Journal of Engineering and Applied Sciences 2 (11): 1651-1660, 2007
ISSN: 1816-949X

3D Formation Evaluation of an Oil Field in the Niger Delta Area of Nigeria Using Schlumberger Petrel Workflow Tool

Z. O. Opafunso
Department of Mining Engineering, Federal University of Technology, Akure, Nigeria

Abstract: In this study, Schlumberger Petrel software was used to evaluate an oil field in the Niger Delta area of Nigeria using digitized well and wire line log data from four wells owned by Chevron Nigeria Limited. Structural and property modeling of the reservoir were carried out. The structural modeling in Petrel workflow tools process deals with 3-dimensional faults and facies modeling while property modeling involves the distribution of petrophysical parameters in the three Dimensional (3D) window. Analysis and interpretation of result showed that the permeability distribution is a direct indication of the pore connectivity within the reservoir reflecting excellent results in the areas with high permeability and vis-versa. The dominant formation orientation is within southwest-northeast dip directions. These channel deposits contain packages of inclined heterolithic stratification, formed from sandstone and conglomerate. The combination of sealed granulation seams as well as closed fractures caused problems for fluid movement horizontally through the reservoir as they create compartments which were not link with each other. Since this phenomenon could lead to a drop in pressure in the production well, alternative injection oil well could be drilled to improve production. The untapped crude oil remaining in the study area could be tapped by drilling extra oil wells.

Key words: Evaluation, modeling, fault, logging, lithology, porosity, permeability

INTRODUCTION

Anglo Dutch Consortium came to Nigeria as Shell D'arcy (now Shell Development Company) in 1937 to start exploration activity after being awarded the sole concession right by the then Colonial Administration in Nigeria. After many years, a commercial deposit of crude oil was discovered in Olobiri in Niger Delta in 1956 and in 1958, Shell began production and exporting from Olobiri field in River State at the rate of 2,000 barrel per day. This quantity was doubled the following year. In the present days, production has increased to millions of barrel per day as other companies also now have concession rights. This is largely due to increasing demand for petroleum products. Crude oil now account for about 95% of total export in Nigeria. Unlike in the United States of America, the Middle East and the Caribbean, Petroleum Industry is a relatively recent venture in the Nigerian economy. The petroleum business is very lucrative and commands a high risk in both exploration and production.

The Niger Delta area of Nigeria is situated in the Gulf of Guinea (Fig. 1) and extends throughout the Niger Delta Province as defined by Klett *et al.* (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 Omatsola, 1990). These depobelts form one of the largest regressive deltas in the world with an area of some 300,000 km^2 (Kulke, 1995), a sediment volume of 500,000 km^3 (Hospers, 2005) and a sediment thickness of over 10 km in the basin depocenter (Kaplan *et al.*, 1994). The Niger Delta Province contains only one identified petroleum system (Kulke, 1995; Ekweozor and Daukoru, 1994). This system is referred to here as the Tertiary Niger Delta (Akata-Agbada) Petroleum System. The maximum extent of the petroleum system coincides with the boundaries of the province (Fig. 1). The minimum extent of the system is defined by the area extent of fields that contain known resources (cumulative production plus proved reserves) of 34.5 Billion Barrels of Oil (BBO) and 93.8 Trillion Cubic Feet of Gas (TCFG) (14.9 Billion Barrels of Oil Equivalent, BBOE) (Petroconsultants, 1996). Currently, most of this petroleum is in fields that are onshore or on the continental shelf in waters less than 200 m deep (Fig. 2) and occurs primarily in large, relatively simple structures. A few giant fields do occur in the delta, the largest contains just over 1.0 BBO (Petroconsultants, Inc., 1996). Among the provinces ranked in the U.S. Geological Survey's World Energy Assessment (Klett *et al.*, 1997), the Niger Delta province

Corresponding Author: Z. O. Opafunso, Department of Mining Engineering, University of Mines and Technology, Tarkwa, Ghana

