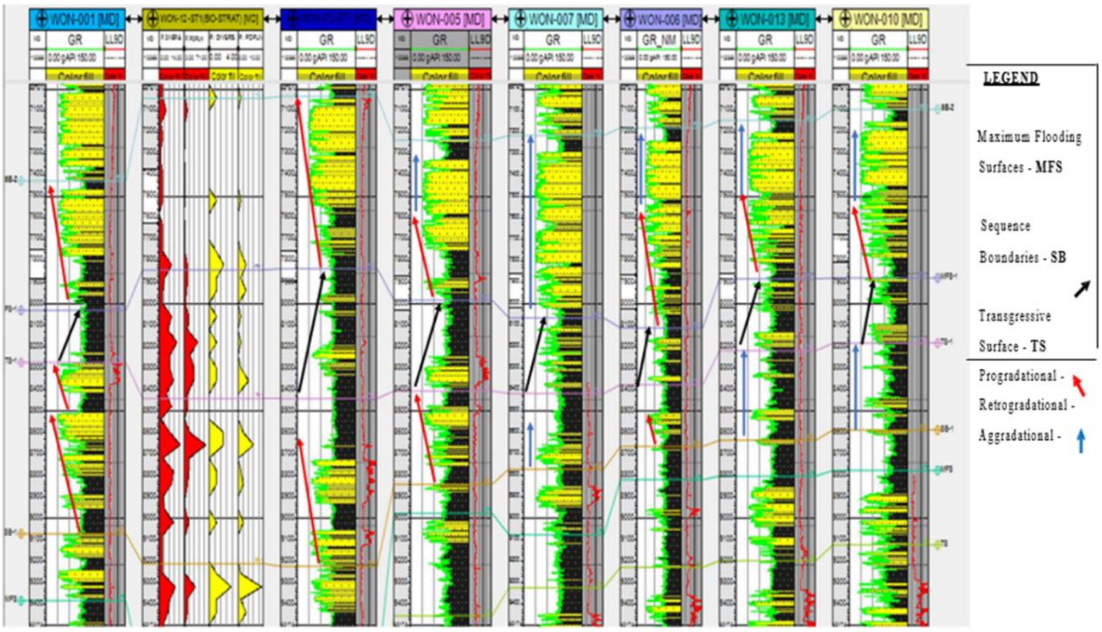

Figure 7: Stratigraphic Surfaces and Parasequence Sets Identification Across the Wells

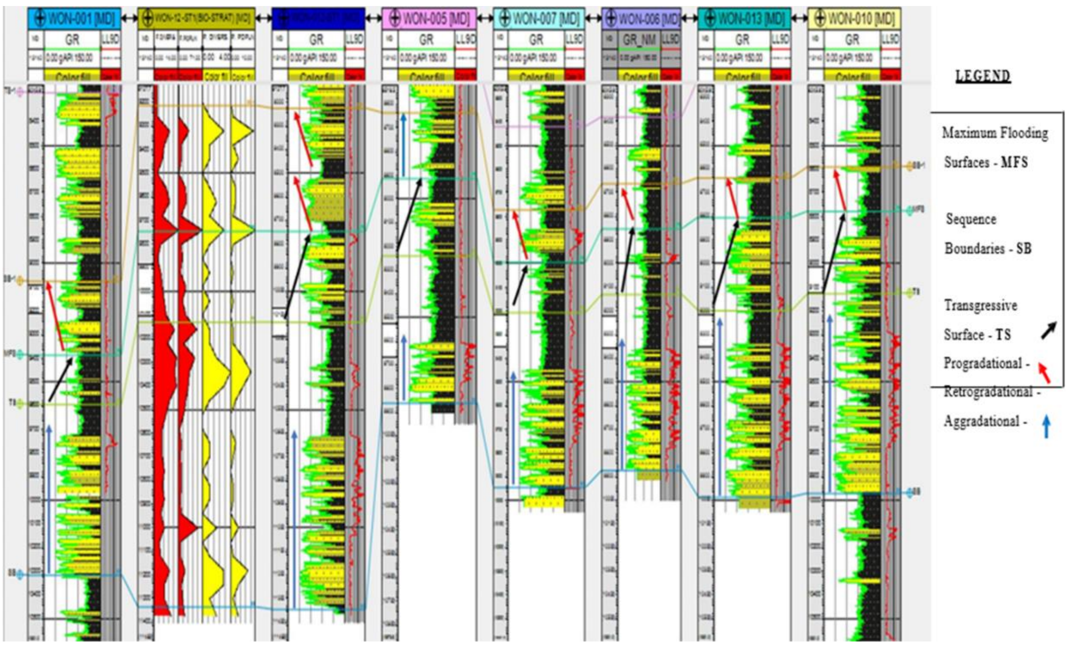

Figure 8: Stratigraphic Surfaces and Parasequence Sets Identification Across the Wells

