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Research Article

PETROPHYSICAL EVALUATION OF RESERVOIR SAND BODIES, ONSHORE FIELD, EASTERN NIGER DELTA, NIGERIA

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ABSTRACT

This study involves the petrophysical evaluation of reservoir quality of sand bodies in an onshore field "D"in the eastern Niger Delta. Four reservoirs designated A, B, C and D were correlated across five wells in field "D" using gamma ray logs and shale resistivity marker. In characterizing the reservoirs, the parameters that were considered, included porosity, permeability, water saturation, hydrocarbon saturation, and bulk volume of water. The reservoir sand bodies have an average net-to-gross thickness, porosity, permeability, hydrocarbon saturation and water saturation of 74.77m, 26.88%, 158.76md, 29.98% and 70.02%, respectively. The porosity ranges from very good to excellent and the permeability varies from good to excellent. The water saturation value is generally less than 45%, while the hydrocarbon saturation is greater than 55%. From the values of the bulk volume of water, the reservoirs are at irreducible water saturation implying that the reservoirs can produce water-free hydrocarbon even with high water saturation of 45%; hence, they are good hydrocarbon reservoirs. The reservoir rock type is basically sandstones intercalated with shales which constitute the source and the seal rocks. This scenario corresponds to what is obtainable in the Agbada Formation.

Keywords: Petriphysics, Reservoir, Niger Delta, Onshore Field

INTRODUCTION

The Niger Delta is a prolific oil province where one petroleum system, the Tertiary Niger Delta (Akata-Agbada) petroleum system has been identified and is one of the largest in the West African (sub-region). Reservoirs in the Niger Delta exhibit a wide range of complexities in their sedimentological and petrophysical characteristics, due to difference in hydrodynamic conditions prevalent in their depositional settings. The Niger Delta basin occupies the Gulf of Guinea continental margin in equatorial West Africa between latitudes 3^0 and 6^0N and longitudes 5^0 and 8^0E.The petrophysical evaluation of reservoir quality of sand bodies is to determine how best the field will produce. Petrophysical evaluation is concerned with the rock proportion that determines the quality, quantity, recoverability of hydrocarbon in a reservoir. A reservoir therefore, has to be a formation that has the capacity to store fluid and the ability to release and flow it. The potential and performance of a reservoir include porosity, permeability and fluid saturation which are fundamental parameters. The relationships among these properties are used to identify and evaluate reservoirs. Petrophysical evaluation of reservoir sand bodies is the continuing process of integrating and interpreting geological, geophysical, petrophysical, fluid and performance data to form a unified, consistent description of reservoir properties throughout the field.

This research work is based on the use of wireline logs from a Niger Delta field to identify and quantify hydrocarbon reserves and evaluate rock properties in the subsurface. The petrophysical analysis with wireline logs provides reservoir qualities (porosity, permeability, and fluid saturation), which were integrated with other data provided a guide and enhanced exploration and development of the reservoir sand bodies.

AIM OF THE STUDY: The aim of this work is to carry out a detailed petrophysical evaluation of reservoir quality of sand bodies. This will provide critically needed input data towards the operator's development of an enhanced reservoir sand development model for the study field in the onshore eastern Niger Delta. Visa-vizdetermininig sand/shale distribution in the field. Evaluation the reservoir quality of sand bodies. Determining the reservoir sand bodies . identifying the various sand bodies and correlate them across the field.

