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# Horizontal Well Design to Enhance Oil Recovery in the Niger Delta Area of Nigeria Using Schlumberger Petrel Software

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**Abstract:** For the purpose of adapting horizontal well drilling technology to enhance oil recovery in the Niger Delta area of Nigeria, well (wireline) logs, deviation data, 3D seismic data and check shot for selected wells were collected for "Erinke" field of Chevron Nig. Limited. Schlumberger Petrel Software was used to analyze the data in order to create a 3D graphic representation of the reservoir. Thereafter, well correlation was carried out on the producer wells: W1500, W900, W1000, W1600, W800 and the injection wells: OLA200, OLA 400, OLA 500, OLA 600 and OLA 300. The wells were correlated to determine the zones that were rich in sand with high permeability, high porosity, high oil saturation and low water saturation. The essence of the well correlation exercise was to determine the hydrocarbon pay-zone by picking the reservoir to be modeled and to suggest the location and sitting of a new horizontal producing oil well, tagged Barnes 1, based on the given data. In order to select a hydrocarbon reservoir, the gamma ray was compared with resistivity log. The results shows that the reservoir trap considered for this study had many discontinuities, which proved to be a good site for the drilling of the proposed horizontal well. The study also confirmed that taken into consideration the proposed location of the horizontal well (Barnes 01), the productivity index was perceived to be higher when compared to drilling a vertical well along the same location. The reservoir was highly permeable and porous with high oil-to-water saturation ratio.

**Key words:** Horizontal, permeable, correlation, wireline, seismic, reservoir, permeability, porosity

## INTRODUCTION

The concept of Horizontal or Multilateral Wells was born from the tentacles of plant roots which deviate from the main stem. In applying this idea, the engineers who were initially producing from the Vertical Wells discovered how much the production output would be if such networking in plants occurs in a well bore (Scofield, 1997). This was primarily aimed at improving production output and was regarded as another means of enhancing oil recovery and reducing Gas-to-Oil Ratio (GOR). Since, this process began in 1928, there has been large increment in the oil output relatively to Vertical Wells. So far, more than 75 000 wells has been drilled in the world and about 2500 of the wells in Russia alone are either Horizontal or Multilateral Wells with improvement production value to about 40-50% guaranteed (Brent *et al*., 1998). Ever since the inception of this well pattern of draining hydrocarbon from the reservoir, it has recorded huge success all over the world. According to Sibneft Chief Engineer, Iskemder Diyashev, he asserted that his company was able to enhance production in its Noyaberk Western Siberia operations with 50% of the increase coming form Horizontal and Multilateral Wells, which only makes 4% of their total well stock (Schuuh, 1989). Similarly, the Chief Reservoir Engineer of Schlumberger Middle-East operations, Fikri Kuchuk examined HW and MW performance, emphasizing the shortfall in performance as a result of: Inadequate clean-up, Water sumps in the wellbore and Uneven distribution in the near-wellbore formation that may reduce the Productivity-Improvement factors (PI) to 30-50% of its potential value.

The use of Horizontal Wells started in the 1950s where the Russians drilled 43 Horizontals. Later on in 1978, ESSO constructed a modern Horizontal Well in Alberta (Hill, 1995). In other to overcome high Gas-Oil Ratio (GOR) and gas and water coning which affected productivity the well management team of Arco proffered a solution which lead to the construction of a Horizontal Well in 1979. By 1979-83, Elf tested 3-onshore horizontals and Elf and Agip constructed their first offshore horizontal in Ropso Mare, Adriantic. Later on in the 80's, over 50 horizontals had been drilled worldwide which was preceded by the Horizontal Well test theory and

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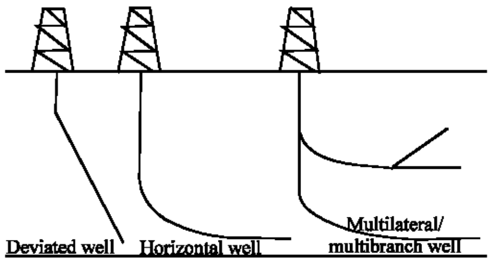


Fig. 1: Common types of deviated, horizontal and multilateral well

Productivity Assessment Guidelines (Schuuh, 1991). Following this trend of universal achievements, horizontals drilled had jumped from 265-1000, just within 1989- 1990. Two years later the count was over 2500 horizontals drilled worldwide, while 75% where found in the North America. The cost of Horizontal well is between 1.5-3 times greater than Vertical Wells. Today, there are more than 2500 horizontal well existing in Russia alone (Lowson, 1998). Figure 1 shows typical features of deviated, horizontal and multilateral wells.

