

Formation evaluation of X7 field in the Niger Delta: evidence from Petrophysical data. Niger Delta, Nigeria.

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Abstract: The reservoirs from three wells of greater ughelli depobelts were evaluated in this study in order to assess the qualities of the reservoirs: The geometric properties, water saturation, and volume of shale were computed and these revealed that the reservoirs are of good qualities. In addition, the depositional environments were characterized using gamma ray log.

Generally, the petrophysical characteristics of the reservoirs are good especially at the areas of interest (hydrocarbon zones). The average total porosity and effective porosity ranges from 0.13%-0.34% and 0.12%-0.31% respectively which is within the range for commercial accommodation of hydrocarbon. The volume of shale values for some of the reservoirs are within the limits that could not affect the water saturation (0.05v/v decimal- 0.21v/v decimal). The water saturation in some zones is appreciably low (0.14%- 0.47%) This makes for high hydrocarbon accumulation in those zones. The neutron -log and density- log responses in well 04 and 06 presume that the hydrocarbon in most zones is gas due to the 'crossover' of the logs.

The gamma ray log shapes of the reservoirs are predominately cylinder (serrated) shape in the three wells which indicates that the depositional environment was deltaic.

Keywords: Depositional Environment, Facies, Hydrocarbon, Niger delta, Petrophysical evaluation.

I. Introduction

The Niger delta is perhaps the most important sedimentary basin in sub-Sahara Africa with respect to petroleum production. There has been an extensive study in Niger Delta Depocenters after a long while of non-productive search in the Cretaceous sediments of Benue Trough (Doust, 1989; Doust and Omastola, 1990). The three major depositional cycles in the coastal sedimentary basins of Nigeria were outlined by Short and Stauble, (1967) and Weber and Daukoru, (1975). The megatectonic setting of the Niger Delta has been discussed by Stoneley, (1966), Burke et.al, (1972). Short and Stauble, (1967) and Weber, et. al (1975), reported that the first sedimentary cycle began with an Albian marine incursion and terminated during the Santonian time while the Proto-Niger delta commenced during the second cycle in the late Cretaceous which ended in the Paleocene time. The third cycle marked the continuous growth of the Niger Delta from Eocene to Recent (Murat, 1972). Sedimentation was at several stages interrupted by uplift and erosion, which gave rise to the cutting and filling of channels known as submarine canyons. The importance of long shore drift and submarine canyons and fans in the development of the Niger delta also has been emphasized by Burke, (1972). The basement configuration, deduced from geophysical data was presented by Hospers, (1965) and the synsedimentary tectonics of the Cenozoic delta was described by Merki, (1972).

The objective of this work is to delineate the reservoir units in the three wells using available composite wireline log, determination of the geometric properties (porosity and permeability) of the reservoir rocks using petrophysical calculation (Wyllie and Rose, 1950), and characterization of depositional environment using the gamma ray log shapes.

II. Methodology

Data sources: Wire-line-log data from three wells of X7 field were used for this study. The wireline log comprises of Gamma ray, Neutron logs, Sonic log, density log, self potential (SP) log, resistivity log (LLD and MSFL) and calipers logs.

Delineation and interpretation of reservoir zones of 'X7' field using available wire-line log.

Prediction of permeability was done using empirical correlation, Wyllie and Rose equation.

$$K = \frac{\sqrt{250x\Phi^3}}{S_{wirr}} \quad (1)$$

Accurate derivation of water saturation (Sw) was done using Archie' equation (1942).

$$Sw = \frac{(aRw)^{1/n}}{\Phi^m R_t} \quad (2)$$

Sw: is the water saturation

Rw: is the formation water resistivity (derived by Picket plot).

Rt: is the uninvaded zone resistivity determined from the deep resistivity log

Φ: is the formation porosity determined from the density log.

m = 1.6 (derived from average value of core interpretation result) cementation factor a: = 1 (Tortuosity factor).

Computation of shale volume from the gamma ray using a linear gamma ray index method as the first step. The volume of shale was then calculated using the Larionov(1969) non linear response method

$$I_{GR} = \frac{GR_{log} - GR_{min}}{GR_{max} - GR_{min}} \quad (3)$$

$$V_{sh} = 0.083(2^{3.71 I_{GR}} - 1) \text{ (For tertiary unconsolidated rocks)} \quad (4)$$

Computations of total porosity and shale corrected ('effective') porosity from deensity log.

