Petrophysical Evaluation of Etu Field Coastal Swamp I Depobelt Niger Delta, Nigeria

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ABSTRACT
Etu field is located along the proximal margin of the Coastal Swamp I depobelt, a subbasin within the Niger Delta clastic wedge formed by margin collapse into underlying undercompacted shale. A Petrophysical framework evaluation for Etu field was constructed by combining data from Seven (7) Well Logs within hundreds of meters thick, define layers of reservoirs and sealing strata formed during episodic progradational and retrogradation of deltaic shorelines. The quality of the reservoirs are moderate to good and in some distal reservoirs, they are excellent. The average porosity values are approximately the same, but have variation in permeability which could be as a result of compaction of older reservoirs on the proximal part of the field. A total of thirty seven (37) reservoirs between 3000-4500 (m) were demonstrated. Sixteen (16) of the reservoirs are oil bearing. Six (6) are gas bearing while Fourteen (14) are water saturated.

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Introduction
Rock physics is the science of measuring rock properties and establishing the relationship between these properties. Petrophysics is a viable tool for detection and evaluation of hydrocarbon bearing layers. One of the fundamental properties of a reservoir rock is porosity. However, for a rock to be an effective reservoir, it must have good pore interconnectivity. The main physical parameters needed to evaluate a reservoir are porosity, hydrocarbon saturation, permeable bed thickness, and permeability etc. These parameters may be derived or inferred from electrical, nuclear, and acoustic Logs, which can be translated to qualitative information of depth/thickness of productive intervals, to distinguish between oil, gas and water in reservoir.

Location of the Study Area
The Etu field is situated in OML-XYZ, in the swamp region of the Niger Delta, Nigeria (Figure 1).

The first discovery was made in 1975 by Etu well-1 which found some 264 ft NGS and 307 ft NOS in 11 intervals. There are 7 completed drainage points in 4 wells all producing under primary recovery technique. Total cumulative oil production as at 1-12-2005 is 3.9 MMBt. The seven wells studied are exploration wells situated in the Gulf of Guinea and extend throughout the Niger Delta Province as defined by Klett and others (1997). From the Eocene to the present, the delta has prograded southwestward, forming depobelts that represent the most active portion of the delta at each stage of its development (Doust and Omatosola, 1990). These depobelts form one of the largest regressive deltas in the world with an area of some 300,000 km² (Kulke, 1995), a sediment volume of 500,000 km³ (Hospers, 1971), and a sediment thickness of over 10 km in the basin depocenter.

Stratigraphy of Niger Delta
The stratigraphy of the Niger Delta is divided into three diachronous units of Eocene to Recent age that form a major regressive cycle. The uppermost unit, the Benin Formation, comprises continental/fluvialite and backswamp deposits up to 2500m thick. These are underlain by the Agbada Formation of paralic, brackish to marine, coastal and fluviomarine deposits, organized into coarsening upwards ‘offlap’ cycles (Short,K.C and Stauble A.J, 1967). The underlying Akata Formation comprises up to 650m of marine pro-delta clays. Shales of the Akata Formation are overpressured and have deformed in response to delta progradation. These shales facilitate regional decollement for updip extension and downdpip compression. Shales of the Akata Fm constitute a world-class source rock (Ekwozor,C.M and Daukoru 1994).

Figure 1. Index Map Niger Delta And the offshore Nigeria.
Structure
The Etu structure is a large collapsed crest rollover anticline trending east-west. Bounded to the north by the major XX boundary fault, it forms part of the larger Baristo structural trend. The hydrocarbons found at shallow depths are trapped against the southern-most anticlinal fault while at deep levels, the hydrocarbons are dip closed in footwall of this same anticlinal fault.

Methods and Materials
Seismic
The Etu 2D survey was acquired as part of the Wemboo 2D seismic survey in 1972 and 3D survey was carried out in 1996. A total of 180 km² and 100 km² of 15 fold data with a 25 x 25m bin spacing were acquired for the Etu 3D survey. The C.10 and D.5.0 reservoir sands are two of the 9 key horizons mapped in the Etu 3D seismic survey. They constitute the two main reservoirs in the Etu field and account for 73% of the currently booked STOIIP volumes. Both sands are oil bearing in all reservoirs in the Etu field and account for 73% of the currently booked STOIIP volumes. The C.10 reservoir sand correlates to the peak of a medium to high amplitude. This is a low to medium frequent maximum (soft kick) seismic loop with good lateral continuity in the field area.

