Recognition and Evaluation of Low Resistivity Pay-Zones: A Case Study of "Amo-Field" in the Tertiary Niger Delta Basin, Nigeria.

M.O. Eze, M.Sc.[1]; A.W. Mode, Ph.D.[2]; and A.O. Anyiam, Ph.D.[2*]

[1]Department of Geology, Micheal Okpara University of Agriculture, PMB 7267,
Umudike, Abia State, Nigeria.
[2]University of Nigeria, Nsukka, Enugu State, Nigeria.

E-mail: tinamine8@yahoo.com*

ABSTRACT

An analysis of the effects shale induces on a reservoir has been one of the most controversial problems to petrophyscists. In this study, the Shaly- sands were lineated using wireline logs of three wells (Well A, Well B, and Well C). Water saturations were calculated by Archie's method and modified Waxman-Smits models of Shaly-sand. The Archie's equation resulted in higher water saturation values which ranges between 0.26%-0.99%.The modified Waxman-Smits model values range from 0.03%-0.58%.Total porosity values of all the wells range from 0.12%- 0.28% with a direct relationship between increasing clay content and decreasing effective reservoir porosities.

The average volume of shale range in well A is 0.10%- 0.25%. The average volume of shale (Vsh) in the reservoirs is within the limits that could affect the value of water saturation (Hilchie, 1978). In well B, the volume of shale ranges from 0.10%-0.14%. In well C, the average volume of shale ranges from 0.10%-0.15%. The reservoirs delineated in this field have good reservoir porosity values. The Low resistivity values range of the study are from 1.81ohm meter to 8.53ohm-meter.

(Keywords: low resistivity pay sands, volume of shale, wireline logs)

INTRODUCTION

Low Resistivity Pay is a common term encompassing many forms of shaly sands (Fanini et al., 2001). Since many years ago; low resistivity formations were of no interest as wireline logging research hinged on the principle that the hydrocarbon-filled rocks have a higher resistivity than that of water-filled rocks depending on the salinity of the formation. By Low resistivity pay sand, one infers that the reservoir contains a commercial quantity of hydrocarbon but the resistivity log reads low, in other words, resistivity log is unable to adequately "see" the hydrocarbon. More so, because of the low resistivity water saturation is computed high and quite often the Low Resistivity zone is overlooked leading to underestimation of net pay and hydrocarbon reserves.

Because of the inherent conductivity of clay and hence shale, it is the primary cause of low resistivity pay (Boyd et al., 1995). Hilchie (1978) notes that the most significant effect of shale in a formation is to reduce the resistivity contrast between oil or gas and water. The Invalidity of Archies definition of equation in Shaly sand Formation led to the developments of numerous equations or empirical relationships, under the generic terminology of "shaly sand equations" (Riders, 1996), to take into account the effect of clay and compute an accurate water saturation.

LOCATION

The Cenozoic Niger Delta (Figure 1) is situated at the intersection of the Benue Trough and the South Atlantic Ocean where a triple junction developed during the separation of the continents of South America and Africa in the late Jurassic (Whiteman, 1982).

