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Integration of Sequence Stratigraphy and Petrophysical Analysis for Reservoir Characterization: A Case Study of "ED" Field, Offshore Niger Delta

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Abstract
Sequence stratigraphic concept for continental settings was assessed to analyze the depositional systems of the formations penetrated by wells in 'ED' Field. Identification and delineation of three sequences and their bounding surfaces was carried out using well logs. Three hydrocarbon bearing reservoirs labelled as ED-R-1000, ED-R-2000 and ED-R-3000 were delineated. Computation of petrophysical properties of reservoir rocks was executed using well established relationship. The stratigraphy comprising of an alternation of sands and shales typically was of the Agbada Formation. The petrophysical analysis results give a good indication of the reservoirs' capability of accumulating hydrocarbon in their interstitial pore spaces. Three stratigraphic surfaces were used to sub-divide the study field into three (3) depositional sequences and further subdivide the sequences into three system tracts. They are 1154ft(m), 382ft(m) and 738ft(m) thick respectively. The depositional environment of the study field includes distributary channel fill, regressive to transgressive shoreface delta, delta front and storm dominated shelf. The best quality reservoir will be found in the lowstand system tract while TST is a good sealing rock in the study field.
Keywords: Stratigraphy, Depositional sequence, Petrophysical, Well logs.
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1. Introduction

According to an article on business day news paper on 3rd of October 2022, Nigerian oil resources may be dwindling faster than expected, with promising fields turning up empty as seen in the latest well on Bonga oilfield, a development that could further compound the challenges in the oil sector. This means that explorationist working on the project will have to use more unconventional technologies in other areas of the field to get positive results and to minimize loss in the cost of well development. Thus combining Sequence stratigraphy and Petrophysical analysis is one of such unconventional technique that will enhance oil recovery and thus save cost. Sequence stratigraphy is a branch of sedimentary stratigraphy that deals with the other, or sequence in which depositionally related strata successions (time-rock) units are laid down in available space called accommodation. Depositional sequence is a stratigraphic sequence bounded by subaerial unconformities or their correlative conformities (Mitchum, 1977). Depositional sequence determination is one of the relevant tools for characterizing hydrocarbon bearing formations and modelling of the depositional settings (Emudianughe and Ohiaeriaku, 2021). Sequence stratigraphic techniques involve the careful evaluation of the interaction between eustacy, subsidence, and sediment supply as equally important controls on changes in accommodation space, which in turn controls depositional geometries and successions (Posamentier and Allen, 1999). Sequence stratigraphy has been applied in several sedimentary basins of the world leading to the discovery and recovery of more hydrocarbon reserves. In the north central Gulf of Mexico, this technique improved reservoir development and management strategies, provided insights into basin fill history, and contributed to the ongoing exploration successes in the basin (Meckel, 2003). The sequence stratigraphic concept was gradually introduced into the Niger Delta Basin exploration, when Durand (1995), Stacher (1995), and Reijers (2011) first applied it in refining the process for prediction of hydrocarbon habitats. Recent developments in the field of sequence stratigraphy (Posamentier and Allen, 1999; Posamentier, 2000; Catuneanu, 2002) offer a definitive approach to stratigraphic analysis of sedimentary strata. This study involves the reconstruction of a sequence stratigraphic framework of the studied section of the Agbada Formation in the "ED" field, offshore depobelt, Niger Delta (Fig. 1), using suites of wireline well logs. The combination of several methods to understand the sequence stratigraphic framework of the study area improves the resolution for definition of key stratigraphic surfaces, depositional facies, and reservoirs units. Quality assessment of key reservoirs in the field focused on depositional environment and petrophysical analysis, resulting in an established relationship between both methods.

