



(RESEARCH ARTICLE)



Reservoir heterogeneity and flow zones in a selected field, offshore Niger delta

Gloria Adaobi Osaji¹ and Fortune Ijeoma Chiazor^{2,*}

¹ Center for Petroleum Geoscience, University of Port Harcourt.

² Department of Geology, Faculty of Science, University of Port Harcourt, Choba, Rivers State, Nigeria.

International Journal of Science and Research Archive, 2026, 18(03), 1048-1057

Publication history: Received on 08 February 2026; revised on 16 March 2026; accepted on 19 March 2026

Article DOI: <https://doi.org/10.30574/ijrsra.2026.18.3.0547>

Abstract

In this study, suites of wire line logs and core data from four oil wells in a field in the Niger Delta was analyzed using stratified modified Lorenz plot (SML) in order to ascertain the flow zones and establish reservoir heterogeneity for optimal production planning and maximum recovery efficiency. SML plot uses conventional porosity, permeability logs and cores data in a simple cross plotting technique where Shaly intervals on the SML plot tend horizontal to low-angle while sandy intervals with the highest proportion in total cumulative storage capacity and cumulative slow has a steeper gradient-slope on the SML plot. Results from the SML cross-plot of cumulative flow capacity and cumulative storage capacity using well log data identified 57 flow units. For the four wells studied using the core data, 24 flow units were delineated and the value obtained from the stratified modified Lorenz plot (SML) ranges between 0.12 to 0.5 and 0 to 0.56 respectively. The findings indicates that the greater portion of the reservoirs in the area were homogenous maximization of the production of the hydrocarbon from the field in the Niger Delta area.

Keywords: Reservoir; Heterogeneity; Flow Zones; Storage Capacity

1. Introduction

Heterogeneity is the variability of rock's characteristics such as porosity, permeability, lithology, and fluid saturation. The petrophysical characteristics and its interaction with the different fluids i.e., gases, liquid hydrocarbons, and aqueous solutions is very crucial to reservoir characterization (El Din et al., 2011). Hydrocarbon reservoir flow zones are the definite parts of a reservoir where the fluid, like water, gas, and oil, can flow with ease. Reservoir heterogeneity directly affects the fluid flow property of the reservoir and therefore hydrocarbon recovery efficiency. They can be measured by their impact on reservoir connectivity, pressure distribution, and sweep efficiency. The paths of fluid flow are influenced by reservoir heterogeneity and create zones of high and low permeability that establish the displacement of oil, gas, and water in the reservoir.

Flow zones are especially important in determining the behaviors of the reservoirs and maximizing the production of hydrocarbons. A flow unit is an area of the total reservoir that can be mapped where geological and petrophysical properties controlling the movement of fluids are consistent and in a predictable way different from the properties of other reservoir rock volume (Ebanks et al., 1992). There are numerous means of defining flow units and establishing reservoir heterogeneities. They can be measured using various statistical parameters such as Dykstra-Parson Permeability variation, Lorenz Coefficient Variation, and Coefficient of Variation (Tausif, 2008).

The aim of this paper is to evaluate the reservoir heterogeneity and zones of flow in a selected field in the deep offshore Niger Delta for optimal production planning and maximum recovery efficiency.

* Corresponding author: Fortune Ijeoma Chiazor

1.1. Geology of the study Area

The study area SAJI field is a Pseudo name for the original Field. It is located between latitude 04° 30' 00"N to 05° 30' 00" N and Longitude 05° 00' 00"E to 06° 30' 00"E of the Niger Delta Basin (Figure 1).

