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Application of Petrel Software for Well Correlation in the Niger Delta Area of Nigeria

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Abstract: The increase demand for petroleum and its related products has necessitated for greater exploration activities in other to meet up with the demand and also take care of future economic disruption. This research was carried out to determine the factors necessary for increase in the production of crude petroleum in the Niger Delta area of Nigeria through the use of Petrel software tools, which deals with integrated oil exploration and production. Eleven wells, code named A10, A15, A16, B2, B4, B8, B9, C2, C4, C5 and C6, in an oil field belonging to Chevron Nigeria Limited were analyzed using the Petrel software to determine the structural styles favourable for hydrocarbon accumulation. Correlations of these wells were made to determine the points of intersection with permeability of reservoir, porosity of reservoir, of the wells with lithofacies in the reservoir and with the oil saturation zones. These parameters helped to detect the oil trap and the point to commence drilling.

Key words: Correlation, petroleum, faults, folds, unconformities, reservoir, formation

INTRODUCTION

The demand for energy in the world has witnessed a sudden increase in the developing regions. This therefore, calls for greater exploration activity and the subsequent discovery of new accumulations in order to meet up with the demand. Petroleum is the world's major source of energy and a key factor in the continued development of the world's economy. Exploration for hydrocarbon (petroleum), which started some 160 years ago, has witnessed great stages, prospects were located by mere surface shows or seeps and random drilling was not uncommon. There is no clear estimate of the total petroleum volume available in the world, because reserves are constantly being discovered daily.

The Niger Delta is a low-lying depositional environment, truncated by an intricate network of streams, creeks and lagoons over extensive sand bars as they flow into the Gulf of Guinea. The Niger Delta, at its southernmost portion where it empties into the Atlantic Ocean, has developed a braided system of 21 estuarine fluvial (freshwater) systems (Avbovbo, 1997). According to Beka and Oti (1995), Niger Delta is one of the foremost oil basins in the world, which has made Nigeria to be the part of the largest oil producers in the world. Ranking 5th in the world, the basin has served as the major economic life line of Nigeria. Niger Delta Area is located in the Southern-most physiographic region of Nigeria protruding into the Gulf of Guinea and extending from the Benin river in the west to the Bonny river in the east. It extends over 450 km from west to east, thus constituting about 60% of the 800 km Nigerian coastline. The Niger Delta is, therefore, an integral part of the southern lowlands and, with a catchment area of over one million sq.km, describes one of the largest delta systems in the world (Evamy *et al*., 1999). The northern limit is at Aboh, where the Niger-Benue river system bifurcates into the Rivers Nun and Forcados, initiating the Niger Delta formation. This northward extension of the Niger delta is known to create tidal influences up to 50 km from the shoreline.

The Niger Delta occupies approximately an area located between longitude 4-9°E and latitude 4-6°N within Southern Nigerian basin. Figure 1 shows the structural features of Southern Nigeria Basins. The Niger Delta region is mainly made of mangrove swamps which increase in relief towards the north. Like some other deltaic structures in the world, marine, mixed and continental depositional environments characterize the Niger Delta. Though the proto Niger Delta is thought to have been associated with a continuous transgression (Archer and Wall, 1996), the modern Niger Delta is generally believed to have originated during the eocene period. The structural geology of the Niger Delta is dominated by E-W trending faults and fold generally described as growth faults and roll over anticlines (Omatsola, 1990; Magoon and Dow, 1976). These structures were however gravity controlled and