**Geology of the niger-delta area of Nigeria:** The 12 km thick Niger Delta classic wedge spans a 75, 000 $km^2$ area in southern Nigeria and the Gulf of Guinea, offshore Nigeria. This classic wedge contains the 12th largest known accumulation of recoverable hydrocarbons, with reserves exceeding 34 billion barrels of oil and 93 trillion cubic feet of gas (Doust and Omotsola, 1990). The Niger-Delta is perhaps the most important sedimentary basin in Sub-Sahara Africa with respect to petroleum production. It is in rank with the major oil deposits in the world, such has the Orinoco basin in Venezuela; Gulf of Mexico etc The Niger-Delta region has been the centre of the world attention since 1957 since oil was discovered in Oloibiri (Whiteman, 1990). Currently having more than 1500 oil fields, with high grade crude production and more reserves being found continuously, it will continue to be an important region for a long time. Coupled with this is the unique geological features it posses compared with other existing deltas in the world. It stands as a typical example of a delta. In geologic time scale, it is within the Cenozoic formation of Southern Nigeria, while it covers an area of about 75,000 $km^2$. It extends from the Calabar flank and the Abakaliki trough in Eastern Nigeria to the Benin flank in the west and it opens to the Atlantic Ocean in the South (Weber, 1991). The Delta protrudes into the Gulf of Guinea as an extension from the Benue trough and Anambra basin provinces. The delta complex merges westwards across the Okitupupa high into the Dahomey embankment. To the southeast, the important line of volcanic rocks comprising the Cameroon volcanic zone and Guinea ridge form the other margin. The tertiary Niger Delta is a sedimentary structure formed as a complex regressive offlap sequence of classic sediments ranging in thickness from 9000-1200 m (Weber and Daukoru, 1995). The undulating plain of the interior lowland consists of a physiographic region north of the coastal lowlands and the Niger Delta, with an average elevation of about 100 m (assumed sea level). They are underlain by young sedimentary formations with a well-drained surface. By far better drained than the other two regions above, its sedimentary deposits describe the Cretaceous and Tertiary rocks of shales, coal, sandstones and clays, with abundance of limestone. The interior lowlands cover upper Lagos, southern Ogun, major parts of Ondo, Edo and Delta States to the west and most parts of Anambra, Imo, Abia and Akwa Ibom States to the east.

**Well design criteria**

**Target definition:** The data used for well design usually include: Target co-ordinates, Entry point into the reservoir, Length of Horizontal Drain, Azimuth of Horizontal Drain, Vertical range of Target, Dip of target, Tolerance in vertical depth and displacement. Figure 2 shows the geometry of a typical horizontal well while Table 1 shows a typical trajectory calculation table.

**Design Calculation (Caradan, 1998)**

**Dogleg severity:** The formular commonly used for dogleg calculation is given as follows:

$DLS$ = $100/MD \; Cos^{-1} [Cos\, I_1\, Cos I_2 + Sin I_1 Sin I_2\, Cos\, (A_2 - A_1)]$

$DLS$ = Dogleg Severity, degree 100 feet.
A = Azimuth direction, degree.
I = Inclination, degrees.
MD = Measured distance, feet.
$\Delta$ = Change between survey stations.
1,2 = Subscripts to denote survey stations.
AE = L Length drilled from A-E
R = $360/2\pi \times \Delta L/\Delta i$ (R= Radius of Curvature)
gbu = $\Delta i/\Delta L$ gbu=rate of build-up degree/10yd
R = 573/gbu (ft)

**Torque and drag designs:** The following equation applies to tripping operations or steering with a downhole motor:

**Horizontal section:**

$$D_h = 0.33\, W_m L;$$

where,

$D_h$ = Drag force in Horizontal section.

