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Reservoir and mathematical modellings for calculating hydrocarbon in place using well log data

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ABSTRACT

A characterization and volumetric analysis of Olomoro field was carried out using data provided by Shell Petroleum Development Corporation in order to determine the reservoir lithology, structure properties and hydrocarbon in-place. The data provided were well logs, structural map and the seismic section of Olomoro field. The well logs utilized included gamma ray, resistivity, caliper, density, neutron and sonic logs. Through the gamma ray log, it was discovered that the interval under investigation had four porous and permeable zones or reservoir interval. The resistivity log revealed with exception of the first to the third reservoir layer of well 1, presence of hydrocarbon which was used to calculate resistivity of the formation and water. The water saturation was calculated which in turn was used to calculate the hydrocarbon saturation. The values derived were used to estimate the hydrocarbon in place within the depth of 3,429m and 4,053.84m for an area of 100km^2. These gave a total of 4.012 x 10^9m^3 or 2.5234 x 10^{10} barrel as the hydrocarbon in-place. It was observed through the structural map and the seismic section that the hydrocarbon trap is a structural trap created by two fault plains and a folded anticline.

Introduction

It is a known fact in the petroleum industry that well logs play a key role in oil and gas exploration and reservoir evaluation.

When a well drilling is completed, a decision must be made as to whether to complete the well or abandon it. Well logs often provide the data that help make the correct decision. It is sometimes used to identify the presence of hydrocarbon where the quantity of the reservoir rock is so good that nearly all traces of hydrocarbons have been flushed from the drilling cuttings circulated to the surface by the drilling fluid.

Well logs are used to calculate the amount of oil and gas in the ground. A well log is a graph of depth in well versus some characteristics or properties of the rock. The rock property is derived from measurements made when instruments are lowered into the well on an electrical wire line or cable. Most measurements are actually recorded as the instruments are raised to the surface from the bottom depth in the well. Once a well is drilled, the only economical means of finding out what is down there is with a well log.

To evaluate the producibility of a reservoir, it is necessary to know how easily fluid can flow through the pore system. This property of the formation rock, which depends on the manner in which the pores are interconnected, is its permeability [1].

The main petro-physical parameters needed to evaluate a reservoir, then are its porosity, hydrocarbon saturation, thickness, area and permeability. In addition, the reservoir geometry, formation temperature and pressure, and lithology can play important roles in the evaluation, completion and production of a reservoir.

Location

Olomoro is located in Isoko South Local Government Area of Delta State, Nigeria. It is bounded in the North by Oleh, North-east is Uzere and Emede communities, North-west by Otor-owhe and South by Iyede community.

Olomoro is in the tropical rain forest area of the Niger Delta. The region experiences high rainfall and high humidity most of the year. The climate is equatorial and is marked by two distinct seasons, the dry and rainy seasons. The inhabitants practice subsistence farming.

Geology

The Niger Delta occurs at the Southern end of Nigeria bordering the Atlantic Ocean. The proto delta developed in the Northern part of the basin during the Campanian transgression and ended with the Paleocene transgression. Formation of the modern delta began during the Eocene. It lies in the South end of Nigeria extending within longitude 3^0 to 9^0 and latitude 4^0 30^1 to 5^0 20^1 N [2] and forms one of the major sedimentary basins in Nigeria.

The Niger Delta consists of three main tertiary stratigraphic units overlain by Quarternary deposits [3]. These three subsurface stratigraphic units in the modern Niger Delta are Benin, Agbada and Akata formations.

The base is the Akata formation comprising mainly of marine shales and sand beds consisting of dark grey sandy, silty shale with plant remains at the top. It is over 4000ft thick.

The underlying Agbada formation is a sequence of sandstones and shales [4]. It consists of an upper predominantly sandy unit with minor shale intercalations and a lower shale unit which is thicker than the upper sandy unit. It is over 10,000ft thick.

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The aquifer in the Benin formation is largely phreatic. These formations are overlain by various types of Quarternary deposits [4]. These areas are made up of top soil, red laterite, clay, fine sand, medium sand and coarse sand in form of pebbles. The thickness is variable but generally exceeds 6000ft.

Methodology and Analysis

Olomoro 2-D seismic survey was acquired in 2002 and the 3D survey was carried out in 2005. A total of $120km^2$ and $60km^2$ of 15 fold data with a 25 x 25m bin spacing were acquired for the Olomoro 3D survey. The seismic survey derived from the survey as provided by United Geophysical company is shown in figure 1. The reservoir area "A" is mainly determined from seismic, combined with geological knowledge. Well production tests, combined with reservoir simulation also play an important role in determining the extent of a reservoir. It is fair to say that in general the reservoir area is one of the most uncertain factors in the determination of the hydrocarbon volume [5]. A total of 5 wells had been drilled in Olomoro structure encountering some reservoirs between the depth of 7000ft (2,134m) and 14000ft (4,267.2m).