Reservoir characterization at the early stage of 'ED' field development where mostly carried out using more of qualitative analysis but geological complexity's problem such as reservoir sand boundaries, heterogeneity of reservoir attribute away from the well has resulted into unexpected declining in production as characterized in this field. This therefore necessitates re-visiting this field with better interpretation to be achieved using quantitative techniques. Proper characterization of reservoirs, therefore, requires an integration of the analysis of two or more types of data acquired from a particular area of interest in order to adequately define the reservoir model. The calculation of the petrophysical parameters of the reservoir units was carried out using the following formula: Porosity is the percentage of fluid within the reservoir unit and it is determined using:

$\Phi = \frac{p_{ma} - p_b}{p_{ma} - p_{fl}}$

Where: p_{ma} = matrix density
p_{fl} = fluid density of the rock matrix
p_b = density of the formation
Φ = porosity of the formation
(Dresser, 1979)
The porosity of the formations in this study will be classified according to (Baker, 2010)
Reservoir thickness = bottom of reservoir unit – top of reservoir unit (that is h2 –h1).
Permeability is defined as the measure of a formation to transmit fluids and it is controlled by the size of the connecting passages between the pores. Permeability (k) was calculated for the reservoirs using the equation below;

$$k_{oil}^{1/2} = \frac{250\emptyset^3}{s_{wirr}}$$

$$k_{gas}^{1/2} = \frac{79\emptyset^3}{s_{wirr}}$$

Where s_{wirr} is the irreducible water saturation,
k_{gas} is the permeability of gas fluid
k_{oil} is the permeability of oil fluid

2. Location of Study Area

The area of study is located in the southeastern part of Niger Delta (Figure 1). It is on the offshore depobelt with Latitude: 04°33'02.368N to 04°49'02.368N and
Longitude: 03°47'42.249E to 04°36'22.239E

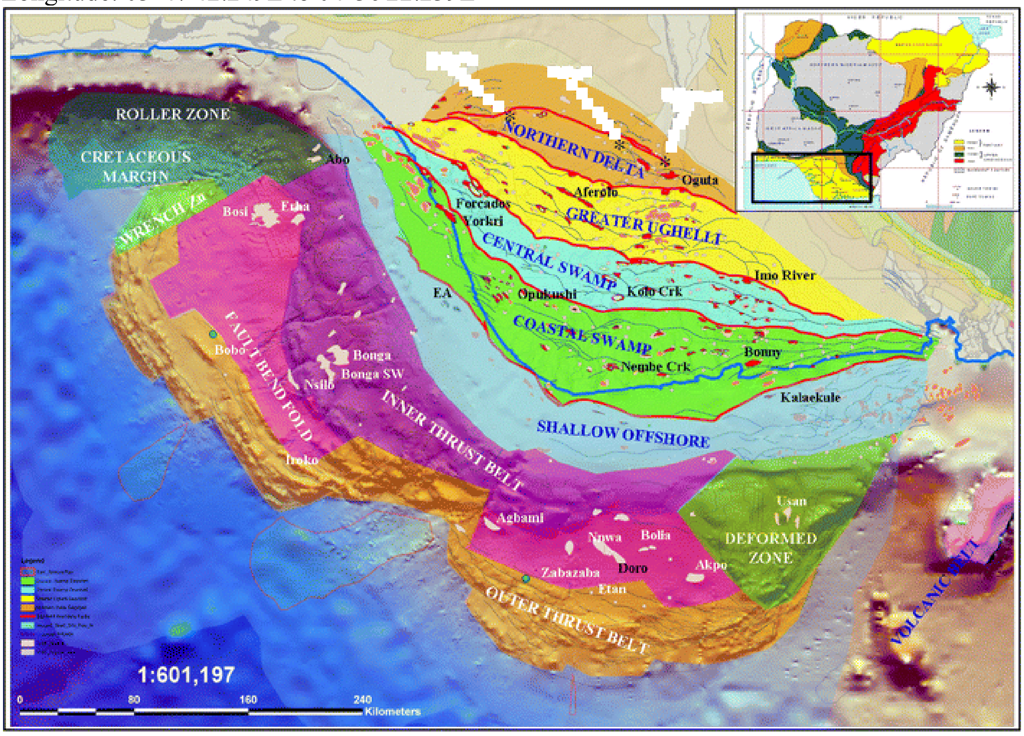

Figure 1, Location map of Nigeria

3. Materials and Methods

Well logs data was provided for the study by the Nigerian Petroleum Development Company (NPDC) through the Department of Petroleum Resources, ministry of petroleum resources, Warri. This dataset was analyzed by the Schlumberger Petrel 2014 software and Rock doc software was used for petrophysical analyses.