Core interpretation data were available for well -05, and it was used to validate the

$$\Phi_D = \frac{\rho_{ma} - \rho_b}{\rho_{ma} - \rho_{fl}} \quad (5)$$

Where:

ΦD = density porosity

ρma = matrix density (sandstone) 2.65g/cm³

ρb = bulk density (log reading) and

ρfl = fluid density = 1.0g/cm (for water), 0.7 for gas, and 0.9 for oil.

III. Results and Discussion

3.1 WELL -04

The qualitative and quantitative log interpretations give the information that support that the well would be a commercial success. In this well, 21 reservoirs were delineated with different thicknesses. They are named A- U. Table 1 summarizes the average reservoir properties of this well. A cut off value of 75 API was determined using the gamma ray log and values below it were shown to be reservoir while those above it were shale. The total density porosity was calculated using 2.65g/cm³ grain density. In this well, the caliper log shows reduction of hole diameter form 3680m-3720m depth. This is an indication of invasion. There are so many gas bearing zones in this well. This was identified by negative crossing over of Density and Neutron logs at the following intervals: 3105- 3125, 3150-3180, 3181- 3240, 3330-3375, 3460- 3470, 3686-3700, 3713-3720, 3777- 3795, 3815- 3838, 3831-3835, 3810- 3930 and 4090-4120 depths. The average volume of shale values in this well are fair enough to allow for free flow of fluid. The average Vsh values are within the limits (15%) that could not affect the value of water saturation. It suggests that the reservoirs are clean. (Hilchie,1978). The average Vsh values ranges from 0.02 to 0.11v/v decimal. The average water saturation value of well -04 ranges from 0.22% in reservoir N to 0.79% in reservoir S. Lower average water saturations and higher porosity rocks are observed in the log calculations (Table1). The true resistivity value ranges from 2.40 in reservoir C - 446.78Ωm in reservoir H. Generally, reservoirs with lower average true resistivity values have higher water saturation and verse visa. Reservoir H (3345-3373mdepth) recorded the highest Rt value. And within this interval, the Rt is greater than Ro and apparent resistivity (Rwa) is greater than the formation water resistivity (Rw). These are evidences that the reservoir is hydrocarbon bearing. Also the negative crossing of neutron and Density log signature in this reservoir indicates that it could be gas. Reservoirs A, E, F, H, I and K have high average hydrocarbon saturation (Hs). Furthermore, reservoirs A and B have the lowest values of Rt values and water saturation value of 0.70 and 0.71v/v decimal respectively. Even though, they have good permeability and porosity values and are relatively clean, but they could be water bearing. The average log determined total porosity for well -04 ranges from 0.21% to 0.34% which indicates good porosity. The permeability of the reservoirs ranges from 5.16md-157.39md. The permeability ranges from good to average which are enough to accumulate hydrocarbon.

Table 1: WELL- 04: Petrophysical properties of well -04 reservoirs.

Reservoirs	Thickness (m)	Depth Interval(M)	Sw(%)	H _s (%)	Rt(Ωm)	V _{shale} (v/v)	Gamma ray log value	BVW	Porosity(%)	K(md)	Eff Φ(%)	R0(Ωm)
A	10	2886-2896	0.07	99.93	251.28	0.02	31.55	0.02	0.29	24.16	0.28	1.61
B	12	2935-2947	0.70	0.30	2.44	0.07	47.68	0.19	0.25	144.05	0.25	10.55
C	8	2951-2965	0.71	29	2.40	0.07	45.78	0.19	0.27	157.39	0.25	1.19
D	19	3003-3022	0.43	57	17.49	0.08	49.34	0.08	0.22	7.30	0.20	2.92
E	20	3105-3125	0.18	82	283.73	0.06	38.49	0.03	0.30	24.26	0.29	1.77
F	27	3150-3177	0.19	81	103.28	0.06	41.93	0.04	0.30	39.19	0.29	1.28
G	55	3182-3237	0.64	36	12.29	0.05	41.43	0.16	0.25	10.96	0.24	1.47
H	28	3345-3373	0.05	99.95	446.78	0.09	51.69	0.02	0.34	60.98	0.31	0.77
I	6	3460-3466	0.14	86	49.18	0.11	58.56	0.04	0.33	46.51	0.30	0.80
J	13	3686-3699	0.25	75	43.18	0.05	41.14	0.05	0.23	8.40	0.22	1.83
K	7	3713-3720	0.19	81	58.75	0.09	54.50	0.05	0.27	18.51	0.25	1.41
L	13	3777-3790	0.22	78	63.63	0.05	40.75	0.05	0.26	14.95	0.25	1.52
M	13	3813-3826	0.33	67	170.44	0.06	41.93	0.03	0.28	19.70	0.26	12.91
N	5	3910-3915	0.22	78	40.09	0.07	46.58	0.05	0.26	14.10	0.24	1.43
O	10	3919-3929	0.60	40	16.90	0.06	45.28	0.10	0.20	5.39	0.19	2.65
P	25	3940-3965	0.74	26	3.69	0.08	50.35	0.16	0.23	65.33	0.21	3.33
Q	12	3971-3983	0.71	29	3.72	0.10	55.52	0.16	0.23	78.32	0.21	2.12
R	17	4090-4107	0.28	72	40.12	0.05	39.65	0.05	0.21	5.16	0.20	2.42
S	15	4140-4155	0.79	21	3.28	0.06	42.59	0.17	0.22	53.91	0.21	2.12
T	8	4161-4169	0.76	24	2.78	0.05	42.36	0.18	0.24	64.42	0.23	1.54
U	30	4191-4221	0.79	21	3.04	0.05	39.47	0.17	0.22	54.59	0.21	1.97