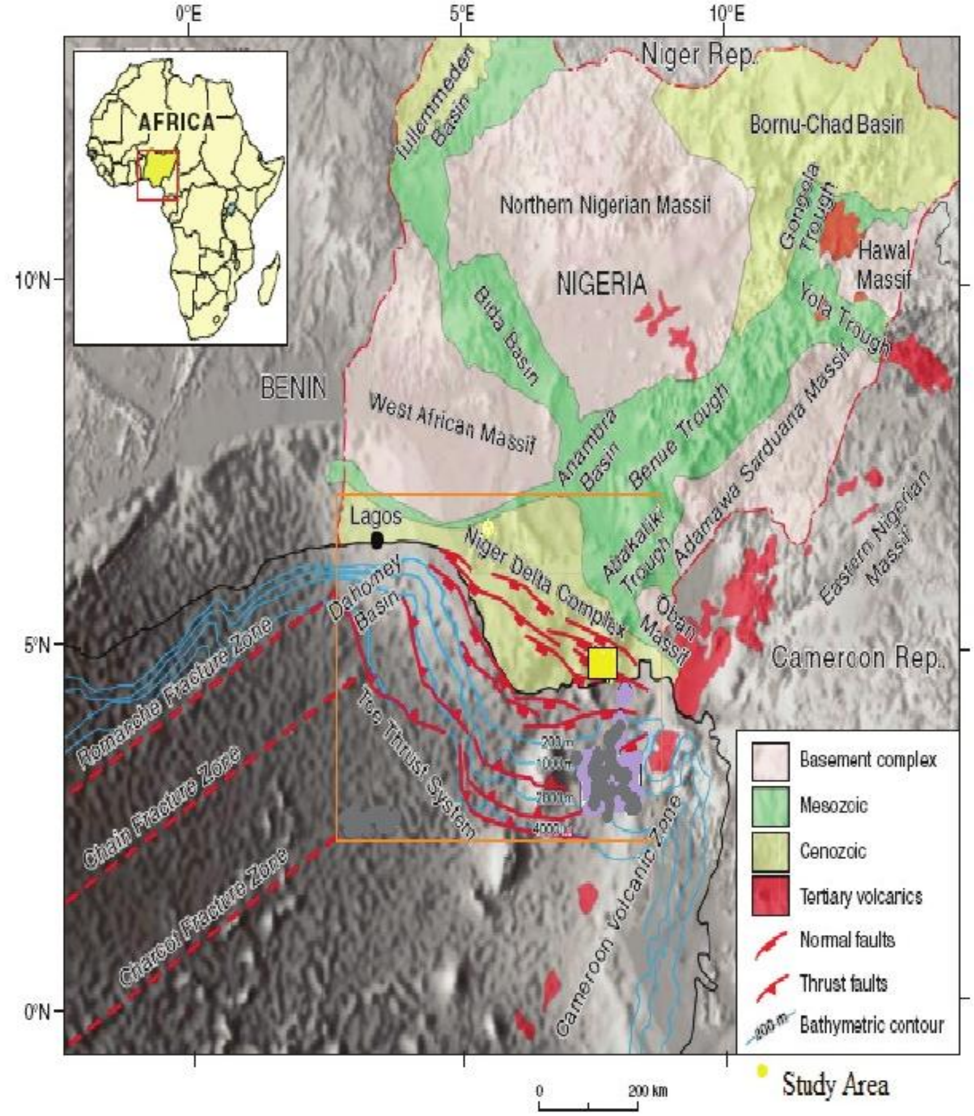

Figure 1: Location map showing field "D", onshore Niger Delta

STUDY LOCATION: The field under study is pseudo-named field"D" in accordance with Shell Petroleum Development Company of Nigeria (SPDC) confidentiality agreement. The field is an onshore field located within the swamp region of the Niger Delta. (See Figures 1,).

The co-ordinates of the location of this field were latitudes 4º35′-4º57′N Longitudes 7º19′15″-7º56′25″E. It covers an areal extent of 19.89km^2. A total of 5 well have been drilled in the D-field, encountering nineteen reservoirs between the depths of (2136.6m) to about (3657.6m).Thirteen of these reservoirs are oil bearing while six are gas bearing. Two of the oil bearing reservoirs are planned for further development. No hydrocarbon bearing reservoirs were logged in Well 1.

LITERATURE REVIEW:

The Niger Delta basin has been intensively studied mostly by the oil industry and academia in recent time, because of its economic importance as a petroliferous province. Most of the workers have investigated and summarized the basic geology, evolution and structural setting, sequence stratigraphy, biostratigraphy, lithology and depositional environment of the basin. Other studies include production characteristics, field development strategies, and optimization mechanisms of the basin. Some of the workers and contributions are discussed below.

Short and Stauble (1967) outlined the general geology of the Niger Delta. They have studied the origin of the Niger Delta basin, and established that the Tertiary deltaic fill of the Niger Delta is represented by a strongly diachronous (Eocene-Recent) sequence, which is divided into three (3) stratigraphic units namely: the Akata Formation, Agbada Formation and Benin Formation.