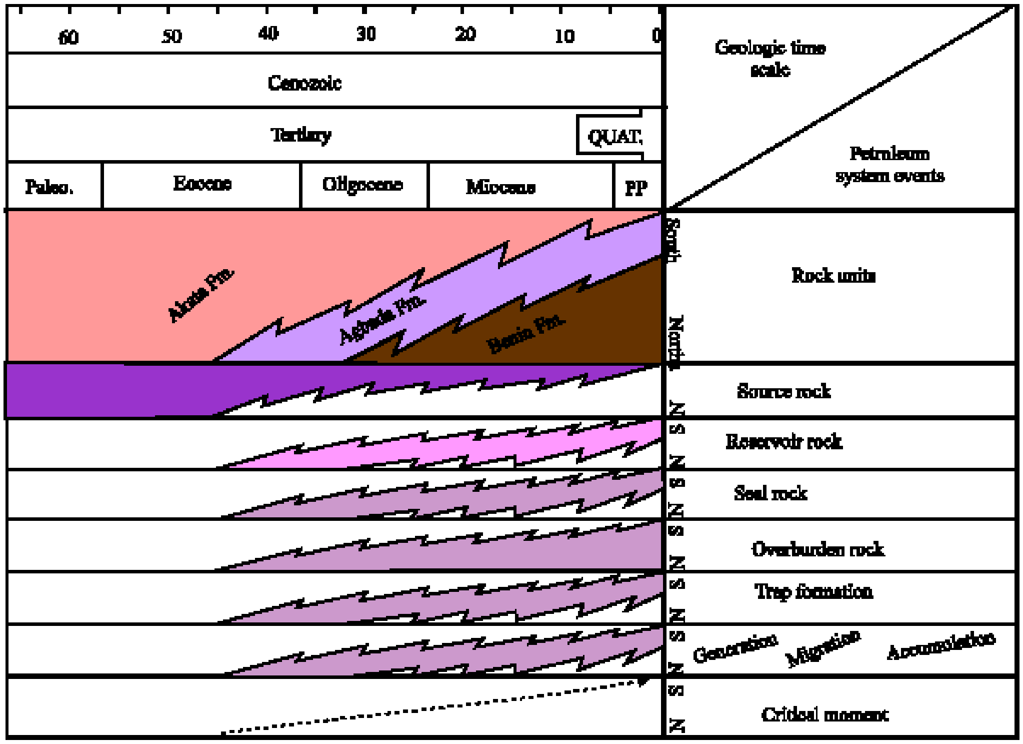

Fig. 1: Events chart for the Niger Delta (Akata/Agbada) Petroleum System

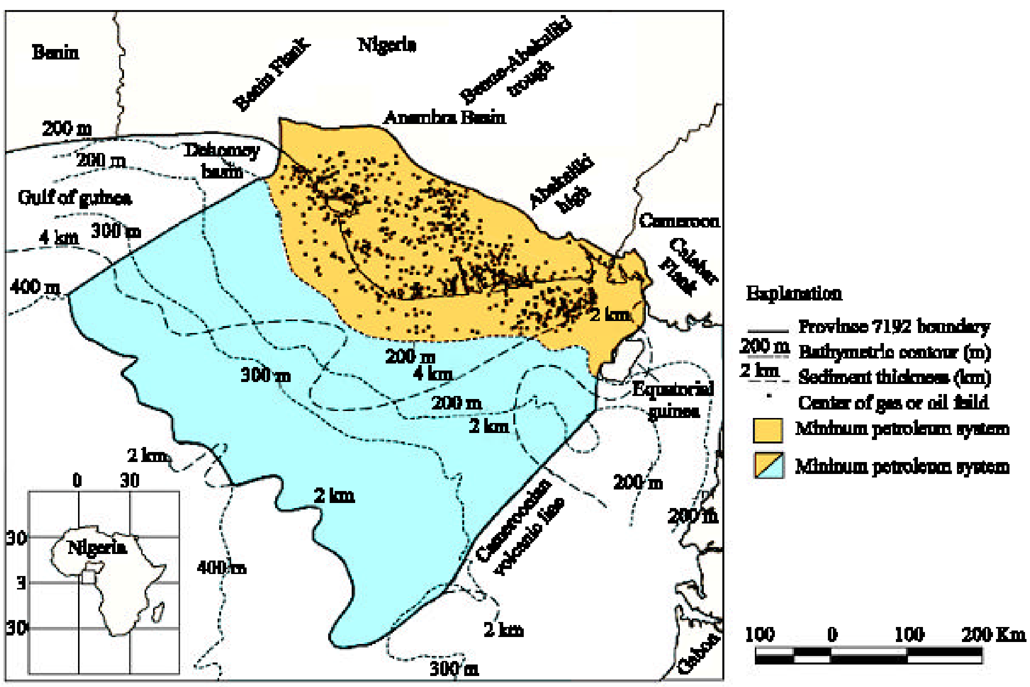

Fig. 2: Index map of Nigeria and Cameroon. Map of the Niger Delta showing Province outline (maximum petroleum system); bounding structural features; minimum petroleum system as defined by oil and gas field center points (data from Petroconsultants, 1996a); 200, 2000, 3000 and 4000 m bathymetric contours and 2 and 4 km sediment thickness

is the twelfth richest in petroleum resources, with 2.2% of the world's discovered oil and 1.4% of the world's discovered gas (Petroconsultants Inc., 1996).

The sedimentary sequence as formed in the subsurface of the Niger Delta has been modified by numerous transgressions which occurred from time to time breaking the continuity of the main overall regression and becoming stratigraphically superimpose (Hospers, 2005). The tertiary section of the Niger Delta is divided into three broad formations representing prograding depositional facies that are distinguished mostly on the basis of sand-shale ratio. However, the three stratigraphic units are usually referred to in the following lithofacie which include: Akata formation, Agbada formation and Benin formation in the ascending order of sedimentation.

Akata formation (Marine shales): The Akata formation at the base of the delta is of marine origin and is composed of thick shale sequence (potential source rock), turbidite sand (potential reservoir in deep water) and mirror amounts of clay and silt (Fig. 1). Beginning in the Paleocene and through the recent, the Akata formation formed during lowstands when terrestrial organic matter and clays were transported to deep water areas characterized by low energy conditions and oxygen deficiency (Michele *et al*., 1999). It is estimated that the formation is up to 7000 m in thickness in the central part of the delta (Doust and Omatsola, 1990). The formation underlines the entire delta and forms the base of the sequence in each depobelt. The marine shale is typically over pressured. It is the deepest formation and is made up of marine shale, clays and silts that underlie the deltaic sequence. The depositional environment is typically marine, therefore, it is the source rock. i.e., where hydrocarbon is generated before migrating to Agbada formation. The Akata formation seems to be continuous but diachronous with the outcropping Imo shale. The formation ranges in age from microcene to recent.

