Reservoir Characterization: Implications From Petrophysical Data of the "Paradise-Field", Niger Delta, Nigeria

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ABSTRACT

The wells of the "Paradise-Field" penetrated the Coastal Swamp II and the shallow western offshore of the Niger Delta. Sandstone reservoirs from five wells were investigated for their petrophysical characteristics and reservoir quality.

The geometric properties (porosity and permeability) from petrophysical analysis and the thickness of the reservoirs reveal a slight lateral variation in the strike section and a remarkably good sand development as the delta prograded distally (basinward) on the dip section. Hydrocarbon saturation in the wells appreciated distantly on the dip section (40-90%), with a proportionate reduction in water saturation at the intervals of interests. Also, the volume of shale (V_{shale}) on the dip section is within the limits that could not affect the value of water saturation (i.e., between 0.037 v/v decimal to 0.13 v/v decimal), and well above the limits (>10-15%) on the strike section.

Generally, the porosity/permeability values of the sandstone reservoirs in the "Paradise-Field" are good enough to accommodate large hydrocarbon yield, but these characteristics tend to improve significantly as sedimentation proceeds basinwards. This makes for good sand development in wells P-004 and P-005 in the study area. Other factors that could reduce the free flow of fluid in the reservoirs are the effects of clays on logging measurement, grain size, sphericity, and sorting due to the energy of the environment of deposition.

(Keywords: petroleum exploration, geology, petrophysical analysis, hydrocarbons)

INTRODUCTION

The prolific demand for hydrocarbon products since the 20th century prompted intensified exploration for oil and gas accumulation in reservoir rocks. This led to an extensive study of the Niger Delta depocenters after a long while of non-productive search in the Cretaceous sediments of the Benue Trough (Doust, 1989 and Doust and Omatsola, 1990).

Petroleum in the Niger Delta is produced from sandstones and unconsolidated sands predominantly in the Agbada Formation. Recognized known reservoir rocks are of Eocene to Pliocene in age, and are often stacked, ranging in thickness from less than 15 meters to 10% having greater than 45 meters thickness. (Evamy et al. 1978). Based on reservoir geometry and quality, the lateral variation in reservoirs thickness is strongly controlled by growth faults; with the reservoirs thickening towards the fault within the down-thrown block (Weber and Daukoru, 1975).

The objectives of the present work are to make detailed use of available wireline log data to delineate the reservoir units in the wells in the field, determine the geometric properties (porosity and permeability) of the reservoir rocks using petrophysical calculation (Wyllie and Rose, 1950), and infer reservoir geometry distribution and reservoir quality trends using the reservoir correlation. Detailed study of the petrophysical results of the "Paradise field" Niger Delta (Figures 1 and 2) will provide an understanding of the geometric properties of the reservoirs, lateral variation in thickness and possible hydrocarbon accumulations.

METHODOLOGY

- Delineation of reservoir units using gamma ray log (Schlumberger, 1972)
- Determination of porosity/permeability of the reservoir sands from the wireline logs using petrophysical calculations (Archie, 1942; Asquith and Krygowski, 2004)

- Interpretation of the results (Asquith & Krygowski, 2004)

Stratigraphic Setting

The study area (Figures 1 and 2) is located within the transition between the Coastal Swamp II and the western Offshore Niger Delta. The Tertiary Niger Delta covers an area of about 75,000 $sqkm^2$ and is composed of an overall regressive clastic sequence which reaches a maximum thickness of 30,000 to 40,000ft (9,000 to 12,000m) (Evamy et al. 1978).

Sedimentation in the basin started in the late Paleocene/Eocene, when sediments began to build out beyond the troughs between the basement horst blocks at the northern flank of the present delta area.

The structural configuration and the stratigraphy of the Niger Delta have been controlled by the interplay between rates of sediment supply and subsidence (Evamy et al. 1978; Doust and Omatsola, 1990). Eustatic sea level changes and climatic variations influence the sedimentation rates while the flexure (tectonics) of the basement and differential loading and settlement on unstable shale may have controlled the subsidence. The growth of the Tertiary Niger Delta is schematically shown by a series of maps with the principal depocenters for selected microfloral units between the Paleocene and the Pliocene (Figure 3).

Hydrocarbons are concentrated along the updip or proximal edge of the successive depocenters. The Niger Delta can be subdivided lithlogically into an upper series of massive sands and gravels (Benin Formation), deposited under continental conditions (Evamy et al., 1978).This grades downward through a transitional series composed mainly of sand but with some shale, into an alternation of sandstone and shale (Agbada Formation), deposited under paralic conditions. Also, in the section below, marine shale predominates and the associated sandstone units are very likely to be turbidites (Figure 4).