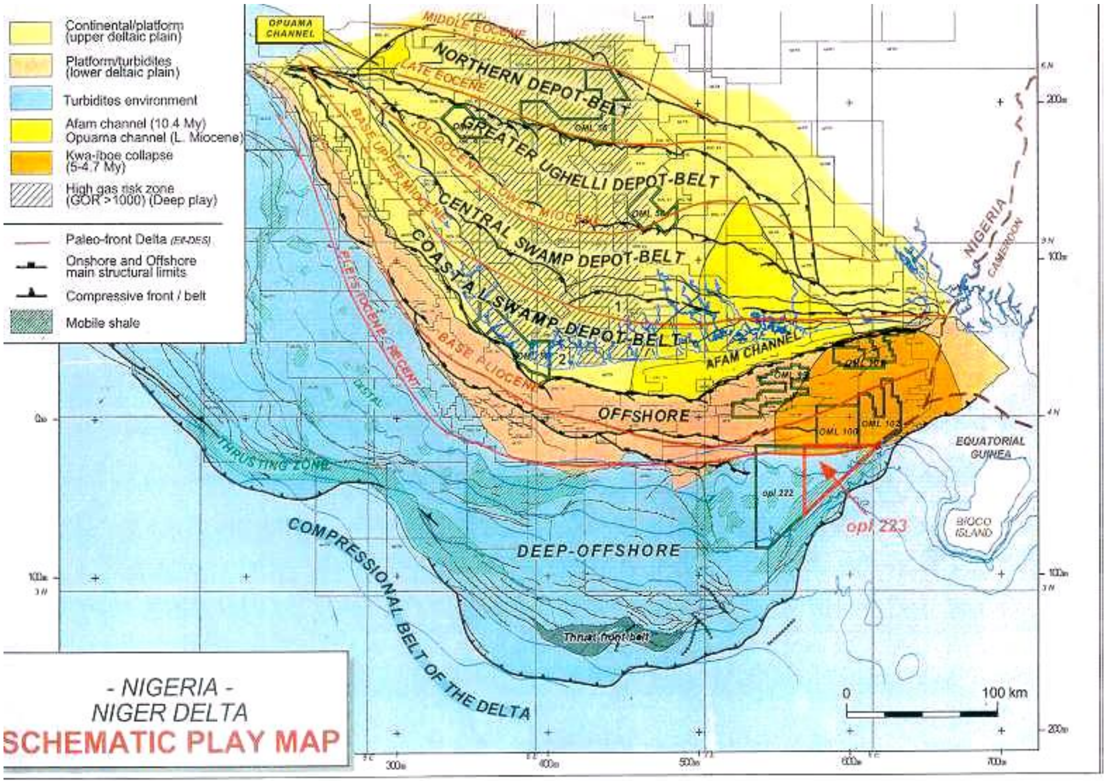

Figure 1: Play Map of the Niger Delta Showing Depobelts (Tuttle et al., 1999).

RESEARCH OBJECTIVE AND SCOPE:

Detailed evaluation of Low resistivity pay zones is the major aim of this work using conventional log data.

-Delineation of the reservoir units in the wells.

-Characterization of these zones (Low resistivity pay zones).

-Accurate estimation of water saturation value of the zones using sand- shale models.

LITERATURE REVIEW

The Niger delta is perhaps the most important sedimentary basin in sub-Sahara Africa with respect to petroleum production. This led to intensified investigation and work on the basic geology, structural setting, lithology and depositional environment of the Niger Delta by several authors. 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 Omastsola, 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, (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 longshore 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).

Weber and Daukoru, (1975) indicated that the Agbada shales are in most places immature and that the Akata shales constitute the major source rocks for hydrocarbons of the Niger delta basin. They concluded that the source rocks of the Niger Delta include the marine Akata Shale and the underlying Cretaceous shale. Mature Eocene and Miocene shales of the Akata and Agbada Formations constitute the major source rocks (Ekweozor and Okoye, 1980; Ejedawe, 1981; Nwachukwu and Chukwura, 1986; Evamy et al., 1978; Weber and Daukoru, 1975; Bustin, 1988). They have also recognized known reservoirs as Eocene to Pliocene in age, often stacked, ranging in thickness from 15m to 45meters. Evamy et al., (1978) has established a model of delta development based on the relation between rate of deposition (Rd) and rate of subsidence (Rs). Based on reservoir geometry and quality, Weber and Daukoru, (1975) stated that the lateral variations in reservoir thickness are strongly controlled by growth faults with the reservoir thickening towards the fault within the downthrown block.

The development of the Tertiary Niger delta has been related to the evolution of the Cretaceous Benue Trough (Obi, 2000). Doust and Omatsola, (1990) recognized six depobelts in the Niger Delta, which are defined in terms of the age of its paralic sequence and the age of the alluvial sands that cap the paralic sequence. These depobelts are Northern delta (Late Eocene –Early Miocene), Greater Ughelli (Oligocenc- early Miocene), Central swamp II (middle Miocene), coastal swamp I and II (middle Miocene), and offshore (late Miocene) (Figure 1). The study area is located in the Greater Ughelli depobelt.

METHODOLOGY

This research work using available data was carried out and this includes:

- A preliminary review of all available data and existing literature on Low Resistivity pay sand.
- Delineation and interpretation of Low Resistivity reservoirs of "Amo-field" using available wireline logs.
- Extracting the correct measurement of Formation resistivity by Picket plot.

- Accurate derivation of water saturation (s_w) using Shaly sand equation.

MODIFIED WAXMAN SMITS EQUATION

This equation is based on the Juhaz (1981) model and makes do without the BQV of Waxman-Smits (Waxman and Smits, 1968) shaly sand equation. Two sets of equation were used: Rw were derived by picket plot. Rwb were taken from resistivity log.