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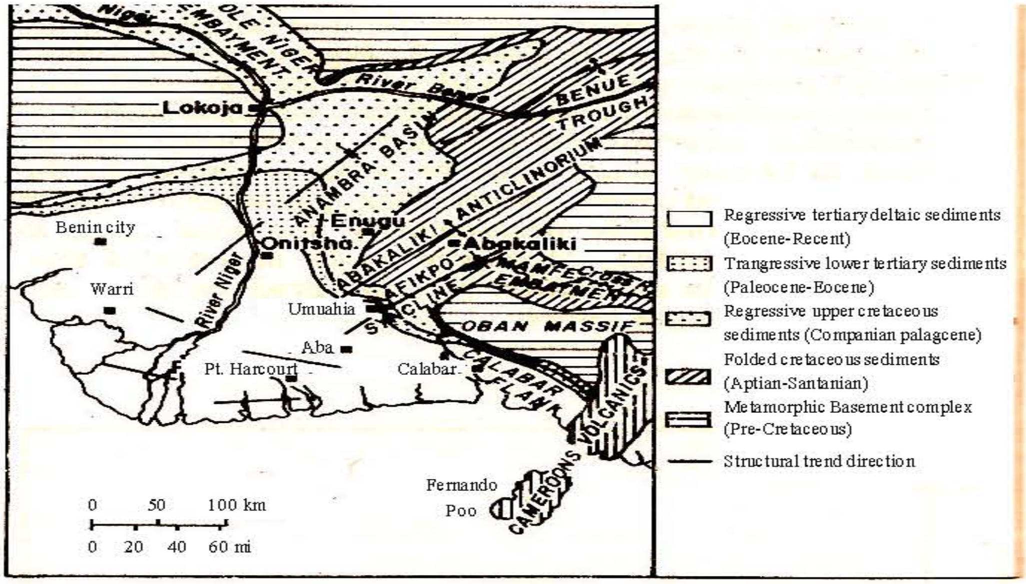

Fig. 1: Structural features of the Southern Nigeria Basins (Peters and Nwajide, 1997)

contemporaneous with sedimentation. They may possibly have been initiated by differential gravity loading of sediments of the Akata formation. The Benin formation which appears not to have been affected by this gravity faulting was subjected to regional tilting southwards (Hospers, 2005). Hydrocarbon has been trapped mostly in the deformed Agbada formation. Hydrocarbon contained requires geological structures with a good trapping mechanism with an overlying impervious cap rock. Geological structures most often involved in gas storage include the dome-shaped anticlinal structures and sand lenses. Cap rocks of suitable quality for hydrocarbon entrapment often have low permeability and porosity and would normally consist of shale, dolomite and limestone with porosity and permeability ranges of about 2-8% and $10^{-6}10^{-4}$mD, respectively (Peters and Nwajide, 1997).

The existence of fractures in the cap rocks often encourages the migration of hydrocarbon into the overlying formations and downgrades the suitability of a formation for hydrocarbon storage. The existence or absence of such cracks and leaks can be ascertained from water tests. Deposition of the three formations (Akata, Benin and Agbada) in the Niger Delta area of Nigeria occurred in each of five overlapping siliciclastic sedimentation cycles that comprise the Niger Delta. Figure 2 shows the structural configuration of the Delta Province of the Niger Delta. These cycles (deplobelts) are 30-60 km wide, prograde southwest 250 km over ocean crust in the gulf of guinea and are defined by sedimentary faulting that occurred in response to variable rates of subsidence and supply (Doust and Omatsola, 1990). The interplay of subsidence and supply rates resulted in deposition of discrete depobelts when further crustal subsidence of the basin could no longer be accommodated, the focus of sediment deposition shifted seaward, forming a new depobelt (Doust and Omatsola, 1990). Each depobelt is a separate unit that corresponds to a break in regional dip of the delta and is bounded landward by growth faults and seaward belt (Evamy *et al*., 1999; Doust and Omatsola, 1990). Five major depobelts are generally recognized, each with its own sedimentation deformation and petroleum history. According to Doust and Omatsola (1990), three depobelts provinces are described based on structure. The northern delta province, which overlies relatively shallow basement, has the oldest growth fault that is generally rational, evenly spaced and increases their steepness seaward. The central delta province has depobelts with well defined structures such as successively deeper rollover crest that shift seaward for any given growth fault. Lastly, the distal delta province is the most structurally complex due to internal gravity tectonic of the modern continental slope.

The Niger Delta area is bounded on both the east and west sides by a strip of low-lying coastal plain known as the coastal lowlands. This area consists of a maze of lagoons, creeks and river estuaries bordering the entire shoreline washed by the Gulf of Guinea. The coastal lowlands to the west depict a remarkably intricate network