Evamy et al. (1978) identified two possible migration pathways in the Niger Delta: Migration along the structure building faults which terminate in the Akata Formation and migration from the seaward facies which change up-dip into the rollover structures. They grouped the fault blocks in the Niger Delta into a hierarchy of macro structural blocks, which constitute separate provinces in terms of time, stratigraphy, deformation, sedimentation, generations and migration of hydrocarbons and their distribution.

Ekweozor and Okoye (1980) carried out petroleum source bed evaluation of Tertiary Niger Delta. They established that the dominant sedimentary kerogen in the Niger Delta were the humic and mixed types. They also stated that habitats of the hydrocarbons are mainly the sandstone reservoirs in the paralic sequence of the Agbada Formation, where the hydrocarbons are characteristically trapped by growth faults at the crest of rollover anticlines.

Omatsola (1982) concluded that reservoir sands of more than 15m thick in most places represent composite bodies, and may consist of two to three stacked channels. The sands are poorly consolidated and have porosities as high as 40% in oil bearing reservoirs. Porosity reduction with depth is gradual and permeability in hydrocarbon reservoirs are commonly in the range of 1-2 Darcy.

The Stratigraphy of the Niger Delta The stratigraphy of the Niger Delta clastic wedge has been documented during oil exploration and production; most stratigraphic schemes remain proprietary to the major oil companies operating concessions in the Niger Delta basin. The composite Tertiary sequence of the Niger Delta consists, in ascending order, of the Akata, Agbada and Benin Formation. They are composed of estimated 28,000ft (8,535m) of section at the approximate depocenter in the central part of the delta (Avbovbo, 1978). There is decrease in age basin ward, reflecting the overall regression of depositional environments within the Niger Delta clastic wedge. Stratigraphic equivalent units to these three formations are exposed in eastern Nigeria (Figs. 6a, 6b and Table 1). The formations reflect a gross coarsening-upward progradationalclastic wedge (Short and Stauble, 1967), deposited in marine, deltaic, and fluvial environments (Weber and Daukoru, 1975; Weber, 1986). The stratigraphic distribution of these rocks is poorly understood because of the lack of drilling information and outcrops (Avbovbo, 1978).

Subsurface		Surface Outcrops		
Youngest known Age	Oldest known Age	Youngest Known Age		Oldest Known Age
Recent Benin Formation (Afam Clay member)	Oligocene	Plio/Pleistocene	Benin Formation	Miocene
Recent Agbada Formation	Eocene	Miocene	Ogwashi-Asaba Formation	Oligocene
		Eocene	Ameki Formation	Eocene
Recent Akata Formation	Eocene	Lower Eocene	Imo shale Formation	Paleocene
		Paleocene	Nsukka Formation	Maastrichtian
		Maastrichtian	Ajali Formation	Maastrichtian
Unknown	Cretaceous	Campanian/ Maastrichtian	Nkporo Shale	Santonian
		Coniacian/ Santonian	Awgu Shale	Turonian
		Turonian	EzeAku Shale	Turonian
		Albian	Asu River Group	Albian

Table 1: Table of Formations of the Niger Delta Area, Nigeria

After Short and Stauble, (1967)

The Akata Formation represents the prodeltafacies of Eastward prograding Tertiary delta (deposited in the front of the advancing delta). It occurs at the base of the delta , and is of marine origin. A type section of the Akata Formation was defined in Akata-1 well, 80km east of Port Harcourt (Short and Stauble, 1967). A total depth of 11,121 feet (3,389.68m) was reached in the Akata-1 well without encountering the base of this formation. The top of the formation is defined by the deepest occurrence of deltaic sandstone beds (7,180ft in Akata well). The formation is estimated to be 18,000ft (about 6000m) thick in the central part of the clastic wedge (Doust and Omatsola, 1989)