Identification of Reservoir Rocks
To discriminate potential reservoir rock from non permeable rock, gamma ray logs (GR) was used. The GR logs measure the natural radioactivity in formation and can be used for identifying lithologies and for correlating zones. Shale – free/sandstones and carbonates have low concentrations of radio-active material and give low GR readings. As content increases, the gamma ray log response also increases because of the concentration of radioactive material in shale.

For a quick look evaluation the following steps were followed:
- A sand line was constructed by reading the average GR level of thick clean sands (sands with lowest. GR) and was called the sand line. Also a GR level in thick shale beds was identified. This reading was assumed to represent 100% shale and called shale line
- A near vertical line was drawn in the middle between the shale line and the sand line (cut-off line) about 65-69.5 API values.
- All intervals where the GR log is on the left of this cut-off line were assumed to be potential reservoirs. (Figure 2)

Determination of Shale Volume
The Niger Delta productive sands are found intercalated with shales. Thus presence of shale or clay minerals in a reservoir can cause erroneous values for water saturation and porosity derived from logs. Hilchie (1978) noted that the most significant effect of shale in a formation is to reduce the resistivity contrast between oil or gas and water. He further suggested that for shale to significantly affect log- derived water saturation, shale content must be greater than 10 – 15%.

There is therefore need to correct for the presence of shale in Niger Delta reservoirs.

The first step in shaly sand analysis is to determine the volume of shale.

The Gamma Ray Index was first calculated as:
\[ I_{GR} = \frac{GR_{log} - GR_{min}}{GR_{max} - GR_{min}} \]  

\[ \text{GR max} \] means the maximum reading on the GR log.
\[ \text{GR min} \] means the minimum reading on the GR log.

The Shale Volume was then calculated using the (Larionov, 1969) nonlinear response method.
\[ V_{sh} = 0.083 \text{(2)}^{1/3} \left( I_{GR} - 1 \right) \]  

(For tertiary unconsolidated rocks).

Where:
- \( GR_{log} \) = GR reading from the log.
- \( GR_{min} \) = GR log reading in clean sandstone
- \( GR_{max} \) = GR log reading in shale zone.
- \( I_{GR} \) = Gamma ray index.
- \( V_{sh} \) = volume of shale.

Evaluating Porosity
Porosity is the ratio of voids to the total volume of rock in percentage, and is usually designated by the Greek letter phi (\( \Phi \)).

\[ \Phi = \frac{\text{Volume of pores}}{\text{Total volume of rock}} \]  

This is usually called the total porosity, but the effective porosity is a function of interconnected void spaces and is most useful in characterizing a reservoir. Consequently, in this project effective porosity will be used.

Density Porosity
The reservoir porosity calculated from the density data for this project was done with this formula.
\[ \Phi_D = \frac{P_{ma} - P_f}{P_{Ma} - P_f} \]  

Where:
- \( P_{Ma} \) = Matrix density (2.64g/cm³ for sandstones).
- \( P_f \) = Formation bulk density (from wire-log).
- \( P_{fl} \) = Fluid density (1.0g/cm³).

Average Neutron Density Porosity
\[ \Phi_A = \frac{(\Phi_D + \Phi_N)}{2} \]  

Where:
- \( \Phi_A \) = Average porosity.
- \( \Phi_D \) = Neutron porosity (from logs).
- \( \Phi_N \) = Density porosity.

Effective Porosity
The average porosity is corrected for shale effects to give effective porosity.
\[ \Phi_{E} = \frac{\Phi_A}{x \cdot 1 - V_{sh}} \]  

Where:
- \( \Phi_E \) = Effective porosity.
- \( V_{sh} \) = Shale volume.
- \( \Phi_A \) = Average porosity.

In general, field appraisal classifications of reservoir porosity are:

Percentage / Decimal
5% - 10% = 0.5 – 0.10 = poor.