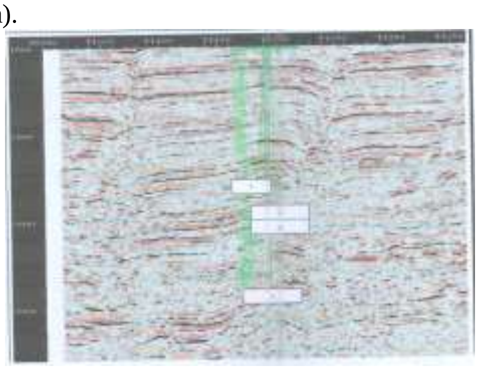
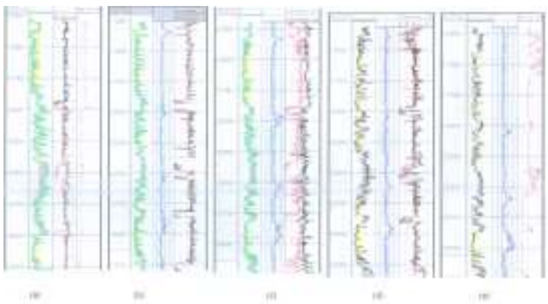


Figure. 1: Olomoro seismic section

The petrophysical method employed in this work for the evaluation of reservoir properties of the Olomoro were the use of well logs. The data collected were imputed into the petreal seismic to simulate the software. The data collected have shown that: (a) Gamma ray, Temperature, Density, Resistivity and Sonic logs were run in wells 1 and 5. (b) Neutron, Density, Gamma ray, Temperature, Sonic and Resistivity logs were run in well 2, 3 and 4 as shown in Figure 2b.

Reservoir characterization of Olomoro field was done by careful defining some reservoir properties. These properties e.g. porosity, fluid saturation, shale content etc. and reservoir area defines the oil or gas in place in the reservoir at initial conditions.



Porosity

The response equation for the neutron porosity log according to [6] is shown below

Φ_N = θe x Sxo x θnw (water term) + θe x (1 – Sxo) x θ_{Nw} (Hydrocarbon term) + V_{sh} x θ_{Nsh} (Shale Term)

+ (1 – V_{sh} – θ_e) x sum (V_i x θ_{Ni}) (Matrix term)………….. 1

This equation is with the assumption that

$\Phi_{Nw} = \Phi_{Nh} = 1.0$, $\Phi_{Ni} = 0.0$, Sxo = 1.0 and that Φ_{Nsh} and V_{sh} are known. This results in.: $\theta_{nc} = \theta_N - V_{sh} \times \theta_{NSH}$ ………………………………………………………. 2

where

Φ_N = porosity from neutron log corrected for lithology or gas (fractional)

Φ_{nc} = porosity from neutron log corrected for shale (fractional)

Φ_{NSH} = apparent neutron log porosity of 100% shale (fractional)

V_{sh} = volume of shale (fractional)

Applying data into equation 2, the various parameters related to the oil in place could be calculated.

Lithology

The lithology of the reservoir was derived from the readiness on density log.

$$\theta = \frac{\rho_{ma} - \rho}{\rho_{ma} - \rho_f} \quad \text{……………………………………3}$$

Applying equation (3) the density and the porosity (Φ) corrected for shale, the matrix density (ρ_{ma}) calculated for the non-shaly zone revealed a sandstone formation. Fluid density (ρ_f) was taken as $1g/cm^3$.

Water Saturation

The Archie's equation was used to solve for water saturation using the resistivity values from the logs in Figure 2. The exponents was calibrated to sandstone zone.

$$R_w = R_o \times \phi_e^m \quad \text{……………………………………. 4}$$

and

$$S_w^{-N} = R_t/R_o \quad \text{……………………………………. 5}$$

where

M = cementation exponent (unitless)

N = satuartion exponent (unitless)

Φ_e = effective porosity (fractional)

R_t = resistivity of the zone (ohm – m)

R_o = resistivity of the zone/rock filled with water (ohm – m)

R_w = water resistivity at formation temperature (ohm – m)

S_w = water saturation from Archie's method (fractional)

Using equation 4 and 5, it was revealed that the water saturation "S_w" in the hydrocarbon zone was less than 50% as shown in table 1 below

The reservoir thickness (h) and net to gross ratio (N/G) were obtained from the gamma ray log as seismic information does not have sufficient vertical resolution to play a very important role in its evaluation.

The C1.0 top structure map indicated variations of depression elevations over the geographic region, relative to sea level, of the top surface of the reservoir rock. Figure 3 is a structural contour map in the region at a depth of 12,800feet. It indicated sandstone structure, the existence of an anticline dome and two fault plains.