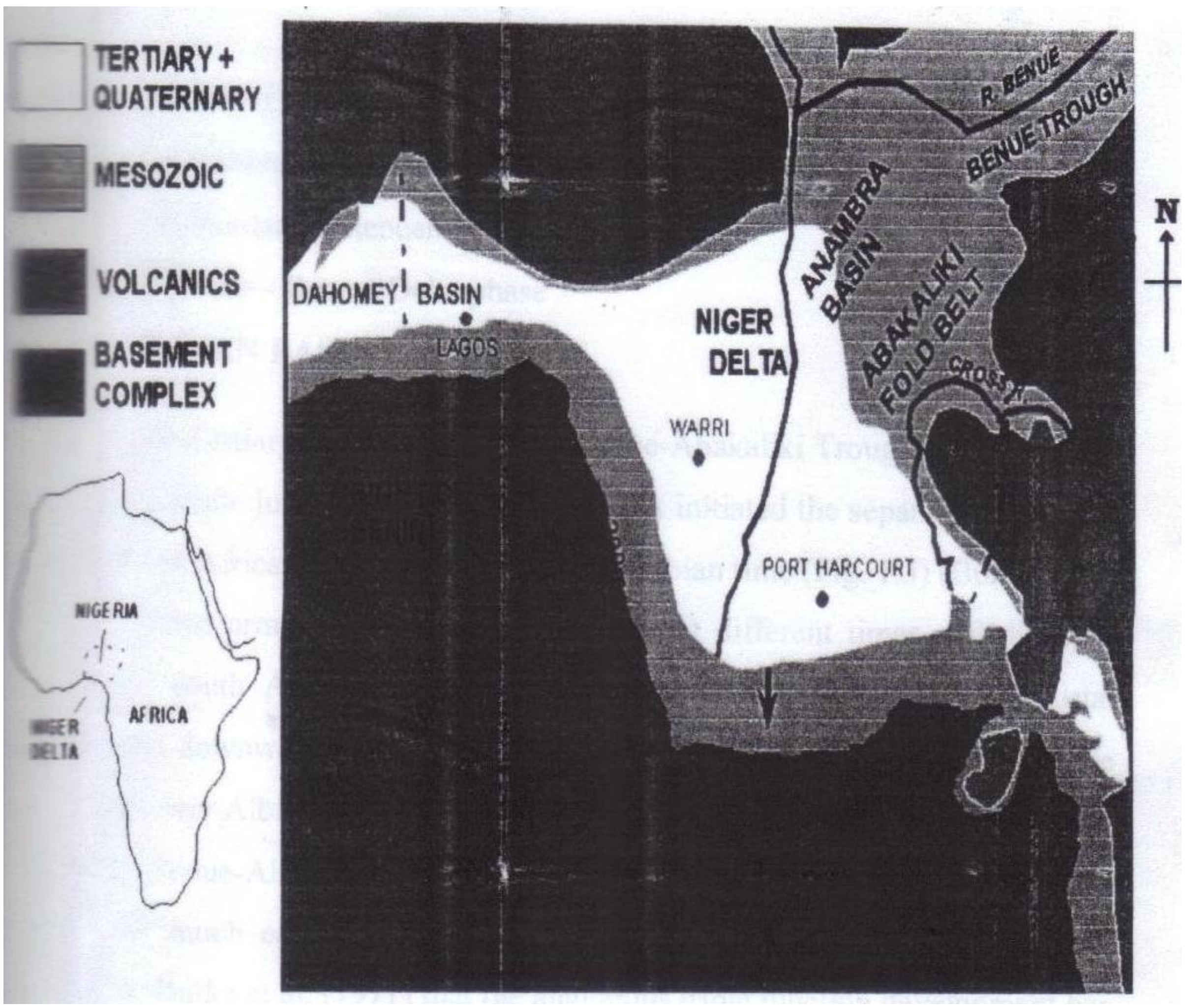

Figure 2: The Map of Niger Delta

METHODOLOGY AND DATA SOURCE

Different methods of study have been adopted in this research for the petrophysical evaluation of the quality of reservoir sand bodies of "D" field. Various research materials were provided by Shell Petroleum Development Company of Nigeria.

(a) Data Available : Base-Map and Contour Map showing the structural element and location of wells.Location map showing the study area,Wireline logs (GR, FDC, CNL RESISTIVITY, CALIPER LOGS).Core photographs

(b) Procedures: The core photographs provided were those of well , four core photographs were studied and observed and were described from bottom upwards. Close observation of the core photos noting the general characteristics and geological succession. Boundaries of each core section were noted.Study of sedimentary structures were carried out noting features like cross-bedding, lamination etc. the degree of bioturbation were indicated.Based on the descriptions, lithology and grain size, dominant sedimentary structures, the lithofacies types were determined and interpreted using the lithofacies classification scheme Core/log Calibration was carried out by using core information to characterize the well logs.