Agbada formation (Paralic clastics): The Agbada formation which is the major petroleum-bearing unit began in the Eocene and continues into the recent. The formation consists of paralic siliciclastics over 3700m thick and represents the actual deltaic portion of the sequence. The clastics accumulated in the delta-front, delta-topset and fluvio-deltaic environments. In the lower Agbada formation, shale and sandstone beds were deposited in equal proportions; however, the upper portion is mostly sand with only minor shale interbeds. As with the marine shales the paralic sequence is present in all depobelts. The sequence is associated with sedimentary growth faulting and contains the bulk of the hydrocarbon reservoirs. The sand is under-compacted and contains autigenic cement material which allowed free movement of hydrocarbon within it (Lambert and Ibe, 2004). The Agbada formation consists of cyclic coarsening upward regressive sequence resulting from disturbance and abandonment. The coarsening upward sequences are composed of alternating shale, siltstone and sandstone. The alternation of sandstone, siltstone and shale are the result of differentiated subsidence variation in the sediment supply and shift of the delta depositional axes that cause local transgression and regression. The Agbada formation ranges in age from Eocene to recent and is up to 4000m thick in the central part of the delta thinning seawards and towards the delta margins.

Benin formation (Continental sands): The Benin formation is the shallowest part of the sequence, is composed almost entirely of non-marine sand. It is a continental latest Eocene to recent deposit of alluvial and upper coatal plain sands that are up to 2000 m thick (Avbovbo, 1998). It is deposited in upper coastal plain environments following a southward shift of deltaic deposition into a new deplobelt. It traps non-commercial quantities of hydrocarbon and has sand percentage of over 8%. The age of this formation is Oligocene (Hospers, 2005). Benin formation which is the youngest formation in the Niger Delta occurs across the entire Niger Delta from Benin-Onitsha in the north to beyond the present coastline. The formation consists of massive, highly porous, freshwater bearing sandstone with local thin shale interbed, which is considered to be of braided stream origin. The sands and sandstone of the Benin formation are coarse to medium to fine grained in general and are poorly sorted.

In 1908, the German Nigerian Bitumen Corporation drilled the first wells in the vicinity of the tar seep deposits in the northern portion of the Delta (Frost, 1997). However, significant oil shows were not found in Tertiary rocks until the early 1950's. Shell-British Petroleum brought the first well on stream in 1958 at 5,100 barrels per day. From 1958 until the Biafran War in 1967, exploration and production increased in Nigeria. The war curtailed both activities until its end in 1970, when world oil prices were rising and Nigeria again benefited economically from its petroleum resources in the Niger Delta. In 1971, Nigeria joined the Organization of the Petroleum Exporting Countries (OPEC) with a total production of 703 million barrels of oil (MMBO) per annum. In 1997, production rose to 810 MMBO (Energy Information Administration, 1998a). Thirty-one percent of this production (251 MMBO) was exported to the United States, making Nigeria the 5th largest supplier of U.S. oil. Despite the political uncertainty in Nigeria today, the country's sustainable production capacity is expected to increase over current production. Petroleum exploration is also expanding, especially in deeper water offshore, with the Nigerian government currently planning to offer six additional lease blocks in water up to 3000 m deep. Considering both oil and gas, the overall success ratio for exploration drilling is as high as 45% (Kulke, 1995).

Applying a reservoir modelling tool effectively is affected by the integrity of the data use and an understanding of the reservoir with the lithology of its host rock. Most of the oil reservoirs in Nigeria are found in the Niger Delta and deep waters of the Bight of Benin. An understanding of these environments is therefore, important in the application of the Petrel Work flow tool in evaluating reservoirs found in them. The presence of networks of granulation seams throughout faulted sandstone reservoirs may lower the bulk permeability of the reservoir and an understanding of this is a crucial part of the input to reservoir simulation and estimates of reservoir productivity. Granulation seams are permeability barriers within the reservoir. The impact on bulk reservoir permeability will depend on the actual permeability of the granulation seams and the density of these seams throughout the rock (Serra, 2004). The search for an economic hydrocarbon reservoir rock is the goal of any exploration operation in the oil and gas industry. In today's global business environment, Exploration and Production (E and P) asset teams are making increasingly challenging and costly decisions earlier in the life cycle of oil and gas reservoirs. Accurate modelling of field scenarios before making significant capital investments can optimize hydrocarbon extraction and yield tremendous savings of both time and money (Shannon and Naylor, 2005). Identifying and recovering hydrocarbons requires an accurate, high resolution geological model of the reservoir structure and stratigraphy. The geology capabilities found within Petrel, all seamlessly unified with the geophysical and reservoir engineering tools enable an integrated study by providing an accurate static reservoir description that evolves with the reservoir (Schlumberger Information Solutions, 2007). In the oil industry, realistic geological models are required as input to reservoir simulation programs which predict the movement of rocks under various hydrocarbon scenarios. An actual reservoir can only be developed and produced once and mistakes can be tragic and wasteful. Using reservoir simulation in evaluating subsurface formations allows Reservoir Engineers to identify which recovery option offers the safest and most economic, efficient and effective development plan for a particular reservoir. The objective of the study is to create a 3-Dimensional computer based model of a reservoir in the Niger delta region of Nigeria using the Schlumberger Petrel software to analyze wireline logs and seismic logs.