Table 1, Well log data showing available logs

Name	Start Depth	Stop Depth	GR log	SP log	Cal. log	Res. log	Den log	Neu log	Sonic log	Check shot	X-(m)	Y- (m)	KB(ft)	TVD (ft)	Total TVD Subsea (ft)
ED-01	42.00	13295.00	+	-	+	+	+	+	+	+	331694.48	220995.48	42.00	13295.00	13337.00
Ed-02	46.00	13027.999	+	-	+	+	+	+	+	-	331708.68	220989.98	46.00	13027.999	13073.999
ED-03	0	11070.00	+	-	+	+	+	+	-	-	33512.18	220884.48	43.00	11070.00	11113

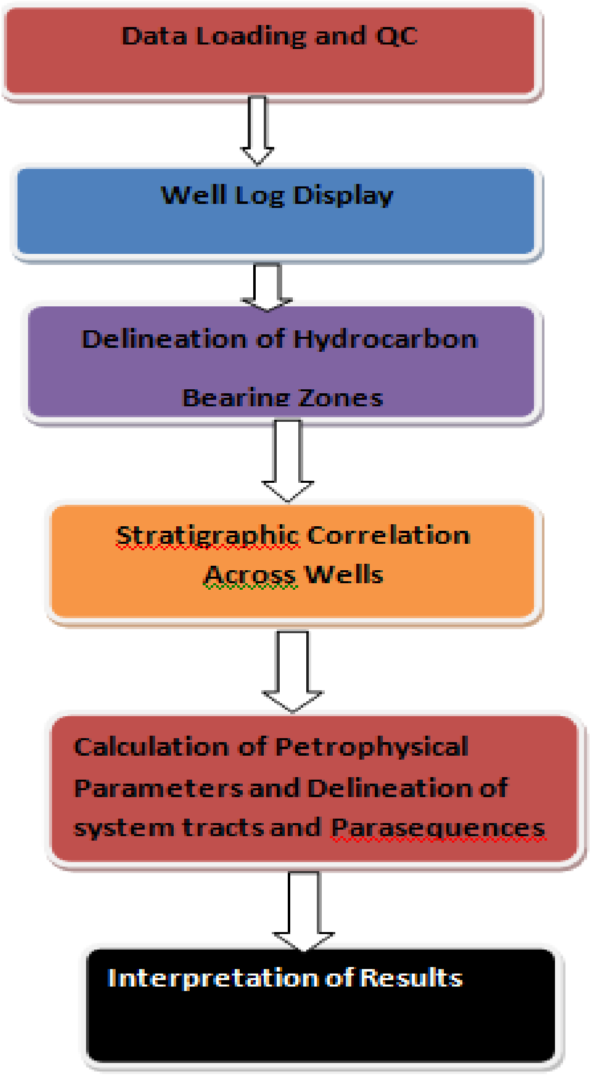

Figure 2. Flowchart of Methodology

The methodology flow chart adopted for this research is in the figure 2 above. The steps of data analysis and interpretation include: data importation and quality control, well log interpretation, log sequence analysis, petrophysical analysis, seismic structural interpretation, seismic stratigraphic interpretation, environment of sediment deposition analysis and rock physics analysis. Schlumberger Petrel 2014 was used for the calibration of the well log data and extraction of the area (sqm) of the study. Well log data for wells were loaded into Petrel software. The software was used to perform well correlation and extraction of the area in sqm, interpret results and produce map. The dataset for each well consists of a suite of logs as follows; spontaneous potential (SP), gamma-ray (GR), resistivity log, density & neutron, and sonic logs. The suite of logs in each well were remodelled to support the division of different lithologies into sub-units (sand, shaly-sand, sandy- shale and shale) which were carried out on the basis of qualitative log interpretation.

4. Results and Discussion

The figure 3 below shows the three reservoirs delineated and named ED-R-1000, ED-R-2000 and ED-R-3000 for which the three reservoirs located at depth between 8730 and 10123ft on ED-01 well. They are located between 9143 and 10643ft on ED-02 well. The reservoirs are located between 8744 and 10234ft on ED-03 and the reservoir ED-R-1000 has oil down through indicated as ODT and the reservoir ED-R-2000 there is an oil-water-contact (OWC) which occurred at 9985m below the surface. The balloon effect displayed by the density-neutron logs shows that there is an associated gas reservoir. Fluid contacts can be gradational in mixed fluid reservoirs but are typically horizontal or nearly so because of the difference in density between gas, oil and water.