(c) Petrophysical Analysis: The following petrophysical analysis were carried out for certain reservoir sand bodies within the three wells in the area of study from wireline logs by using petrophysical calculation (Archie, 1942; Asquith and Krygowski, 2004): Net-to-cross (N/G), Porosity ( ), Permeability (K), Volume of Shale (Vsh), Formation factor (g), Water saturation (Sw), Irreducible water saturation (Swirr), Bulk Volume Water (BVW) and Hydrocarbon saturation (SH).

RESULTS AND INTERPRETATION

The results show the variations of petrophysical parameters and hydrocarbon potentials within the reservoir sands and among different reservoir sand bodies (i.e. vertically and laterally) in well 2,3 and 4.It also contains the pictures of some cored intervals of "D field-well 4", and their descriptions based on parameters explained.

(A) WELL CORRELATION: Well correlation was carried out to determine the continuity and equivalence of lithologic units for the reservoir sands and marker sealing shales of the five wells in the study area. The wells were correlated using the gamma ray logs as an initial quick look to identify the major sandstones unit; and the deep resistivity log for detailed correlation work with emphasis on the shale sections. The reasons for concentrating correlation work on shales include but are not limited to the fact that, clay and mud particles which make shales are deposited in low energy regimes. These low energy environments are responsible for shale deposition commonly over large geographic areas. Therefore, the log curves in the shale are highly correlatable from well to well and can be recognized over long distances.

Secondly, prominent sand beds are often not good correlation markers because they frequently exhibit significant variation in thickness and character from well to well and are often laterally discontinuous.

In addition, the resistivity curves for the same sand and two well logs being correlated may be due to fluid in the sand (Tearpock and Bischke, 1991). The aims of the correlation were to derive information from the subsurface such as:

- Lithologic continuity
- Formation tops and bases
- Depth to and thickness of hydrocarbon bearing zones and
- Integration of the information derived with well logs, as well as core samples and seismic to infer the reservoir sand bodies.

Therefore, each well has four (4) hydrocarbon bearing reservoirs that were correlated across the five wells named reservoirs A, B, C and D.

(B) PETROPHYSICAL EVALUATION: Total of five (5) wells were provided, wells 1-5". Petrophysical characteristics were computered for wells 2,3 and 4 (because complete set of log suites were carried out in them [Gamma Ray, porosity logs (neutron density) and resistivity logs] The evaluated parameters were Volume of Shale, porosity (corrected for shale volume), Formation Factor, Water Saturation, Irreducible Water Saturation, Hydrocarbon Saturation, Bulk Volume Water and Permeability.Table 4 shows the summarized average petrophysical values for each reservoir in D wells 2,3 and 4. Petrophysical evaluation was broadly subdivided into qualitative and quantitative interpretation.

(i) D- well 2 -reservoir A: This occurs at the depth range of 3451.68-3627.12m. It has a gross thickness of 175.26m and net sand thickness of 132.26m. The net-to-gross is 75.47%. The porosity values of the reservoir range from 19-30% with an average value of 26.5%.

The Permeability values range from 6.98-180.59md with average value of 1769md. It interpreted that the reservoir has very good to excellent porosity and has good permeability.

The water saturation values range from 4-69% with an average of 32% , while the hydrocarbon saturation ranges from 31-96% with an average of 68%. The hydrocarbon is down to 3580m (HDT), WUT 3550m and GOC is at 3543.3m.

From the bulk water volume values which are constant or nearly constant, the reservoir is said to be homogenous and at irreducible water saturation. This implies that the reservoir can produce water free hydrocarbon under reservoir pressure .

(ii) D- well 2 -reservoir B: This occurs at the depth range of 3657.6-3771.9m. It has a gross thickness of 114.3m and net sand thickness of 72m. The net-to gross is 63.25%. The porosity values of the reservoir range from 17-44% with an average value of 25.5%. The permeability values range from 4.73-2055.81md with average value of 89.60md. it is interpreted that the reservoir has good to excellent porosity and has excellent permeability.

