Reservoir Flow Unit Analysis of Akos Field in Niger Delta

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Authors' contributions

Article Information

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ABSTRACT

In this study, the flow units of reservoirs of Akos field have been computed with the Stratigraphic Modified Lorenz plot. Cumulative flow capacity and cumulative storage capacity were used for constructing the Stratigraphic Modified Lorenz Plot (SMLP). The flow capacity and storage capacity are functions of calculated permeability and porosity values considering their sampling depth. The porosity and permeability were obtained from composite well logs of eight oil wells in the study area. Two reservoirs A and B were delineated from the well logs. The stratigraphic Modified Lorenz Plots (SMLP) revealed a total of one hundred and twelve (112) Flow units (FU) in the two observed reservoirs A and B. Reservoir A has a total of 53 FU (25 speed zones, 18 baffle zones and 10 barrier zones) and reservoir B has a total of 59 FU (29 speed zones, 16 baffle zones and 14 barrier zones) which cut across all the wells. The flow units in both reservoirs fall within the speed zones, baffles and barrier unit categories. The speed zone units with equal flow and storage capacities are the dominant flow units in both reservoirs. This is an indication that the sediments have good reservoir qualities. The baffle zones have more storage capacity than the speed zones. The barrier zones within the reservoirs are acting as a seal to the flow of fluid.

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1. INTRODUCTION

Reservoir characterization plays a fundamental part in oil and gas industry. The understanding of the reservoir rock properties such as porosity; permeability and pore throat assists engineers in improving reservoir characterization. Reservoir characterization involves the integration of all available data, tools and disciplines in order to understand and identify the flow units of the reservoir and predict the inter-well distributions of reservoir properties. Flow unit is a common way of characterizing/zoning a hydrocarbon reservoir.

Flow unit is the ability of a rock to store and transmit fluids. The flow unit is a mappable portion of a reservoir within which the geological and petrophysical properties that affect hydrocarbon flow is consistent and different from the properties of other zones [1]. Most times the flow unit is in communication with others. Flow units can be obtained from the combination of porosity, permeability and bed thickness [2].

Various graphical techniques such as stratigraphic flow profile (SFP), stratigraphic modified Lorenz plot (SMLP) and modified Lorenz plot (MLP) have been established to determine reservoir flow units based on physical structure, rock and pore throat types, reservoir speed process and flow and storage capacity of the reservoir. The concept of hydraulic flow unit and petrophysics has been well documented in recent time [3-17].

The Stratigraphic Modified Lorenzo (SML) plots techniques [5,18], will be used to determine flow units and the hydraulic behaviour of observed sand-bodies. The SMLP method involves the crossplot of cumulative flow capacity and cumulative storage capacity. Fractional flow capacity and storage capacity values are determined from inflection points on the Lorenz plot, which correspond to changes in flow capacity or storage capacity associated with factors that affect reservoir quality [19]. The aim of this study is to use the Stratigraphic Modified (SML) Lorenz plot to delineate reservoir flow units of the Akos field.

2. GEOLOGY OF THE STUDY AREA

The study area (Akos Field) is located in the onshore coastal swamp depositional belt in the eastern part of Niger Delta (Fig. 1) and it is within latitudes 4° 19′ 00” N and 4° 50′ 00” N and Longitudes 6° 02′ 30” E and 7° 10′ 00” E. The base map of the study area showing the seismic lines and well locations is shown in Fig. 2.
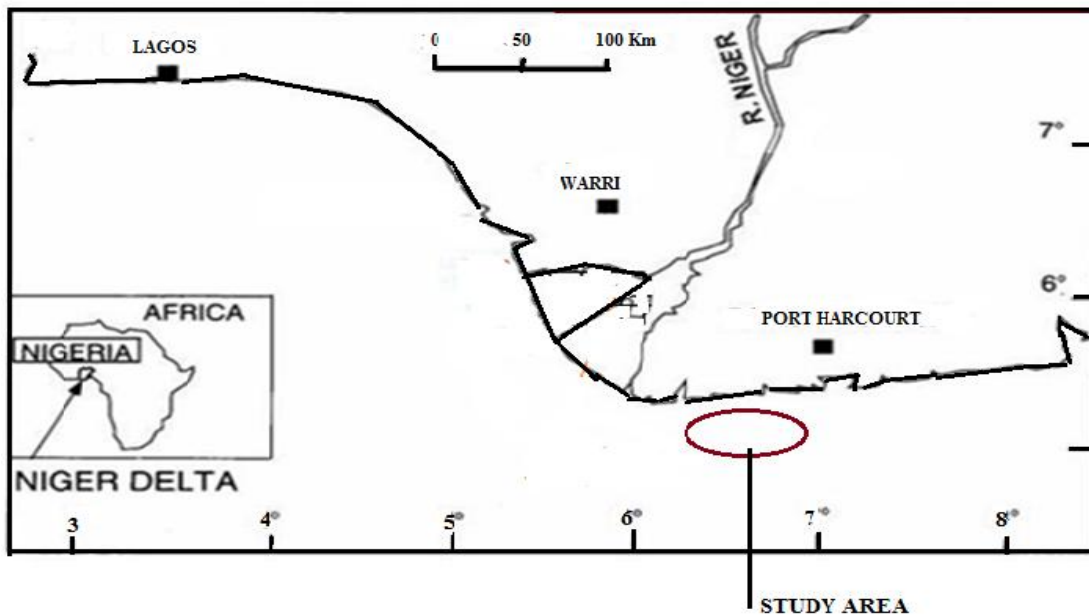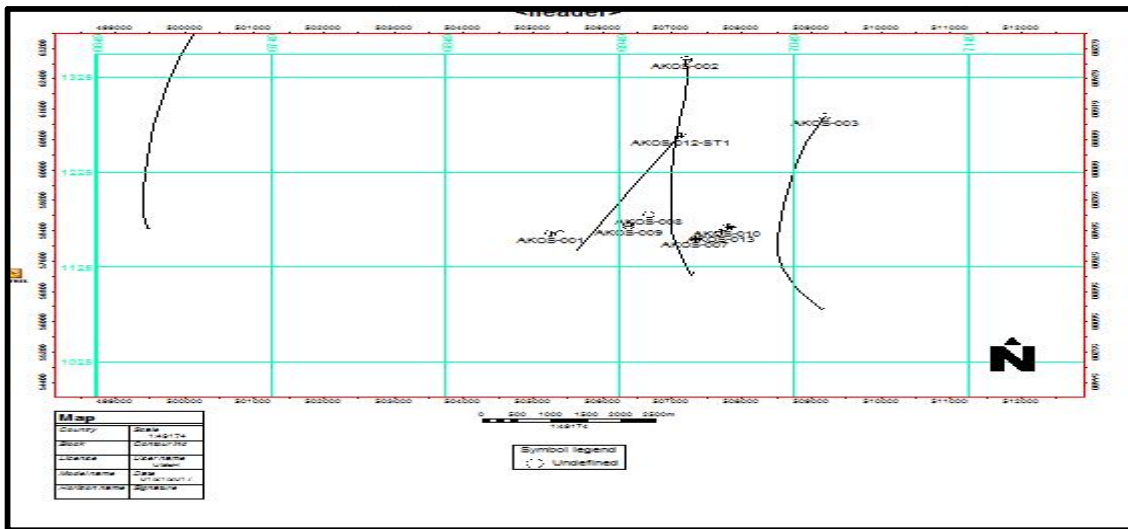