Table 1: Trajectory table

| Kick of point (K) | Measured depth L(TMD) | Vertical depth Z (TVD) | Inclination | Displacement |
|---|---|---|---|---|
| | $Z_k$ | $Z_k$ | O | O |
| End of deviation (E) | $L_E = Z_k + (\pi iR/180)$ | $Z_E = Z_k + R\mathrm{Sin}\ i$ | I | $D_E = R(1- \mathrm{Cos}\ i)$ |
| Target (T) | $L_T = Z_k + (\pi iR/180) + ((Z - Z_k - R\mathrm{Sin}\ i)/ \mathrm{Cos}\ i)$ | Z | I | D |

Where D = Displacement, $Z_k$ = Kick of point, i = angle of inclination, Z = vertical depth of Target

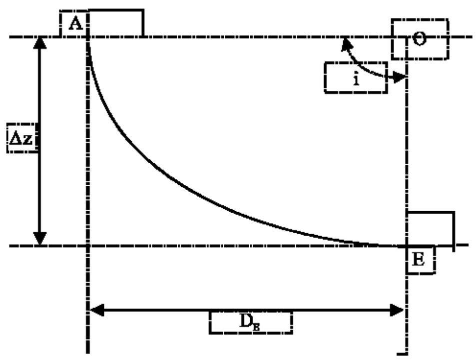


Fig. 2: Geometry of a typical horizontal well

**Build-up curve:** The drag force in the build-up section is a function of the axial compression force ($F_o$) at the end of the build curve (Craig and Randall, 1996). Assuming a single build-up curve, then the axial compression force at the end of the build- up curve is the sum of the Weight-On-Bit (WOB) and drag force in the horizontal section:

$$F_o = D_h + WOB$$

If $F_o < 0.25$ Wm R, then the drag force ($D_b$) in the build curve is given by:

$$D_b = 0.4\ W_m\ R$$

If $F_o > 0.25\ W_m$ R, then drag force ($D_b$) in the build curve is given by

$$D_b = 0.25\ W_m\ R + 0.69\ F_o$$

**Critical buckling force:** $1F_c = 550\ [\ (I\ W_{dp}\ (65.5 - MW)\ \mathrm{Sin}\ \theta)/\ D_H - D_{TJ}]^{1/2}$

Where,

$F_c$ = Critical buckling force, Ib.

I = Moment of Inertia of pipe, $in^4 = A_s/16\ (OD^2 + ID^2)$.

OD = Ontside diameter pie body.

ID = Inside diameter pipe of body.

$W_{dp}$ = Weight of drillpipe of pipe in air, Ibft.

MW = Mud desity.

$D_H$ = Hole diameter.

$D_{TJ}$ = Diameter of tool joint, in.

θ = Hole angle, degrees.

**Overview of petrel workflow tools:** The development of Petrel began in 1996, a software owned by Schlumberger (2003), in an attempt to combat the growing trend of increasingly specialized geoscientists working in increasing isolation. The result was an integrated workflow tool that allows Exploration Production companies to think critically and creatively about their reservoir modeling procedures and allows specialized Geoscientists to work together seamlessly (Schlumberger, 2003). With the enhanced geophysical tools available together with the integration of ECLIPSE and Streamline simulation, Petrel is a complete Seismic to Simulation tool. The application of Petrel to well designs include design of well tracks in 3D and it help to minimize the total cost of your drilling program.

The objective of the study is to use Petrel Software workflow tools for horizontal well design to enhance oil recovery in the Niger Delta area of Nigeria. This would be applicable to old-existing oil wells and newly developed fields.

## MATERIALS AND METHODS

**Data collection:** The data used for this study which were collected from “Erinke” field of Chevron Nig. Limited consisted of:

- Well (wireline) logs for seven wells. This was written in the LAS format.
- Deviation data for wells 4 and 7 (these wells were deviated wells).
- 3D seismic data in the SEGY format.
- Checkshot for each of the wells.