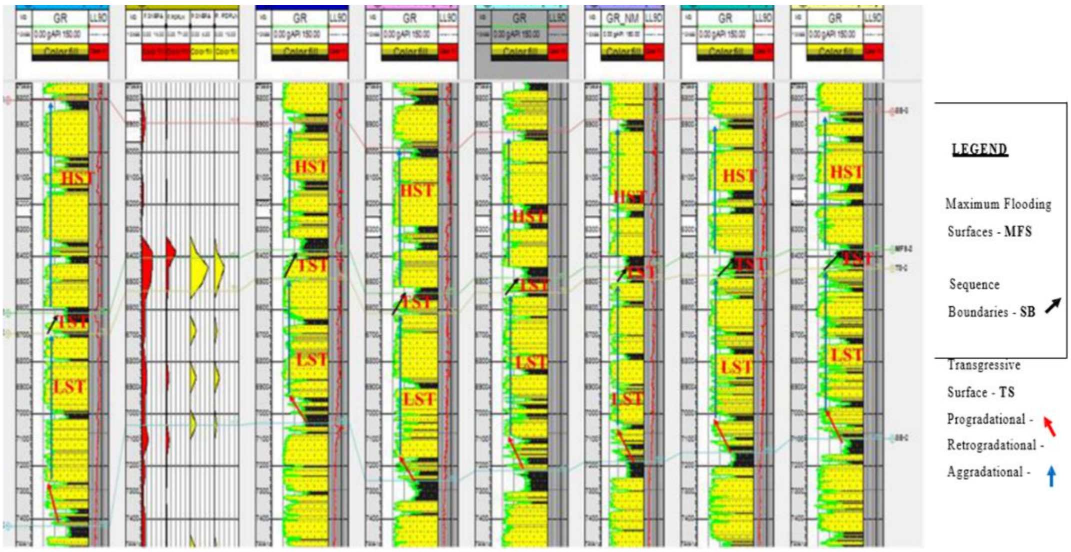

Figure 9: System Tracts and Parasequence Sets Identification Across the Wells

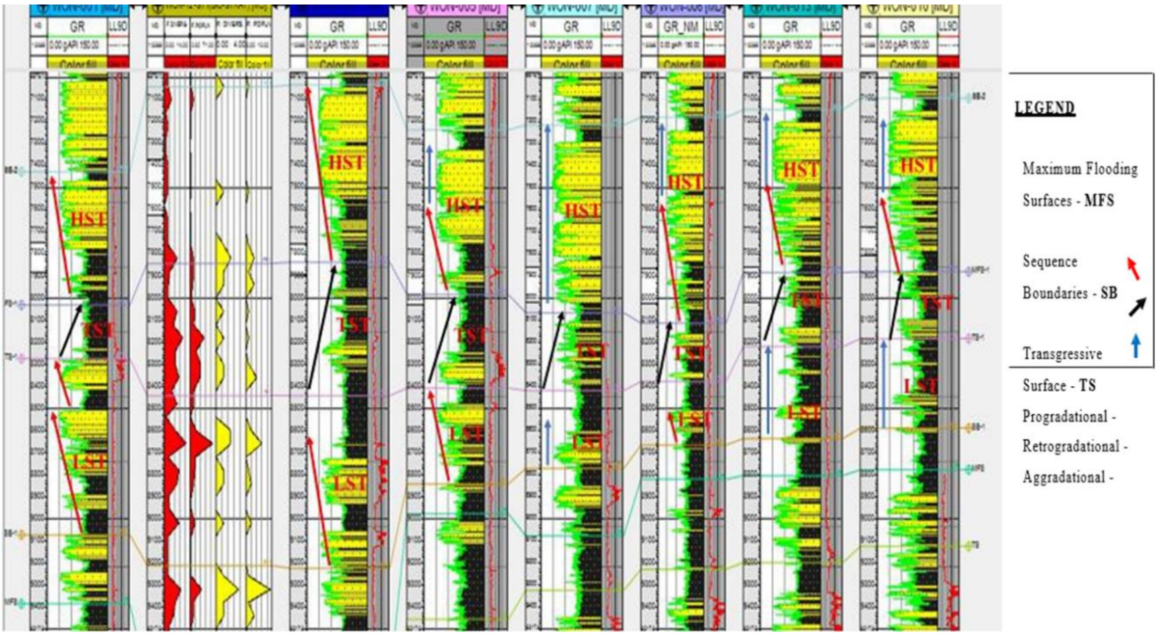

Figure 10: System Tracts and Parasequence Sets Identification Across the Wells

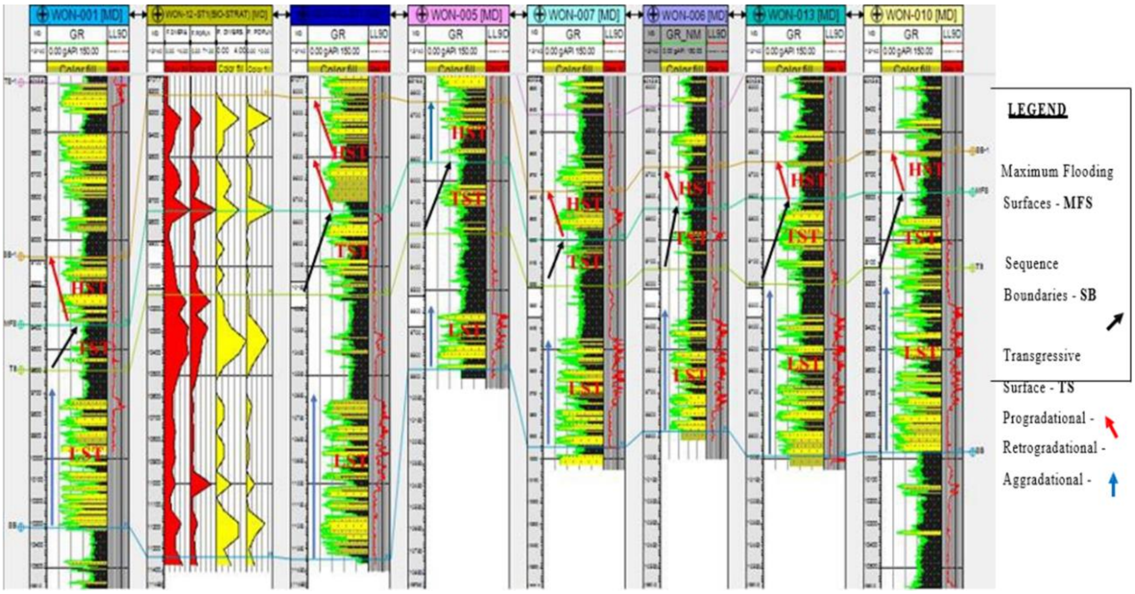

Figure 11: System Tracts and Parasequence Sets Identification Across the Wells

SEQUENCE 1: The oldest sequence of deposits, Sequence 1, ranges in depth from 8415 feet to

130445 feet with an average thickness of 1479 feet. This sequence demonstrates mostly fluid processes that represent a progressive pattern of stacking parenchyma sequences. Low stand system tracts (LST) were thought to be basin floor fans because they created thick deposits and shale intercalations. The underlying system tract's oil-saturated sands are sealed off by thick shale units with thin sediments in the transgression systems tracks. The maximal flooding surfaces are exhibited by the transgressive systems tracts (TST) in an upward and retro gradational pattern. With a funnel-shaped, coarsening upward prograding parasequence sets, the high stand system stretches on top of the TST.

SEQUENCE2: The low stand system tracts, transgressive system tracts, and high stand system tracts are included in this sequence. It offers a depth range of 7035 feet to 9420 feet and an approximate thickness of 1525 feet. In this sequence, the low stand Systems Tract (LST) formed with a prograding fan complex that is marked by an overall upward coarsening trend and coast face sand bodies that prograde into hemipelagic shales. There is a distinctive retrogradational stacking of a thick transgression systems tract overlying the transgressive erosion surface.

Above the transgressive surface is the maximum flooding surface (MFS), which is followed by the highstand systemstract that shows some prograding units before starting to demonstrate a more pronounced stacking pattern.