Fig. 1. Map Niger Delta showing the study area

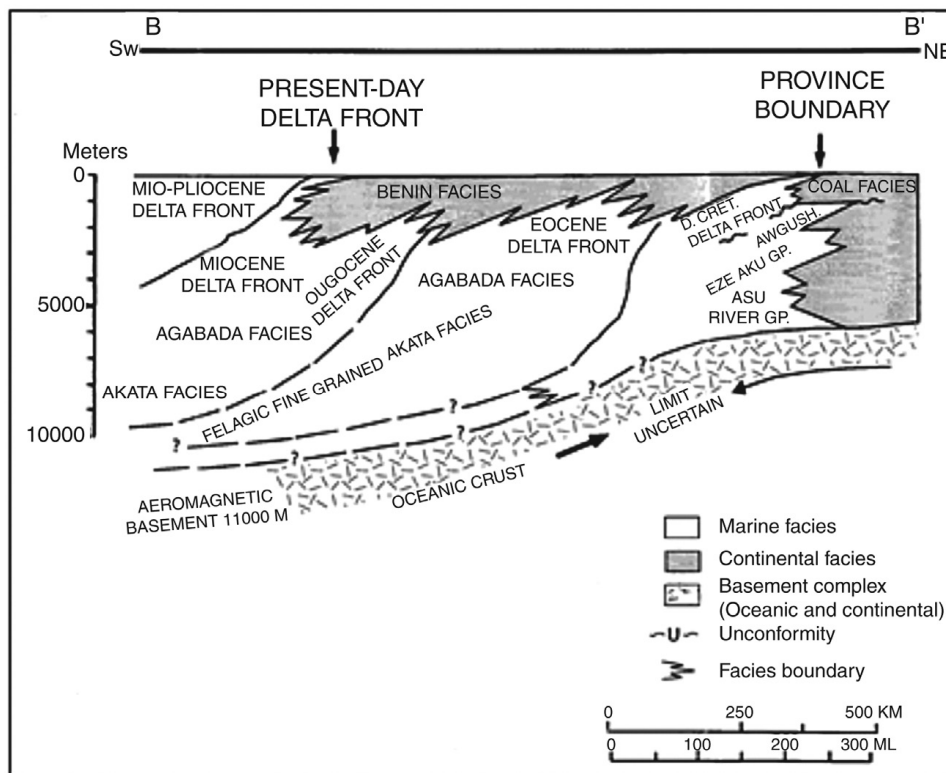**Fig. 2. Schematic base map showing the study area**

Fig. 3. Generalized dip section of the Niger Delta showing the structural provinces of the Delta (Adapted from [25])

The Niger-Delta forms one of the world's major Hydrocarbon provinces and it is situated on the Gulf of Guinea on the west coast of Africa (Southern part of Nigeria). It covers an area between longitude 4 – 9ºE and Latitude 4 - 9º N. It has an area of 75,000 km^2 with an average thickness of about 12 km. It is composed of an overall regressive clastic sequence. The Niger Delta was formed as a result of the separation of the African and South American plates, at the

site of the triple junction in the late Jurassic and continuing into the Cretaceous, thus leading to the opening of the Southern Atlantic.

The Niger Delta is a low gradient delta plain-shelf slope wedge. The tectonic framework of the continental margin along the west coast of Equatorial Africa is controlled by Cretaceous fractured zones expressed as trenches and ridges in the deep Atlantic. The trough represents a failed rift triple junction associated with the South Atlantic. After the rifting ceased, gravity tectonism became the primary deformation process. The Niger Delta province contains only one identified petroleum system referred to as the Tertiary Niger Delta (Akata-Agbada) petroleum system [20-23]. The Niger Delta has built out over the collapsed continental margin at the site of the triple junction formed during the Middle Cretaceous [24].