MATERIALS AND METHODS

Location of the study area: The tomboy oilfield where the data for the study was collected is owned and managed by Chevron Nigeria Limited. It is an onshore field located in the Eastern part of the Niger Delta Area of Nigeria. The Niger Delta area is situated in the Gulf of Guinea between longitude 5°E to 8°E and latitude 3°N and 6°N. The precise location of the field was not disclosed by the operator company in line with current practices by oil and gas industries in Nigeria.

Research design: Petrel was chosen to model this reservoir because it is window based software for 3D visualization with a user interface based on the Windows Microsoft standards. Schlumberger Petrel is a software application package for subsurface interpretation and modelling, allowing you to build and update reliable subsurface models. Geophysicists, Geologists, Geological Engineers, Mining Engineers and Reservoir Engineers can move across domains, through the Petrel integrated tool kit. Petrel is one of the latest reservoir rmodeling sofware recently deployed by Schlumberger Information Solutions Inc. For the purpose of this study, a data base was created within petrel, clearly delineating the different information and data needed to complete the study. The geophysical, geological and petrophysical data were imported to petrel within the main data base. This made it possible to generate and visualize the imported data in 2D as well as 3D. The work flow design used for the study and wide range of functional tools in the Petrel software include: 3D visualization, well correlation, creation of synthetic seismograms, 2D and 3D seismic interpretation and modelling, 3D mapping, 3D grid design for geology and reservoir simulation, Well log up scaling, Facies modelling, Petrophysical modelling, Data analysis, Volume calculation, 3D well design, Streamline simulation, Simulation post processing and Plotting.

Data import: The steps undertaking for the data import modules include: Import well trajectories, well headers, deviations and logs separately or combined; use the open spirit plug in to access and update well data in GeoFrame or openworks databases; edit existing logs or generate new ones from any number of curves using the powerful well log calculator; interpret discrete properties interactively and sample data from a property model along well trajectories.

Data analysis: Features used included data transformations, trend and distribution analysis, interactive modeling of variograms, histogram and cross plot generation.

Surface imaging: This feature was used to display images such as scanned maps, attribute maps, seismic time-slices or satellite images, draped over structural models.

Modeling: Three dimensional (3D) modeling in Petrel used for this study could be classified into two interdependent steps. These are structural and stratigraphic modeling.

Structural modeling: Structural modeling was the first step used for building geological model with Petrel workflow tools. It was subdivided into three processes as follows: Fault modeling, pillar gridding and vertical layering. All the three operations were performed one after the other to form one single data model - a three dimensional grid.

Fault modeling: This was the first step used for building structural models with Petrel workflow tools. The processes were used to construct linear, vertical, listric, S-shaped, reverse, vertically truncated, branched and connected faults. Fault modeling processes were used to create structurally and geometrically correct fault representations within horizon one two and three. The model consists of 8 primary faults. These faults were built using Key Pillars which is a vertical, linear, listric or curved line defined by two to five Shape Points; two for vertical and linear, three for listric and five for curved.

Pillar gridding: A pillar grid which is a way of storing XYZ locations to describe a surface was used to generate the 3D framework. A 3D grid then divided space up into boxes (cells) within which it assumes materials were essentially the same. Therefore, each grid cell had a single rock type, one value of porosity and the same value of water saturation. These referred to the properties of each cell. The grid was represented by pillars (coordinate lines) that define the possible position for grid block corner points.

Vertical layering: The Make Horizons process step was the first step used in defining the vertical layering of the 3D grid in Petrel. This presented a true 3D approach in the generation of 2D surfaces which were gridded in the same process, taking the relationships between the surfaces into account (erosion, on-lap, etc), as well as honoring the fault model to ensure proper fault definitions in the surfaces and keeping the well control (well tops). The 3D grid could have as many main layers as number of horizons inserted into the set of pillars. This is shown as horizons in the Models window of the Petrel Explorer. The Make Zones and Make Sub Zones processes were the two last steps used in defining the vertical resolution of the 3D grid. The Make Sub Zones process allowed the definition of the final vertical resolution of the grid by setting the cell thickness or the number of desired cell layers. The next step was to start the interpretation of the well logs to stipulate contacts between different facies identification of unconformities. The top and bottom of this specific unit were identified within the well sections and well tops inserted to be displayed within the well section in 3D. The next step was the identification of the sand units above and below the shale because they contain the granulation seams.

Correlation: The development of geologic pattern display by structural and stratigraphic units that are equivalent in time, age, or stratigraphic position through the use of electric wireline logs is generally referred to as log correlation (Reed, 1999). It is a product of basic geological principles, which include sound understanding of depositional processes and environment, concepts of logging tools and measurements, reservoir engineering fundamentals and qualitative and quantitative log analyses. Based on the depth range covered by the available data, stratigraphic units within the interval in the study area were correlated using composite logs.

Reservoir modeling: Reservoir modeling generally refers to the techniques of constructing hypothetical three dimensional representations of the observed and anticipated characteristic of the recognized subsurface reservoir. The reliability of a model depends on quantity, quality, distribution and accuracy of data. Geostatistical or stochastic methods generates samples of the sequence of data interpretation from probability distribution. It involves interpolation between data measurements through a random draw from a cumulative data distribution function to simulate the value at a given location (Schlumberger Petrel Online Help, 2004). Schlumberger Petrel's in-built geostatistical methods were used in constructing models of the identified sand rich reservoirs (facies modeling) and the distribution of their matching petrophysical properties.