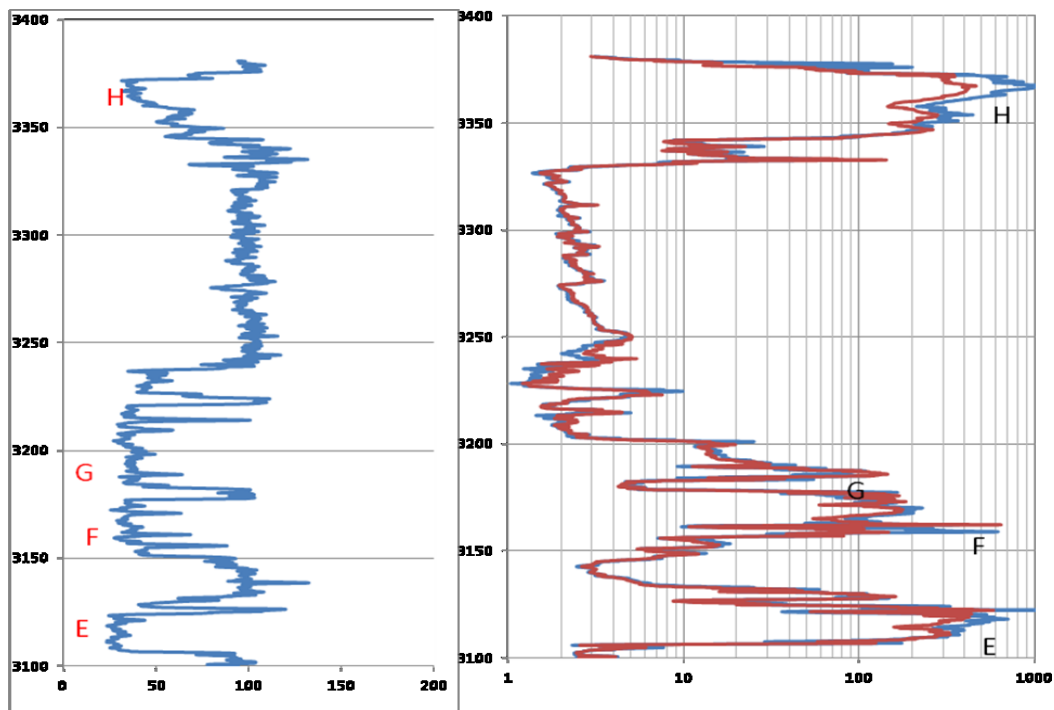
Table 2: Petrophysical properties of well -05 reservoirs