One of the most conspicuous geological features of the Niger Delta is its growth fault pattern. The Niger Delta oil province is characterized by East-West trending syn-sedimentary faults and folds. Most of the oil accumulated in the Niger Delta is contained in the rollover anticline structure. The oil in these structures may be trapped in dip closures or against a Synthetic or antithetic fault (Fig. 3).

3. MATERIALS AND METHODS

The data used for this study are suite of well logs obtained from eight oil wells in the Akos field. The composite logs consist of gamma ray, resistivity, and density logs. The techniques adopted for the determination of the reservoir flow zones are as follows;

3.1 Determination of Petrophysical Properties

The available gamma ray and resistivity logs in the composite logs from the eight wells are used for the determination of the reservoir. A low gamma ray zone correlating with a high resistivity value was taken as a reservoir. The density log was used for computing the porosity while the permeability was obtained from the computed porosity.

3.2 Flow Unit Determination

The [5] method was adopted to subdivide the observed reservoir into Flow units. [5,6] presented a graphical method for quantifying the

flow units, according to the petrophysical rock/pore types, flow and storage capacities (Kh) and (Φh) and reservoir process speed (K/Φ). After subdividing the reservoir, into flow units, a Stratigraphic Modified Lorenz Plot (SMLP) was generated using cumulative flow capacity (Khcum) and cumulative storage capacity (Φhcum). The flow capacity (Kh) and storage capacity (Φh) are functions of permeability and porosity values considering their sampling depths [5,18]. The values of cumulative flow capacities were determined as follows [5,26-30].

$$(Kh)cum = k1(h1-ho) + k2(h2-hi) + \ldots ki(h1-hi)/\Sigma ki(h1-hi-n) \qquad (1)$$

Where

k = permeability (md)
h= thickness of the sample interval (m)
Kh_{cum} = cumulative flow capacity

Similarly, the cumulative storage capacity value is obtained from the equation

$$(\Phi h)cum = \varphi 1(h1-h0) + \varphi 2(h2-h1) + \ldots \varphi i(h1-hi)/\Sigma\varphi 1(h1-hi-n) \qquad (2)$$

Where:

h = thickness of the sample interval (m)
Φ = Fractional porosity
$(\Phi h)_{cum}$ = cumulative storage capacity

The various points of inflections observed on the crossplot of cumulative flow capacity versus cumulative storage capacity are interpreted to define the number of flow units in the Stratigraphic Modified Lorenzo Plot (SMLP).

4. RESULTS AND DISCUSSION

4.1 Lithology and Reservoir Properties

Two major lithologies were identified in the gamma ray log. The lithologies are sand and shale. The gamma ray logs show alternation of sand and shale lithologies which is an indication of the Agbada Formation in the Niger Delta. Two hydrocarbon reservoirs A and B are delineated from the gamma ray and resistivity logs and correlated across the oil wells (Fig. 4).

4.2 Observed Flow Units

The SML cross-plots for the reservoirs A and B are shown in Figs. 5a to 5h and Figs. 6a to 6h for the eight wells respectively. The shape of the

SML plots is a representation of the reservoir flow performance. The break or inflection points indicate the number of flow units in the Stratigraphic Modified Lorenzo Plots. Zones with steep slopes have a greater percentage of reservoir flow capacity compared to storage capacity. These segments have high reservoir process speed and they are known as speed zones. Zones on the SML plot with gentle slopes are associated with high storage capacity and little flow capacity. These zones are typical of baffle sections of the reservoir. Barrier units are impermeable units with very low flow and storage capacities. Segments on the SML plots with very low or flat slope are regarded as impermeable units having very low flow and storage capacity. In this study, these three main types of flow units have been delineated on the SML plots based on [31-34].

4.2.1 Reservoir A flow units

In reservoir A, the numbers of flow units delineated for each well within the reservoir ranges between six and nine (Table 1). For Akos 001, six flow units (FU1-FU6) are identified (Fig. 5a). The speed zones are FU1, FU2 and FU5.