The water saturation values ranges from 17-60% with an average of 45%, while the hydrocarbon saturation range from 44-83% with average of 55%. The hydrocarbon is down to 3880m (HDT), WUT 3860m and GOC is at 3634.74.

From the bulk water volume values which are constant or nearly constant, the reservoir is said to be homogenous and at irreducible water saturation: This implies that the reservoir can produce water-free hydrocarbon.

(iii) D- well 2 –reservoir C: This occurs at the depth range of 3825.5-5901.4m. It has a gross thickness of 76.2m and net sand thickness of 64.2m. The net-to gross is 84.25%. The porosity values of the reservoir ranges from 15-30% with an average value of 23%.The permeability values range from 1.49-153.98md with average value of 39.44md. it is interpreted that the reservoir has very good porosity and good permeability.

The water saturation values ranges from 19-50% with an average of 39%, while the hydrocarbon saturation range from 49-81% with an average of 61%. The hydrocarbon is down to 3880m (HDT) and WUT 3860m. GOC and OWC could not be determined exactly. From the bulk water volume values which are constant or nearly constant, the reservoir is said to be homogenous and at irreducible water saturation. This implies that the reservoir can produce water-free hydrocarbon.

(iv) D- well 2 -reservoir D: This occurs at the depth range of 3924.3-4015.74m. It has a gross thickness of 91.44m and net sand thickness of 64.44m. The net-to gross is 69.38%. The porosity values of reservoir range from 19-24% with an average value of 22.2%.

The permeability values range from 9.54-39.41md with average value of 25.37md. It is interpreted that the reservoir has good to very good porosity and has moderate to good permeability.

The water saturation values range from 8-50% with an average of 32.4%, while the hydrocarbon saturation ranges from 50-92% with an average of 67.6%. The hydrocarbon is down to 3975m (HDT), WUT 3975m and OWC is at 3975m. From the bulk water volume values which are constant or nearly constant, the reservoir is said to be homogenous and at irreducible water saturation: This implies that the reservoir can reduce water-free hydrocarbon (Appendix A4).

(v) D well 3-reservoir A: This occurs at the depth range of 3429-3619.5m. it has a gross thickness of 190.5m and net sand thickness of 174.5m. the net-to gross is 91.6%. The porosity values of the reservoir range from 19-31% with an average value of 23.7%.

The permeability values range from 4.45-200.17md with average value of 44.20md. It is interpreted that the reservoir has very good to excellent porosity and has good permeability. Therefore, the water saturation values ranges from 5050% with an average of 38.1%, while the hydrocarbon saturation range from 50-95% with an average of 61.9%. The hydrocarbon is down to 3610m (HDT), WUT 3560m, GOC is at 3459.48m and OWC is at 3489m. Hence, this is an oil and gas reservoir. From the bulk water volume values which are constant or nearly constant, the reservoir is said to be homogenous and at deducible water saturation: This implies that the reservoir can produce water-free hydrocarbon.

(vi) D well 3-Reservoir B: This occurs at the depth range of 3642.36-3733.8m. It has a gross thickness of 91.44m and net sand thickness of 51.44m. The net-to gross is 56.26%. The porosity values of the reservoir ranges from 14-42% with an average value of 25.4%.

The permeability values range from 1.18-1600.89md with average value of 172.85md. It is interpreted that the reservoir has very good to excellent porosity and has good to excellent permeability.

The water saturation values range from 4-35% with an average of 21.7% , while the hydrocarbon saturation ranges from 65-96% with an average of 78.3%. The hydrocarbon is down to 3730m (HDT), WUT 3710m, while GOC is at 3654.55m and OWC is at 3703.2m. From the bulk water volume values which are constant or nearly constant, the reservoir is said to be homogenous and at irreducible water saturation. This implies that the reservoir can produce water-free hydrocarbon.

(vii) D well 3-Reservoir C: This occurs at the depth range of 3817.62-3886.2m. It has a gross thickness of 68.52m and net sand thickness of 45.52m. The net-to gross is 66.43%. The porosity values of the reservoir range from 19-29% with an average value of 25.2%. The permeability values range from 9.26-146.16md with average value of 69.28md. It is interpreted that the reservoir has good to very good porosity and has good to very good permeability.