**Data preparation:** The logs for the respective wells were first converted from the LAS format using Microsoft Notepad (The LAS-file contains header data and log data). The header is not read, only the base. The number of header lines is auto-detected. Logs with standard names such as PORO, PERM, amongst others, are detected and listed during import. It was then sorted out to create the well header for the wells, the well path and well deviation data for the deviated wells.

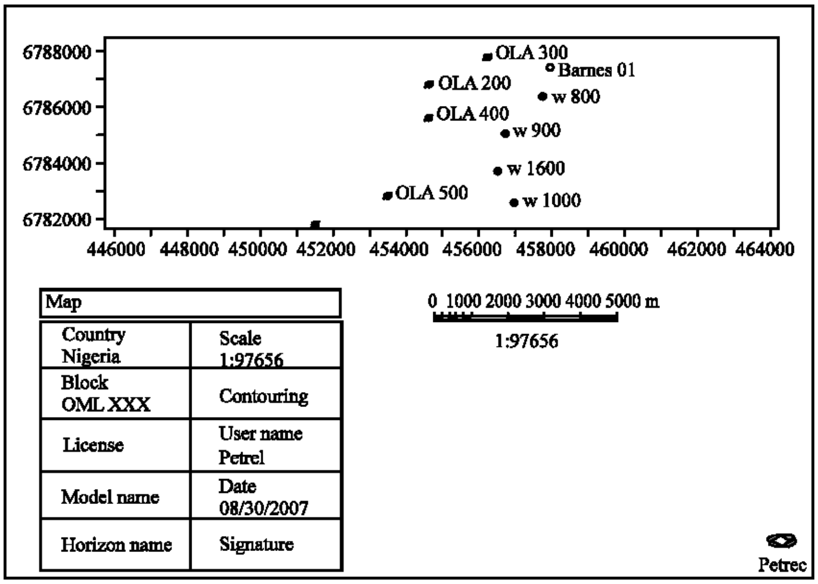


Fig. 3: Base-map showing the location of barnes 01, injector wells and producing wells

**Data analysis and presentation:** The above data were analyzed using Schlumberger Petrel workflow tools 2003 and windows based software like the Microsoft excel, WordPad, Microsoft Visio and Paint for the analysis and the presentation of the data. The data presentation was first converted from the bitmap format using Microsoft Paint before presentation. The process involves the use of wireline and seismic logs gotten from the wells in the Niger Delta Region of Nigeria and then the use of Petrel Software, to analyze this data to create a 3D graphic representation of the reservoir. This processes involved the following steps:

**Input the data into the software:** This is the first step carried out before any operation is carried out in Petrel. The algorithm for the importation is stated below:

Input Well Header/Create Well Header Info➜
Input well deviation ➜ Input well logs ➜
Input Well tops/Create Well tops.

**Creation of base map:** A base map of the field was then created to show the position of the available wells. Figure 3 shows the Base-Map of the location of Barnes 01, injector wells and producing wells.

**Well correlation:** Well correlation was carried out on producer wells W1500, W900, W1000, W1600 and W800 and the Injection wells, OLA200, OLA 400, OLA 500, OLA 600 and OLA 300. These wells were correlated to determine their zones rich in sand, high permeability, high porosity, high oil saturation and low water saturation. And this was achieved by picking the top of the sands which showed the presence of hydrocarbon. The essence of well correlation is to determine the hydrocarbon pay-zone by picking the reservoir to be modeled and to suggest the location and sitting of a new Producing Oil Well (Barnes 1) based on the given data. In order to select a hydrocarbon reservoir the gamma ray was compared with resistivity log. And the horizons were picked from the comparison. In all seven horizons were picked, named as Akata (Top of reservoir model), Esso 1, Esso 2, Esso 3, Onyinye 1, Onyinye 2 and Eko (Base of reservoir model).

**Seisimic interpretation:** The seismic data was loaded into the software and this was used to model the surface in time. From this data, the in lines and the cross lines were generated and the faults were modeled on the inline. A synthetic seismogram was generated and the faults were modeled on the inline. A synthetic seismogram was generated for the seismic data and this was used to quality check the previous Horizons that was picked from the well section window.