The baffle zones are FU3 and FU6 while FU4 is a barrier zone. In Akos 002, six hydraulic flow units are observed (Fig. 5b). The speed zones are FU2 and FU5. The observed baffle zones are FU3, FU4. FU1 and FU6 are barrier zones. Six flow units were identified in Akos 003 (Fig.5c). FU3, FU5 and FU6 are speed zones. FU1, and FU2 are baffle zones while FU4 is a barrier Zone. Five flow units were delineated in AKOS 004 (Fig. 5d). The speed zones are FU1 and FU4 while FU2, and FU3 are baffle zones. FU5 was identified as a barrier zone. In Akos 007, six flow units were observed (Fig. 5e). FU1, FU2 and FU4 are speed zones. FU3, and FU5 are baffle zones while FU6 is a barrier zone. In Akos 008, seven hydraulic flow units were identified (Fig. 5f). The speed zones are FU2, FU4, FU6 and FU7. The baffle zones are FU3 and FU5 while the barrier zone is FU1. Eight hydraulic flow units were observed in Akos 009 (Fig. 5g). The speed zones are FU2, FU4 and FU7. The interpreted baffle zones are FU1, FU3, FU5 and FU6. FU8 is identified as the barrier zone. In Akos 012, nine HFU were observed (Fig. 5h). FU1, FU3, FU5, FU7 and FU9 are speed zones. FU4 and FU8 are baffle zones while FU2 and FU6 are barrier zones.
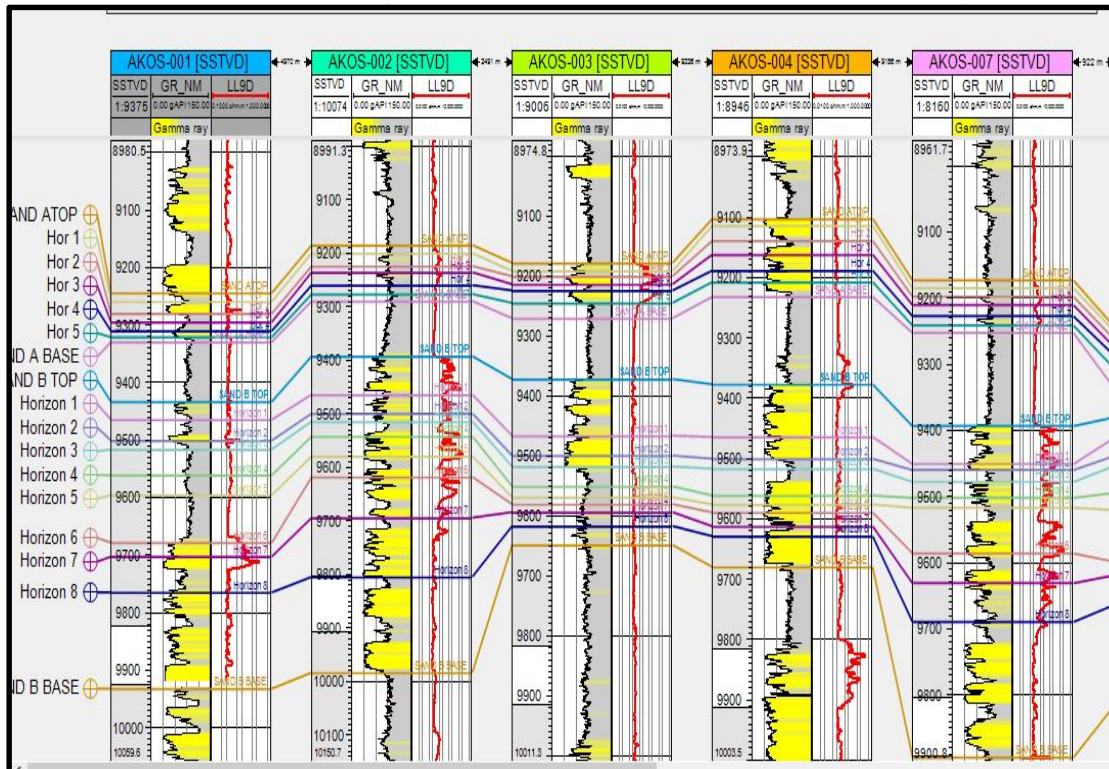
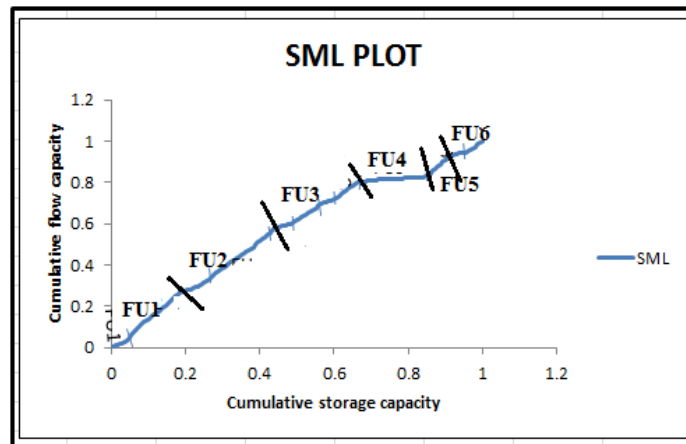

Fig. 4. Zones of Reservoir A and B along the wells

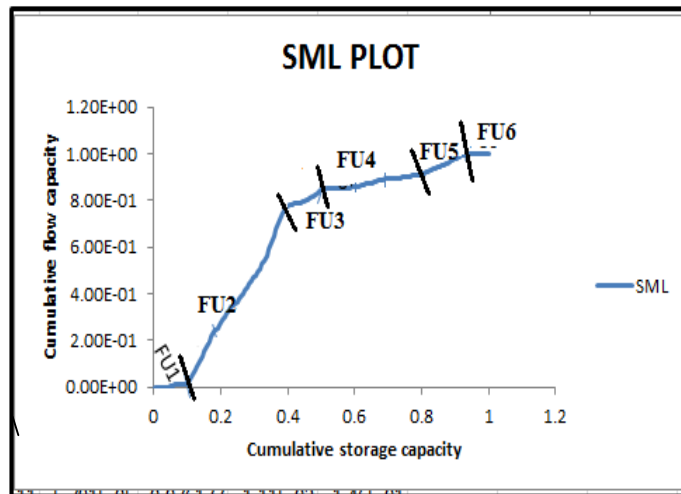**Fig. 5a. Graph of SML plot showing the flow unit in Akos 001**

Fig. 5b. Graph of SML plot showing the flow unit zone in Akos 002
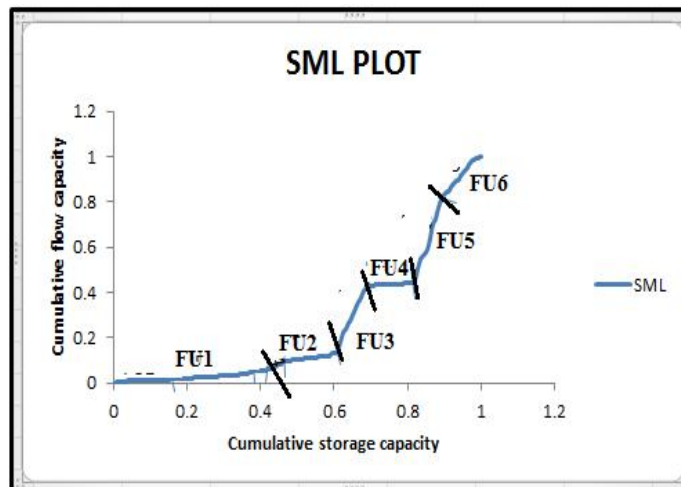