Figure 2. schematic presentation of gamma ray log, showing the cut-off line (red dotted line)
10% - 20% = 0.10 – 0.20 = good.
Above 20% = above 0.020 = very good.

Resistivity of Formation Water (Rw)

The resistivity of water was determined in this project using the pickets plot. Figure 3.

![Figure 3. Determination of Rw from a Pickett plot. A linear scale plot.](image)

The value ranges between 0.01 – 10Ωm. A clean water bearing reservoir was identified for each well and porosity was plotted against uninvaded zone resistivity RT on a double logarithmic plot (pickets plot). A best fit line was drawn through the point; the intersection point of this best fit line on the resistivity axis will be the value of the Rw.

Determination of the Water Saturation (Sw)

The amount of pore volume in a rock that is occupied by formation water is referred to as water saturation. The pores of the formation may be filled with gas, oil or water and the sum of the saturation of all the fluids in the formation must total 100%.

Archie’s equation (1942) was used to estimate Sw:

\[
Sw = \left( \frac{a x Rw}{RT \times \phi^m} \right)^{1/n} \tag{7}
\]

Where:
- Sw = water saturation (in v/v decimal or percentage).
- Rw = is the resistivity of formation water.
- RT = Uninvaded zone resistivity from deep formation.
- \( \phi \) = Porosity of the zone.
- a = Tortuosity factor = (0.81) or local correction factor
- m = is cementation factor = 2.
- n = is the saturation exponent = 2.

Flushed Zone Water Saturation

Flushed zone water saturation was determined using Archie’s equation, but two variables were changed, mud filtrate resistivity (Rmf) given at the log header in place of formation water resistivity (Rw) and flushed zone resistivity (Rxo):

\[
S_{xo} = \left( \frac{a x Rmf}{R_{xo} \times \phi^{m}} \right)^{1/n} \tag{8}
\]

Sxo = Flushed zone water saturation.
Rmf = Resistivity of the mud filtrate
Rxo = Invaded zone resistivity determined (from the shallow resistivity log).
\( \phi \) = Formation porosity determined from the neutron and density.
- a = 0.81.
- m =2
- n = 2.

Determination of Hydrocarbon Saturation

The Hydrocarbon saturation is the fraction of reservoirs pore volume occupied by hydrocarbons.

\[
Sh = 1 - Sw. \tag{9}
\]

Where:
- Sh = hydrocarbon saturation
- Sw = water saturation.

Determination of Bulk Volume Water (Bvw)

The proportion of water in the total formation is referred to as bulk volume water. It can be used as an indicator that the formation is at irreducible water saturation. It is a product of the formations water saturation and porosity. When a formation is at irreducible water saturation (Swirr), values of the Bvw calculated over a range of depths in a formation are constant or very close to constant. Water in the uninvaded zone (Sw) does not move because it is held on grains by capillary pressure. Therefore hydrocarbon production from a zone at irreducible water saturation should be water free (Morris and Biggs, 1967). Thus Bvw increases with decreasing grain size.

\[
Bvw = Sw \times \phi \tag{10}
\]

Where:
- Bvw = Bulk volume water.
- Sw = Water saturation.
- \( \phi \) = Porosity.

Determination of Permeability (k)

Permeability is the ease of a rock to transmit fluids and is controlled by the size of the pore throat. It is measured in Darcy’s (or milidarcy md). The Wyllie & Rose (1950) log derived permeability equation was used. It is valid for estimating permeability in formations at irreducible water saturation (Schlumberger, 1985). Then values gotten are compared to values of nearby producing wells of the same formation.

\[
k = \left[ 250 \times \phi^3 \right]^{1/6} \tag{11}
\]

Where:
- k =log derived permeability
- Swirr = Irreducible water saturation.
- \( \phi \) = Porosity of the zone.

Reservoir permeability may be loosely described as follows:
- Very low: k < 1 md
- Low: 1 md < k < 10md.
- Fair: 10md < k < 50md.
- Average: 50md < k < 200md.
- Excellent: k > 500md.

Reservoir permeability varies widely, from 0.001md for tight gas sand in East Texas to 4000md for unconsolidated sands in the Niger Delta.