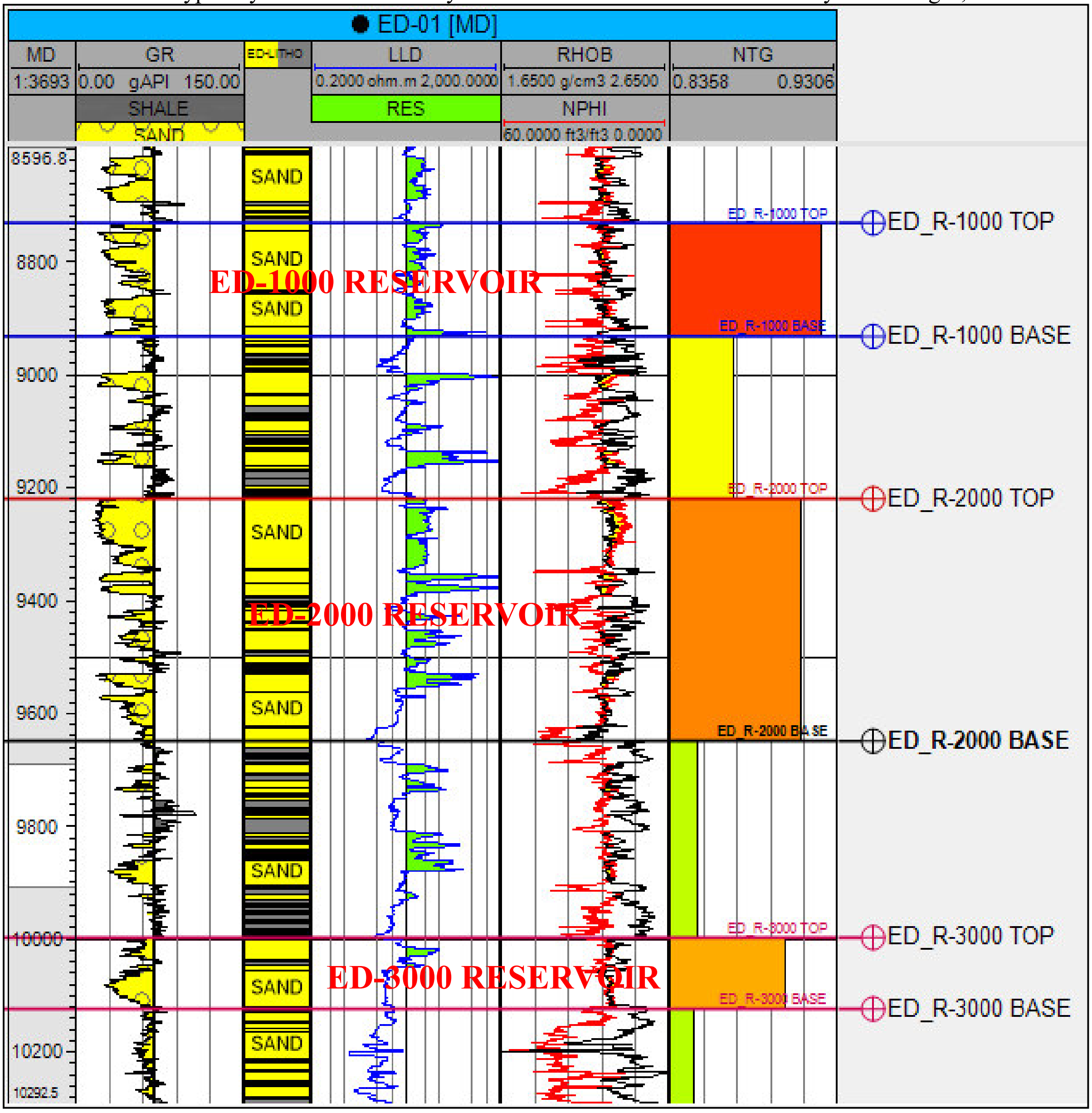

Figure 3: Reservoir Delineation on ED-01 Well

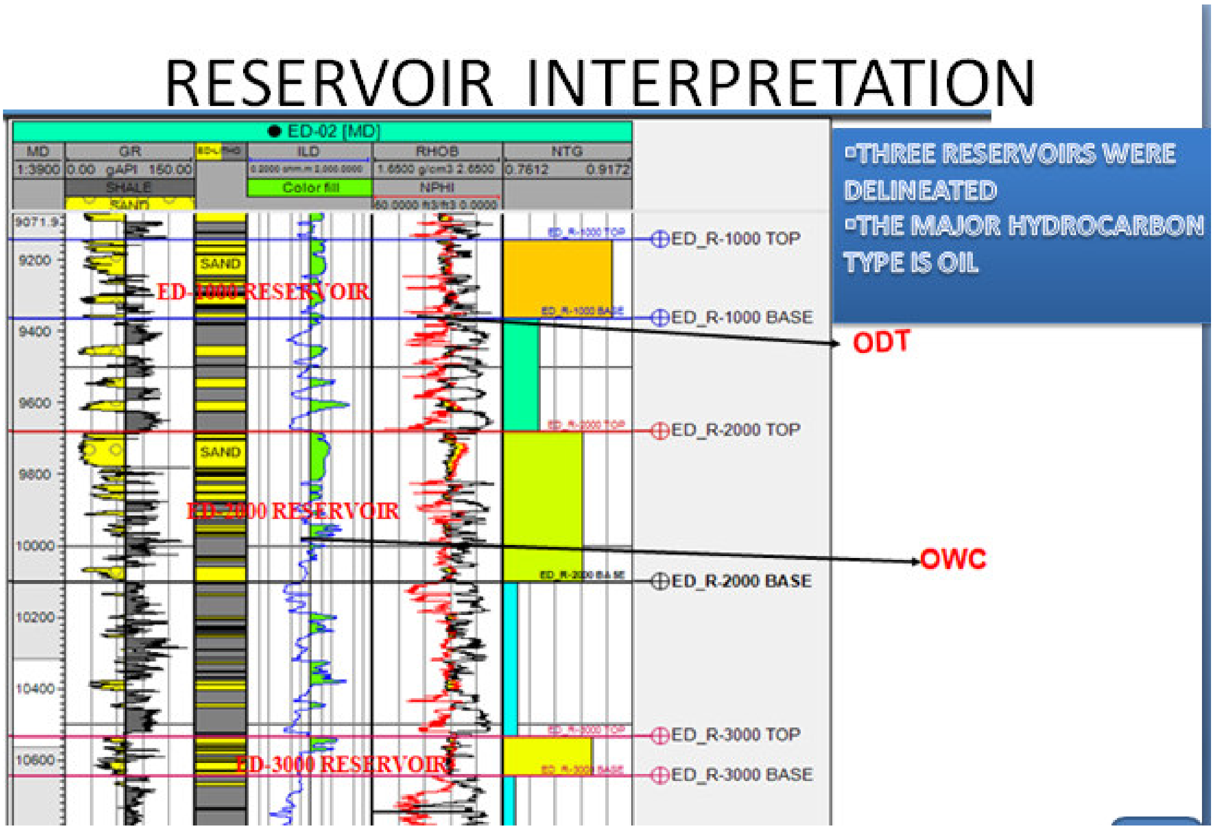

Figure 4: Reservoir Delineation on ED-02 Well

The gamma ray log motif was used for the determination of key stratigraphic surfaces. Figures 5 depict sequence stratigraphic analysis of the three wells. The spatial distribution of the recognized constrained stratigraphic surfaces identified include transgressive surfaces (TS), maximum flooding surfaces (MFS) and sequence boundaries (SB). These surfaces were used to subdivide the studied field into three depositional sequences and system tracts. Parasequence stacking pattern including progradational, aggradational and retrogradational was principally used for the log motif.

Then chronostratigraphic correlation of the three well within the field of study was done where stratigraphic surfaces identified from each of the three wells including maximum flooding surfaces, transgressive surfaces and sequence boundaries as well as system tracts were correlated at different depths across the wells. There is variation in sediment thickness across the wells, with varied number of systems tracts in each sequence. These subdivided 3 depositional sequences are as discussed below:

4.1. Depositional Sequence One

Depositional sequence one is the oldest depositional sequence and the deepest in ED-field. It has three stratigraphic surfaces which are sequence boundary (SB), maximum flooding surface (MFS) and trangressive surfaces (TS). It is enclosed by MFS-1 below and MFS-2 above (Figure 5). The depositional sequence is about 1154ft thick. The sediments in this sequence is believed to be deposited as distributary channel in the deltaic depositional environment. Three system tracts are identified within this sequence. The tracts are lowstand, trangressive and highsand System Tracts. Lowstand system tract is predominantly aggradational and progradational stacking pattern, trangressive system tract is retrogradational stacking pattern of fining upward sequence and highstand system tract is progradational stacking pattern of coarsening upward sequence. The highstand system tracts (HST) lies on the MFS-1 and it is about 393 ft. The lowstand system tracts (LST) is then enclosed by the SB below and the TS above. The tract is about 322ft thick. The trangressive system tracts is enclosed by the TS below and the MFS-2 above, the tract is about 130ft thick. The LST and HST are probarbly potential reservoir rocks while TST is a good sealing rock.

4.2 Depositional Sequence Two

Depositional sequence two directly overlies the depositional sequence one. It also has three stratigraphic surfaces which are sequence boundary, maximum flooding surface and trangressive surfaces. It is enclosed by MFS-2 below and MFS-3 above. The depositional sequence is about 382ft thick. This sequence is also believed to be deposited as pelagic in the deltaic depositional environment. Three system tracts of lowstand, trangressive and highstand System Tracts were also identified with the thickness of each tract being 156ft, 113ft, and 95ft respectively. The HST is enclosed by the MFS-2 below and SB above. The LST is bounded by the SB below and the TS above. The TST is bounded by the TS below and the MFS-3 above. The LST and HST are potential reservoir rocks while TST is a good sealing rock.

4.3 Depositional Sequence Three

Depositional sequence three, directly overlies the depositional sequence two. It also has three stratigraphic surfaces which are sequence boundary, maximum flooding surface and trangressive surfaces. It is enclosed by MFS-3 below and MFS-4 above (Figure 5). The depositional sequence is about 738ft thick. This sequence is also believed to be deposited as shoreface channel in the deltaic depositional environment. Three system tracts of lowstand, trangressive and highstand System Tracts were also identified with the thickness of each tract being 260ft, 443ft, and 49ft respectively. The HST is enclosed by the MFS-3 below and SB above. The LST is bounded by the SB below and the TS above. The TST is bounded by the TS below and the MFS-4 above. The LST and HST are potential reservoir rocks while TST is a good sealing rock.