SEQUENCE3: This sequence consists of the youngest sequence in the field, with an average thickness of 1310 feet and a depth range of 5800 feet to 7430 feet. Transgressive systems tracts (TST), highstand system tracts (HST), and the progressive and aggradational parasequence stacking pattern make up the lowstand system tracts (LST).A brief phase of transgressive system deposits covers the LST, and the maximum flooding surface caps it.These sequences in the field are traced by the high stand systems. It is composed of many parasequence sets that are gradually grading into a progradational stacking pattern, which ended the field's examined depositional episode at the border of the Benin formation.

6. Depositional Environment and Sedimentary Facies

The resistivity logs and gamma ray data from the study show the existence of bell-, funnel-, and cylindrical-shaped motifs (Figure 6, 7 and 8). Short patterns can be incorporated into longer ones. Shorter coarsening upward patterns can therefore lead to a larger coarsening upward pattern.

6.1 Cylindrical Shaped Succession

Top and bottom curves on gamma-ray logs are sharp, giving them a cylindrical appearance. It could be smooth or spiky. It implies that energy was present consistently throughout the deposit. Its location is shown in Figure 6 by the blue arrow. The LST and HSTo of the depositional sequence usually show this pattern.

Low gamma-ray reading values in this shape also suggest that the lithology is convex sandstone, box-shaped, created by clastic deposits during a stable sea level period. Sand types found in underwater canyon fans, turbiditefan, and distributional channel fill are represented by this log pattern. Additionally, it displays how arapid gradiental deposition ends with terminal boundaries.

6.2 Bell Shaped Succession

A bell-shaped succession is defined by an abrupt, smooth or serrated bottom boundary and a transitional upper limit. The sequence is fining upward, and it might be a drape over a reef, tidal channel, transgression marine, or an alluvial or fluvial channel inside a channel. This shape's top is distinguished by the presence of shale that exhibits a retrogradational sequence and a high gamma ray reading. According to Sierra and Sulpice (1975), it is a sequence in which the gamamaray value rises steadily from a minimal value and suggests rising clay content. In Figure 6, it is represented by a black accent arrow.

6.3 Funnel Shaped Succession

The abrupt upper boundary and transitional lower boundary of the funnel-shaped succession, in contrast to the bell-shaped succession, are suggestive of a coarsening upward sequence, or more energy toward the end of a cycle. Barrier bars, regressive marine sand, delta front, crossbedding, and distributary mouth bars are all represented by the log themes. In Figure 6, it is shown by a red arrow. It is possible for the high energy of deposition to be shallow marine or deltaic degradation.

7. Hydrocarbon Implication of Systemstract

The low stand systems tract of sequences 1 and 2 and the transgressive systems tract of sequence 2 were found to be the primary locations of hydrocarbon accumulation based on the petrophysical parameters that were evaluated. The channels, sand shorefaces, and HSTs, which showed low Gamma Ray and high Resistivity values, respectively, were the primary reservoirs indicated in the "WONDER Field". The TST's extremely thick shale and thin sands make it a potential source of rock for the reservoirs.

8. Interpretation of Petrophysical Parameters of the Well

The major petrophysical parameters, such as porosity (effective and total), were studied from seven (7) wells (Figure 2). This study project defined the reservoir's thickness (net and gross), water saturation (Archie and dual water model), and shale volume.

8.1 Identification of Reservoir Characteristics

Three reservoirs were found (Figure 2) when these seven wells, dubbed "WON1," "WON 5," "WON 6," "WON7," "WON 10," "WON 12-ST1," and "WON 13," were analyzed to determine the fluids that saturated the reservoir. The reservoirs were inferred from the high resistivity log reading and the correlation between the resistivity log reading and the density log reading. The reservoir range and thickness for every well are displayed in Table 3.

WON 1

The calculated petrophysical parameter of the reservoirs is shown in Table 4. Reservoirs A, B, and C were situated within the following depth ranges: 6060 feet–6590 feet, 7010 feet–7785 feet, and 9720 feet–10335 feet, in that order.

Reservoir A

This reservoir is located data depth of 6060ft–6590ft.Ithasa thickness of530ft, its volume of shale 9.9%. The effective and total porosity within the reservoir is 25% and 30% respectively. The pores are saturated with water of 42%, hence hydrocarbon saturation of 58%. The irreducible water saturation is 6 % having a permeability value of 7890. 5md.It has formation factor to be 8.96.

Table 3: Reservoir Sands Interval for All Wells in the Study Area.