1. When Rw>Rwb **(EQUATION 1)**

Ro =F* RW*Rwb/ (Rwb * (1- Vclay) + Vclay * Rw)

SWT = (Ro/RT)^(1/n)

2. When RW<=Rwb, X=Vcl*(Rwb-Rw)/2*Rwb, **(EQUATION 2)**

SWT= (X^2+F*RW)/RT)^(1/n)+X

Where,

Ro= Resistivity of water zone

F*= $\frac{a_1}{\Phi_t^{m*}}$ **(EQUATION 3)**

Rw = Resistivity of the formation.

Rwb= Resistivity of clay bound water.

Vclay=volume of clay

m*=clay corrected cementation factor

Selection of n* and m*: They were computed using equations based on common experience (Shell Petroleum Development Company).

n*=1/0.38829+0.56062* **(EQUATION 4)**

m*=2.008-0.946* **(EQUATION 5)**

EVALUATION AND INTERPRETATION FOR “WEL A” LOW RESISTIVITY PAY RESERVOIRS

The depth drilled for well A is 4245meters. The low Resistivity pay reservoirs evaluated in this well are labeled A1-A5. They have average porosity values of a typical Niger Delta reservoirs ranging from 0.21%v/v decimal in reservoir A4 and A5 to 0.28% v/v decimal in reservoir A1). The petrophysical summary table results are shown in Table 1.

The reservoir thicknesses are 14m-reservoir A1, 5m- reservoir A2, 27m- reservoir A3, 14m-reservoir A4 and 5m- reservoir A5. For the volume of shale, these criteria were bases for calculation: GR_{clean} = 25 API units, GR_{shale} = 150API units. The results from the Archie’s equation (Archie, 1942) indicate high values of water saturation, ranging from 0.47% in reservoir A1 to 0.73% in reservoir A4, while the results from modified Waxman-Smits equation give lower percentage water saturation values between 0.03% in reservoir A2 and 0.58% in reservoir A3.

The Archie’s equation was applied with Rw= 0.16ohm-m (derived by picket plot), Cementation factor (m) of 1.6 (derived from average value of core interpretation result) and saturation exponent n of 1.9. The average resistivity log responses are 6.98ohm-meter, 4.41 ohm-meter, 8.53 ohm-meter, 3.0ohm-meter, 4.10ohm-meter and 3.16ohm-meter for reservoir A1-A5 respectively. The low values confirm that they are low resistivity zones.

Volume of shale greater than 10v/v decimals occurring in sands affects their water saturation values (Hilchie, 1978). The average volume of shale (Vsh) in reservoirs A1-A5 are within the limits that could affect the value of water saturation(>10%-15%). Their volume of shale ranges from 0.10%v/c decimal in reservoir A4 and A5 to 0.26% in reservoir A2. A direct relationship exists between increasing clay content and decreasing effective reservoir porosities (table 1)

EVALUATION AND INTERPRETATION FOR “WELL B” LOW RESISTIVITY PAY RESERVOIRS

The total depth drilled for well B is 4413meters. Eleven Low Resistivity pay zones labeled B1 –B11 were evaluated in this well. Their thicknesses are B1- 8m, B2- 9m, B3- 12m, B4- 6m, B5- 10m, B6-21m, B7- 22m, B8- 14m, B9- 11m, B10- 30m, and B11- 16m, respectively. The general configuration of the gamma ray and the mutual disposition of the neutron- and density-porosity show the likelihood of shale in the reservoir.

The petrophysical summary table results for well B are shown in Table 2. In the absence of core data, a preliminary evaluation approach was used in well B by applying the Archie equation with R_w = 0.14 ohm m (derived by picket plot), Cementation factor (m) of 1.6 (derived from core interpretation result) and saturation exponent n of 1.9. The Clay was corrected for well B by applying the modified Waxman-Smits equation. A value of 1.9 was used for the clay-corrected cementation factor (m*). For the volume of shale, these criteria were the bases for calculation: GR_{clean} =20 API units, GR_{shale}=150 API units.