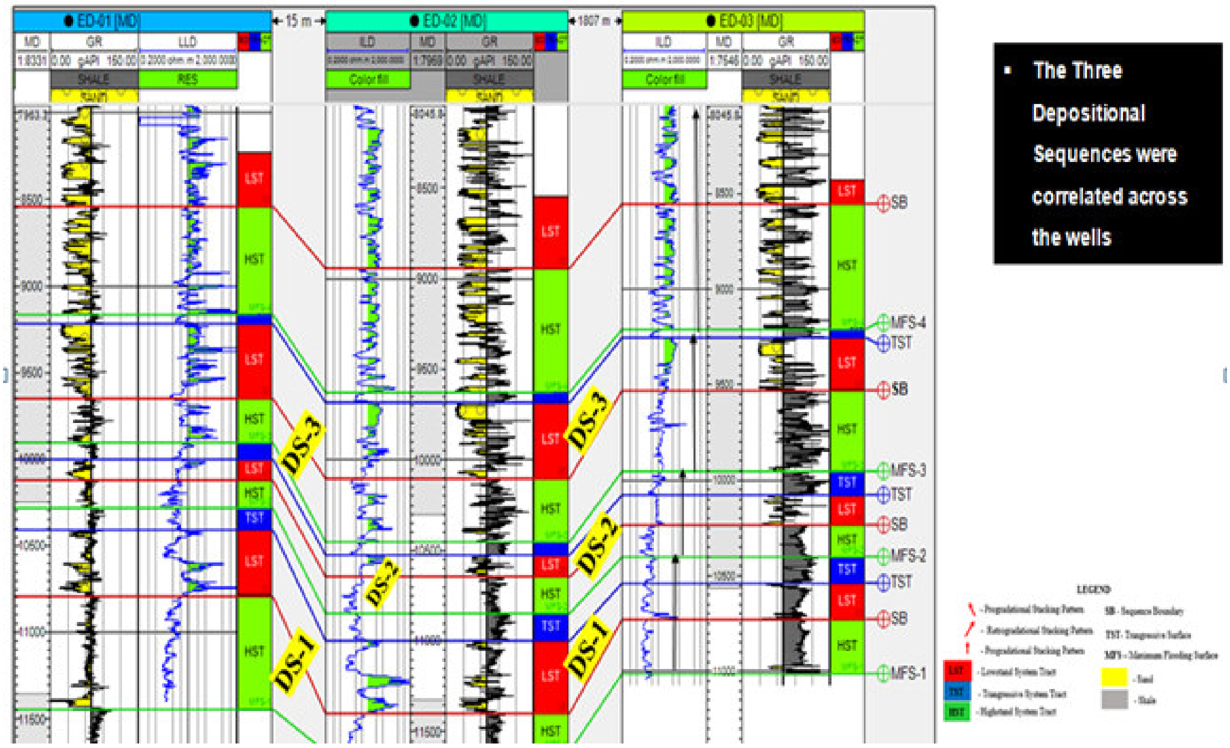

Figure 5: Chronostatigraphic correlation of reservoirs across Wells

4.4 Petrophysical Interpretation

Petrophysical properties of the three reservoirs (ED-R-1000, ED-R-2000 and ED-R-3000) were determined quantitatively to understand the reservoir parameters and also to define hydrocarbon storage capacity within the reservoirs. Tables 2, 3 and 4 shows the computed petrophysical parameters of ED-R-1000, ED-R-2000 and ED-R-3000 reservoirs respectively. Petrophysical parameters of interest calculated include: gross thickness, net thickness, volume of shale, porosity, effective porosity, permeability, water saturation and hydrocarbon saturations. The petrophysical parameters revealed reservoir (ED-R-1000) has an average net-to-gross of 78% and shale volume of 11%. The reservoir has effective porosity ranges from 19 to 20%, permeability from 310 to 447mD and hydrocarbon saturation from 51 to 52%. ED-R-2000 has an average net-to-gross of 67% and shale volume of 15%. The reservoir has effective porosity ranges from 16 to 18%, permeability from 92 to 206mD and hydrocarbon saturation from 47 to 50%. Similarly, reservoir ED-R-3000 has an average net-to-gross of 74% and shale volume of 14%. The reservoir has effective porosity ranges from 16 to 21%, permeability from 59 to 551mD and hydrocarbon saturation from 3 to 28%. The results of porosity and permeability of the reservoirs confirm that it ranges from fair to good. It suggests reservoirs have considerably high connectivity.

Table 2, Petrophysical properties of Reservoir ED-R-1000

Wells	Top (ft)	Base (ft)	Gross Thickness(ft)	Net Sand(ft)	NTG (%)	V_{SH} (%)	Φ_D (%)	Φ_{Eff} (%)	F	K (mD)	S_w (%)	S_h (%)
ED-01	8730	8931	201	192	95	10	22	19	21	310	49	51
ED-02	9143	9363	220	156	71	11	23	20	20	410	48	52
ED-03	8744	8982	238	161	68	12	23	20	19	477	48	52

Table 3, Petrophysical properties of Reservoir ED-R-2000

Wells	Top (ft)	Base (ft)	Gross Thickness(ft)	Net Sand(ft)	NTG (%)	V_{SH} (%)	Φ_D (%)	Φ_{Eff} (%)	F	K (mD)	S_w (%)	S_h (%)
ED-01	9219	9143	420	357	83	12	20	18	25	168	50	50
ED-02	9649	10101	420	234	56	14	21	18	24	206	54	46
ED-03	9254	9531	277	177	64	19	21	17	29	92	52	48

Table 4, Petrophysical properties of Reservoir ED-R-3000

Wells	Top (ft)	Base (ft)	Gross Thickness (ft)	Net Sand(ft)	NTG (%)	V_{SH} (%)	Φ_D (%)	Φ_{Eff} (%)	F	K (mD)	S_w (%)	S_h (%)
ED-01	9997	10123	126	117	93	11	20	18	26	145	84	16
ED-02	10533	10643	111	87	79	12	24	21	18	551	72	28
ED-03	10080	10234	154	78	51	21	20	16	33	59	97	3

5. Conclusion

The research revealed two major lithologies sand and shale. The sand units comprise of thin shale interbedding which decrease in thickness with depth. The shale layers also increase in thickness with depth. It is a typical Agbada Formation. Three hydrocarbon bearing reservoirs labelled as ED-R-1000, ED-R-2000 and ED-R-3000 were delineated. The hydrocarbon-type contained in most of the reservoirs is oil. Well log correlation of the three wells revealed the lateral continuity of the sand units.