WELLS	RESERVOIR A		RESERVOIR B		RESERVOIR C	
	TOP (ft)	BASE (ft)	TOP (ft)	BASE (ft)	TOP (ft)	BASE (ft)
WON 1	6060	6590	7010	7785	9720	10335
WON 5	6025	6520	6900	7750	9605	9960
WON 6	5920	6395	6790	7830	9360	9865
WON 7	5960	6440	6850	8020	9445	9880
WON 10	5890	6350	6735	7790	9285	9960
WON 12-ST1	5925	6330	6660	7570	8730	9435
WON 13	5915	6370	6770	7780	9360	9940

Table 4: Average Petrophysical Parameters of the Reservoir Sands in 'WON 1' Well.

Reservoirs	Top(ft)	Bottom(ft)	Vsh (%)	ϕe (%)	ϕt (%)	F	Swirr (%)	K (mD)	SW (%)	SHC (%)
A	6060	6590	9	27	30	7.64	6	7890	42	58
B	7010	7785	12	24	27	8.96	6	6868	29	71
C	9720	10335	18	19	21	15.77	8	2951	25	75

Vsh = Volume of Shale; **ϕe =** Effective Porosity; **ϕt =** Total Porosity; **F** = formation factor; **Swirr =** Irreducible water saturation; **K =** Permeability; **SW =** Water Saturation; **SHC =** Hydrocarbon saturation.

Reservoir B

This reservoir is locate data depthof7010ft–7785ft.Ithasa thickness of775ft, its volume of shale is12%. The effective and total porosity within the reservoir is24% and27% respectively. The pores are saturated with water of 32%, hencehydrocarbonsaturationof68%. It has a formation factor of 8.9. Their reducible water saturation is 6%, having a permeability value of 6868.3md.

Reservoir C

This reservoir is locate data depthof9720ft–10335ft.Ithasa thicknessof615ft, its volume of shale is18%. The effective and total porosity within the reservoir is19% and21% respectively. The pores have a water saturation value of 25%, hence hydrocarbonsaturationof75%. It has formation factor to be15.7. Their reducible water saturation is 8% having a perme ability value of 2951.8md.

WON 5

Table5showsthecomputedpetrophysicalparameterofthereservoirs. Three (3) reservoirs namely reservoir A, Band C were located within a depth range of 6025ft–6520ft, 6900ft–7750ft and 9605ft – 9865ft respectively.

Reservoir A

This reservoir is located at a depth of 6025ft – 6520ft. It has a thickness of495ft, its volume of shale 10%. The effective and total porosity within the reservoir is26% and29%

Table 5: Average Petrophysical Parameters of the Reservoir Sands in 'WON 5' Well.										
Reservoirs	**Top(ft)**	**Bottom(ft)**	**Vsh (%)**	**ϕe (%)**	**ϕt (%)**	**F**	**Swirr (%)**	**K (mD)**	**SW (%)**	**SHC (%)**
A	6025	6520	10	26	29	8.13	6	8176	43	57
B	6900	7750	13	24	28	8.27	6	7215	32	68
C	9605	9865	22	20	25	11.72	7	4896	17	83

Vsh = Volume of Shale; **ϕe =** Effective Porosity; **ϕt =** Total Porosity; **F** = formation factor; **Swirr =** Irreducible water saturation; **K =** Permeability; **SW =** Water Saturation; **SHC =** Hydrocarbon saturation.

Reservoir B

This reservoir is locate data depth of 6900ft–7750ft. It has a thickness of 850ft, its volume of shale is 13%. The effective and total porosity within the reservoir is24% and28% respectively. The pores are saturated with water of 32%, hence hydrocarbon saturation of 68%. It has a formation factor of 8.2. Their reducible water saturation is 6%, having a permeability value of 7215md.

Reservoir C

This reservoir is locate data depth of 9605ft–9865ft. It has a thickness of 260ft, its volume of shale is 22%. The effective and total porosity within the reservoir is20% and25% respectively. The pores have a water saturation value of17%, hence hydrocarbon saturation of 83%. It has formation factor to be11.7. Their reducible water saturation is7%having a permeability value of 4896md.

WON 6

Table 6 shows the computed petro physical parameter of the reservoirs. Three (3) reservoirs namely reservoir A, B and C were located within a depth range of 5920ft–6395ft, 6790ft–7830ft and 9360ft – 9865ft respectively.