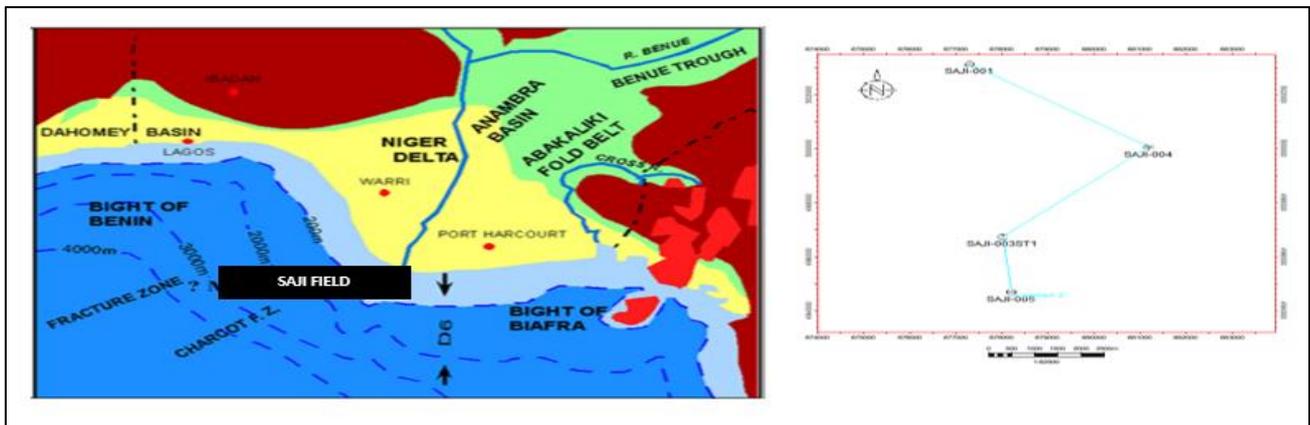


Figure 1 Location (Ogbahon and Afolabi, 2020) and Base map of the study Area

The Niger Delta basin where the study area is located, tectonically act along the west coast of equatorial Africa to influence the structural evolution and tectonics of the Niger Delta Basin. The framework itself is determined by Cretaceous fracture zones expressed as trenches and ridges in the deep Atlantic Ocean. Such fracture zone ridges divide the margin into distinct basins and form the boundary faults of the Cretaceous Benue-Abakaliki Trough in Nigeria. The Benue-Abakaliki Trough, an important structural feature, extends extremely deep within the West African shield and is a failed arm of a rift triple junction related to the opening of the South Atlantic. Rifting in this part started in the Late Jurassic, going through into the Middle Cretaceous (Short and Stauble (1967)

After the Late Cretaceous, rifting came to a halt in the Niger Delta area, and gravity tectonism became the chief process of deformation in this region. This represented the transition from extension to deformation by sedimentary load and weak materials in the subsurface. Gravity tectonism in the Niger Delta was mainly caused by the ability of shale to move internally, which caused serious deformation from the within. This deformation, according to Kulke (1995), is attributed to the following causes: First, there is diapir formation, which occurs through the over-pressured, poorly compacted clays of the Akata Formation in the prodelta and delta-slope areas through a loading process with denser sands of the delta front from Agbada Formation. The two formations possess much differential density, producing much vertical stress and mobilization of the clays into diapiric structure. The second condition was sloping unbalance, as there had been no lateral, basin ward support for the under-compacted clays of the delta slope, i.e., the Akata Formation, which finally resulted in basal deformation all along the slope.

Before the deposition of the formation in Benin, any gravity tectonics for a particular depobelt ceased in the Niger Delta. The structural representations of this tectonic activity are so very complicated and range from shale diapirs to rollover anticlines, from collapsed growth-fault crests to back-to-back fault systems, as well as steeply dipping, closely spaced flank faults. These all combine to define a particular structural identity of the Niger Delta (Evamy et al., 1978) of a schematic seismic section from the Niger Delta continental slope and rise, which shows the incidences of gravity-driven tectonics on sediments in the distal parts of the depobelt (Stacher 1995). These distal tectonic features are crucial for today's understanding of sedimentary deformation and hydrocarbon distribution within the basin.

Thus, the structural evolution of the Niger Delta illustrates the interplay between tectonic processes and sedimentary processes. The affirmative initial rifting during the Late Jurassic and Cretaceous created the most general structural framework of the basin, while later gravity tectonism proved to exercise internal deformation.