**Time-depth relationship:** Analysis was carried out on the checkshot data from the wells to determine if there is a relationship between the time and depth.

**Pillar gridding:** This was done to define the geometry of the faults that have been selected from the inline of the seismic data.

**Making of surfaces:** The Horizons were converted to surfaces.

Table 2: Typical well report from petrel for horizontal well design

| Exit Zone | Enter Zone | X | Y | Z | MD | Segment | Dip angle | Dip azimuth |
|---|---|---|---|---|---|---|---|---|
| | Zone 1 | 457514.7 | 6788402.8 | -1942.31 | 2398.53 | Segment 9 | 5.79 | 8.08 |
| Zone 1 | Esso 3 | 457401.4 | 6788420.7 | -1976.82 | 2518.33 | Segment 9 | 7.38 | 279.82 |
| Esso 3 | | 457215.6 | 6788433.1 | -2003.59 | 2707.18 | Segment 14 | | |
| | Onyinye 1 | 456949.3 | 6788432.3 | -2020.15 | 2974.01 | Segment 14 | 13.68 | 296.4 |
| Onyinye 1 | Onyinye 2 | 456810.4 | 6788431.8 | -2028.4 | 3113.14 | Segment 14 | 22.81 | 290.72 |
| Onyinye 2 | Esso 1 | 456640.3 | 6788431.9 | -2033.19 | 3283.27 | Segment 14 | 18.61 | 284.78 |
| Esso 1 | Esso 2 | 456530.6 | 6788431.9 | -2036.28 | 3393.07 | Segment 14 | 15.15 | 294.8 |
| Esso 2 | Onyinye 1 | 455575.8 | 6788431.9 | -2063.18 | 4348.26 | Segment 18 | 8.4 | 261.58 |
| Onyinye 1 | Onyinye 2 | 455408.3 | 6788431.9 | -2068.81 | 4515.82 | Segment 18 | 9.59 | 256.65 |
| Onyinye 2 | Esso 1 | 455213.5 | 6788431.8 | -2075.82 | 4710.7 | Segment 18 | 13.43 | 278.03 |
| Esso 1 | Esso 2 | 455086.7 | 6788431.8 | -2080.38 | 4837.63 | Segment 18 | 12.77 | 293.81 |
| Esso 2 | Esso 3 | 454475 | 6788431.8 | -2102.37 | 5449.71 | Segment 18 | 7.58 | 220.15 |
| Esso 3 | | 454151.7 | 6788431.7 | -2114 | 5773.24 | Segment 1 | | |
| | Onyinye 1 | 453972.3 | 6788431.7 | -2120.45 | 5952.78 | Segment 1 | 8.78 | 301.05 |
| Onyinye 1 | Onyinye 2 | 453732.2 | 6788431.7 | -2129.08 | 6193 | Segment 1 | 15.17 | 299.19 |
| **Fault** | | | | | | | | |
| Main Fault NS 2 | | 455575.8 | 6788431.9 | -2063.18 | 4348.25 | Segment 18 | 8.4 | 261.58 |
| **Endpoint** | Zone | | | | | | | |
| | Onyinye 2 | 453481.7 | 6788431.9 | -2136.98 | 6443.67 | Segment 1 | | |