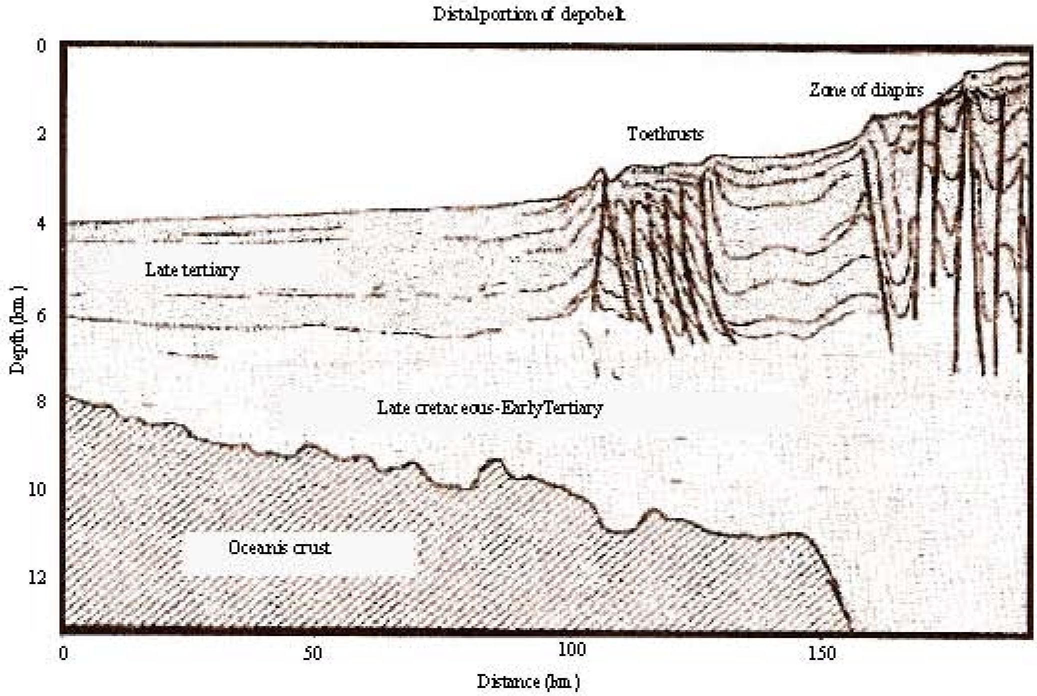

Fig. 2: Structural configuration of the delta province of the Niger Delta (After Short and Stauble, 1967)

of lagoon inlets, meandering creeks and extensive lagoons, with the Lagos Lagoon representing the largest lagoon system in West Africa. This area is also characterized by well developed river estuaries, such as those of the rivers Ogun, Shasha and Benin which flow into the vast network of creeks and lagoons. The coastal lowland east of the Niger Delta is a uniform low-lying area terminating into creeks and swampy terrain at the shoreline. The prominent Cross River basin, of numerous tributaries, enters the Gulf of Guinea through the Cross River estuary. The reduced tidal influence, due to distance upstream of the estuary, makes possible the development of vast areas of freshwater swamp forest along the inland stretches, comprising the wetlands of the Eket and Calabar areas (Udegbunam and Odoegbu, 1989). This explains the existence of extensive freshwater swamp forest dominated by the raffia palm and the rich oil palm bush in the area. The unique, monotonous configuration of low-lying swamp terrain at the shoreline gives rise to the strand coastline formation of the east, while the prograding sand bars of the west result in the formation of the barrier ridge-lagoon complex.

The objective of the study is to demonstrate the use of Petrel software to determine the depth and trap locations in a reservoir, through correlation of selected wells in the Niger Delta area of Nigeria.

MATERIALS AND METHODS

The software used to accomplish this study is the petrel workflow tool. Development of PETREL began in 1996 in an attempt to combat the growing trend of increasingly specialized geoscientist working in increasing isolation. The result was an integrated workflow tool that allows exploration production companies to think critically and creatively about the reservoir modeling procedures and allows specialized geoscientist to work together seamlessly (PWT, 2003). Petrel workflow tool is a single software application for: Well correlation, 3D visualization, 3D mapping, 3D grid design for geology and reservoir simulation, 3D depth conversion, 3D reservoir modeling, Upscaling, Volume calculation, Plotting and Post processing.