2. Materials and Methods

Materials used in this study include: Core data from four wells, suite of well logs (Gamma ray, Resistivity, Neutron, Density, and Sonic log and units of derived logs), collected from Shell Petroleum Development Company (now Renaissance Africa Energy Company) through the Nigerian Upstream petroleum regulatory commission (NUPRC).

3. Methods of Data Analysis

Standard Petrophysical Analysis techniques using well logs and core data was used in determining porosity, permeability, volume of shale which are the main parameters in assessing a reservoirs heterogeneity. Reservoir Heterogeneity was measured Using Lorenz Co-Efficient.

This involves Sorting the permeabilities, calculating the storage capacity (Eoh) and flow capacity (Ekh) and then having a plot of flow capacity vs. the storage capacity which is CFC / CSC. The Lorenz plot was then created. A curve was drawn through the data points from beginning of the line of 45 degree to the end. Then we calculated the area between the curve and the straight line under the shaded area. The length of each one of the small boxes is 0.2. If A is area under F-C curve, Lorenz coefficient is $LC = 2 \text{ (Area between F-C curve and 45o line)}$ Like VDP, LC is 0 for homogenous reservoirs and 1 for infinitely heterogeneous reservoirs.

Stratified Modified Lorenz Plot after Slatt (2006) was used to characterize the flow zones.

Slatt (2006), explained that the technique was used since it only uses conventional porosity and permeability logs and cores data, and is facies identification independent, and involves a simple cross plotting technique.

The equation of adding one cumulative-flow-capacity value is as follows (Maglio-Johnson, 2000).

$$(Kh)_{cum.} = \frac{K_1(h_1-h_0) + K_2(h_2-h_1) + \dots + K_i(h_i-h_{i-1})}{\sum K_i(h_i-h_{i-1})} \quad 1.0$$

Where k = permeability (md), h = thickness of the sample interval.

A similar equation is used to determine a single cumulative-storage-capacity value,

$$(\phi h)_{cum.} = \frac{\phi_1(h_1-h_0) + \phi_2(h_2-h_1) + \dots + \phi_i(h_i-h_{i-1})}{\sum \phi_i(h_i-h_{i-1})} \quad 1.1$$

Where ϕ = fractional porosity

Shaly intervals on the SML plot tend horizontal to low-angle while sandy intervals with the highest proportion in total cumulative storage capacity and cumulative flow has a steeper gradient-slope on the SML plot (Slatt, 2006).

The obtained storage capacity-flow capacity plot will be partitioned into a few plateaus (line segments) of varying range of slopes, divided by points of inflection. all plateaus represent a hydraulic flow unit (HFU) of reservoir sequence, i.e., the given reservoir from this graph can be divided into some hydraulic flow units (favorable and unfavorable zones).

Based on the results of petrophysical and lithological analysis, flow units were established. These are reservoir intervals that possess uniform properties such as porosity, permeability, and fluid type, which influence the way the reservoir will produce fluids upon development.

4. Results and Discussion

The calculated petrophysical properties for the various identified reservoirs are presented in table 1 and the hydrocarbon reservoirs identified in the four wells are presented in Figure 2. Petrophysical analysis revealed that effective porosity is between 0.22 – 0.28 (frac), permeability between 117.5 – 180.32 (mD) and contains water saturation of 0.29 – 0.46 (frac). Seven flow units was defined for this reservoir by SAJI-001 and 004-STI bearing 3 and 4 flow unit respectively (Figures 3 and 4) an indication of heterogeneity of reservoir rock unit. petrophysical parameters of this zone is depicted in Table 1 and was defined across SAJI 001 and 004-STI well. Petrophysical analysis showed that the variable effective porosity varied from 0.09 – 0.36 (frac), the permeability ranges were 91 – 1308 (mD) and water saturation varied from 0.15 – 0.93 (frac). Four flow unit was found for this reservoir with SAJI-001 and 003-ST1 (fig. 5) having three and one flow unit respectively a sign that SAJI-001 has a heterogenous flow unit while 003-ST1 well is homogenous in the There were eight flow unit present in this reservoir with SAJI-001, 003-ST1 and 004 having 3, 1 and 4 flow unit respectively an indication of heterogeneity in the reservoir rock unit between wells. reservoir rock units. The reservoir 3 petrophysical