Well report, Model name: Woye2007, Grid name: woyes final, Well name: Barnes01

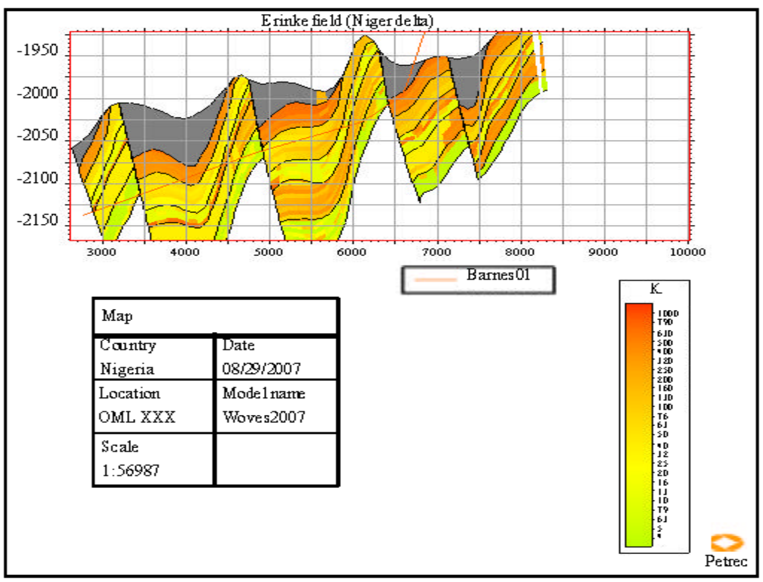


Fig. 4: Showing the permeability of reservoir and the point of contact with barnes 01

**Depth conversion:** Here, the surfaces and the models created so far in the seismic time cube were converted to depth so that it can be combined with the wells and the logs generated in depth format.

**Zonation:** The zones were then inserted inside the depth and converted the pillar grids to obtain a 3-D structural framework of the reservoir.

**Well design:** The next step we took was to digitize the well path after which we did a quality control by creating a vertical well intersection to display different types of data on it. Also, a synthetic well log was generated along the well path based on the input from the model generated. The synthetic logs include that of porosity, permeability, oil and water saturation. Lastly, a well report was created which is the document needed by the drilling team when drilling operations start. The well report generated indicates the exit and entries of the designed wells in the reservoir selected. Table 2 shows a typical well report created in the course of this study.

## RESULTS AND DISCUSSION

Figure 4-7 indicates point of contact of the proposed well, Barnes 01, with various reservoir characteristics, such as porosity, permeability, Gas to oil Contact, Oil-Water Contact, Oil Saturation.

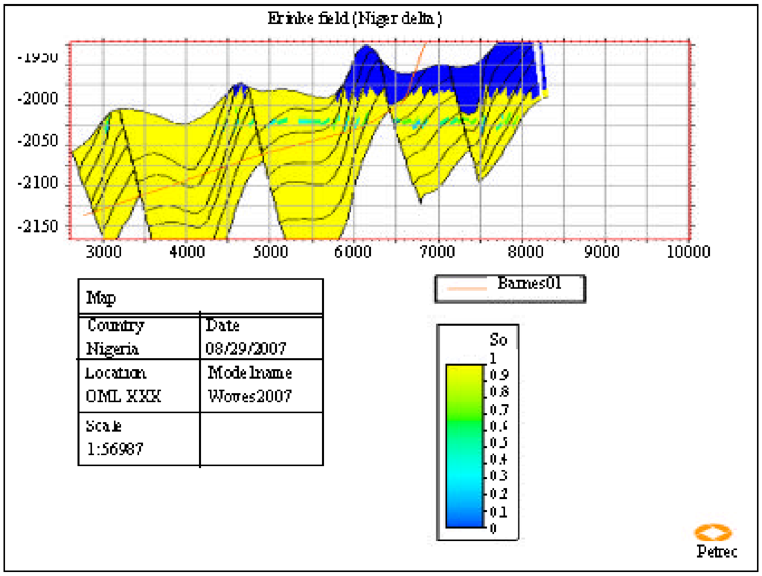


Fig. 5: Showing the oil saturation of reservoir and point of contact with barnes 01