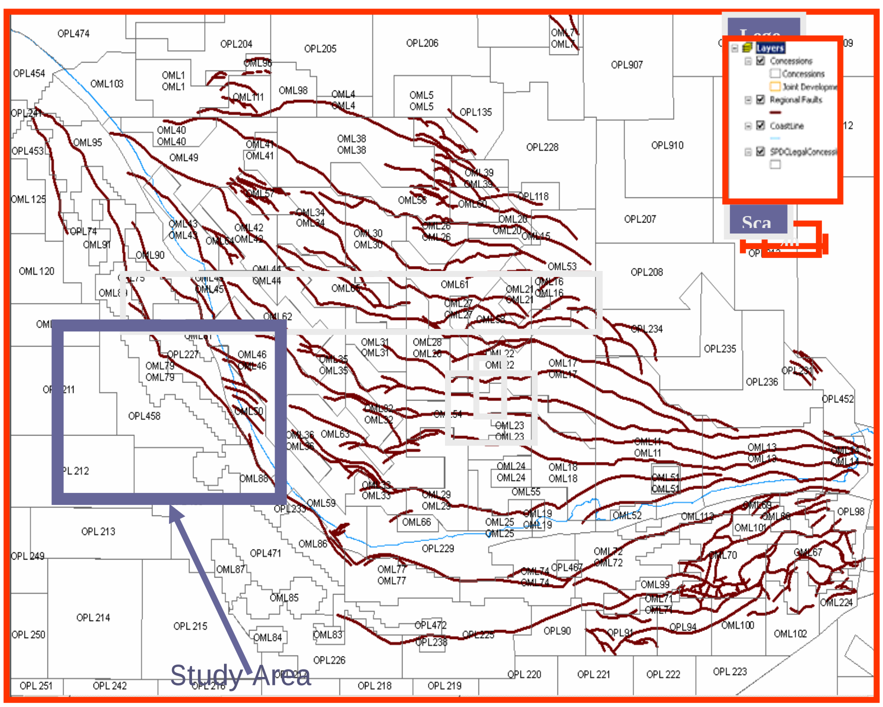

Figure 1: Simple Concession Map of Niger Delta Showing Structural Building Faults, Exploration Bocks, and Study Area.