Table 1 Petrophysical properties Sums and Averages

	Well	Zones	Top	Bottom	Gross (ft)	Net (ft)	Net to Gross	Av_Shale Volume (ft3/ft3)	Av_Porosity (ft3/ft3)	Av Water Saturation (ft3/ft3)	Av_PHIE_D	Av_PERM_WR
1	SAJI-001	H_TOP	6819.00	7050.64	231.64	231.50	0.98	0.23	0.28	0.46	0.22	180.32
2	SAJI-001	F_TOP	8080.32	8169.79	89.47	89.29	0.98	0.18	0.28	0.11	0.24	253.14
3	SAJI-001	GG	9026.74	9058.89	32.15	29.89	0.93	0.30	0.25	0.31	0.18	92.37
4	SAJI-001	E_TOP	9242.82	9299.14	56.32	56.14	0.98	0.15	0.21	0.16	0.18	91.89
5	SAJI-001	A_TOP	9982.03	10080.58	98.55	79.00	0.80	0.27	0.19	0.43	0.13	39.28
6	SAJI-003-ST1	H_TOP	6881.78	7230.16	348.38	337.16	0.97	0.24	0.27	0.79	0.23	188.35
7	SAJI-003-ST1	F_TOP	7788.31	7842.65	54.34	42.15	0.78	0.17	0.26	0.41	0.24	248.66
8	SAJI-003-ST1	E_TOP	8111.17	8150.06	38.89	36.56	0.94	0.08	0.24	0.40	0.23	200.07
9	SAJI-003-ST1	ED_TOP	9339.51	9378.20	38.69	38.20	0.99	0.12	0.29	0.08	0.27	468.72
10	SAJI-003-ST1	D_TOP	9549.55	9568.44	18.89	18.44	0.98	0.08	0.05	0.26	0.05	0.76
11	SAJI-004-ST1	H_TOP	7680.96	7788.73	107.77	107.23	0.99	0.02	0.09	1.00	0.09	3.11
12	SAJI-004-ST1	G_TOP	8211.08	8220.39	9.31	8.89	0.96	0.15	0.33	0.36	0.33	920.36
13	SAJI-004-ST1	F_TOP	8338.54	8508.54	170.00	167.54	0.99	0.15	0.23	0.32	0.20	109.75
14	SAJI-004-ST1	E_TOP	8695.79	8745.79	50.00	47.79	0.96	0.07	0.31	0.15	0.30	572.92
15	SAJI-004-ST1	D_TOP	9657.44	9688.55	31.11	31.05	0.99	0.04	0.25	0.17	0.24	216.41
16	SAJI-004-ST1	A_TOP	9782.25	9797.81	15.56	13.81	0.89	0.14	0.23	0.64	0.20	105.21

17	SAJI-004-ST1	AA_TOP	10748.20	10762.20	14.00	13.70	0.98	0.06	0.24	0.24	0.24	227.24
18	SAJI-004-ST1	AB_TOP	10818.10	10826.20	8.10	6.20	0.77	0.22	0.24	0.22	0.21	146.83
19	SAJI-005	H_TOP	6252.08	6282.82	30.74	30.32	0.99	0.00	0.31	0.93	0.31	581.78
20	SAJI-005	F_TOP	6728.54	6774.63	46.09	45.63	0.99	0.09	0.29	0.35	0.28	385.27
21	SAJI-005	E_TOP	6893.51	6897.59	4.08	3.59	0.88	0.00	0.36	0.20	0.36	1308.27
22	SAJI-005	D_TOP	7104.06	7119.99	15.93	15.49	0.97	0.03	0.30	0.25	0.30	516.53
23	SAJI-005	C_TOP	7628.67	7633.98	5.31	4.98	0.94	0.00	0.25	0.61	0.25	245.49
24	SAJI-005	A_TOP	7882.30	7912.30	30.00	29.80	0.99	0.06	0.26	0.72	0.25	248.71
25	SAJI-005	Ac_TOP	10022.40	10030.20	7.80	7.70	0.99	0.02	0.32	0.40	0.32	669.08
26	SAJI-005	Ad_TOP	10230.60	10312.40	81.80	81.40	0.99	0.01	0.30	0.18	0.30	546.97
27	SAJI-005	Ae_TOP	11040.00	11054.50	14.50	14.50	0.99	0.08	0.22	0.29	0.20	117.5