Determinations of the Movable Hydrocarbon Index (Mhi)

The ratio of water saturation (Sw) to flushed zone water saturation (Sxo) gives the amount of hydrocarbons which have been moved by the invasion process. The ratio is referred as the moveable hydrocarbon index. This provides an estimate of the producibility of oil.

\[
\frac{Sw}{Sxo} = \left( \frac{R_{xo} \times Rt}{R_{mf} \times Rw} \right)^{1/2} \tag{12}
\]

If the ratio Sw/Sxo is equal to or greater than 1.0, then hydrocarbon were not moved during invasion. This is true regardless of whether or not a formation contain hydrocarbons. Whenever the ratio is less than 0.7 for sandstones, the moveable hydrocarbon index. This provides an estimate of the producibility of oil.

Identifying the Hydrocarbon Bearing and Water Bearing Layers (OWC)

Hydrocarbon and water bearing layers can be easily delineated using resistivity log. From Archie’s equation (1942).

\[
R_f = \frac{Rw}{\phi^{m} Sw^n} \tag{13}
\]
Rt increases when porosity (Φ) decreases or density increases with lithology and Sw constant.

Water bearing intervals was outlined by low resistivity and trame lining between density and resistivity. The density decreases when the water is replaced by oil in the formation with the same porosity, thus the hydrocarbon bearing intervals was not only characterized by high resistivity but often by an anti-correction between the density and the resistivity logs. 

**Distinguish Between Oil and Gas. (OGC).**

Gas or light hydrocarbons within the zone of investigation of the Density or Neutron devices causes the apparent porosity from density log to increase and the Neutron log to decrease. On a Density-Neutron plot, this results in a shift (from the liquid-filled point of the same porosity) upward and to the left, almost parallel to the iso-porosity lines. This implies that Density and Neutron logs in a crossplot will be shifted in opposite directions in a hydrocarbon bearing zones. Thus zones with large density-neutron separation are identified as gas bearing zones and zones with small separation as oil bearing zones.

**Results and Discussions**

**Etu- Well 01**

Six major reservoirs intervals A1-A6 were delineated for this well as showed in figure 4. The reservoirs are clean sand shown by their V-shale values of 0.02 – 0.05 v/v decimal. Reservoir B1 has low average resistivity values of 56.7 ohm – m at 3105 – 3200m; this reduces to an average of 3.70 ohm – m at depths below 3105m suggesting that the fluid content in the intervals below this depth is water. This infers an oil-water (OWC) at that point.

**Etu – Well 03.**

Four major Reservoirs intervals C1 – C4 were delineated for this well as showed in figure 6.

<table>
<thead>
<tr>
<th>Reservoir</th>
<th>Net Oil (m)</th>
<th>Average density (g/cm³)</th>
<th>Average Porosity (Φ)</th>
<th>Average Resistivity (ohm/m)</th>
<th>API</th>
<th>Gross oil</th>
<th>Average shale (v/v)</th>
<th>Field type</th>
</tr>
</thead>
<tbody>
<tr>
<td>B1</td>
<td>95</td>
<td>82.7</td>
<td>0.04</td>
<td>2.50</td>
<td>10.8</td>
<td>25.9</td>
<td>0.06</td>
<td>WATER</td>
</tr>
<tr>
<td>B2</td>
<td>10</td>
<td>3.7</td>
<td>0.03</td>
<td>0.54</td>
<td>14.1</td>
<td>63</td>
<td>0.09</td>
<td>WATER</td>
</tr>
<tr>
<td>B3</td>
<td>7</td>
<td>4.1</td>
<td>0.04</td>
<td>0.92</td>
<td>13.6</td>
<td>65</td>
<td>0.08</td>
<td>WATER</td>
</tr>
<tr>
<td>B4</td>
<td>16</td>
<td>3.9</td>
<td>0.09</td>
<td>0.83</td>
<td>18.1</td>
<td>67</td>
<td>0.08</td>
<td>WATER</td>
</tr>
<tr>
<td>B5</td>
<td>10</td>
<td>1.9</td>
<td>0.04</td>
<td>0.44</td>
<td>26.4</td>
<td>44</td>
<td>0.07</td>
<td>OIL</td>
</tr>
<tr>
<td>B6</td>
<td>10</td>
<td>1.2</td>
<td>0.02</td>
<td>0.47</td>
<td>25.4</td>
<td>41</td>
<td>0.05</td>
<td>OIL</td>
</tr>
<tr>
<td>C1</td>
<td>5</td>
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<td>0.03</td>
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</tbody>
</table>