Reservoirs	Thickness(m)	Depth Interval(M)	Sw(%)	H _s (%)	Rt(Ωm)	V _{shale} (v/v)	Gamma ray log value	BVW	Porosity(%)	K(md)	Eff Φ(%)	R0(Ωm)
A	20	3160-3180	0.25	75	40.89	0.06	42.78	0.05	0.22	56.87	0.21	0.19
B	19	3261-3280	0.88	22	2.40	0.10	56.52	0.19	0.22	43.89	0.18	0.19
C	19	3331-3350	0.81	29	2.85	0.12	68.54	0.18	0.23	140.52	0.18	0.18
D	40	3370-3410	0.88	22	2.88	0.05	40.88	0.18	0.20	28.90	0.19	0.19
E	25	3425-3450	0.79	21	2.80	0.18	70.02	0.18	0.23	67.35	0.19	0.18
F	5	3500-3505	0.91	19	2.20	0.05	39.43	0.20	0.22	47.44	0.21	0.18
G	15	3533-3548	0.88	22	2.30	0.13	65.48	0.20	0.23	49.85	0.20	0.18
H	20	3580-3600	0.89	21	3.26	0.07	48.49	0.17	0.19	23.02	0.18	0.20
I	39	3642-	0.87	23	2.76	0.07	49.40	0.18	0.21	33.08	0.20	0.19

		3681										
J	10	3810-3820	0.36	64	44.95	0.14	62.02	0.06	0.18	20.61	0.16	0.21
K	24	3850-3874	0.30	70	49.07	0.08	51.56	0.05	0.17	11.66	0.16	0.21
L	67	3875-3942	0.82	18	8.88	0.06	46.06	0.11	0.14	3.57	0.13	0.23
M	40	4000-4040	0.40	60	97.69	0.07	45.13	0.07	0.19	20.35	0.18	0.20
N	45	4179-4240	0.53	57	34.77	0.07	45.62	0.07	0.15	4.24	0.14	0.23
O	35	4285-4320	0.52	48	32.23	0.07	45.65	0.07	0.13	2.60	0.12	0.24

Table 3: Petrophysical properties of well-06

Reservoirs	Thickness(m)	Depth Intervals(M)	Sw(%)	H _s (%)	Rt(Ω m)	V _{shale} (v/v)	Gamma ray log value	BVW	Porosity(%)	K(md)	Eff Φ(%)	
A	3	2480-2483	0.12	0.88	84.84	0.06	55.6	0.04	0.32	1217.4	0.30	1.15
B	17	2488-2505	0.90	0.10	1.96	0.07	58.6	0.22	0.25	375.86	0.22	1.8
C	21	2600-2621	0.31	0.69	90.15	0.03	40.0	0.08	0.26	748.60	0.26	0.17
D	20	2622-2642	0.51	0.49	47.46	0.03	42.48	0.12	0.25	433.94	0.24	0.18
E	10	2760-2780	0.54	0.46	41.83	0.06	5.92	0.14	0.24	389.60	0.23	0.18
F	30	2810-2840	0.48	0.52	74.44	0.05	45.33	0.12	0.25	221.83	0.23	0.18
G	10	2890-2900	0.61	0.39	4.29	0.09	65.19	0.14	0.27	178.46	0.27	0.17
H	45	3015-3060	0.34	0.66	92.13	0.06	55.00	0.08	0.25	224.41	0.24	0.17



Gamma ray log shape

LLD
MSFL

FIG 1: log responses of well 04 at 3100- 3400 depth

3.2 WELL 05

A total number of fifteen reservoirs were characterized in this well named A- O. The average porosity values of the reservoirs H, K, L, N, and O, are in 13% to 15% range and as high as 25% in E. While the permeability values range from 5.16md -157.39md. The porosity/permeability values 13.0%/ 140.52md) are good enough to permit free flow of fluid. The resistivity curves of most reservoirs in this well are dominantly low. This is an indication of water filling the pores. While resistivity curves of the following reservoirs in 3160-3180, 3810-3820, 3850-3874 and 4000-4040 intervals show higher values .The true resistivity values of these reservoirs are greater than the water bearing resistivity (Ro) (Hinges, 1959; see Table 2). These are indications that these zones are hydrocarbon bearing.

The neutron-log and Density-log responses (NPHI and DPHI) through the sandstone support the presumption that the hydrocarbons are gas; The density curve reads much higher porosity than the neutron log-“crossover”, due to gas in the formation (Asquith, 2004). The cross over in some intervals in this well are relatively small and it could be that the zones are high pressure zones as low-pressure zones either at shallow depths or depleted from production tend to show large crossover (Asquith, 2004).The average Volume of shale (Vsh) values are low in most reservoirs and this is an evidence of clean sand development. Within 4000-4320 depth interval the average Vsh values is approximately 0.07v/v decimal.