Table 6: Average Petrophysical Parameters of the Reservoir Sands in 'WON 6' Well.										
Reservoirs	**Top (ft)**	**Bottom(ft)**	**Vsh (%)**	**ϕe (%)**	**ϕt (%)**	**F**	**Swirr (%)**	**K (mD)**	**SW (%)**	**SHC (%)**
A	5920	6395	14	25	29	7.87	6	8214	49	51
B	6790	7830	20	23	28	15.47	6	7573	41	59
C	9360	9865	26	20	27	10.51	6	6508	36	64

Vsh = Volume of Shale; **ϕe =** Effective Porosity; **ϕt =** Total Porosity; **F** = formation factor; **Swirr =** Irreducible water saturation; **K =** Permeability; **SW =** Water Saturation; **SHC =** Hydrocarbon saturation.

Reservoir A

This reservoir is located at a depth of 5920ft – 6395ft. It has a thickness of475ft, its volume of shale 14%. The effective and total porosity within the reservoir is25% and29% respectively. The pores are saturated with water of 49%, hence hydrocarbon saturation of51%. The irreducible water saturation is 6 % having a permeability value of 8214md. It has formation factor to be 7.8.

Reservoir B

This reservoir is locate data depthof6790ft–7830ft.Ithasa thickness of 1040ft, its volume of shale is20%. The effective and total porosity within the reservoir is 23% and 28% respectively. The pores are saturated with water of 36%, hence hydrocarbon saturation of 64%. It has a formation factor of 15.4.The irreducible water saturation is 6%, having a permeability value of 7573md.

Reservoir C

This reservoir is located at depthof9360ft–9865ft.Ithasa thickness of505ft, its volume of shale is26%.The effective and total porosity within the reservoir is20% and27% respectively. The pores have a water saturation value of 22%, hence hydrocarbon saturation of 78%. It has formationfactortobe10.51. Their reducible water saturation is 6% having a permeability value of6508md.

WON 7

Table 7 shows the computed petro physical parameter of the reservoirs. Three (3) reservoirs namely reservoir A, Band C were located within a depth range of 5960ft–6440ft, 6850ft–8020ft and 445ft – 9880ft respectively.

Table 7: Average Petrophysical Parameters of the Reservoir Sands in 'WON 7' Well.										
Reservoirs	**Top(ft)**	**Bottom(ft)**	**Vsh (%)**	**ϕe (%)**	**ϕt (%)**	**F**	**Swirr (%)**	**K (mD)**	**SW (%)**	**SHC (%)**
A	5960	6440	3	28	29	8.30	6	8391	43	57
B	6850	8020	5	27	28	8.25	6	7668	32	68
C	9445	9880	7	23	25	13.00	7	5428	34	66

Vsh = Volume of Shale; **ϕe =** Effective Porosity; **ϕt =** Total Porosity; **F** = formation factor; **Swirr =** Irreducible water saturation; **K =** Permeability; **SW =** Water Saturation; **SHC =** Hydrocarbon saturation

Reservoir A

This reservoir is located at a depth of 5960ft – 6440ft. It has a thickness of480ft, its volume of shale 3%. The effective and total porosity within the reservoir is 28% and 29% respectively. The pores are saturated with water of 43%, hence hydrocarbon saturation of57%. Their reducible water saturation is 6% having a permeability value of 8391md.It has formation factor to be8.3.

Reservoir B

This reservoir is located at a depth of6850ft – 8020ft. It has a thickness of1170ft, its volume of shale is 5%. The effective and total porosity within the reservoir is27% and 28%respectively. The pores are saturated with water of 32%, hence hydrocarbon saturation of 68%. It has a formation factor of8.2. Their reducible water saturation is 6%, having a permeability value of 7668md.

Reservoir C

This reservoir is located at a depth of 9445ft – 9880ft. It has a thickness of435ft, its volume of shale is 7%. The effective and total porosity within the reservoir is23% and 25% respectively. The pores have a water saturation value of 34%, hence hydrocarbon saturation of 66%. It has formation factor to be13. Their reducible water saturation is7%having a permeability value of 5428md.

WON 10

Table 8 shows the computed petrophysical parameter of the reservoirs. Three (3)reservoirs namelyreservoirA, BandCwerelocatedwithinadepthrange of 5890ft–6350ft, 6735ft–7790ft and 9285 ft – 9960ft respectively.