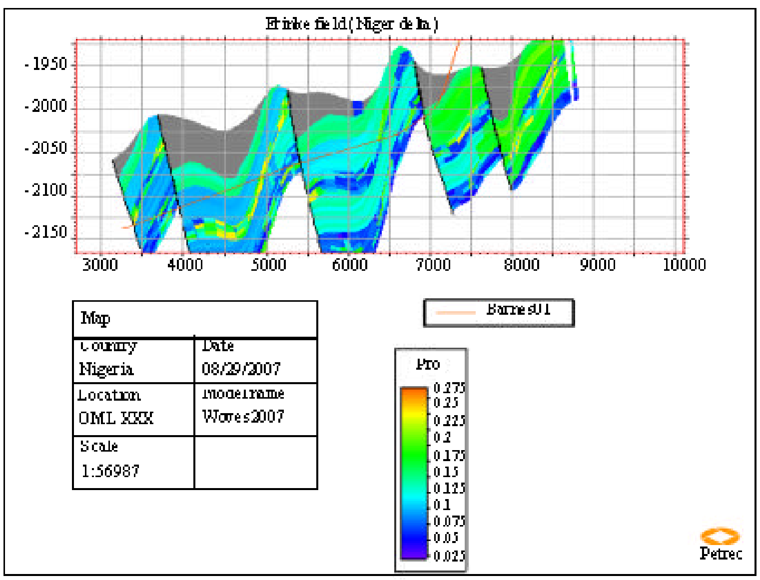


Fig. 6: Showing the porosity of reservoir and point of contact with barnes 01

Figure 4 shows the permeability of reservoir and the point of contact with Barnes 01, while Fig. 5 shows the oil saturation of reservoir and point of contact with Barnes 01. Also, Fig. 6 shows the porosity of reservoir and point of contact with Barnes 01, while Fig. 7 shows the point of contact of GOC/OWC with Barnes 01. These figures show the recovery index and justify the location of the Proposed well, Barnes 01. The Horizontal Well design was carefully located to cut through the major faults in the reservoir considered. During the design, High Pressure and High Temperature (HPHT) regions where avoided, so as not lead to loss of lives and assets. Barnes 01 is quite long with MD put at 3,718.87m and an assumed kick of point from 1,206.27 m. The Maximum DLS considered is put at 3. The software was also used to design three-dimensional (3D) and two-dimensional (2D) models of the reservoir to make drilling of Barnes 01 easy. The 3D modeling (design) of Barnes 01 showing point of intersection with gas-oil-contact/oil-water-contact (GOC/OWC) is shown in Fig. 8, while Fig. 9 shows the 2D design of Barnes 01 showing assumed location of

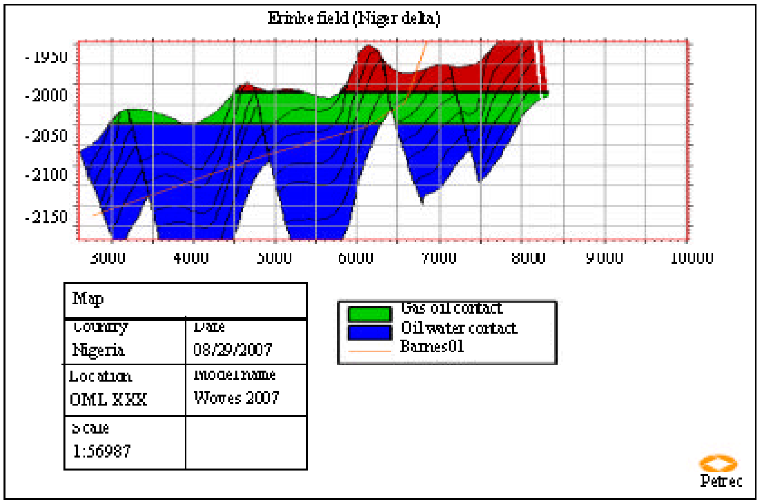


Fig. 7: Showing the point of contact of GOC/OWC with barnes 01

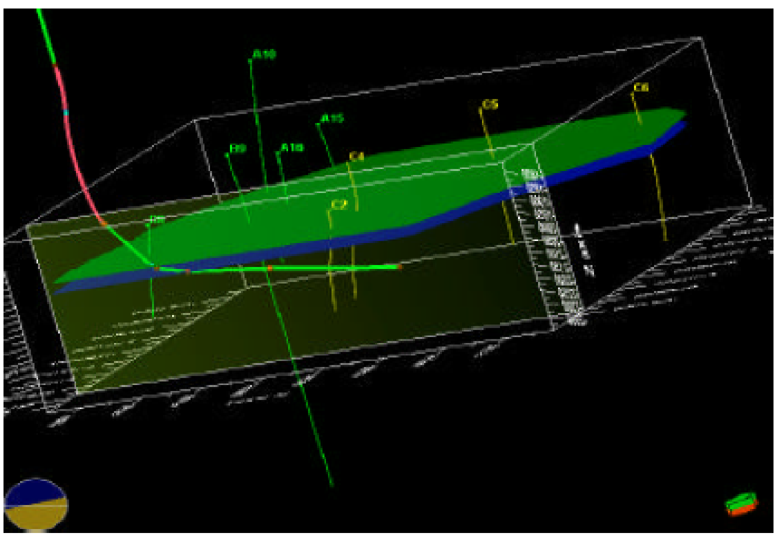

Fig. 8: 3D modeling of barnes01 showing point of intersection with GOC/OWC Contact