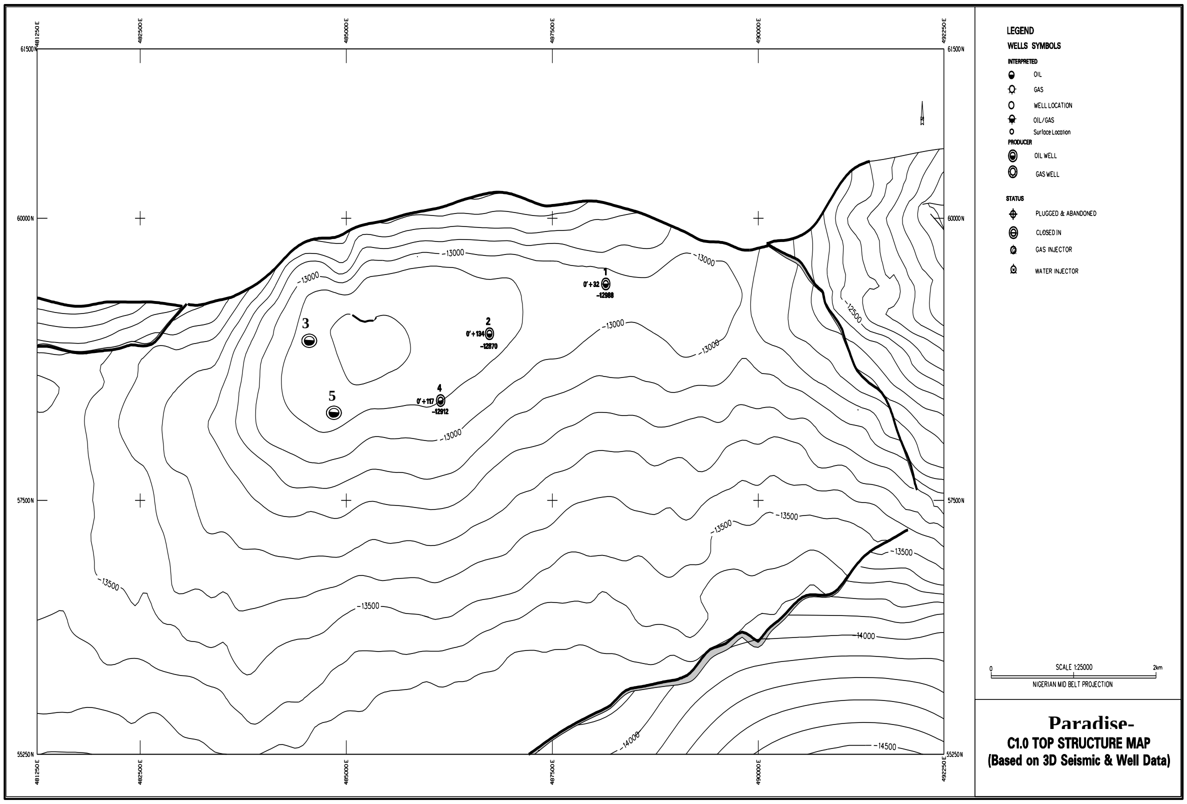

Figure 2: Location and Top Structural Map of the Paradise Field, Niger-Delta.

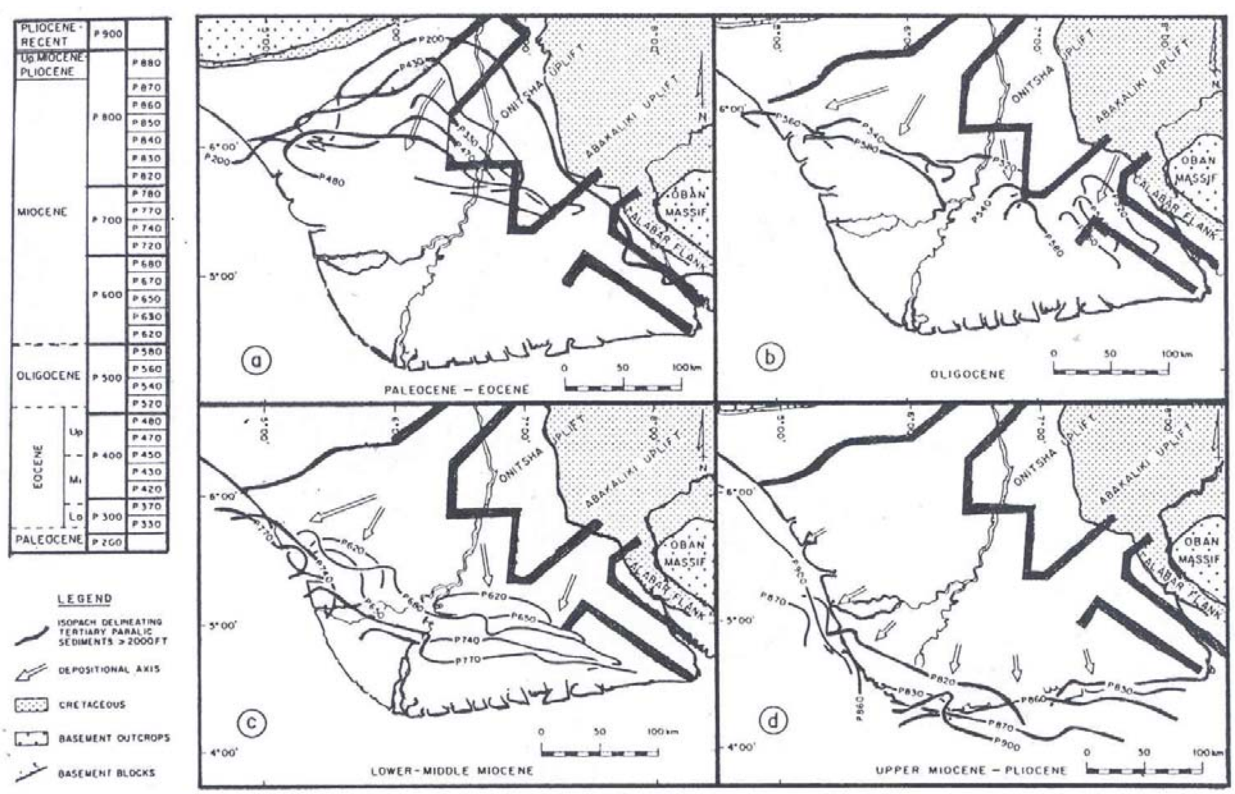

Figure 3: Stratigraphic Evolution of Tertiary Niger Delta (Evamy et al., 1978).