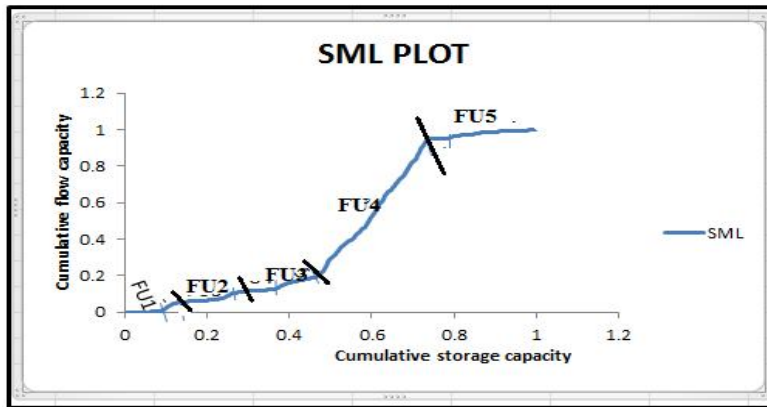**Fig. 5c. Graph of SML plot showing the flow unit in Akos 003**

Fig. 5d. Graph of SML plot showing the flow unit in Akos 004
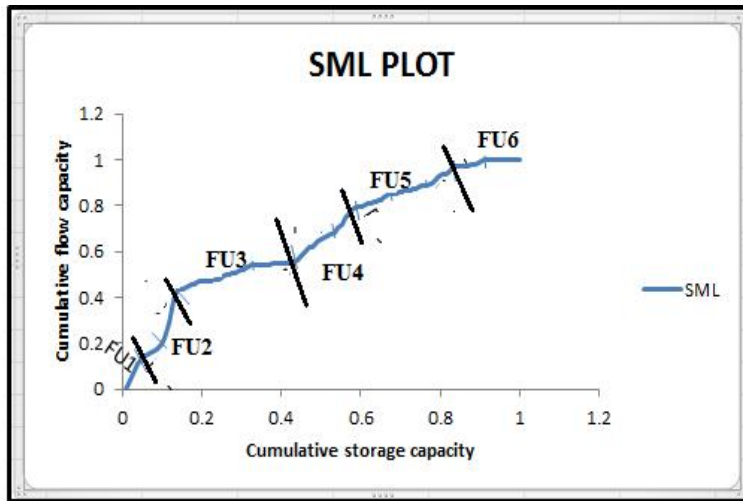

Fig. 5e. Graph of SML plot showing the flow unit in Akos 007
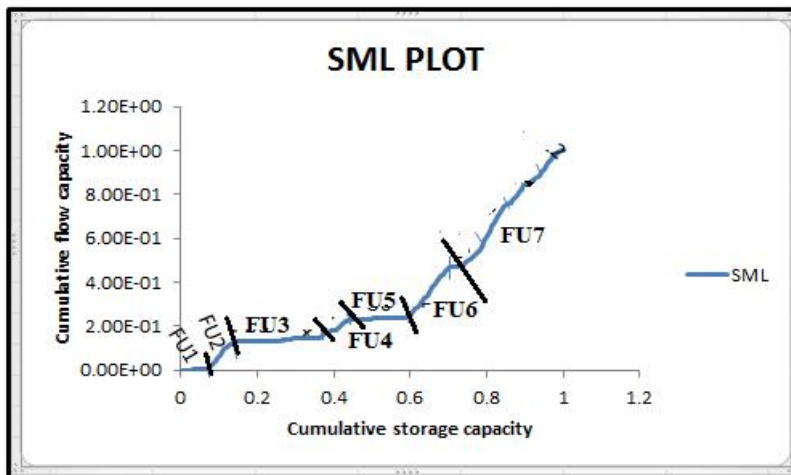

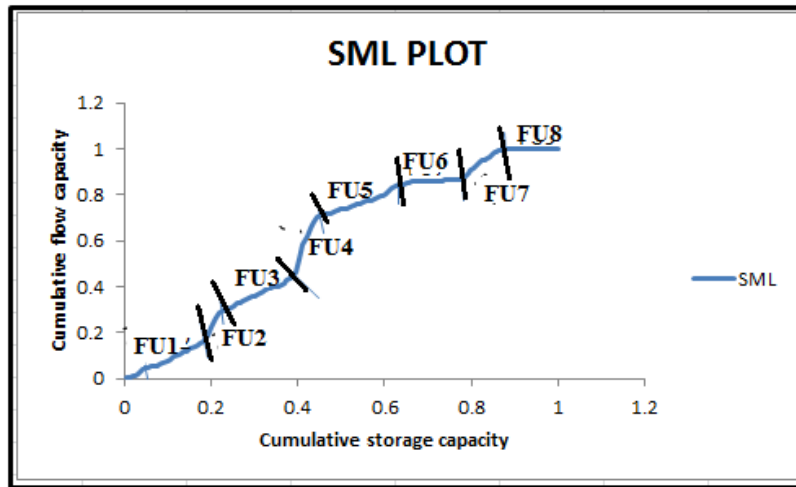**Fig. 5f. Graph of SML plot showing the flow unit in Akos 008**