Therefore, the water saturation values ranges from 5-50% with an average of 23.3%, while the hydrocarbon saturation ranges from 50-95% with an average of 76.7%. The hydrocarbon is down to 3880m (HDT), WUT 3853m while GOC is at 33825.24m. From the bulk water volume values which are constant or nearly constant, the reservoir is said to be homogenous and at irreducible water saturation: This implies that the reservoir can produce water-free hydrocarbon (Appendix A7).

(viii) D-well-Reservoir D: This occurs at the depth range of 3909.6-3985.26m. It has a gross thickness of 76.2m and net sand thickness of 59.2m. The net-to gross is 77.69%. The porosity values of the reservoir range from 23-29% with an average value of 25.4%.

The permeability value ranges from 25.61-136.56m with average value of 60.08md. It is interpreted that the reservoir has very good porosity and has good permeability. Therefore, the water saturation value ranges from 4-32% with an average of 16.2%, while the hydrocarbon saturation ranges from 68-96% with an average of 83.8%. The hydrocarbon is down to 3970m (HDT), WUT 3965m while OWC is at 3970.02m. From the bulk water volume values which are constant or near constant, the reservoir is said to be homogenous and at irreducible water saturation. This implies that the reservoir can produce water-free hydrocarbon .

DISCUSSION

This research work is basically aimed at evaluating the reservoir quality of sand bodies in an onshore field "D" of the eastern Niger Delta. This was done on the basis of well logs of five wells in the field, and core sample photographs of some intervals.

Log analysis provided basic information that was used to determine petrophysical properties of the reservoir in order to discriminate between reservoir and non-reservoir, determine formation thicknesses, determine porosity and permeability, while the core samples were used to determine the lithofacies characteristics and sedimentary structures. The qualitative interpretation was based on the logs. The correlation of the wells shows that the four reservoirs are continuous across the five wells. These reservoirs are labelled A, B, C and D. The lithology of these reservoirs is basically sandstones. The intrinsic properties were determined quantitatively and this include the calculation of net-gross, porosity, permeability, hydrocarbon and water saturation as well as other parameters such as formation factor, irreducible water saturation, bulk water volume, etc.

In well 2, the net-gross for the four reservoirs A, B, C and D are 75.47, 63.25, 84.25 and 69.38%,respectively (thus, has a producible reservoir thickness), the porosity decreases downward very gradually in reservoir A, B, C and D are with an average of 26.25, 25.0, 22.88, and 22% , respectively (thus, very good to excellent). The permeability for the four reservoirs A, B, C, and D are 89.60, 1641.35, 39.44 and 25.37md, respectively (good to excellent). In addition, the hydrocarbon saturation for the four reservoir A, B, C and D are 68.1, 54.8, 61.4 and 67.7% , respectively (thus, are good reservoirs for oil/or gas). The water saturation for the four reservoirs A, B, C and D are 89.60, 1614; 35, 39.44, and 25.37md, respectively and are inversely proportional to hydrocarbon saturation.

On the other hand, the bulk water volume ranges from 2-18% with an average irreducible water saturation of 9.3% throughout the four reservoirs implying that they can produce water-free hydrocarbon, and even though they have high water saturation, these make good reservoirs. It is important to note that the values of the aforementioned petrophysical parameters vary gradually vertically and across the corresponding reservoirs in the wells.

CONCLUSION

This study was carried out to integrate wire line logs and core sample data in order to evaluate the reservoir quality of sand bodies in five wells of field "D" in the onshore Niger Delta.

Consequently, petrophysical evaluation of the reservoir shows that the porosity ranges from very good to excellent while the permeability varies from good to excellent. There was a gradual decrease in porosity with depth. The permeability values show slight decrease with depth, most likely as a result of diagenesis and compaction associated with depth of burial of the older sediments as deposition occurred.

The water saturation value is generally less than 45%, while the hydrocarbon saturation of the field is greater than 55%. From the value of the bulk volume of water, the reservoirs are at irreducible water saturation, implying that the reservoirs can produce water-free hydrocarbon

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