Data collection method: The data used for this study which were collected from Chevron Nigeria Limited included: Seismic data in SEGY format, shot hole data, geophysical logs in ASCII format, LAS and oil well data. The data were imported directly into the Petrel workflow software. Geophysical wire line logs from eleven wells, code named: A10, A15, A16, B2, B4, B8, B9, C2, C4, C5 and C6, were used for this study. They were used to compliment the structural interpretation. The logs used were the Gamma ray log and the Permeability log. The logs

Table 1: Import data table

Data type		Format	Category domain
Wells	Well header Deviation Logs	Well headers Well path/deviation Well logs (ASCII) Petrel well Tops (ASCII)	Under input data tab; attach attribute to corresponding file
Well tops			Under input data; attach corresponding column in file under input data tab: attach each log to correct template
Fault polygon	Zmap+line (ASCII)	Fault	Time
Isochors	Zmap+grid (ASCII)	Thickness	Depth
3D Seismic line	Seiswork Horizon Picks (ASCII)	Horizon	Time

Table 2: Basic logs used for well correlation

Log	Correlates on	Condition for best use	Uses or advantages
SP	Permeable beds vs shale beds	Uncased hole Good contrast between R_{wf} and R_w Low to moderate formation resistivity Fresh mud (but shill useful in saline mud)	Displays easily read shale-sand profiles Much used (usually with resistivity for correlation Not affected by washed out holes or deep or variable invasion
Gamma ray	Radioactivity associated with shaliness Radioactive beds	Moderate hole size with no large washed out zones	Insensitive to drilling fluid; thus can be used in oil or salt based muds and in air or gas filled holes Can be used in cased hole
Short spacing resistivity (SN, LLB, SFL)	Invaded, porous beds dellection depends on formation factor, water resistivity and shaliness Dense strata (low water content and nonconductive matrix)	Uncased hole Fresh mud Invaded formations not too resistive	Mush used (usually with SP or gamma ray for correlation
Amplified short spacing resistivity	Same as above	Same as above	Useful for correlation in shales or other low resistivity sections
Deep laterolog	Same as above	Uncased hole Fresh to salt mud high R_t IR_w ratio	Useful for salt mud, resistive formations
Induction log	Variations of water content (and salinity) in beds with non-conductive matrix (porous zone response varies with formation porosity and pore fluid conductivity)	Uncased hole Fresh mud Formation resistivity below 100 ohm m	The induction conductivity curve is useful for correlation in shales or other low-resitivity sections
Sonic	Δt (dependent on Lithology and porosity)	Liquid filled gas free holes	Good porosity correlation, useful in low resistivities provides Δt parameter measurement for identification of lithological markers
Neutron	Hydrogen content of formation Large shale response	Depends on tool type	Good porosity correlation Good in combination with other logs for gas detection Provides ϕ_N parameter measurement for identification of lithological markers Useful in cased holes (often run with gamma ray)
Density	Formation density (dependent on Lithology and porosity)	Uncased hole with little mud cake and no hole-wall porosity	Chiefly useful for identification of lithological markers.
Callper	Hole size variation (washouts, noncircular boreholes, fracturing)	Uncased hole	Seldom correlateable by itself, but often helps resolve ambiguities on other logs

furnished information about the lithology penetrated by the wells. Table 1 shows the import data type while Table 2 shows the basic logs used for the well correlation.

Gamma ray logs: The gamma ray log is a measurement of the natural radioactivity of the formations. In sedimentary formations the logs normally reflect the shale content of the formations. This is because the radioactive elements tend to concentrate in clays and shale's. Clean formations usually have a very low level of radioactivity, unless radioactive contaminant such as volcanic ash or granite wash is present or the formation water contains dissolved radioactive salts (Petroconsultants, 1996).

Permeability log: Permeability is a measure of the ease with which a formation permits a fluid to flow through it. To be permeable, a rock must have interconnected porosity (pores, vugs, capillaries, fissures, or fractures). Greater porosity usually corresponds to greater permeability, but this is not always the case. Pore size, shape and continuity as well as the amount of porosity influence formation permeability. Some fine grained sands have high interconnected porosity, although the individual pores and pore channels are quite small. Shale's and clays, which are composed of exceedingly fine grained particles often exhibit very high porosity. However, because the pores and pore channels are equally small, most shale's and clay exhibit, for all practical purposes, zero permeability.

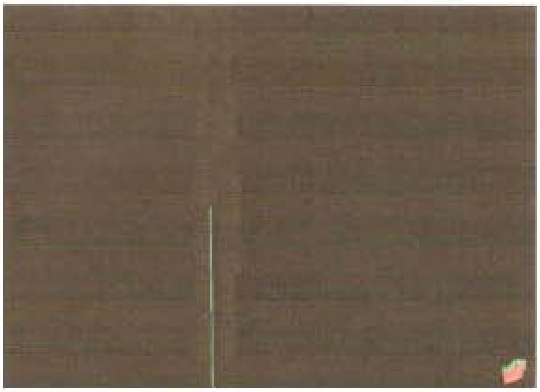

Fig. 3: Display of well Logs in 3D window

Data import steps: In carrying out this study, data on the reservoir like well heads, well deviation, well log and well top were imported into the petrel software and viewed in the 3D window, which gave the wire line log shown in Fig. 3.