Facies modeling: Facies modeling is a means of distributing discrete facies throughout the model grid. For this study, the well logs with discrete properties were up-scaled into the model grid having defined necessary trends.

RESULTS AND DISCUSSION

Structural models: Figure 3 shows the oil well positions within fault model. The 3D window with grid lines shown on X and Y axis are UTM coordinates while sub-sea true vertical depths (SSTVD) are shown on Z axis. Table 1 shows a typical well report from Petrel showing XYZ Coordinates. The green arrow at the bottom right hand corner of Fig. 3 points to the geographical north direction. The wells have ball shape symbol and are displayed in distinct colors. The relief of the model seems to imply that the possibility of the sediments being sourced from the west or south-western part of the basin. Four Major faults were identified within the modeled area. They have Northwest-Southeast (NW-SE) trend and divide the reservoir into blocks or segments. These faults gradually die out as they extend vertically.

Porosity and permeability distribution: Figure 4 presents a porosity-permeability plot of host rock sandstone and granulation seams clearly showing the affect that the granulation seams has on the porosity and permeability within a rock. The granulation seams was mainly found within the sand units in the reservoir. There source could be attributed to the rolling of sand grains over one another creating seal like fractures within the sand beds.

Facies models: Figure 5 shows the facies model as it displays the distribution of the up-scaled facies logs in the 3D grid using Petrel's in-built Sequential Indicator Simulation algorithm. Four facies types were modeled: sand, silty sand, shaly sand and shale. The facies pattern and distribution show northwest-southeast trend. Relatively high permeability areas are depicted with green/yellow/orange colour while areas with blue colour have low permeability values. The green arrow points to the north direction. The observed incised valley features are filled with permeable sands. These areas may be selected for detailed study as they could be rich in hydrocarbon resources.

East–west cross section: Figure 6 show the location of the wells within zones 1, 2 and 3. Figure 7 shows how the wells are cut off on the East and West by two confining

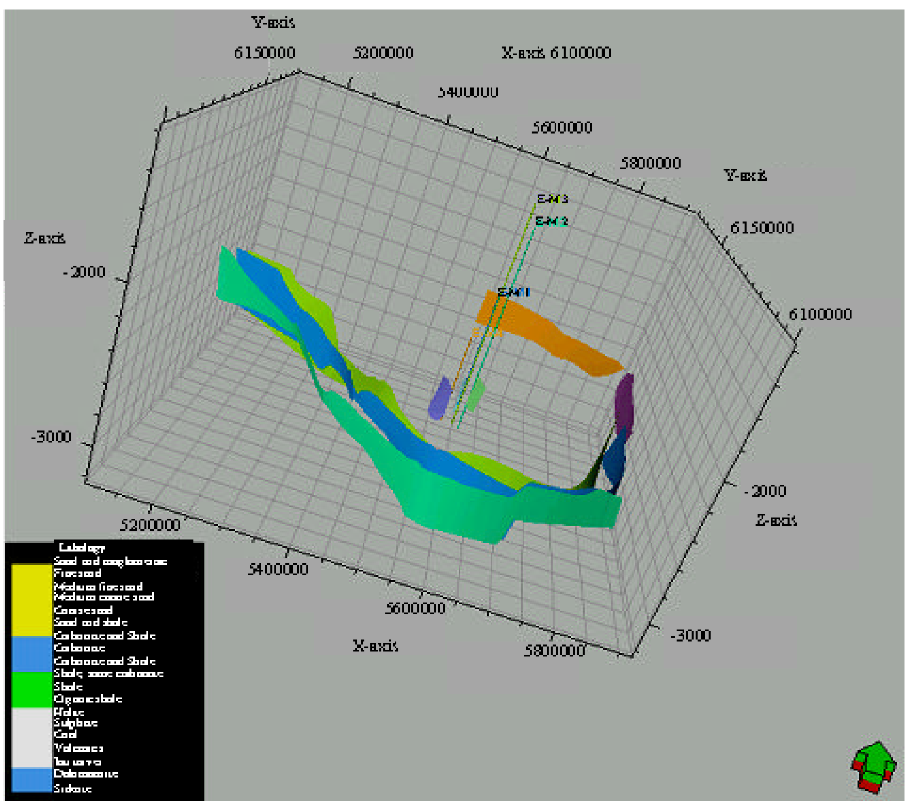

Fig. 3: Well positions within fault model (arrow points to the north)

Table 1: Typical Well Report (Well Deviation) from Petrel showing XYZ Coordinates

X	Y	Z	TANGENT	MD	INCL	AZIM	DX	DY	TVD	DLS
457949.7	6788334	-1809.40	0	1809.4	73.21	279.04	0.00	0.00	1809.40	0
457299.1	6788432	-1997.15	1	2494.34	83.55	273.78	-650.63	98.20	1997.15	3
456831.8	6788432	-2027.46	0	2962.65	86.44	269.81	-1117.90	98.35	2027.46	0
455527.7	6788432	-2064.54	0	4267.34	88.39	270.00	-2422.06	98.35	2064.54	0
453481.7	6788432	-2136.98	1	6314.62	91.46	270.83	-4468.03	98.40	2136.98	3