**The Petrophysical results are summarized in Table 3.**

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<td>23.9</td>
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<td>0.03</td>
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<td>81</td>
<td>0.04</td>
<td>0.45</td>
<td>23.9</td>
<td>15</td>
<td>0.03</td>
<td>OIL</td>
</tr>
</tbody>
</table>
The Petrophysical properties are summarize in Table 4. The reservoirs are well developed with good thickness ranging from 12 – 51m. There porosity $\Phi$, permeability $k$, and moveable Hydrocarbon index MHI values, are excellent to allow free flow of fluids.

**Table 4. Summary of the Petrophysical Results for Etu-Well 03.**

<table>
<thead>
<tr>
<th>Reservoir intervals (m)</th>
<th>Net Sand Count (%)</th>
<th>Average porosity (%)</th>
<th>Average saturation (H2O)</th>
<th>Average permeability (md)</th>
<th>Average Water Saturation (%)</th>
<th>Fluid Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1 2450-3238</td>
<td>95</td>
<td>96</td>
<td>0.30</td>
<td>0.4</td>
<td>615</td>
<td>OIL</td>
</tr>
<tr>
<td>C2 2290-2577</td>
<td>97</td>
<td>65</td>
<td>4.1</td>
<td>0.6</td>
<td>10.4</td>
<td>WATER</td>
</tr>
<tr>
<td>C3 2550-2713</td>
<td>65</td>
<td>35</td>
<td>2.1</td>
<td>0.4</td>
<td>12.25</td>
<td>OIL</td>
</tr>
<tr>
<td>C4 2740-2775</td>
<td>10</td>
<td>15</td>
<td>2.1</td>
<td>0.4</td>
<td>18</td>
<td>WATER</td>
</tr>
<tr>
<td>C5 3100-4118</td>
<td>46</td>
<td>51</td>
<td>2.5</td>
<td>0.4</td>
<td>10.1</td>
<td>WATER</td>
</tr>
</tbody>
</table>

Reservoirs $C_1$ and $C_3$ show evidence of hydrocarbon saturation as the total resistivity ($R_t$) value are greater than the $R_o$ values. Below 3969m depth in reservoir $C_4$ could be water. Reservoir as indicated by high water saturation values 69% marking the oil – water contact (OWC). Also, Reservoir $C_2$ and $C_4$ could be water as indicated by high water saturation and $R_t$ approximately equal to $R_o$ ($R_t = R_o$).

**Etu – Well 04.**

Seven major reservoirs intervals $D_1$ – $D_7$ were delineated for this well as shown in Figure 7.

**Figure 7. Schematic presentation of petrophysical interpretation of Etu-04.**

A cut off values of 67.5 API were determined. The Petrophysical properties are summaries in Table 5.

**Table 5. Summary of the Petrophysical results for Etu-well 04.**

<table>
<thead>
<tr>
<th>Reservoir intervals (m)</th>
<th>Net Sand Count (%)</th>
<th>Average porosity (%)</th>
<th>Average saturation (H2O)</th>
<th>Average permeability (md)</th>
<th>Average Water Saturation (%)</th>
<th>Fluid Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>D1 2710-2732</td>
<td>10</td>
<td>25</td>
<td>110</td>
<td>0.00</td>
<td>0.45</td>
<td>OIL</td>
</tr>
<tr>
<td>D2 2790-2803</td>
<td>90</td>
<td>20</td>
<td>2.2</td>
<td>0.04</td>
<td>0.35</td>
<td>WATER</td>
</tr>
<tr>
<td>D3 2870-2878</td>
<td>75</td>
<td>20</td>
<td>120</td>
<td>0.06</td>
<td>0.56</td>
<td>3143</td>
</tr>
<tr>
<td>D4 3400-4046</td>
<td>90</td>
<td>25</td>
<td>120</td>
<td>0.05</td>
<td>0.4</td>
<td>18</td>
</tr>
<tr>
<td>D5 3460-4050</td>
<td>21</td>
<td>25</td>
<td>120</td>
<td>0.05</td>
<td>0.47</td>
<td>10</td>
</tr>
<tr>
<td>D6 3940-4050</td>
<td>46</td>
<td>25</td>
<td>26</td>
<td>0.06</td>
<td>0.4</td>
<td>2015</td>
</tr>
<tr>
<td>D7 4510-4535</td>
<td>11</td>
<td>25</td>
<td>120</td>
<td>0.45</td>
<td>0.25</td>
<td>1294</td>
</tr>
</tbody>
</table>