Table 1: Petrophysical Summary Table for Well A

Well /Reservoir name		Depth interval(m)	GR-comp(API)	Rt(ohm-m)	Vsh(v/v)	Φ_T(v/v)	Φ_e(v/v)	Archie’s Sw	Wax-smit Sw (modified)	Total Tk((m)(m)	Fluid
	A1	2468-2482	63	6.98	0.12	0.28	0.25	0.47	0.07	14	H-C
	A2	2737-2742	90	4.41	0.25	0.26	0.20	0.58	0.03	5	H-C
	A3	3007-3034	62	8.53	0.12	0.24	0.20	0.51	0.58	27	H-C
	A4	3970-3984	60	4.10	0.10	0.21	0.20	0.73	0.12	14	H-C
	A5	4144-4150	52	3.16	0.10	0.21	0.26	0.58	0.24	5	H-C

Table 2: Petrophysical Summary Table for Well B.

Well /Reservoir name		Depth interval(m)	GR-comp(API)	Rt(ohm-m)	Vsh(v/v)	Φ_T(v/v)	Φ_e(v/v)	Archie's Sw	Wax-smit Sw(Modifeid)	Total Tk((m)(m)	Fluid
WELL B	B1	2867-2875	64	2.00	0.14	0.22	0.21	0.89	0.34	8	H-C
	B2	2880-2889		1.73	0.12	0.25	0.23	0.89	0.39	9	H-C
	B3	2923-2935	57	2.02	0.12	0.22	0.20	0.95	0.35	12	H-C
	B4	2947-2953	70	2.67	0.14	0.18	0.12	0.79	0.31	6	H-C
	B5	2998-3008	60	2.25	0.13	0.22	0.21	0.84	0.35	10	H-C
	B6	3020-3041	60	2.05	0.12	0.24	0.23	0.82	0.33	21	H-C
	B7	3430-3452	70	2.77	0.13	0.22	0.20	0.76	0.33	22	H-C
	B8	3534-3548	64	2.74	0.12	0.21	0.18	0.86	0.32	14	H-C
	B9	3596-3607	54	2.53	0.10	0.22	0.19	0.89	0.33	11	H-C
	B10	3609-3639	55	2.58	0.10	0.20	0.19	0.86	0.32	30	H-C
	B11	3930-3946	66	5.04	0.14	0.17	0.15	0.70	0.26	16	H-C

The average density porosity for the reservoirs ranges from 0.17%v/v decimal for reservoir B11 to 0.25% v/v decimal for reservoirs B6. The effective porosities value range between 0.12v/v to0.23v/v decimal. The reservoirs have good porosity values. The volume of shale was calculated using the non-linear response method- Larionov (1969).The average volume of shale of the reservoir B1, B2, B3, B4, B5, B6, B7, B8, and B11 are over the threshold (i.e. >10%-0.14%) that affect the water saturation of a reservoir.

The average volumes of clay for reservoirs B9 and B10 are moderate and do not explain the resistivity anomaly in these zones. The predominant clay mineral for reservoir B9 and B10,and may be clay mineral with low CEC like Kaolinite and this could result in a negligible amount of electro-chemical bound water, (moderate V_{sh}).

Examination of the Sandstones of Agbada Formation of Niger Delta by scanning electron microscopy showed that authigenic kaolinite and to a lesser extent authigenic smectite was present(Lambert-Aikhionbare,1982). The average resistivity values for the reservoirs are B1-2.0ohmm, B2-1.73ohm-meter, B3-2.02ohmm, B4-2.67ohmm, B5-2.25ohmm, B6-2.05ohmm, B7-2.77ohmm, B8-2.74ohmm, B9-2.53ohmm, B10-2.58ohmm, B11-5.04ohmm.

The calculated average water saturation (S_{WT}) using the Archie's equation ranges from 0.70% for reservoir B11 to 0.95% for reservoir B3 while the modified Waxman-Smits water saturation gave lower values that range from 0.26% in B11-0.39% in B2 (Table 3). The water saturation equation values calculated using the Archie's equation is high as a result of presence of clay in the reservoirs.

EVALUATION AND INTERPRETATION FOR WELL C LOW RESISTIVITY

The total depth drilled for well C is 3166m. The low Resistivity evaluated in this well are five in number, labeled C1, C2, C3, C4 and C5. The average True resistivity log values range from 1.82 ohm meter in C5 to 8.2 ohm meter in C3. The Low Resistivity values confirm that they are Low Resistivity zones. It has good reservoir development. The average reservoir thickness ranges from 9m for reservoir C4 to 50m in reservoir C3.