Well log correlation: One of the first uses of well logs was well correlation of equivalent strata from one well to the other. Stratigraphic correlation determines the continuity and equivalence of Lithology units particularly reservoir sands or marker sealing shale's across regions of the subsurface. The lithologic units were delineated in vertical succession by distinct surfaces representing changes or lithologic character. Well logs provided a continuous record over the entire well. There were no missing sections as is usually the case with core samples. Also, because sound depths were recorded, there was no ambiguity as to the depth of the various markers. Different types of logs could be used for correlation but the most frequently used ores are the resistivity, SP, deep laterolog, induction log, sonic log and gamma ray logs. For the purpose of this study, resistivity and gamma ray logs were used. Eleven reservoirs of interest i.e A10, A15, A16, B2, B4, B8, B9, C2, C4, C5 and C6, were identified on the well logs and correlation was made to determine the distribution across the study area. To accomplish this, the intervals on logs from the wells were matched for similarity or characteristics log responses to lithology markers. The well to well correlation thus permit accurate subsurface mapping and was used to determine the elevations of formations present in the well relative to other wells outcrops, or geophysical projections; whether or not the well is within a given major geological structure; whether well depth has reached a known productive horizon and if not, approximately how much remains to be drilled; the presence or absence of faults and the existence of dip, folds, unconformities; the thickening of lithology sections or lateral changes of sedimentation. It should also be noted that for the best correlation, the log should respond to some property of the stratum that does not vary too much from well to well.

Correlation process and procedure: The first step in correlation is to identify in event or marker which is laterally continuous and therefore present in almost, if not all the wells. Since sand and carbonates are not laterally extensive owing to the way in which they were deposited, therefore shale was used in the first stage of the correlation exercise, as it represent low energy and laterally extensive bodies. As low energy deposit, they are laid down close to the horizontal on the field. At initial stage, shale with marked character will be selected to established correlation that is, used as a datum and other shale using this direction trend. The shale should be roughly parallel provided there are no missing sections and then repetition should be looked for. When the shale 'trim line" have been determined, correlation of the sands or other deposits in between may be attempted. Where shale are not present in between sand layers, sand should be correlated using the top of each sand body, as the base may be erosive and therefore not at a constant relative position.

RESULTS AND DISCUSSION

Log and lithologic interpretation of well logs: Log interpretation is the process by which measurable parameters such as resistivity, bulk density, interval transit time and spontaneous potential hydrocarbon content were translated into petrophysical parameters of porosity, hydrocarbon saturation, permeability, productivity and lithology (PWT, 2003). This translation was further complicated by the drilling process itself. In drilling through a formation, the fluid in the pores of the rock surrounding the borehole may be displaced or contaminated by the invasion of the drilling fluid. Occasionally, the rock matrix may even be altered. However, lithologic interpretation of well log deals with the identification of the lithology penetrated by the wells. It allows one to study the lateral and geometric distribution of various sand and shale beds traversed by the well. Gamma ray logs and permeability were used to identify the sand and shale lithologic sections of the field. Figure 4 shows the three-dimensional modeling of the 5 wells showing point of intersection with permeability of reservoir, while Fig. 5 shows the three-dimensional modeling of the wells showing point of intersection with porosity of reservoir. It should be noted that accurate porosity determination is more difficult when