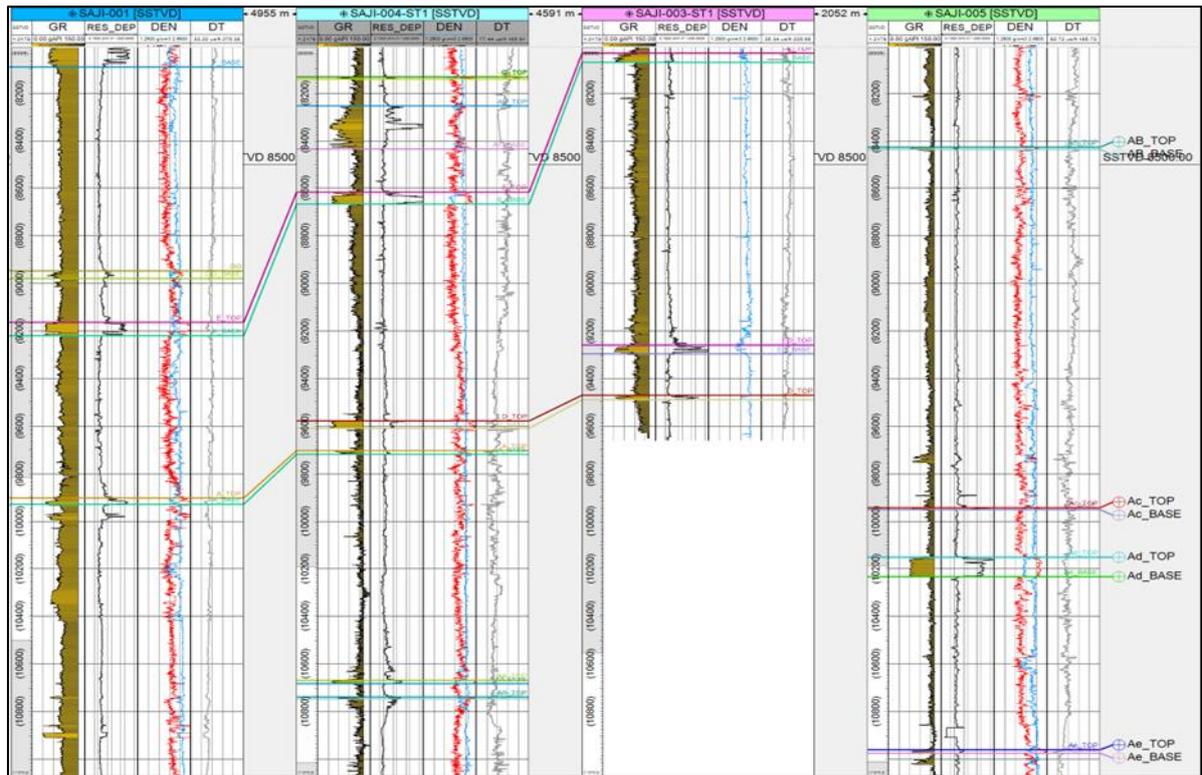


Figure 2 Well logs correlation of the four wells showing the reservoirs identified

The Lorenz coefficient of the reservoirs ranges from lowest to highest i.e. from 0.12 to 0.5 the majority of the reservoirs have low Lorenz coefficient i.e. less than 0.2 (well 1, well 2ST1, well 3ST1) which implies homogenous reservoir only a single well has Lorenz coefficient 0.5 which is from well 3 can be concluded as highly heterogenous.