Reservoirs $D_1$, $D_2$, $D_3$, $D_4$, $D_5$, could be hydrocarbon as indicated by their high resistivity $R_t$ and low water saturation $Sw$. Reservoir $D_3$ & $D_4$ could be gas considering the neutron and density log separation while reservoirs $D_2$ and $D_5$ could be water as evident from their low resistivity and high water saturation values.

**Etu – Well 05.**

Seven major Reservoirs intervals $E_1$ – $E_7$ with average net sand ranging 7 – 25m thick were delineated Figure 8.

**Figure 8. schematic presentation of petrophysical interpretation of Etu-05.**

The Petrophysical properties are summarized in Table 6.

**Table 6. Summary of the Petrophysical Results of Etu-Well 05.**

<table>
<thead>
<tr>
<th>Reservoir intervals (m)</th>
<th>Net Sand Count (%)</th>
<th>Average porosity (%)</th>
<th>Average saturation (H2O)</th>
<th>Average permeability (md)</th>
<th>Average Water Saturation (%)</th>
<th>Fluid Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>E1 2870-2880</td>
<td>90</td>
<td>25</td>
<td>110</td>
<td>0.00</td>
<td>0.45</td>
<td>OIL</td>
</tr>
<tr>
<td>E2 2790-2803</td>
<td>90</td>
<td>20</td>
<td>2.2</td>
<td>0.04</td>
<td>0.35</td>
<td>WATER</td>
</tr>
<tr>
<td>E3 2870-2878</td>
<td>75</td>
<td>20</td>
<td>120</td>
<td>0.06</td>
<td>0.56</td>
<td>3143</td>
</tr>
<tr>
<td>E4 3400-4046</td>
<td>90</td>
<td>25</td>
<td>120</td>
<td>0.05</td>
<td>0.4</td>
<td>18</td>
</tr>
<tr>
<td>E5 3460-4050</td>
<td>21</td>
<td>25</td>
<td>120</td>
<td>0.45</td>
<td>0.25</td>
<td>1294</td>
</tr>
<tr>
<td>E6 3940-4050</td>
<td>46</td>
<td>25</td>
<td>26</td>
<td>0.06</td>
<td>0.4</td>
<td>2015</td>
</tr>
<tr>
<td>E7 4510-4535</td>
<td>11</td>
<td>25</td>
<td>120</td>
<td>0.45</td>
<td>0.25</td>
<td>1294</td>
</tr>
</tbody>
</table>

The Pickett plot aided in the determination of the resistivity of the formation water. The indication of high resistivity $R_t$ ($R_t > R_o$) and low water saturation about 18% of Reservoirs $E_1$, $E_3$, $E_4$, $E_5$, and $E_7$ could be probably Hydrocarbon reservoirs. The negative separation of neutron and density log signatures distinct in reservoir $E_4$ could be an indication of gas filled reservoir (Figure 8). Reservoirs $E_5$ and $E_6$ could be water filled as indicated by high water saturation values.

**Etu – Well 06.**

Four reservoirs $F_1$ - $F_4$ with average net sand ranging 7 – 25m thick were delineated. The Petrophysical properties are summarized in Table 7.