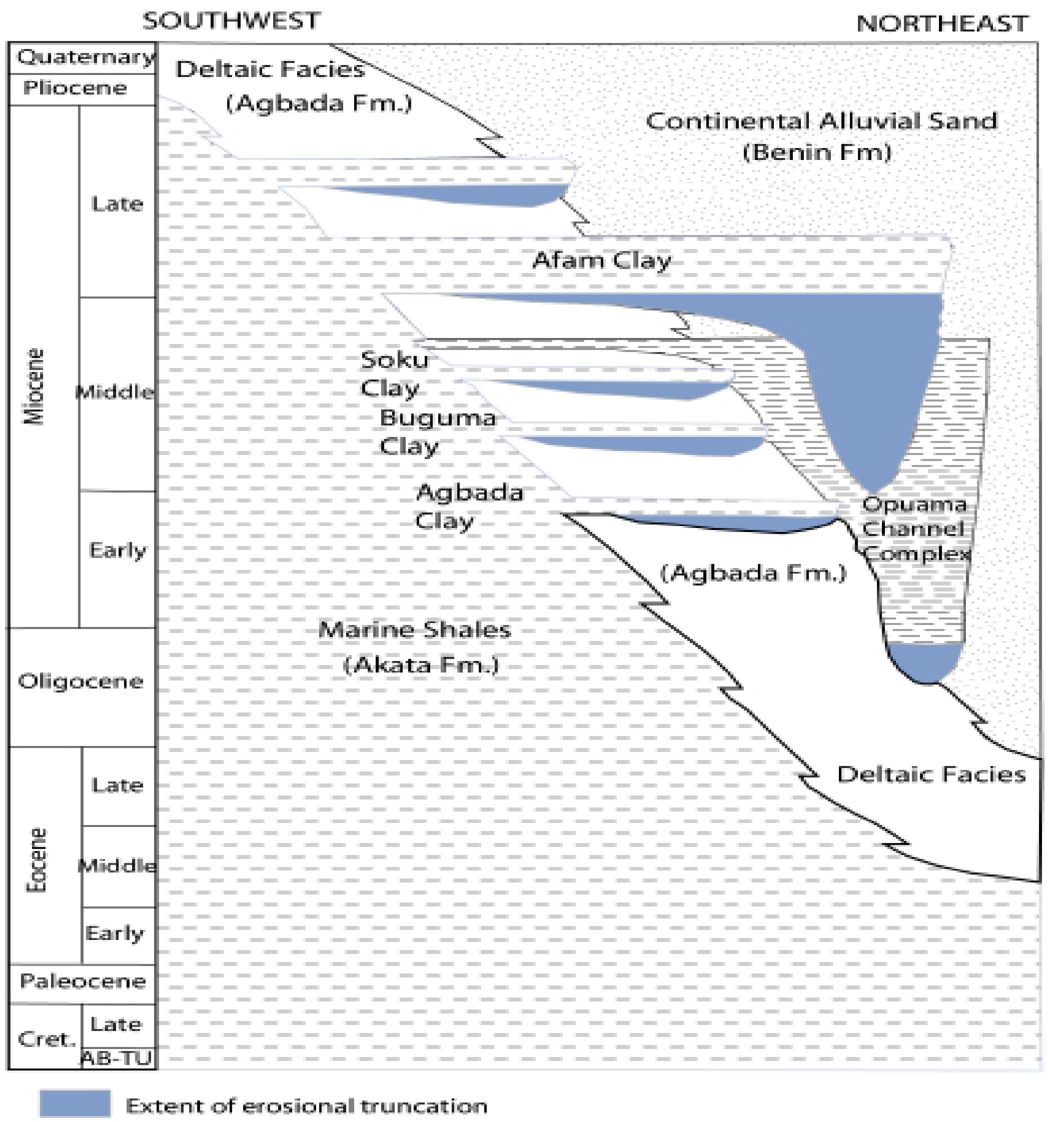

Figure 4: Stratigraphic Column Showing the three Formations of the Niger Delta. After Shannon and Naylor (1989), and Doust and Omatsola (1990).

Paleocene – Eocene (P 200) – During the Paleocene and earliest Eocene times, marine shales were deposited over much of the southern Nigerian sedimentary basin. The delta of the Niger River first became apparent during the time designated as P330 to P430. The Niger Delta continued to grow in the Eocene, initially in response to the positive eperogenic movements along the Benin and Calabar flanks (Murat, 1972).

Near the end of the late Eocene (P480), a major regression commenced which accelerated the expansion of the Niger Delta. The regressive phase has continued until the present, and frequently interrupted by minor transgressions.