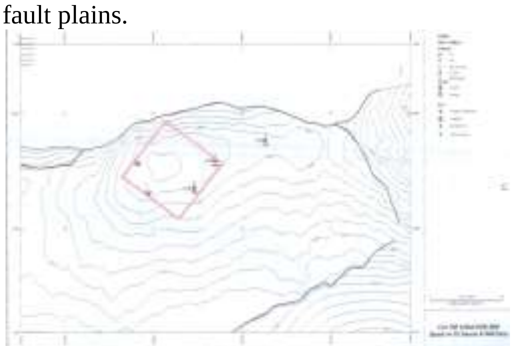


Figure 3: C1.0 top structure for Olomoro field

Hydrocarbon in Place

In order for a rock to be considered a reservoir rock, it must have adequate porosity and permeability for the conditions present. Porosity, along with oil saturation, indicates oil-in-place, or reserves, while permeability indicates the ability to produce these reserves.

Once the total volume of the rock containing oil was obtained, it was multiplied by the porosity Φ, which provided the volume of the void space within the reservoir that may contain oil. The volume multiplied by oil saturation and proper conversion factors applied to convert the resultant volume into barrels was the value in original oil-in-place (OOIP) expressed in reservoir barrels (RB) [7]

There are two methods normally used to estimate the in-place hydrocarbon resource volumes in petroleum reservoirs – the volume – tric method and the material balance method. However, the volumetric method was adopted for this work. This uses the geologic subsurface maps, well log and fluid analysis data to quantify the reservoir. Reservoir areas are always expressed in acres, while oil volumes are in acre-ft or barrels, gas volumes in cubic feet (ft^3)

At a neighbouring point in the same well, the value of hydrocarbon pore volume may be different [8]. Thus, in order to sum the total oil-in-place (OIP), an integration of hydrocarbon pore volume with respect to depth and area was made by applying the formula

$OIP = \sum \Phi(1 - S_w)\, hA$ ………………………………..… 6

Applying well-to-well correlation in figure 3, the value of "h" was calculated while the structural map was used to show well placement. These together with equation 7 were used to calculate for the initial oil volume.

$HCIP = N/G \times A \times h \times \Phi \times (1 - S_w)$ …………………….. 7

where

HCIP = volume of hydrocarbon in place

A = area of the reservoir

h = thickness of the reservoir from logs and

N/G = Net-to-Gross (i.e fraction of the reservoir that consist of porous rock e.g. sand or carbonate, hence excluding shale) determined from logs and cores.

Φ = porosity of the reservoir, determined from logs and cores

S_w = water saturation, determined from logs for an area of $1 \times 10^8\ m^2$ (24711acres), logs 1 -5 (well-to-well correlation), averages for reservoir thickness (layers 1- 4), hydrocarbon saturation, porosity, subsurface thickness and net-to-gross, the hydrocarbon volume in place was calculated for each layer as shown in table 2.

Findings and Discussion

This study provided a basis for using a combination of well logs, seismic section, structure map and mathematical models to characterize and model Olomoro field interval under investigation towards calculating the hydrocarbon in place. It was observed that the sets of reservoir layers between 11,250 – 13,350ft were interpreted in terms of their reservoir properties.

From the Gamma Ray log a linear interpolation of fine scale between 0 (clean base line) and 1.0(shale base line) points enabled the shale content (V_{sh}) to be read for any point on the log.

The reservoir structure from the seismic session identified a large collapsed crest rollover anticline trending east-west bounded to the north by a major boundary fault. The hydrocarbons found at shallow depths were trapped against the southern-most antithetic fault while at deep levels, dip-closed in footwall of this same antithetic fault.

The structural map can be used in addition to the conventional way of directly delineating the reservoir [9] to measure well spacing. The well spacing together with the log readings were used to delineate the reservoir by drawing a transverse line (East-to-West) across the structure map finding best fit in between the well positions (Figure 4). Thus the reservoir trap extrapolated from the wells showed a trap that is structural in origin as it was created by an anticline (depositional sequence) and two fault plain. (Figure 5)

Four layers that were porous and permeable were identified and differentiated by the gamma ray, neutron and density log. The hydrocarbon in place was calculated using Net-to-Gross on an area of $100 km^2$ (24,711 acres) which revealed that the cumulative hydrocarbon in place was 3,252,700.51 acre – foot ($4.012 \times 10^9\ m^3$ or 2.5234×10^{10} Barrel).