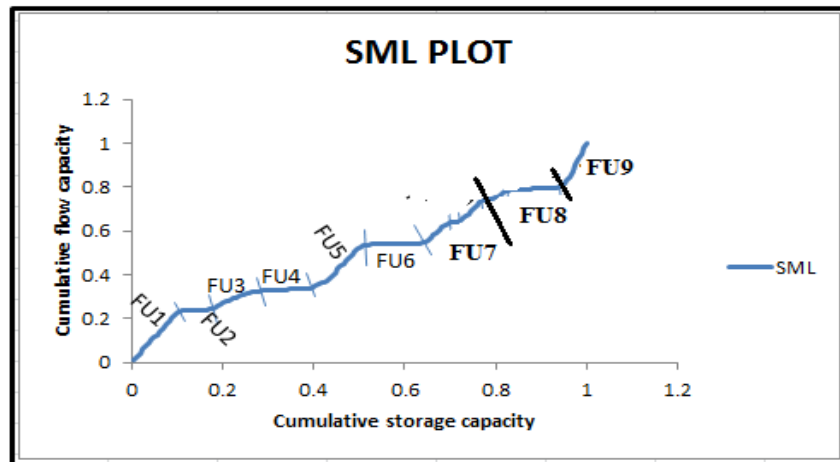**Fig. 5g. Graph of SML plot showing the flow unit in Akos 009**

Fig. 5h. Graph of SML plot showing the flow unit in Akos 012

Table 1. Reservoir A flow unit characterization

Akos wells	No. of flow unit	Flow unit characterization		
		Speed zones	**Baffles**	**Barriers**
Akos 001	6	1, 2, 5	3, 6	4
Akos 002	6	2, 5	3, 4	1, 6
Akos 003	6	3, 5, 6	1, 2	4
Akos 004	5	1, 4	2, 3	5
Akos 007	6	1, 2, 4	2, 3	5
Akos 008	7	2, 4, 6, 7	3, 5	1
Akos 009	8	2, 4, 7	1, 3, 5, 6	8
Akos 012	9	1, 3, 5, 7,9	4, 8	2, 6

4.2.2 Reservoir B flow units

In reservoir B, the numbers of flow units delineated for each well within the reservoir range between six and eight (Table 2). In Akos 001, eight hydraulic flow units are observed (Fig. 6a). FU3, FU5, FU7 and FU8 are speed zones. FU1 and FU6 are baffle zones while FU2 and

FU4 are barrier zones. In Akos 002, eight flow units are observed. FU3, FU5, FU7 and FU8 are speed zones. FU2 is a baffle zone while FU1, FU4 and FU6 are barrier zones. Eight hydraulic flow units were observed in Akos 003 (Fig. 6c). FU2, FU3, FU5, FU6 and FU8 are speed zones. FU1, FU4 and FU7 are baffle zones. In Akos 004, seven flow units were observed (Fig. 6d). FU2, FU4, and FU7 are speed zones. FU5 is a baffle zone while FU1 and FU3 and FU6 are barrier zones. In Akos 007, seven hydraulic flow units were observed (Fig. 6e). The observed speed zones are FU2,

FU5, and FU7. FU1, FU3 and FU6 are baffle zones while FU4 is a barrier zone. In Akos 008, six flow units are observed (Fig. 6f). The delineated speed zones are FU3, and FU5. FU2. FU4 and FU8 are baffle zones while FU1 is a barrier zone. In Akos 009, seven flow units are observed (Fig. 6g). FU3, FU5 and FU7 are speed zones. FU2, and FU6 are baffle zones while FU1 and FU4 are barrier zones. In Akos 012, eight flow units are observed (Fig. 6h). FU1, FU3, FU5, and FU8 are speed zones. FU4 and FU6 are baffle zones while FU2 and FU7 are barrier zones.