Oligocene and earliest Miocene (P520 –P630) – At this period, the successive depocenters in the west considerably overlapped, reflecting in a pronounced subsidence and a relatively slow advance of the delta front towards the west and southwest.

The overlapping depocenters resulted in a thick development of paralic sediments in the western part of the delta. The eastern depocenters are clearly separated from those of the west by a period of erosion or non-deposition (P580 – P630).

Miocene to Present (P650 – P900) – In the early Miocene, the separated depocenters gradually merged, and the enlarged delta began to prograde along a wide front (P680). More rapid subsidence, and corresponding slower rate of advance of the delta front, continued to characterize the western part of the delta. Depocenters continued to develop during the late Miocene and Pliocene (P830 to P900). A large depocenter of the Miocene (P860) is present in the eastern offshore, while the youngest depocenter is in the western offshore (P900) (Evamy et al., 1978). The study area falls within the transition between the Coastal Swamp II and the Offshore, and the age is upper Miocene.

Petrophysical Evaluation of the Reservoirs

Three major reservoirs (A-C) each were delineated for Wells P-1, P-2 and P-4, while four reservoirs (A-D) each ere also delineated for Wells P-3 and P-5, using the gamma ray log.

Well P-1

The average shale volume content (V_{shale}) of the reservoirs in Well P-1 is between 0.038 to 0.39v/v decimal. This suggest that reservoir A with V_{sh} value of 0.39v/v decimal is above the limit of 15% that can effect the water saturation value (Hilchie,1978).The average neutron-density derived porosity for the reservoirs are between 18.5 to 23%, which indicates moderate porosity. The average total resistivity (3.95-11.19Ωm) and water saturation (61-68%) for the reservoirs suggest that the reservoirs are mainly water bearing, with only reservoir C showing little indication of hydrocarbon bearing. On the other hand, the negative crossing of the density log and neutron log signature at reservoir C (13000-13020ft) with high resistivity value at that zone suggests that it could be a gas zone.

Well P-2

The resistivity log of Well P-2 was not completely run. This limits the calibration and calculation of other parameters that will aid in the computation of the permeability of the reservoirs. Nevertheless, their porosities range from 18.3 - 30.5%. The thickness of the reservoirs also ranges from 12ft in reservoir "A" to 237ft in reservoir "B". Their volume of shale (V_{shale}) is fair enough to allow for free flow of fluid if the permeability is good (Table 1).

Well P-3

The reservoirs in this well have average thicknesses from 31ft in reservoir A to 2264ft in reservoir C. The average shale volume content (V_{sh}) of the reservoirs is between 0037v/v decimal in reservoir C to 0.13v/v decimal in reservoir A.

These V_{sh} values are within the limits that could not affect the value of water saturation (Hilchie, 1978) and suggests that the reservoirs are relatively clean. This is reflected in the good average permeability values that range from 85md in reservoir B to 5422.1md in reservoir A. The average porosities of the reservoirs are good (23.5-26%) and the total resisitivity (R_t) are high enough (7.93-295Ωm) to indicate the presence of hydrocarbon (Halliburton,1994). Top of reservoir C recorded the highest R_t values (12840-12950ft). Within this interval, and that reservoir D, the total resisitivity is greater than the water bearing resisitivity (R_o) and the apparent resistivity (R_{wa}) is greater than the formation water resistivity (R_w).These are indications that the zones are hydrocarbon bearing. Also, the negative separation of neutron and density log signatures in reservoir D indicates that it could be gas. Reservoirs A, C and D have high average hydrocarbon saturation (H_s) (Table 1).

Well P-4

This well is located on the structural dip, southern part of the roll-over anticline in the study area (Figure 5). The reservoirs are also well developed with thickness ranging from 34ft in reservoir A to 224ft in reservoir C. They have good average porosity values of a typical Niger Delta reservoirs ranging from 23% in reservoir C to 26.2% in reservoir A. The two reservoirs (A&C) show evidence of hydrocarbon saturation as the average total resisitivity values are greater than the water bearing resistivity (R_o) values (Hingles, 1959; Table 1). The low water saturation in reservoirs A & C (20% and 30% respectively) indicates 80% and 70% hydrocarbon saturation respectively.