The Volume of shale values are within the limit that can affect the reservoir characteristics (0.10%-0.15%) except for well C5. For the volume of shale, these criteria were the bases for calculation: GR_{clean} =22 API units, GR_{shale}=180 API units. The Archie's equation was applied with Rw= 0.2ohm-m (derived by picket plot), Cementation factor (m) of 1.6 (derived from average value of core interpretation result) and saturation exponent n of 1.9.

Table 3: Petrophysical Summary Table for Well C.

Well /Reservoir name		Depth interval	GR-comp	Rt(ohm-m)	Vsh(v/v)	ϕ_T(v/v)	ϕ_e(v/v)	Archie's Sw	Wax-smit Sw(Modified)	Total Tk((m)(m)	Fluid
Well -06	C1	2265-2280	70	3.5	0.11	0.26	0.24	0.74	0.34	15	H-C
	C2	2290-2310	80	2.5	0.14	0.22	0.20	0.52	0.43	20	H-C
	C3	2475-2530	81	8.2	0.15	0.22	0.20	0.93	0.40	50	H-C
	C4	2531-2540	83	1.62	0.14	0.27	0.23	0.99	0.47	9	H-C
	C5	2550-2560	71	1.81	0.10	0.28	0.26	0.90	0.44	10	H-C

The reservoirs have well to excellent porosity values (Φ_D= 0.22% for C2 and C3 to 0.28 for C4 and C5 with effective porosity range of 0.20%v/v decimal to 0.26%v/v decimal) and can accommodate good hydrocarbon saturation. The water saturation computed by the Archie's equation gives high water saturation value that range from 0.52%-0.99% as a result of shale in the reservoir. The petrophysical summary Table is shown in table 3. By using the Modified Waxman-Smits shaly sand equation to correct for the effect of shale, water saturation is reduced to the range of 0.40% in C3 to 0.47% in C4.

CONCLUSION AND RECOMMENDATION

The primary cause of Low Resistivity pay zones is clay because of its inherent conductivity within sands and has led to several problems during formation evaluation. All log responses and interpretation tools are influenced by the presence of clay. A total of twenty one Low Resistivity pay zones were delineated using data from a complete composite log suite in the Three wells- Well A, Well B, and Well C studied in this work.

For Well A, five low Resistivity reservoir zones were delineated with their porosities ranging from 0.21%-0.28%. The results from the Archies' equation indicate water saturation ranging from 0.47% to 0.73%, while the results from modified Waxman-Smits shaly sand equation gave lower value of 0.03% and 0.58%. The average Resistivity values ranges from 3.16ohmm-6.98ohmm. The volume of shale is within the limit that can affect the reservoir quality (0.10%-0.28%).

Eleven of the reservoir intervals recorded Low resistivity value in Well B with average Total porosity ranging from 0.12% to 0.25%. The water saturation values ranges from 0.76%-0.95% and 0.26%-0.39% for the Archie's and modified Waxman-Smits model respectively.The average resistivity values ranges from 1.73ohmm to 5.04ohmm while average volume of shale values of 0.10%-0.14% were recorded. The total porosity values for Well C ranges from 0.22%- 0.28% while the water saturation ranges from 0.34%-0.47%(Modified Waxman-Smits equation). Water saturation calculated using the Archies equation gave higher values(0.54%-0.99%) than the those generated using the modified Waxman-Smits equation.

In addition to the use of standard shaly sand log analyses (e.g., using the Waxman-Smits, Dual-water model), it is recommended that the logging tools with high vertical resolution and very deep penetration should be used during data acquisition. This is in view of the fact that most of our reservoir intervals, especially within parallic deposits petroliferеous Niger Delta basin are characterized with intervals with thin-bedded, shaly reservoir sands (Low Resisitivity Pay zones). When such newer technologies are used together with integrated petrophysical evaluation, the bye-passed productive intervals are better delineated.

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ABOUT THE AUTHORS

M.O. Eze, M.Sc., is a Lecturer II in the Department of Geology, College of Physical and Applied sciences, Micheal Okpara University of Agriculture Umudike, Abia State.

She specializes in geology and petroleum geology/geophysics.

A.W. Mode, Ph.D., is a Senior Lecturer in the Department of Geology, Faculty of Physical sciences, University of Nigeria, Nsukka, He specializes in geology, geochemistry, and paleontology.

O.A. Anyiam, Ph.D. is a Senior Lecturer in the Department of Geology, Faculty of Physical Sciences, University of Nigeria, Nsukka. He specializes in geology and geochemistry.

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