Reservoir A

This reservoir is located at a depth of 5890ft – 6350ft. It has a thickness of 460ft, its volume of shale 12%. The effective and total porosity within the reservoir is 25% and 29% respectively. The pores are saturated with water of 42%, hence hydrocarbon saturation of 58%. The irreducible water saturation is 6 % having a permeability value of 7847md.It has formation factor to be 7.6.

Reservoir B

This reservoir is located at depthof6735ft–7790ft.Ithasa thickness of 1055ft, its volume of shale is15%. The effective and total porosity within the reservoir is24% and29% respectively. The pores are saturatedwithwaterof35%, hence hydrocarbon saturation of 65%. It has a formationfactorof8.Theirreduciblewatersaturationis6%,havingapermeab ilityvalueof 7889md.

Reservoir C

This reservoir is located at depth of 9285ft–9960ft.Ithasa thickness of 675ft, its volume of shale is19%. The effective and total porosity within the reservoir is22% and 26% respectively. The pores have a water saturation value of23%, hence hydrocarbon saturation.

Table 8: Average Petrophysical Parameters of the Reservoir Sands in 'WON 10' Well.

Reservoirs	Top(ft)	Bottom(ft)	Vsh (%)	ϕe (%)	ϕt (%)	F	Swirr (%)	K (mD)	SW (%)	SHC (%)
A	5890	6350	12	25	29	7.69	6	7847	42	58
B	6735	7790	15	24	29	8.04	6	7889	35	65
C	9285	9960	19	22	26	11.52	7	6206	32	68

Vsh = Volume of Shale; **ϕe =** Effective Porosity; **ϕt =** Total Porosity; **F** = formation factor; **Swirr =** Irreducible water saturation; **K =** Permeability; **SW =** Water Saturation; **SHC =** Hydrocarbon saturation of 77%. It has formation factor to be 11.5. The irreducible water saturation is 7% having a permeability value of 6206md.

WON 12-ST1

Table 9showsthecomputedpetrophysicalparameterofthereservoirs.Three (3) reservoirs namely reservoir A, B and C were located within a depth range of 5925ft–6330ft, 6660ft–7570ft and 8730ft – 9435ft respectively.

Reservoir A

This reservoir is located at depth of 5925ft–6330ft.Ithasa thickness of405ft, its volume of shale 4%. The effective and total porosity within the reservoir is 26% and 28% respectively. The pores are saturated with water of 41 %, hence hydrocarbon saturation f59%. Their reducible water saturation is 8% having a permeability value of 6978md. It has formation factor to be7.5.

Reservoir B

This reservoir is located at depthof6660ft–7570ft.Ithasa thickness of910ft, its volume of shale is 4%. The effective and total porosity within the reservoir is 27% and 28% respectively. The pores are saturated with water of30%,hence hydrocarbon saturation of 70%.Ithasaformation factor of8.6.Theirreduciblewatersaturation is 6%, having a permeability value of7235md.

Reservoir C

This reservoir is located at depthof8730ft–9435ft.Ithasa thickness of705ft, its volume of shale is 8%. The effective and total porosity within the reservoir is24% and 26%

Table 9: Average Petrophysical Parameters of the Reservoir Sands in 'WON 12-ST1' Well.

Reservoirs	Top(ft)	Bottom(ft)	Vsh (%)	ϕe (%)	ϕt (%)	F	Swirr (%)	K (mD)	SW (%)	SHC (%)
A	5925	6330	4	26	28	7.52	8	6978	41	59
B	6660	7570	4	27	28	8.63	6	7235	28	72
C	8730	9435	8	24	26	12.81	7	5882	28	72

Vsh = Volume of Shale; **ϕe =** Effective Porosity; **ϕt =** Total Porosity; **F** = formation factor; **Swirr =** Irreducible water saturation; **K =** Permeability; **SW =** Water Saturation; **SHC =** Hydrocarbon saturation respectively. The pores have a water saturation value of 28%, hence hydrocarbon saturation of 72%. It has formation factor to be 12.8. The irreducible water saturation is 7% having a permeability value of5882md.

WON 13

Table10showsthecomputedpetrophysicalparameterofthereservoirs.Thre e (3) reservoirs namely reservoir A, B and C were located within a depth range of 5915ft–6370ft,6770ft–7780ft and 9360ft – 9940ft respectively.