Well P-5

The good sand development of the down dip sedimentation continued in this Well with reservoir thickness ranging from 30ft in reservoir A to 296ft in reservoir D. Also clean san development in reservoir D is indicated in its low value of volume of shale content (V_{sh}) within 12870-13030ft depth interval with an average value of 0.078v/v decimal. \the porosity/permeability values (18.5%/354.87md) are good enough to permit free flow of fluid. The average total resisitivity value for reservoirs A, C and D (58.75Ωm, 72.53Ωm and 76.33Ωm respectively) is a quick look indication that the interval contain hydrocarbon Table 1 and Figure 6).

Table 1: Average Petrophysical Values for the Wells in the Paradise Field

Well P-1

Reservoir	Thickness (ft)	V_{shale}	Porosity (%)	$R_{t(\Omega m)}$	$R_{o(\Omega m)}$	$R_{w(\Omega m)}$	S_w	$H_s(\%)$	K(md)	$R_{wa(\Omega m)}$
A	13	0.39	23	7	2.23	0.07	0.61	39	18.76	0.4
B	209	0.132	22.5	3.95	1.96	0.066	0.68	32	5.47	0.187
C	259	0.038	18.5	11.19	2.9	0.07	0.648	35.2	172.31	0.54

Well P-2

Reservior	Thickness (ft)	V_{shale}	Porosity (%)	$R_{t(\Omega m)}$	$R_{o(\Omega m)}$	$R_{w(\Omega m)}$	S_w	$H_s(\%)$	K(md)	$R_{wa(\Omega m)}$
A	12	0.15	30.5							
B	237	0.067	18.3							
C	198	0.073	18.5							

Well P-3

Reservior	Thickness (ft)	V_{shale}	Porosity (%)	$R_{t(\Omega m)}$	$R_{o(\Omega m)}$	$R_{w(\Omega m)}$	S_w	$H_s(\%)$	K(md)	$R_{wa(\Omega m)}$
A	31	0.13	24	295	2.93	0.16	0.20	80	5422.1	22.61
B	122	0.051	25	7.93	2.74	0.158	0.78	22	85	2.35
C	264	0.037	23.5	113.79	3.22	0.153	0.39	61	556.16	6.25
D	30	0.093	26	255	2.15	0.15	0.12	88	2253.73	20.97

Well P-4

Reservior	Thickness (ft)	V_{shale}	Porosity (%)	$R_{t(\Omega m)}$	$R_{o(\Omega m)}$	$R_{w(\Omega m)}$	S_w	$H_s(\%)$	K(md)	$R_{wa(\Omega m)}$
A	34	0.138	26..2	46.2	1.77	0.105	0.20	80	427.2	3.57
B	170	0.094	23.1	4.69	3.69	0.105	0.70	30	52.79	0.22
C	224	0.057	23.0	33.98	2.21	0.11	0.30	70	174.88	2.22

Well P-5

Reservior	Thickness (ft)	V_{shale}	Porosity (%)	$R_{t(\Omega m)}$	$R_{o(\Omega m)}$	$R_{w(\Omega m)}$	S_w	$H_s(\%)$	K(md)	$R_{wa(\Omega m)}$
A	30	0.102 5	22.0	58.75	1.90	0.09	0.20	80	254.80	2.92
B	69	0.101	21.2	4	2.01	0.09	0.72	28	17.13	0.19
C	381	0.086	23.5	72.53	2.24	0.145	0.50	50	2687.5	3.78
D	296	0.078	18.5	76.33	2.30	0.09	0.38	62	354.87	3.68

Although, the reservoirs have better to excellent porosity and permeability values, hydrocarbon accumulation could be traced only in reservoirs "A", "C", and "D". The resistivity values (R_t) are well greater than R_o values (1.90Ωm, 2.24Ωm &2.30Ωm). Their water saturation (S_w) are low (20%, 50% 738%), which invariably are indications that the hydrocarbon saturations are high (S_h = 80%, 50% & 62%). The hydrocarbons in reservoirs "A" and "D" could be oil with the tracking together of the density and neutron log signatures while the reservoir "D" could be gas with the negative crossing of the neutron and density logs. On the other hand, the high water saturation (S_w) values of reservoirs "B" and lower part of "C" (13040 – 13160ft) are evident that they are water filled (S_w = 72 - 78%).

DISCUSSIONS AND CONCLUSIONS

The quality of the reservoirs in the "Paradise-field" Niger Delta is moderate to good and in some distal reservoirs, they are excellent. The average porosity values are approximately the same, but have variations in permeability which could be as a result of compaction of the older reservoirs on the proximal part of the field (Wells P-1&P-2). The escalator regression sedimentation model of the Niger Delta makes it clear that younger sediments are found in the distal part of the basin with pronounced thickness greater than that on the proximal part. Compaction initiates early in the older rocks of proximal facies and grades down basinward.