Log sequence interpretation of the three wells was performed using gamma ray log motifs. Three stratigraphic surfaces namely transgressive surfaces, maximum flooding surfaces and sequence boundaries were identified. These surfaces were used to divide the study field into three (3) depositional sequences and further subdivide the sequences into three system tracts. The system tracts include lowstand, trangressive and highstand system tracts. Lowstand system tract is predominantly aggradational and progardational stacking pattern, trangressive system tract is retrogradational stacking pattern of fining upward sequence and highstand system tract is progardational stacking pattern of coarsening upward sequence. Depositional sequence one is the oldest a depositional sequence and the deepest in ED-field. It is enclosed by MFS-1 below and MFS-2 above. The depositional sequence is about 1154ft thick. Depositional sequence two directly overlies the depositional sequence one. It is enclosed by MFS-2 below and MFS-3 above. The depositional sequence is about 382 ft thick. Depositional sequence three directly overlies the depositional sequence two. It is enclosed by MFS-3 below and MFS-4 above. The depositional sequence is about 738ft thick.

The evaluated petrophysical properties of reservoir ED-R-1000 revealed that it is has an average net-to-gross of 78%, shale volume of 11%, effective porosity ranges from 19 to 20%, permeability from 310 to 447mD and hydrocarbon saturation from 51 to 52 %. ED-R-2000 has an average net-to-gross of 67% and shale volume of 15%, effective porosity ranges from 16 to 18%, permeability from 92 to 206mD and hydrocarbon saturation from 47 to 50%. Reservoir ED-R-3000 has an average net-to-gross of 74% and shale volume of 14%, effective porosity ranges from 16 to 21%, permeability from 59 to 55mD and hydrocarbon saturation from 3 to 28%. The petrophysical evaluation results give a good indication of the reservoirs' capability of harbouring hydrocarbon in their interstitial pore spaces.

6. Acknowledgments

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7. References

Baker D. R. (2010); A Call for New Geoscience Education Agenda. Journal of Research in Science Teaching. 47(2)p 121-129

Catuneanu O. (2002); Sequence stratigraphy of clastic systems: concepts, merits and pitfalls. Journal of African Earth Science 35:1–43

Dresser Atlas (1979); Log Interpretation Charts. Houston Dresser Industries, Inc., p 107

Durand J.I. (1995) High-resolution sequence stratigraphy (genetic stratigraphy) in reservoir sedimentology. Examples from the Niger Delta Fields. Bull Niger Assoc Petrol Explor 10(1):66–72

Emudianughe, J.E and Ohiaeriaku, D.C. (2021): Integration of Sequence Stratigraphy and Petrophysical Analysis for Reservoir Characterization: A Case Study of “KO” Field, Central Niger Delta FUPRE Journal of Scientific and Industrial Research Vol.5, (2), 2021. Pp 95-109

Meckel L.D. (2003), Fourth-order deep-water genetic stratigraphy, stratigraphic architecture and reservoir stacking patterns. In: AAPG international conference, Barcelona

Mitchum R.M. (1977); Seismic stratigraphy and global changes of sea level, part 11; In Payton CE (ed) Seismic Stratigraphy - applications to hydrocarbon exploration. AAPG Memoir, Vol 26. AAPG, Tulsa, pp 205-212.

Posamentier H.W. (2000); Seismic stratigraphy into the next millennium; a focus on 3D seismic data, American Association of Petroleum Geologists Annual Convention, New Orleans, Abstracts Vol. 9 (2000), p. A118

Posamentier H.W., and Allen G.P. (1999); Siliciclastic sequence stratigraphy: concepts and applications. Society of Economic Paleontologists and Mineralogists (SEPM), Concepts in Sedimentology and Paleontology no. 7, 210 pp

Reijers T.J.A. (2011); Stratigraphy and sedimentology of the Niger Delta. Geologos 17(3):133–162

Stacher P (1995); Present understanding of the Niger Delta hydrocarbon habitat. In: Postma MNOG (Ed) Geology of deltas. A. A. Balkema, Rotterdam, pp 257–267