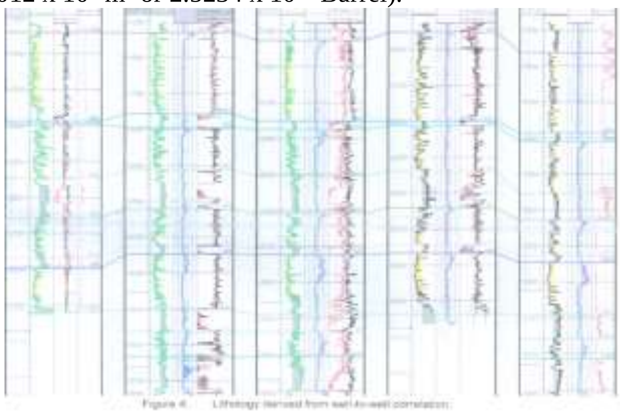
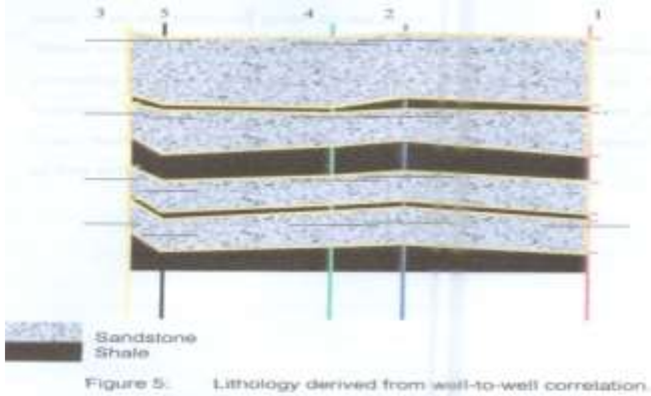


Figure 4: Lithology derived from well-to-well correlation



Conclusion

The sets of reservoir layers between 11,250ft (3,429m) and 13300ft (4,053.84m) were interpreted in terms of their reservoir properties. The seismic section showed that the structure is a large collapsed crest rollover anticline trending east-west and bounded to the north by the major boundary fault, it forms part of the larger structural trend. The hydrocarbons found at shallow depths are trapped against the southern-most antithetic fault while at deep levels, the hydrocarbons are dip closed in foot wall of this same antithetic fault. The reservoir is bounded by two fault plains, a minor and major fault.

Delineating and characterizing the reservoir from logs readings indicated that the porous and permeable interval was composed of sandstone interbeded with shales. Well to well correlation revealed that the field was composed of 4 reservoir layers. Hydrocarbon was found at all wells except for the first three sandstone layers around well 1. Gas was detected in the fourth sandstone layer of well 1 and the first sandstone layer of well 4.

The cumulative reservoir thickness was 1475.00ft (449.58m) and the net-to-gross determined on the basis of total interval thickness and reservoir thickness was 0.58.

The hydrocarbon in place calculated using Net-to-Gross revealed that in an area of $100km^2$ (24711 acres), layer 1 had in place 1,268,858.46 acre-foot, layer 2 had 807,068.26 acre-foot, layer 3 had 545,749.79 acre-foot and layer 4 had 631,024.00 acre-foot. The cumulative hydrocarbon in-place was 3,252,700.51 acre-foot (4.012×10^9 m^3 or 2.5234×10^{10} barrel).

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Table 1: Water saturation values in suspected hydrocarbon zones

Well Name	Depth (Feet)	Porosity corrected for shale, Φ	R_o Ω - m	R_t Ω - m	S_w
1	11400 – 11900	–	–	–	–
	12025 – 12424	0.18	–	–	–
	12700 – 12925	0.12	–	–	–
	13000 – 13275	0.15	–	–	–
2	11325 – 11900	0.21	4	300	0.12
	12000 – 12375	0.22	1	70	0.12
	12550 – 12800	0.20	1	10	0.32
	12875 – 13200	0.17	1	40	0.16
3	11250 – 11900	0.21	3	700	0.07
	11950 – 12375	0.23	2	800	0.05
	12525 – 12750	0.24	5	800	0.08
	12825 – 13100	0.18	4	500	0.09
4	11375 – 12000	0.21	4	40	0.32
	12050 – 12350	0.23	2	7	0.53
	12625 – 12850	0.20	9	100	0.30
	12925 – 13250	0.20	7	200	0.19
5	11400 – 11975	0.22	2	4	0.71
	12050 – 12375	0.22	4	300	0.12
	12575 – 12825	0.16	4	500	0.09
	12875 – 13175	0.16	4	800	0.07

Table 2: Hydrocarbon In-Place

Layer	Average Reservoir thickness "h" (feet)	∑ h (feet)	∑Φ/4	Average hydrocarbon saturation ($1 - S_w$)	Thickness of layer "H" (feet)	N.G	Area (acres)	HCIP (acres – foot)
1	606.25		0.17	0.70	2550.00	0.58	24711	1268858.46
2	325.00		0.23	0.80	2550.00	0.58	24711	807068.26
3	237.50	1475.00	0.20	0.80	2550.00	0.58	24711	545749.79
4	306.25		0.18	0.87	2550.00	0.58	24711	631024.00
SUMMED TOTAL								3252700.51