The cumulative flow capacity (CFC) and the cumulative storage capacity (CSC) were calculated with the stratified modified Lorenz plot (SML) and ranges from 260.07mD to 5,896.65mD. The flow zones number shown for this analysis varies from the lowest which is 1 to 7 flow units (Figs 3 to 6).

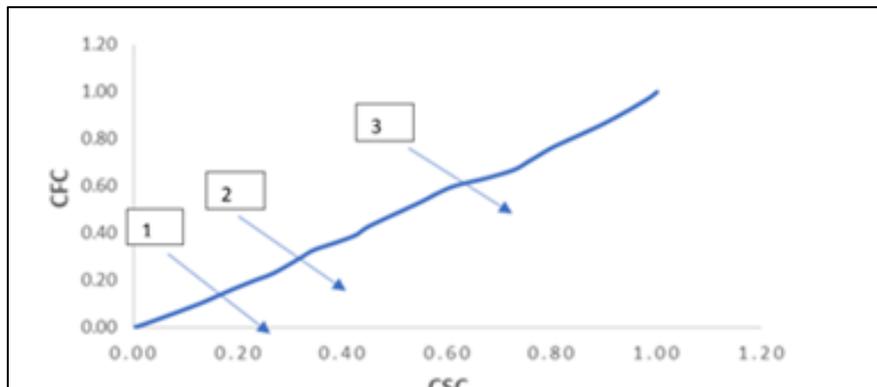


Figure 3 Graph of SML plot showing the flow unit in well 001

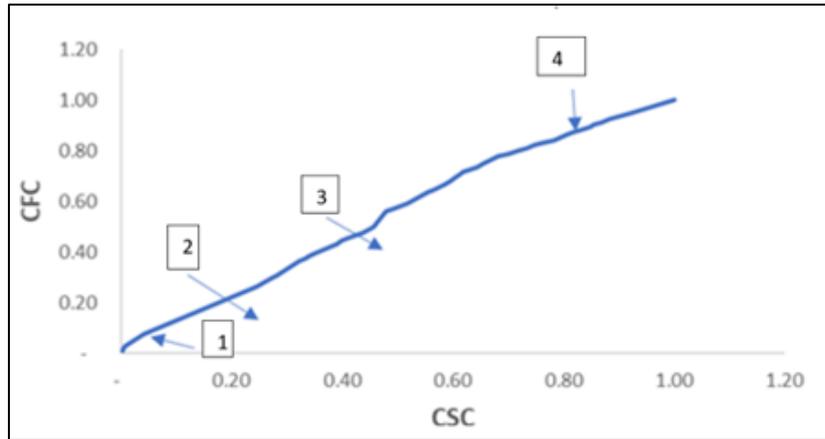


Figure 4 Graph of SML plot showing the flow unit in well 004 ST1

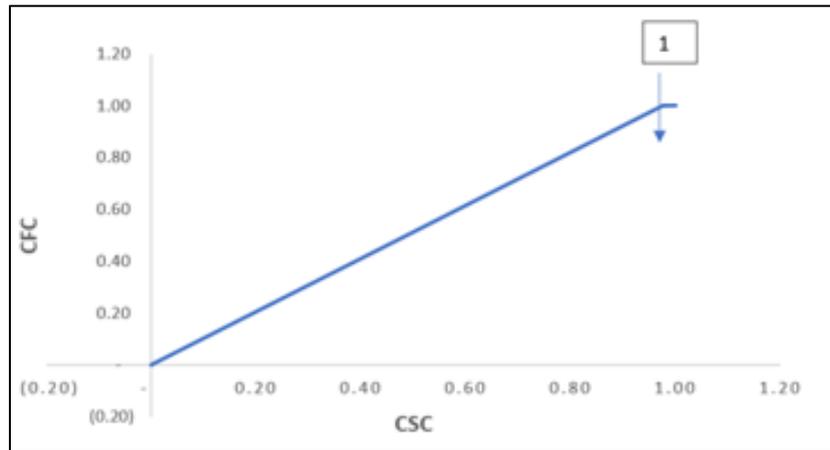


Figure 5 Graph of SML plot showing the flow unit in well 003 ST1

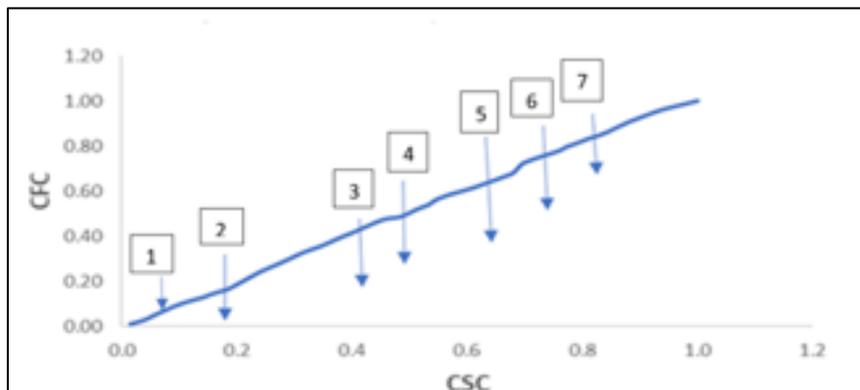


Figure 6 Graph of SML plot showing the flow unit in well 003

Petrophysical analysis of the zones of interest in the four (4) wells indicate very low shale volume, an indication of reservoir having very good quality sand and little shale. Total and effective porosity result is >20% relative to Rider's classification scheme (table 2) which categorized the reservoir sand as very good thus inferring the sand zone are highly porous and good for the trapping of fluids. Based on Riders classification schemes the permeability range in the zones of interest are excellent to very good and therefore fluid flow within the reservoir units will be effortless. Reservoir flow

unit identified within the various reservoir of the various well possessed various heterogeneity for most of the well apart from reservoir 2 and 5 on SAJI-001 well which was homogenous in flow throughout the reservoir unit (Table 3 and 4)