Reservoir A

This reservoir is located at a depth of 5915ft – 6370ft. It has a thickness of455ft, its volume of shale 9%. The effective and total porosity within thereservoiris27% and 29% respectively. The pores are saturated with water of 42%, hence hydrocarbon saturation of58%. The irreducible water saturation is 6 % having a permeability value of 8185md.It has formation factor to be7.49.

Reservoir B

This reservoir is located at depth of 6770ft–7780ft.Ithasa thicknessof1010ft, its volume of shale is13%. The effective and total porosity within the reservoir is 25% and 29% respectively. The pores are saturated with water of 35%, hence hydrocarbon saturation of 65%. It has a formation factor of 8.2. The irreducible water saturation is 6%, having a permeability value of 7648md.

Table 10: Average Petrophysical Parameters of the Reservoir Sands in 'WON 13' Well.

Reservoirs	Top(ft)	Bottom(ft)	Vsh (%)	ϕe (%)	ϕt (%)	F	Swirr (%)	K (mD)	SW (%)	SHC (%)
A	5915	6370	9	27	29	7.49	6	8185	42	58
B	6770	7780	13	25	29	8.23	6	7648	35	65
C	9360	9940	20	20	25	13.11	7	5314	32	68

Vsh = Volume of Shale; **ϕe =** Effective Porosity; **ϕt =** Total Porosity; **F** = formation factor; **Swirr =** Irreducible water saturation; **K =** Permeability; **SW =** Water Saturation; **SHC =** Hydrocarbon saturation

Reservoir C

There is a recorded depth of 9360–9940 feet in this reservoir. It is 580 feet thick and contains 13% shale volume. Within the reservoir, the effective and total porosities are 29% and 25%, respectively. The hydrocarbon saturation of 68% is a result of the pores' 32% water saturation value. It has a 13.1 formation factor. Their permeability value is 5314 md and their reducible water saturation is 7%.

9. Conclusions

Petrophysical assessment and sequence stratigraphic appraisal have been executed with success. "WONDER" field in Nigeria's Delta region. The purpose of this study is to calculate the parameters of the reservoirs and ascertain whether sediment deposition patterns have an impact on the distribution and potential for hydrocarbons in the area. Three (3) sequences are identified from the sequence stratigraphic analysis corresponding to three maximum flooding surfaces obtained. All sequences are type-1 sequences containing two or three of the system tracts. The Transgressive systems tract (TST) was made of retro grading shale and sand units. The High stand systems tract was made of prograding sands with decreasing hale volume upwards. Hydrocarbon accumulation was discovered in the LST, TST and HST using the resistivity log and some derived petrophysical parameters (hydrocarbon saturation). In terms of hydrocarbon exploration, the sand units of the LST and HST formed the basin floor fans, channel and shore face sands of the delta. The high resistivity log values (30 to 500ohmm) revealed that they are good hydrocarbon reservoirs. The shales of the TST in which most of the MFS were delineated could form seals to the reservoir units. A combination of the reservoirs and of the LST and HST and the shale units of the TST can form good stratigraphic traps for hydrocarbon and hence should also be targeted during hydrocarbon exploration. The results of this research have restated the importance of the use of well log sequence stratigraphic analysis in basin characterization.

A lithologic correlation panel was created based on the results of the petrophysical research to demonstrate the continuity of the reservoirs across wells. Figures 4 and 5 illustrate the findings that the lithologic correlation of the field's wells is composed of sand-shale intercalation (Reijerset al., 1997). This fits the Niger Delta's generally observed lithology. According to an analysis of well logs from the "WONDER" field in Niger Delta, the "WON 12-ST1" well is the most economically drilled well in this field and has the highest payload. Water saturation-porosity trends are typically not firmly established in the wells. Reservoir compartmentalization can arise due to the presence of laminated clays in the shale sands, which can act as a barrier to flow during production.

The majority of the wells found in the wells contain producible oil as long as they meet the set criteria and cutoff time.

Recommendations

It is impossible to overstate the significance of sequence stratigraphic analysis in reservoir characterisation. Therefore, it is advised that a thorough sequence stratigraphic investigation of the research region be done. In order to better analyze the depositional systems in terms of age differentiation, this should combine sequence stratigraphic analysis, high-resolution biostratigraphic analysis, and integration of 3D seismic stratigraphic analysis. Since the type and volume of shale have a major impact on the quality of the reservoir, more petrographic investigation of the field must be done in order to determine the kind and distribution of shale inside reservoirs.

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