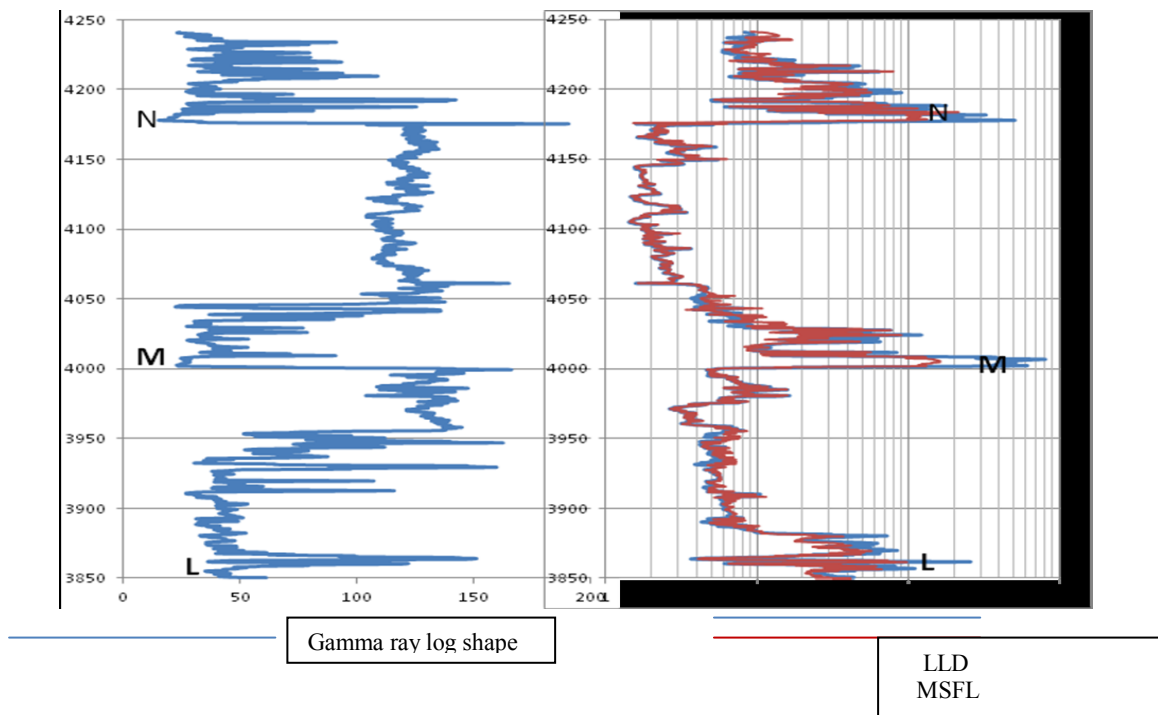


FIG 2: log responses of well 05 at 3850- 4250 depth

3.3 WELL 06

A total number of eight reservoirs were delineated in this well. Their thicknesses have average value from 10m to 45m. The vsh values are low, an indication that the reservoirs are clean. The resistivity curves of reservoirs “A” “C” “F” “H” show moderately high values. Their values range from 41.83 to 92.13Ωm. The sands are well developed. The porosity and permeability values have well to excellent values. They range from 0.22%- 0.30% and 178.46-1217.4 md respectively. The average water saturation value of reservoir ‘B’, ‘E’, and ‘G’ are high. This and the true resistivity value (1.60 Ωm-4.29 Ωm) suggest that the reservoirs are water bearing. Reservoir ‘A’, ‘C’, ‘D’, ‘F’, and ‘H’ show an evidence of hydrocarbon bearing. Their water saturation values range from 0.31% - 0.54%. The hydrocarbon in ‘A’ and ‘C’ could be gas because of the negative crossing of neutron and density logs at that interval while hydrocarbon in reservoir ‘F’ and ‘H’ could be oil because of tracking of the two logs..