**Table 7. Summary of the Petrophysical Results for Etu-Well 06.**

<table>
<thead>
<tr>
<th>Reservoir intervals (m)</th>
<th>Net Sand Count (%)</th>
<th>Average porosity (%)</th>
<th>Average saturation (H2O)</th>
<th>Average permeability (md)</th>
<th>Average Water Saturation (%)</th>
<th>Fluid Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>F1 2780-3100</td>
<td>90</td>
<td>25</td>
<td>110</td>
<td>0.00</td>
<td>0.45</td>
<td>OIL</td>
</tr>
<tr>
<td>F2 2890-2910</td>
<td>100</td>
<td>18</td>
<td>5.5</td>
<td>0.04</td>
<td>0.35</td>
<td>WATER</td>
</tr>
<tr>
<td>F3 3580-3510</td>
<td>44</td>
<td>20</td>
<td>4.6</td>
<td>0.03</td>
<td>0.55</td>
<td>15.8</td>
</tr>
<tr>
<td>F4 3780-3800</td>
<td>90</td>
<td>19</td>
<td>120.5</td>
<td>0.05</td>
<td>0.55</td>
<td>2971</td>
</tr>
</tbody>
</table>
The Average resistivity values for F2 and F3 is 5.7 ohm-m and 5.6 ohm-m with water saturation values are 65% and 46% respectively, suggesting water as the fluid content. Reservoir F1 & F2 with a high resistivity value of 128.5 ohm-m and low water saturation of 24% could suggest hydrocarbon.

The Neutron – density crossplot showed that reservoir F1 contain gas figure 9.

The average MHI values of 0.56 and 2971.5 md of permeability in reservoir F1 & F2 suggest good fluid moveability.

**Etu – Well 07.**

Table 8. Summary of Petrophysical Results for Etu-Well 07.

<table>
<thead>
<tr>
<th>Reservoir Interval (Ft)</th>
<th>Net Sand Count (%)</th>
<th>Average Porosity (%)</th>
<th>Average Resistivity (ohm-m)</th>
<th>Average Values (API Decimal)</th>
<th>Average MHI</th>
<th>Average Resistivity (ohm-m)</th>
<th>Average Water Saturation (%)</th>
<th>Fluid Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>G1</td>
<td>47</td>
<td>29</td>
<td>4.1</td>
<td>0.029</td>
<td>0.99</td>
<td>19</td>
<td>65</td>
<td>WATER</td>
</tr>
<tr>
<td>G2</td>
<td>45</td>
<td>25</td>
<td>3.4</td>
<td>0.220</td>
<td>0.01</td>
<td>21</td>
<td>75</td>
<td>WATER</td>
</tr>
<tr>
<td>G3</td>
<td>92</td>
<td>26</td>
<td>8.0</td>
<td>0.023</td>
<td>0.16</td>
<td>20</td>
<td>85</td>
<td>GAS</td>
</tr>
<tr>
<td>G4</td>
<td>90</td>
<td>29</td>
<td>0.2</td>
<td>0.200</td>
<td>0.09</td>
<td>21</td>
<td>66</td>
<td>WATER</td>
</tr>
</tbody>
</table>

Four reservoirs G1 - G4 were delineated with good sand sedimentation. Average Net sand ranging 7 – 70m thick.

The Petrophysical properties are summarize in Table 8. Reservoir G3 with high resistivity value 89 ohm-m and low water saturation of 17% suggests a hydrocarbon filled reservoir. The neutron density crossplot showed that G3 could contain gas Figure 10. Average resistivity values of G1, G2 and G3 are 8.1, 4.5 and 3.2 ohm-m and water saturation are 85, 75 and 65% respectively suggest reservoir filled water.

**Conclusion**

The quality of the reservoirs in the Etu Field Niger delta are 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. 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. So the geometric properties (porosity and permeability) are bound to vary relatively. A total of seven wells have been drilled into the Etu structure encountering thirty seven (37) reservoirs between 3000-4500m. Sixteen (16) of the reservoirs are oil bearing, six (6) are gas bearing while fourteen (14) are water saturated, that is, water bearing reservoirs. The hydrocarbon found at the shallow depths are trapped against the southernmost anti-thetic fault while at deep levels hydrocarbons are dip closed in footwall of this same anti-thetic fault.

**References**