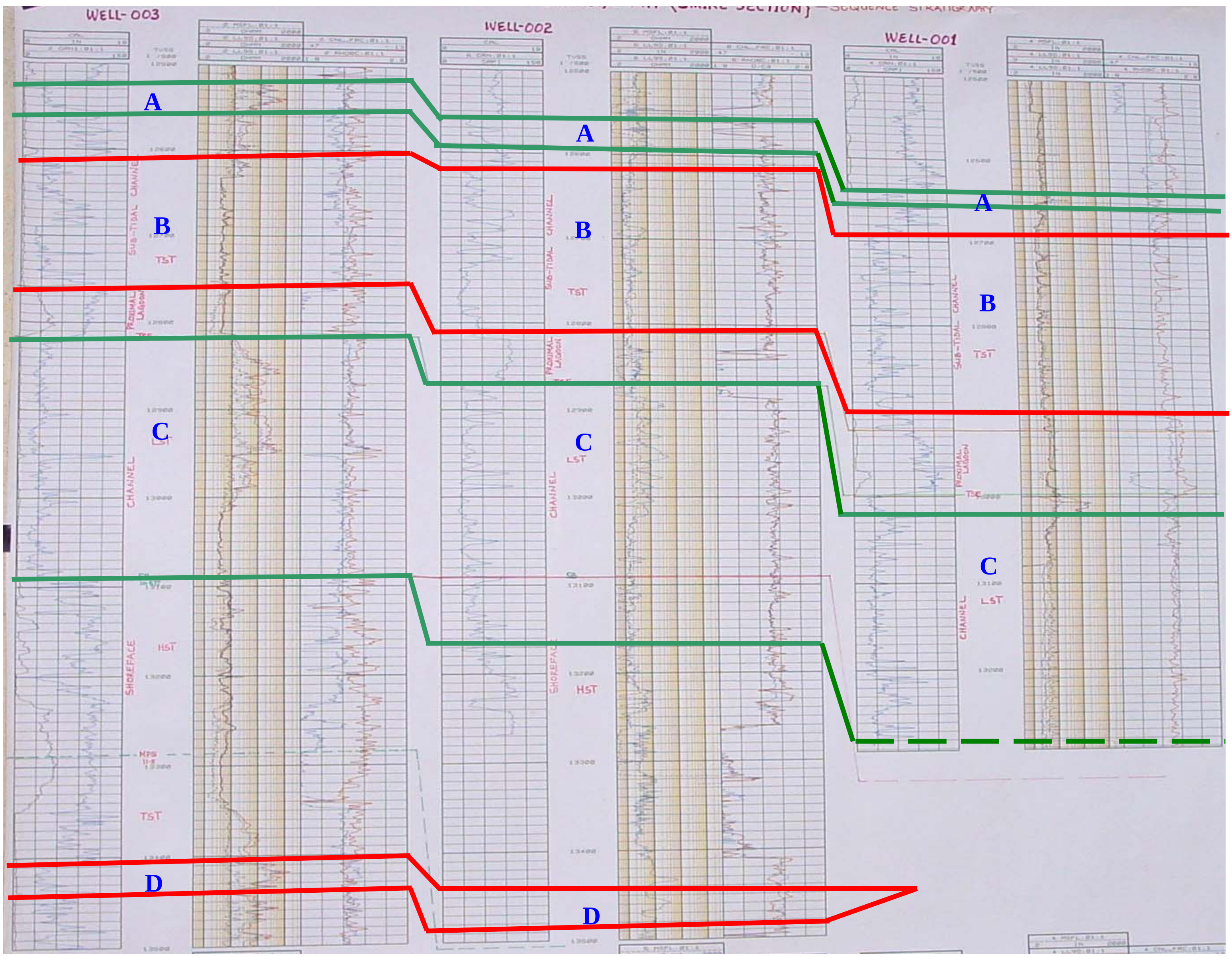

Figure 5: Paradise Field Reservoir Correlation on the Strike Section.

So, the geometric properties (porosity and permeability) are bound to vary relatively from Well P-1 to Well P-5. On the strike section (Figure 5), the reservoir thickness varies laterally with approximately the same sand development (Wells P-1, P-2 & P-3). On the other hand, the dip section (fig.6) shows remarkable reservoir thickness as the delta progrades distally (basinward), giving rise to good sand development towards the basin.