Fig. 6a. Graph of SML plot showing the flow unit in Akos 001

Fig. 6b. Graph of SML plot showing the flow unit in Akos 002

Fig. 6c. Graph of SML plot showing the flow unit in Akos 003

Fig. 6d. Graph of SML plot showing the flow unit in Akos 004

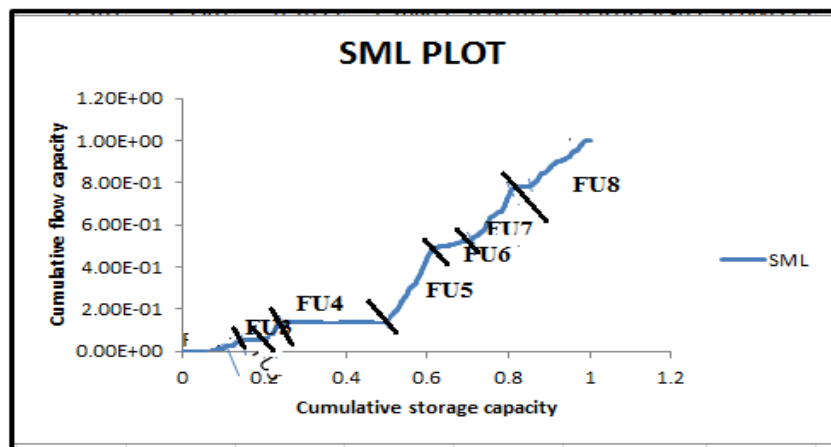**Fig. 6e. Graph of SML plot showing the flow UNIT in Akos 007**
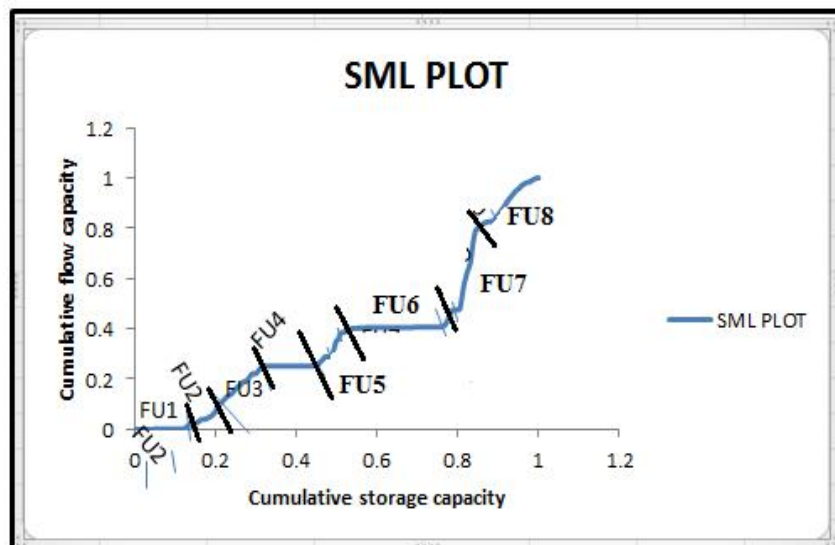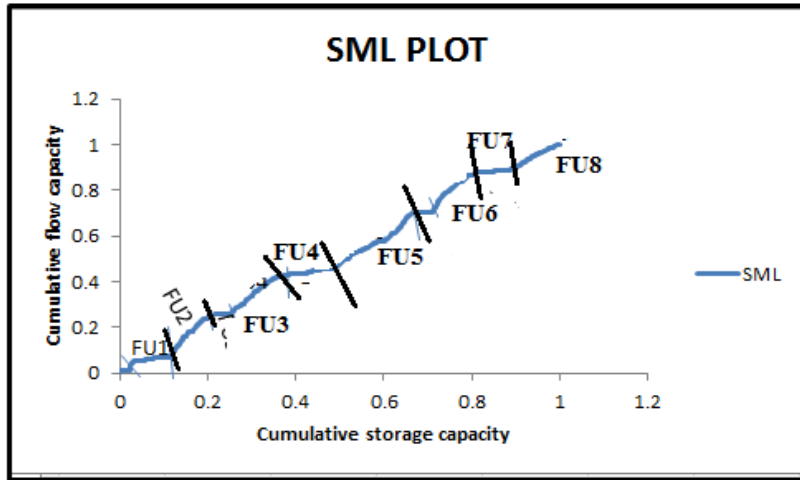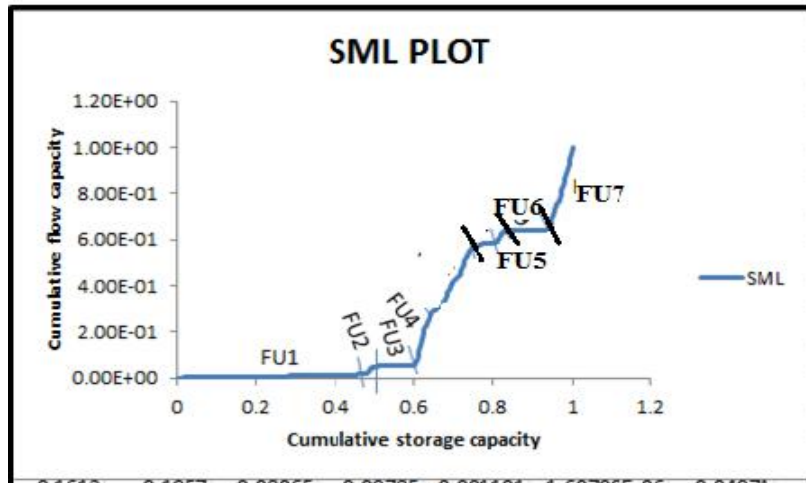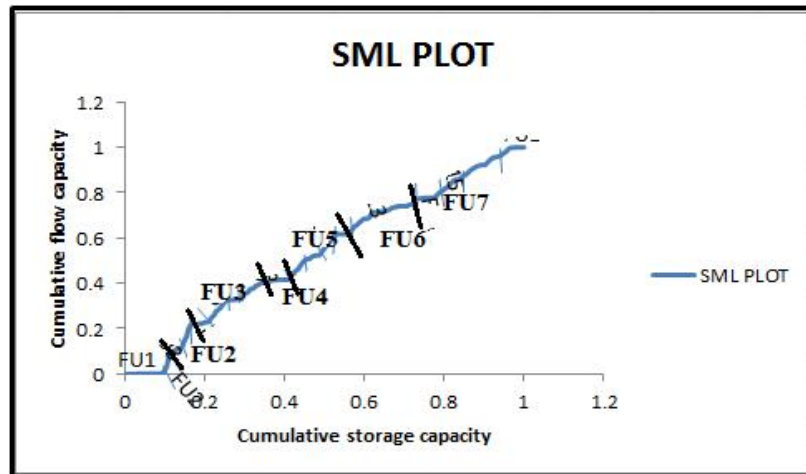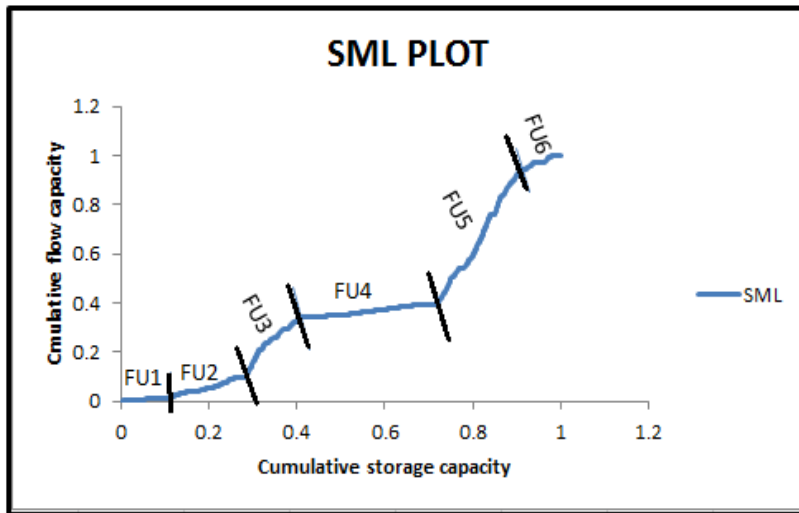
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Fig. 6f. Graph of SML plot showing the flow unit in Akos 008
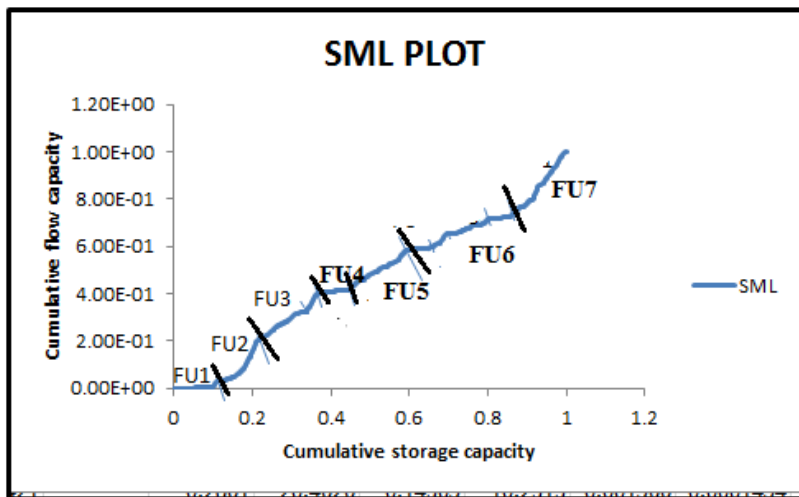