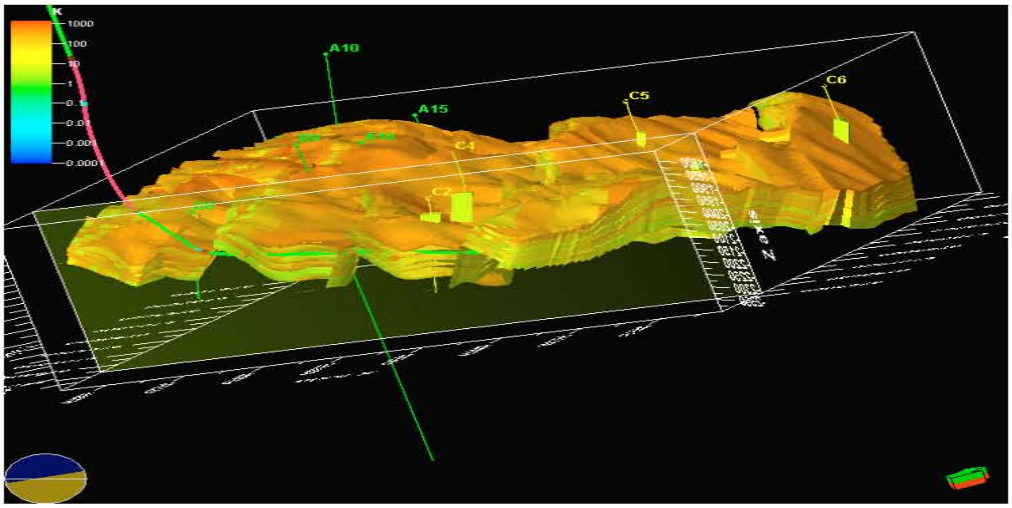

Fig. 4: Three-dimensional modeling of wells showing point of intersection with permeability of reservoir

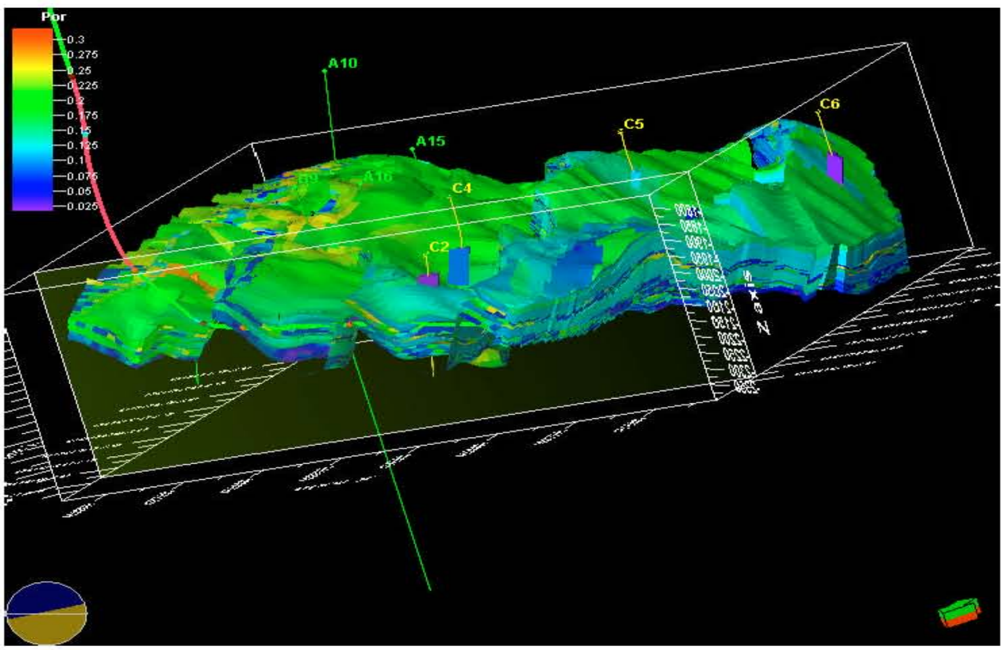

Fig. 5: Three-dimensional modeling of wells showing point of intersection with porosity of reservoir

the matrix lithology is unknown or consist of two or more minerals in unknown proportions. Determination was further complicated when the response of the pore fluids in the portion of the formation investigated by the tool differs appreciably from that of water. In particular, light hydrocarbons (gas) significantly influenced the response of porosity log.

Well correlation: Correlation of equivalent strata from wells, code named A10, A15, A16, B2, B4, B8, B9, C2, C4, C5 and C6, was made with each other. Intervals of logs from the different wells were matched for similarity or for characteristic log response to lithological markers. The general lithology was established as an alternation between sand, shale and water logged wells with the aid of the permeability and gamma log. The point of intersection of the wells, in three dimensions, with lithofacies in the reservoir is shown in Fig. 6, while Fig. 7 shows the three-dimensional modeling of well showing point of intersection with theoil saturation zones.