This suggests that with good structural and stratigraphic traps basinward, the offshore depobelt holds better prospect for the Paradise-field (Niger Delta). It is pertinent to note that the sand development in Agbada and Benin Formations of the Niger Delta has limits in the deep-water portion where they thin and disappear. The reservoirs for the discovered hydrocarbons are sandstones within the Agbada Formation, while the reservoirs for undiscovered petroleum below currently producing intervals in the distal portions of the delta system may include turbidite sands within the Akata.

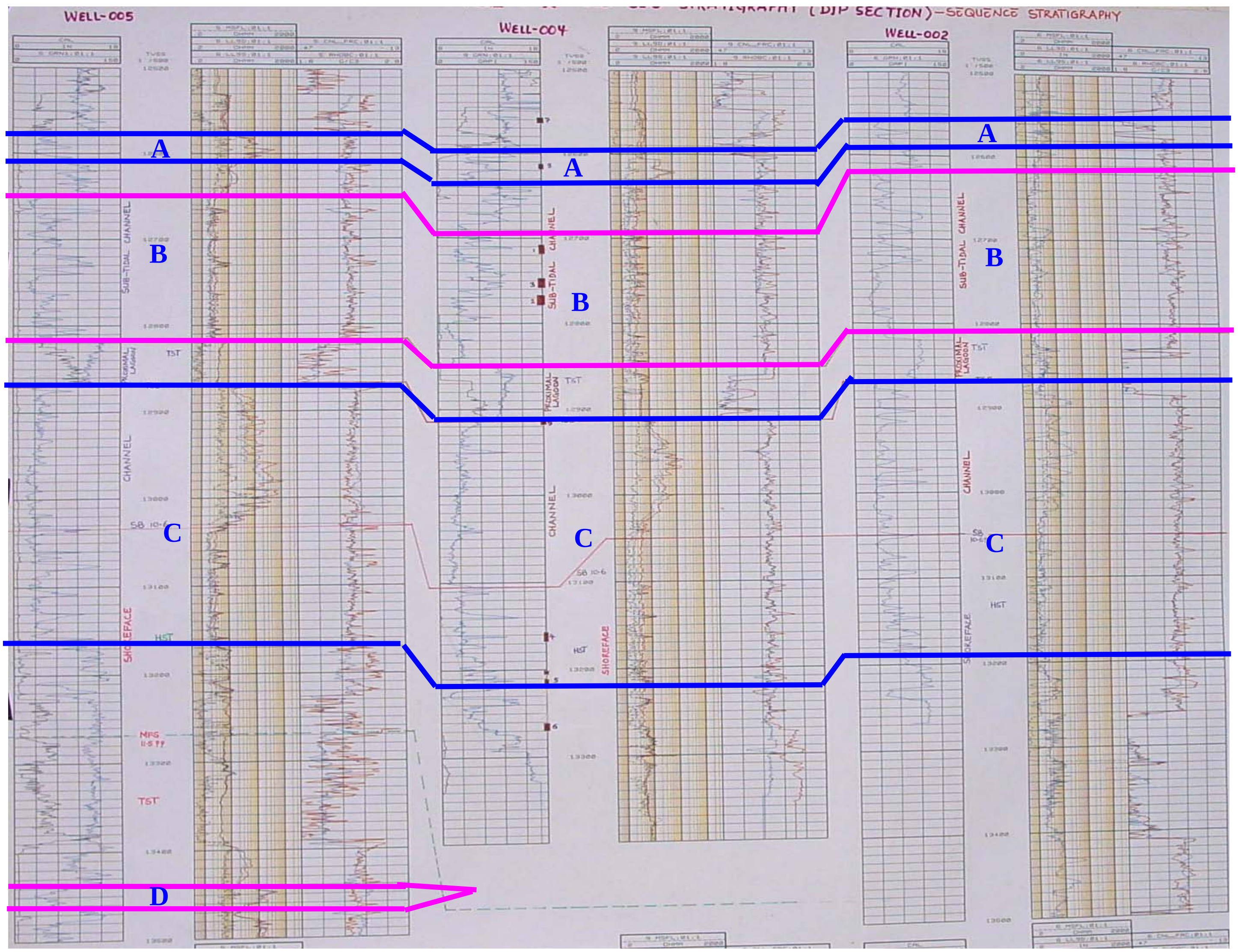

Figure 6: Paradise Field Reservoir Correlation on the Dip Section.

Generation of hydrocarbon occurred in the study area from the north (Well P-1) to the south (Well P-5) as progressively younger sediments entered the oil window. This is evident from the amount of inferred hydrocarbon accumulation in the reservoirs which increases from the north to the south.

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