Fig. 6g. Graph of SML plot showing the flow unit in Akos 009
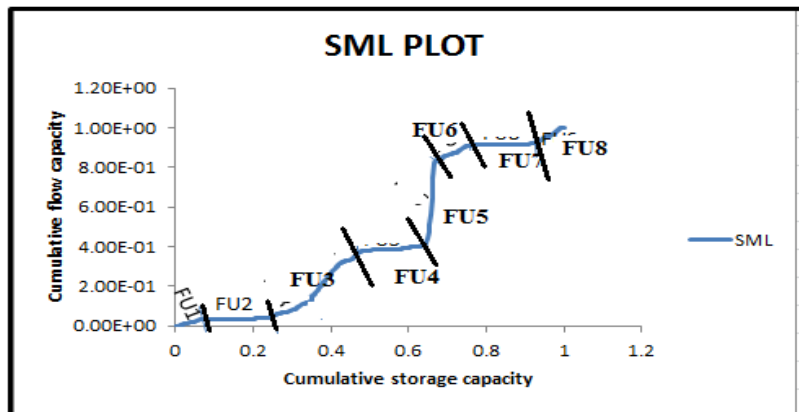

Fig. 6h. Graph of SML plot showing the flow unit in Akos 012

Table 2. Reservoir B flow units characterization

Akos wells	No. of flow unit	Flow unit characterization		
		Speed zones	**Baffles**	**Barriers**
Akos 001	8	3, 5, 7, 8	1, 6	2, 4
Akos 002	8	3, 5, 7, 8	2	1, 4, 6
Akos 003	8	2, 3, 5, 6, 8	1, 4, 7	-
Akos 004	7	2, 4, 7	5	1,3,6
Akos 007	7	2, 5, 7	1, 3, 6	4
Akos 008	6	3, 5, 6	2, 4	1
Akos 009	7	3, 5, 7	2, 6	1, 4
Akos 012	8	1, 3, 5, 8	4, 6	2, 7

The speed zone units have approximately equal flow and storage capacities. This unit occurs in all the wells in the two reservoirs A and B. This is an indication that the sediments deposited in the environments have good reservoir qualities. The speed zones are indicative of permeable high performance flow units [35].

The baffle (zones that control formation fluid movement) units have low flow and high storage capacities. The baffle zone indicate reservoir interval with very low porosities and permeabilities. This may have been caused by the presence of shale that occurred as intercalations in the reservoirs and also the lower parts of the reservoirs stratigraphically fall within the lower shoreface dominated by silty/mud or shaly facies. The slope of the baffle zone on the SMLP is very low (Almost horizontal).

The barriers are zones or segments that are neither flow nor storage portion of the reservoir. The barrier (seal to flow) units may be due to the presence of sealing faults which hinder the flow of fluid. A total of one hundred and twelve (112) flow units have been identified from the SMLP for the two reservoirs. The major controlling factors accounting for the hydraulic delimitation of each sand body are the facies characteristics and petrophysical parameters evolving from the relationship in the rock fabrics.

A total of 53 flow units is observed in the wells in reservoir A. The speed, baffle and barrier zones are 25, 18 and 10 respectively. The result also revealed a total of 59 flow units in the wells in reservoir B out of which 29, 16 and 14 are speed zones, baffle zones and barrier zones respectively. The number of barrier zones in reservoir B is more than that in A. This may be attributed to compaction of the sediments and diagenesis with depth.

5. CONCLUSION

The reservoir in the Akos field has been characterized by flow unit techniques using the Stratigraphic Modified Lorenz plot (SMLP). The method is simple and very fast. The flow zones obtained for the two reservoirs (A and B) delineated from the composites logs have been classified into speed, baffle and barrier zones. The flow zone was determined from computed porosity, permeability and zone interval thickness. A total of 53 and 59 flow units were identified from the Stratigraphic Modified Lorenz plots for reservoirs A and B respectively. The outcome of this researched will aid in the development of the reservoirs by the engineers.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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