Fifty-seven flow units (Table 3) of this reservoir has been defined by SAJI-001, 003-ST1 and 005 with 3 flow unit each respectively stating that SAJI-001, 003-ST1 and 005 well has a heterogenous flow unit in the reservoir rock unit. For Reservoir 7, Petrophysical reservoir parameters for this zone is depicted in Table 1 and was found only on SAJI 001 well. Effective porosity value is 0.252 (frac), permeability value is 442.188 (mD) and possesses water saturation value of 0.157 (frac).

3 flow unit was found for this reservoir on SAJI-001 which means that SAJI-001 well have a heterogenous flow unit in the reservoir rock unit. For Reservoir 8, Reservoir petrophysical parameters of this zone is shown in Table 1 and was found only on SAJI 001 well.

Petrophysical analysis provided the effective porosity value as 0.204 (frac), permeability value as 230.801 (mD) and has the water saturation value as 0.301 (frac). The 2-flow unit was marked for this reservoir on SAJI-001 indicating that SAJI-001 well will have a heterogenous flow unit in the reservoir rock unit. The petrophysical characteristics of the reservoir of this zone is as shown in Table 1 and was present in SAJI 001 well only. Value of effective porosity is 0.173 (frac), value of permeability is 230.801 (mD) and has water saturation value of 0.834 (frac). 3 flow unit was present for this reservoir on SAJI-001 which is an indication that SAJI-001 well have a heterogenous flow unit in the reservoir rock unit.