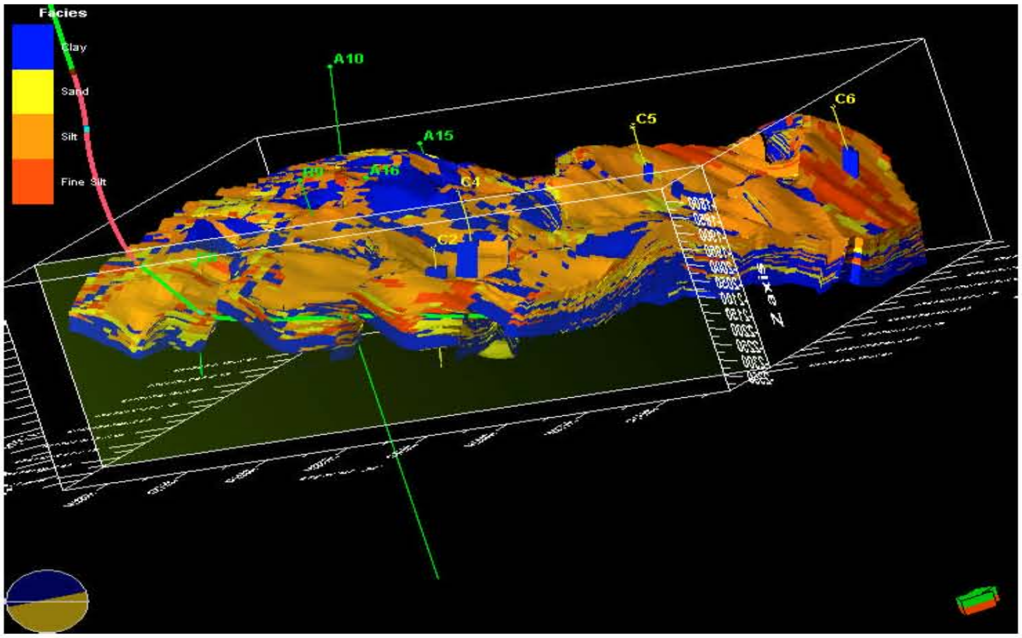

Fig. 6: Three-dimensional modeling of wells showing point of intersection with lithofacies in the reservoir

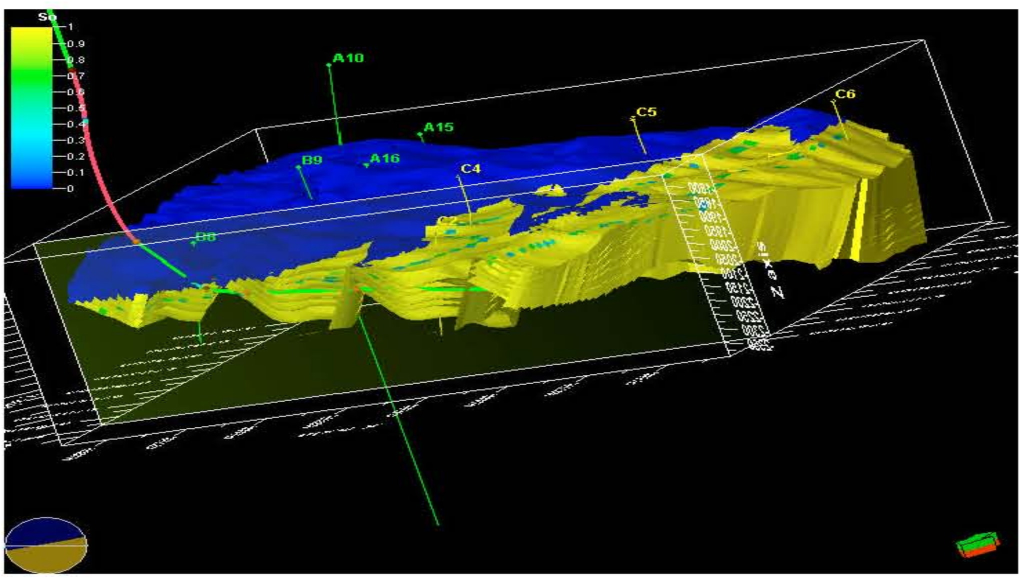

Fig. 7: Three-dimensional modeling of wells showing point of intersection with the oil saturation zones