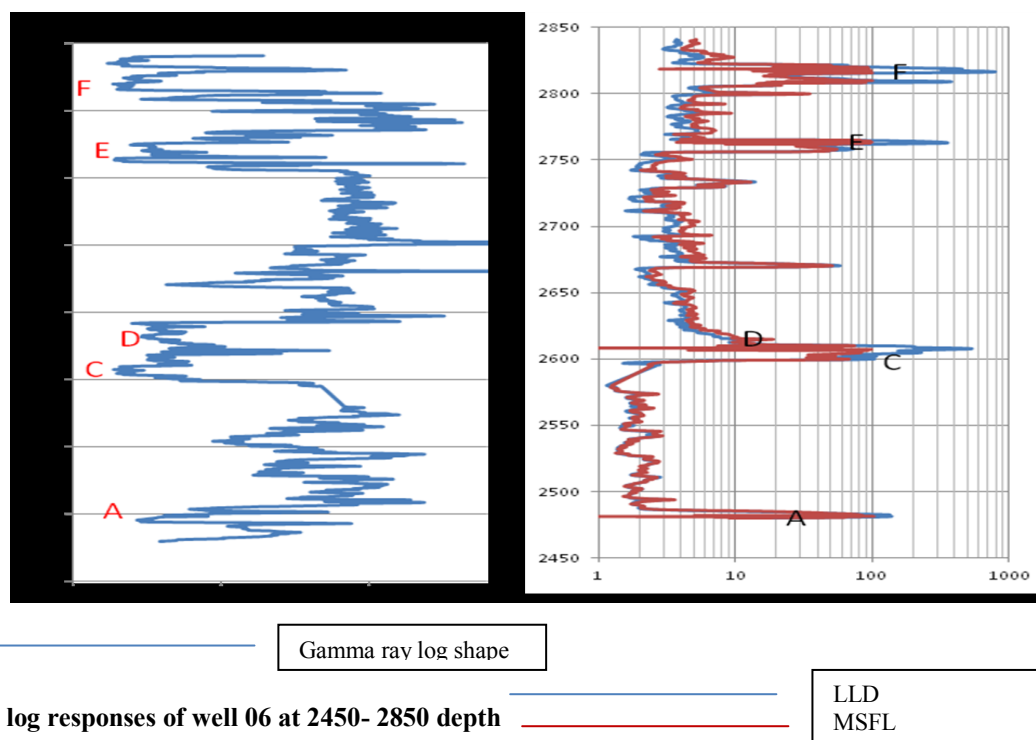


FIG 3: log responses of well 06 at 2450- 2850 depth

IV. Facies Interpretation and Depositional Environment

Since the gamma ray log measures the shaliness of a formation, it can indicate the lithofacies and depositional environment of a rock. Gradual changes in shaliness are associated with changes in grain size and sorting that are controlled by facies and depositional environment as well as rock. The shapes of gamma ray were used in interpreting the various depositional environment of the study area. The gamma ray log is complemented by resistivity logs. The depositional environments and thus facies characteristics determine the overall reservoir properties of sandstone.

In well -04, reservoir E, F, G and H's gamma ray log shape were characterized. Reservoirs E, F and G have cylinder (serrated) gamma ray log shape while reservoir H has a funnel shaped gamma ray log shape (fig. 1)

In well-05, Reservoir L, M, N's gamma ray shapes were characterized. The gamma rays log shape of reservoir L is a cylinder-shaped (serrated) while reservoir M and N have bell shaped (serrated). (fig. 2)

In well-06, reservoir C, E and F were selected in this well and C and E have cylinder shaped (serrated) gamma ray shapes while reservoir F has bell (serrated) shape (fig. 3)

The cylindrical shaped gamma ray curve indicates massive, featureless, non- graded sand normally associated with channel fills. The bell shaped gamma ray signatures indicates upward fining fluvial deposited sand. The funnel -shape is a coarsening- up barrier bar sand which may be a deltaic progradation or a shallow marine progradation (Riders, 1996).

V. Summary

A funnel shaped gamma ray log indicates a decrease in clay contents. Thus, the volumes of shale of all reservoirs with this gamma ray log shape have low value (0.05v/v in reservoir H -0.09v/v). Barrier bars is part of the Deep sea environment and characteristics of the inner Fan channel environment. Deposits in the inner fan Environment are coarse and clean enough to be regarded as potential reservoir beds (Coleman and Prior, 1980). The reservoir H of well -04 has excellent qualities with 0.34% porosity, 0.09v/v decimal Vsh value, water saturation as low as 0.05%. The deltaic-fluvial environment indicated by cylindrical gamma ray log commonly consists of well sorted sands; this evidenced in the good porosities of the reservoirs with this feature, their porosity values are of good values. They range between 0.14%- 0.30% and obvious potential reservoirs for hydrocarbon. The computed values of Bulk volume water (BVW) of all the reservoirs are near constant to constant and this is an indication that those zones would water free hydrocarbon.

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