Table 2 Classification of sandstone reservoir based on porosity and permeability (Rider, 1986)

Percentage porosity	Qualitative description	Average permeability	Qualitative description
0-5	Negligible	<10.5	Poor to fair
5-10	Poor	15-50	Moderate
15-20	Good	50-250	Good
20-30	Very Good	250-1000	Very Good
>30	Excellent	>1000	Excellent

Table 3 Summary of the total flow units for Well log data

Wells	Reservoir 1	Reservoir 2	Reservoir 3	Reservoir 4	Reservoir 5	Reservoir 6	Reservoir 7	Reservoir 8	Reservoir 9
SAJI-001	3	1	2	4	1	3	3	2	3
SAJI-003-ST1	2	3	3	6	4	3	-	-	-
SAJI-004	-	-	3	5	-	-	-	-	-
SAJI-005	-	-	-	-	3	3	-	-	-
TOTAL	5	4	8	15	8	9	3	2	3

Table 4 Summary of the total flow units for Core data

Wells	FLOW UNITS
Well 1	3
Well 2	2
Well, 2ST1	1
Well, 2ST3	2
Well 3	7
Well, 3ST1	1
Well 4	4
Well, 4ST1	4

5. Conclusion

The influence of reservoir heterogeneity on fluid flow has adequate impacts both in well design, production design, and also secondary recovery project. This study has verified that all of the reservoir intervals of this study possess the minimum to be considered very good reservoir rocks according to Rider's system of classification. Petrophysical analysis revealed excellent to good quality reservoir rocks that are economically producible because of low shale volume, high net to gross, excellent and good effective porosity and permeability, good value of hydrocarbon saturation and high degree of heterogeneity for all those zones except two zones having homogeneous flow rate.

Compliance with ethical standards

Disclosure of conflict of interest

The authors declare that there is no conflict of interest.

Statement of informed consent

Informed consent was obtained from all individual participants included in the study.

References

- [1] Ebanks, W. J. Jr., Scheihing, M. H., Atkinson, C. D. (1992). Flow unit for reservoir characterization. In: D. Morton-Thompson, A.M. Woods (Eds.) Development geology Reference Manual, AMER, Association Petrol. Geol. Methods in Exploration Series. 10:282-284.
- [2] El Din, S. Serag, Dernaika, M. R., and M. Z. Kalam. (2011) "The Impact of Heterogeneity on Laboratory Petrophysical Measurements." Paper presented at the SPE Reservoir Characterization and Simulation Conference and Exhibition, Abu Dhabi, UAE, Doi: <https://doi.org/10.2118/147950-MS> 1-12
- [3] Evamy, B. D., Haremboure, J., Kamerling, P., Knaap, W. A., Molloy, F. A., and Rowlands, P. H. (1978). Hydrocarbon habitat of the Tertiary Niger Delta. American Association of Petroleum Geologists Bulletin, 62(1), 1-39.
- [4] Kulke, H. (1995). Sedimentation and tectonics in the Niger Delta. American Association of Petroleum Geologists Bulletin, 79(11), 1563-1580.
- [5] Maglio-Johnson T (2000) Petrophysical definition of flow units in deep-water sandstone, Lewis Shale, Wyoming (abs.). Am Assoc Pet Geol Bull 84(11):1867.
- [6] Ogbahon, O. A., and Afolabi, M. O. (2020). High-resolution biostratigraphic, sequence stratigraphic and paleoenvironmental analyses of Motun-1 Well, Niger Delta, Nigeria. Earth and Environmental Science Research and Reviews, 3(4), 184–190
- [7] Rider, M.H., (1986). The Geological Interpretation of Well Logs. 2nd Ed. Whittles Publishing: Caithness

- [8] Stacher, P. (1995). Present Understanding of the Niger Delta hydrocarbon habitat, In, M. N Oti and G. Postma (eds.), *Geology of Deltas*: Rotterdam, A.A. Balkema, 257-267.
- [9] Slatt, R. M. and Galloway, W. E. (1993): Geological Heterogeneities. In: Morton-Thompson, D. and Woods, A. M.(eds), *Development Geology Reference Manual*. American Association of Petroleum Geologists methods in exploration, Series No. 10, p. 278- 281.
- [10] Tausif, A. (2013): Investigating the Relationship Between Reservoir Quality and Heterogeneity in Carbonate Reservoirs. M.Sc. Unpublished Thesis. Department of Earth Science and Engineering Centre for Petroleum Studies, Imperial College London, p. 1- 40.