Figure 8 shows the position of the five of the correlated wells. Well B8-indicates a high Gamma and low Permeability at depths between approx 2110- 2190 m. This shows a shale occurrence. This occurs at depths of 1890-1930 in well A10, 1990-2100 m in well A15, 2030-2080 m in well B2. Sand occurs in well B8 at the top of the well and between the depths of 1800-1900 in well A10 and 2000-2020 in well B2. Correlation result from the study area revealed a variation in the reservoir thickness of a particular well to the other. This confirms the non-uniformity in the rate of sediment deposition and compaction from one location to the other. The result also revealed that movement of oil commenced from well B8. Result from well B2 revealed a hydrocarbon-water formation with a tendency of very little exploitable hydrocarbon present. In view of the above facts, the

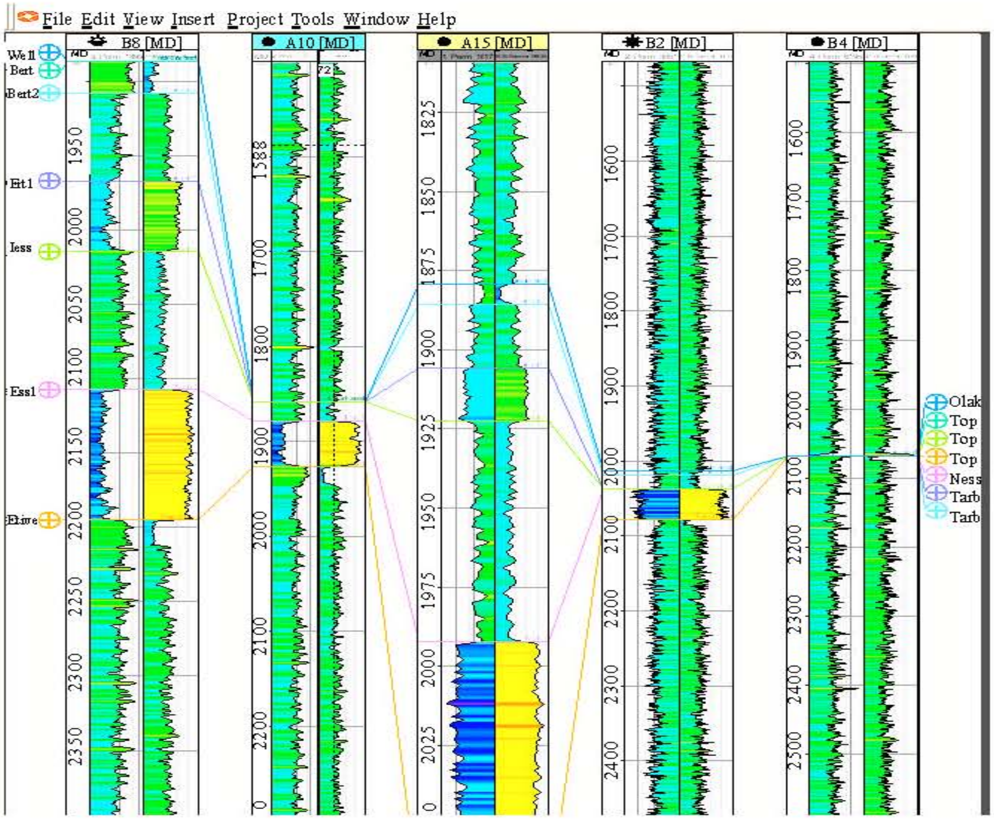

Fig 8: Diagrams showing the position of the five correlated wells

study has demonstrated the effectiveness of the use of well log for geophysical exploration as there were no missing sections as it used to be the case with core samples. The study also revealed that three of the wells i.e A_{10}, A_{15} and B_4 were prolific in hydrocarbon accumulation.

CONCLUSION

In this study, eleven wells namely: A10, A15, A16, B2, B4, B8, B9, C2, C4, C5 and C6, in an oil field belonging to Chevron Nigeria Limited were analyzed using the Petrel software workflow. This was done to determine the structural styles favourable for hydrocarbon accumulation. Correlations of these selected wells were made to determine the points of intersection with permeability and porosity of reservoir. The intersections of the wells with lithofacies in the reservoir and with the oil saturation zones were also determined. These parameters helped to detect the oil trap and the point to commence drilling. Result from the study suggests that one of the well code named B2 was a hydrocarbon-water formation with a tendency of very little exploitable hydrocarbon present. However, three of the wells, code named A10, A15 and B4 were prolific in hydrocarbon accumulation. The study also demonstrated the effectiveness of the use of well log for geophysical exploration as there were no missing sections as it used to be with exploration method using core samples.

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