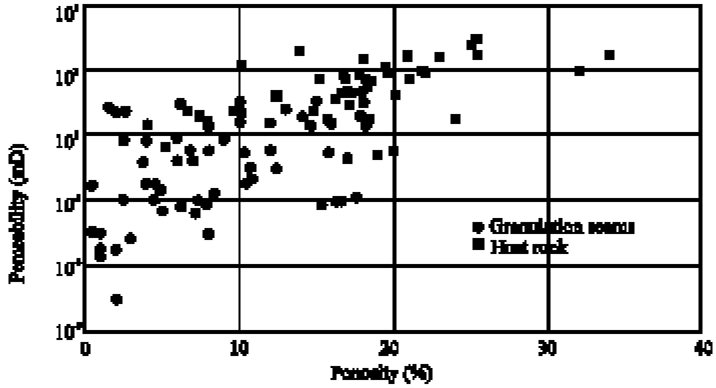

Fig. 4: Porosity vs. Permeability

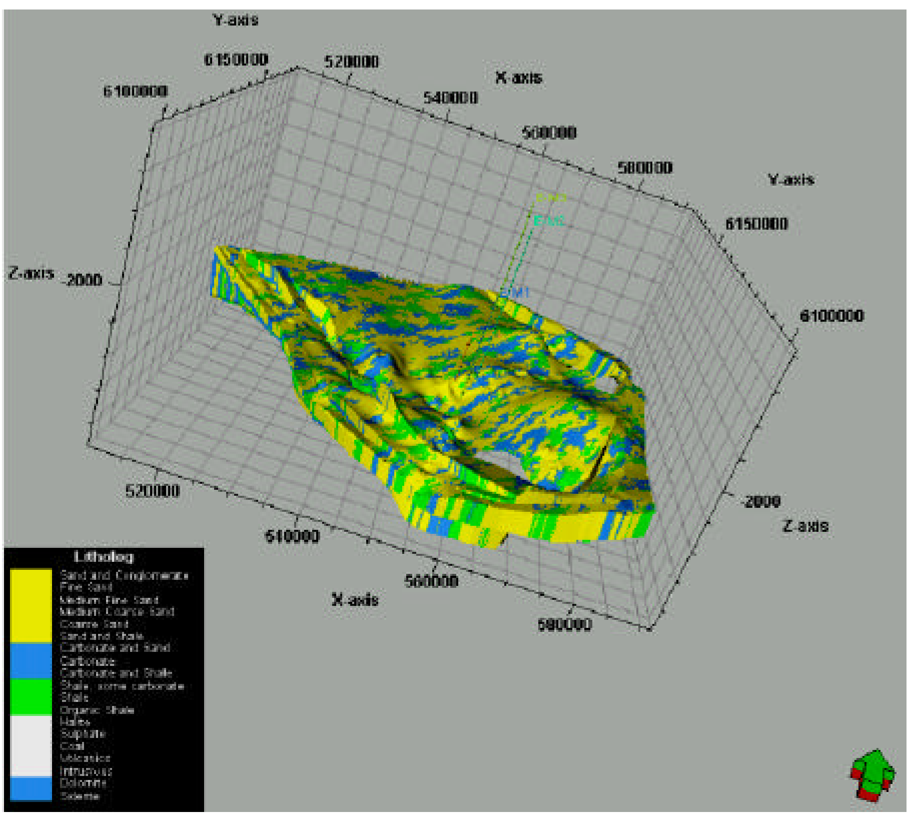

Fig. 5: Facies model displays the distribution of the up-scaled facies logs

faults further compartmentalizing the area. Two smaller faults are situated between E-M 2 and E-M 3 confining these two wells to their own compartments as shown in the Fig. 7. Visible within the cross-section, E-M 1 (blue) is