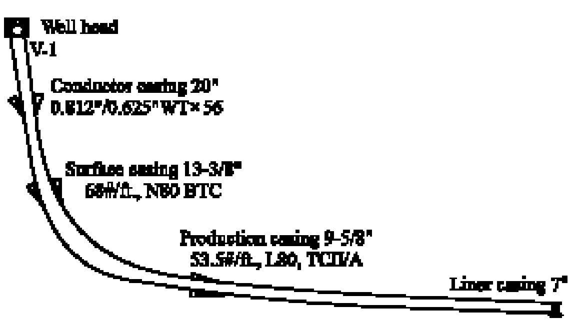


Fig. 9: 2D representation of barnes 01 showing assumed location of casings

casings. The field being studied had five wells which were producing oil before the design of Barnes 01, The wells are: W1500, W 1000, W800, W1600 and W900. It also had four water injectors namely: OLA200, OLA400, OLA500 and OLA600; and one gas injector, OLA300. The Fig. 10 is an upscale log generated form the processed data. The figure shows that the well has high permeability and porosity which makes the location of Barnes 01 suitable in that region. The well log generated acts as a preliminary log for easy analysis of the well prior to Measurement While Logging (MWL) process. This helps to determine regions to be cased and perforated.

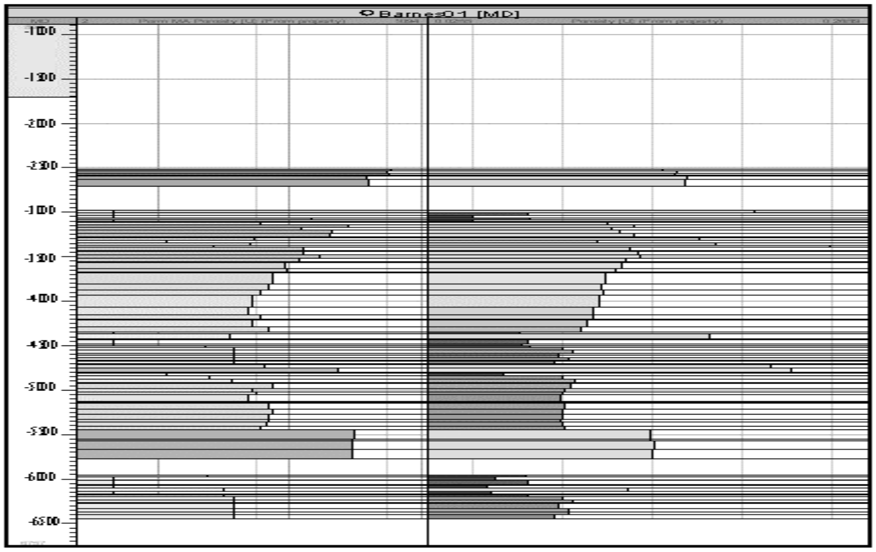

Fig. 10: Generated well log from upscaled data for barnes 01

## CONCLUSION

The reservoir trap of "Erinke" field in the Niger Delta area of Nigeria, considered for this study has proven to have many discontinuities, which is a good site for the drilling of Barnes01. In this regard it is imperative that the well be spudded on time. Considering the Location of Barnes 01, the productivity index is perceived to be high compared to drilling a vertical well along the same location. The reservoir is highly permeable and porous with high Oil-to-water saturation ratio. The water and gas reservoir regions of the trap have been carefully dealt with in this design. With the well report having been generated, pre-drilling time would have been reduced thereby saving cost. More information will be revealed as logging takes place. This will help to identify clearly, the regions to be perforated, blocked or artificially fractured.

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