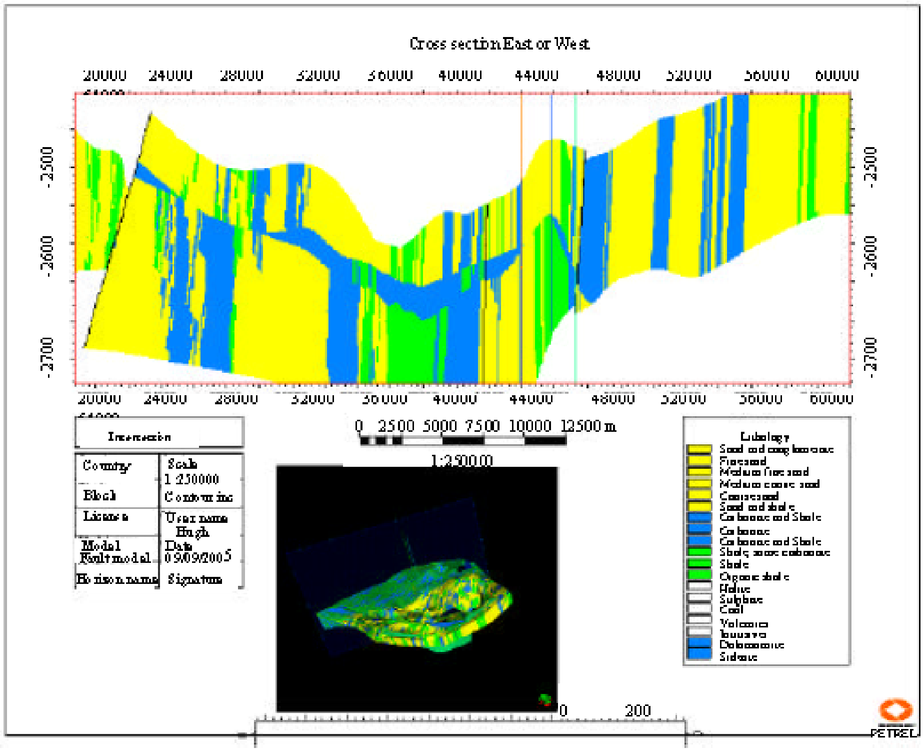

Fig. 6: Well location within zone 1, 2,

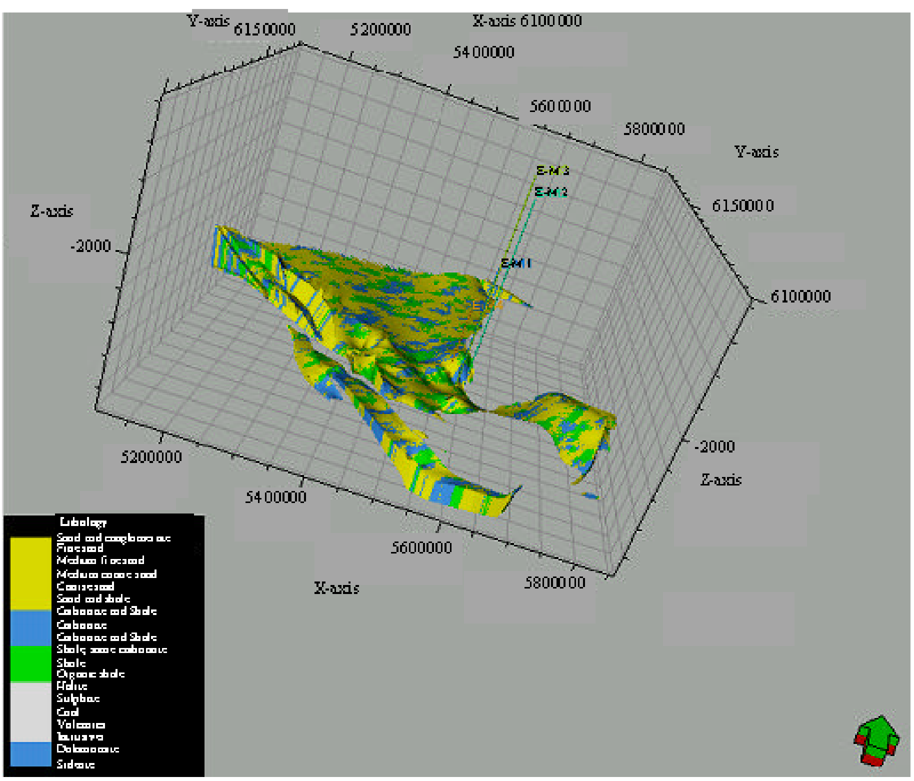

Fig. 7: Cut-Off of the Wells on the East and West by Confining Faults

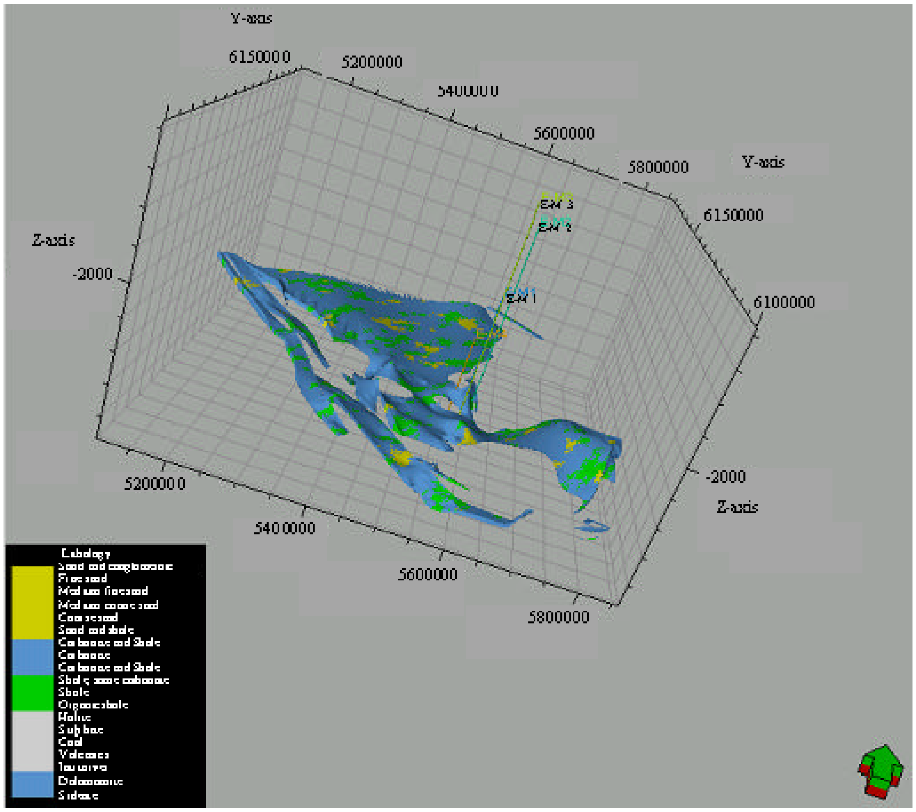

Fig. 8: Top Zone 2 showing the distribution of the confining shale layer

the only well not restricted by the shale (light blue) layer dividing the reservoir as indicated by the red arrows and box as shown in the figure. Figure 7 also shows sand rich bottom zone 3 showing possible re-entry points. The re-entry points shown within the model could provide possible entry points later within the exploration or production of this field. If the opening is used as entry point, it will connect the top and the bottom halve of the reservoir which would improve the production rate within this field. Figure 8 shows the effect of top zone 2 as it divides the reservoir into two compartments and shows the distribution of the confining shale layer. The zone acts as a seal preventing fluid flow from bottom halve of the reservoir to the top halve. The permeability within this zone is zero as it is densely compacted by shales.

CONCLUSION

The sandstone reservoir units encountered by the four central basin wells have been investigated in this study within the limit of the available data. The available data was comprehensively analyzed to determining porosity, permeability and lithology distribution over the reservoir. The reservoir was mainly dominated by sand with thin interbedded shales consisting of two main facies: a fluvial and shallow marine facies. Porosity varied over the reservoir between 5-15%. Permeability has been found depleted in some areas where it has dropped to as low as 0.6 mD in contrast to areas where permeability was as high as 800 mD. The permeability distribution was a direct indication of the pore connectivity within the reservoir reflecting excellent results in the areas with high permeability and visa versa. The dominant formation orientation was within southwest-northeast dip directions. These channel deposits contained packages of inclined heterolithic stratification formed from sandstone and conglomerate. The combination of sealed granulation seams as well as closed fractures was causing problems for the mobility of fluid movement horizontally through the reservoir as they create compartments which were not in fluid communication with each other. This could lead to a drop in pressure in the production well. The trapping mechanism observed within the area of study was essentially structural while the reservoirs were sealed by marine shales and condensed sections developed during their respective transgressive phases.

ACKNOWLEDGMENT

The contribution of Mr Adigun Oluwole in the area of data collection is hereby acknowledged.

REFERENCES

Avbovbo, A.A., 1998. Tertiary Lithostratigraphy of Niger Delta: American Association of Petroleum Geologists Bulletin, 62: 295-300.

Doust, H. and E. Omatsola, 1990. Divergent and Passive Basin of the Niger Delta, AAPG Memoir 48:, American Association of Petroleum Geologist, Tulsa, pp: 239-248.

Ekweozor, C.M. and E.M. Daukoru, 1994. Niger Delta Depobelt Portion of the Akata-Agbada Petroleum System, AAPG Memoir 60: American Association of Geologist, Tulsa, pp: 599-604.

Energy Information Administration, 1998. http://www.eia.doe.gov/emeu/cabs/ngriasar.html

Frost, B.R., 1997. A Cretaceous Niger Delta Petroleum System, in, Extended Abstracts, AAPG/ABGP Hedberg Research Symposium, Petroleum Systems of the South Atlantic Margin, November 16-19, 1997, Rio de Janeiro, Brazil, pp: 2-3

Hospers, J., 2005. Gravity Field and Structure of the Niger Delta, Nigeria, West Africa: Geological Society of American Bulletin, 76: 407-422.

Kaplan, A., C.U. Lusser, I.O. Norton, 1994. Tectonic Map of the World, Panel 10: Tulsa, American Association of Petroleum Geologists, Scale 1:10,000,000, pp: 67.

Kulke, H., 1995. Regional Geology of the World Part II: Africa, America, Australia and Antarctical: Berlin, Gebruder borntraeger, Kulke, Ed., pp: 143-172.

Klett, T.R., T.S. Ahlbrandt, J.W. Schmoker and J.L. Dolton, 1997. Ranking of the World's Oil and Gas Provinces by known Petroleum volumes: U.S. Geological Survey Open-file Report-97-463, CD-ROM, pp: 56-58.

Lambert-Aikhionbare, D.O. and A.C. Ibe, 2004. Petroleum Source-bed Evaluation of the Tertiary Niger Delta: discussion: American Association of Petroleum Geologists Bulletin, 68: 387-394.

Michele, L.W.T., R.C. Ronald and E.B. Michael, 1999. The Niger Delta Petroleum System: Niger Delta Province, Nigeria Cameroon and Equatorial Guinea, Africa, pp: 41-43.

Petroconsultants, 1996. Petroleum Exploration and Production Database: Houston, Texas, Petroconsultants, Inc., Houston, Texas, pp: 23-25.

Reed, K.J., 1999. Environment of Deposition of Source Beds of High-wax Oil: American Association of Petroleum Geologists, Bulletin, 53: 1502-1506.

Schlumberger Information Solutions, 2007. Schlumberger Publication, pp: 66.

Schlumberger Petrel Online Help, 2004. Petrel 2004 Version.

Serra, D.H., 2004. Advanced Interpretation of Wireline Logs, Schlumberger Publication, pp: 87.

Shannon, P.M. and N. Naylor, 2005. Petroleum Basin Studies: London, Graham and Trotman Limited, pp: 153-169.