# Wabi Field Lithology and Fluid Characterization via Well Log Interpretation and Clustering

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## ABSTRACT

Formation evaluation analysis and log-facies classification are powerful tools for identification and assessment of hydrocarbon - bearing zones. In this paper, petrophysical evaluation of well logs data from a suite of four wells (WABI 05, 06, 07 and 11) in the study area was carried out by integrating conventional log analysis and cluster analysis of some reservoirs in WABI field located in the Niger Delta Basin of Nigeria. The methods employed are based on conventional formation evaluation models and cluster analysis techniques. Cluster analysis of different log properties was generated to recognize the lithologic variability and pore-fluid type. The final output is the set of petrophysical curves, fluid type and fluid contacts and neutron–density cluster analysis. Eight reservoirs were delineated and established to be mainly sandstone with intercalation shale. Neutron–Density cross-plot analyses revealed the presence of oil, gas or brine in all wells. Gas intervals showed very big cross over on neutron-density curves and are also supported by very high resistivity readings. The Neutron log versus Density cross-plot is colour-coded with gamma ray in WABI 07. It discriminates the reservoirs into shale, brine sands, oil sands and gas sands. Some reservoirs are made up basically of gas or gas and brine. From the results, the reservoirs are prolific and feasible for hydrocarbon production. This study has shown that the integration of conventional log analysis and cluster analysis are robust methods in the determination of the production potentials of hydrocarbon reservoirs.

**KEYWORDS:** Fluid Type, Fluid Contacts, Hydrocarbon, Cluster analysis WABI

## 1. INTRODUCTION

The understanding of reservoir dimension is an essential factor in quantifying producible hydrocarbon from reservoirs; and the required information includes the area extent of the reservoir and its thickness (Schlumberger, 1989). These parameters are essential because, they serve as actual inputs data for reservoir volumetric analysis (Edward, 1988). Accurate determination of hydrocarbon reservoir thickness is best obtained from petrophysical well logs. This thickness estimation is basically carried out on resistivity and gamma ray logs (Asquith, 2004). Oil and gas produced are connected to accumulations in pore spaces of lithologies like carbonates and sandstones.

The current faced challenges in reserve estimation and developments are sometimes credited to clay volume effects on the reservoirs (Asquith, 2004), complex lithology and reservoir heterogeneity which lead to poor reservoir characterization (Bassiounni and Velic, 1996). Besides, there are issues relating to inadequate prediction of reservoir parameters and lithofacies from well log analysis due to inconsistent well log data acquisition methodology and statistical analysis techniques deployed. Such well information is also usually wrongly correlated with seismic data and the result will be marred with uncertainties. As a result of these poor data, detailed petrophysical evaluation is usually required for optimized development and production of hydrocarbon, particularly in the highly heterogeneous environments like the paralic successions in deep reservoir of Wabi field situated in the Agbada Formation of the Niger Delta.

To address this issue, the use of well log cross-plots and petrophysical models to predict the reservoir parameters and lithofacies are employed. Cross-plotting known as cluster techniques enable evaluation of pore fluid and lithology variations on regional and detailed reservoir scales (Lamont et al., 2008; Hunze and Wonik, 2007). Anderson and Gray (2001) verified that many diverse lithologies like carbonates, shale, coal, sandstone

and gas saturated sands can be identified by cross-plots of well logs such as density versus gamma ray , neutron versus density etc.

The aim of this research is to carry out formation evaluation analysis and log-facies classification for proper characterisation in order to achieve the identification and assessment of hydrocarbon bearing zones (i.e prospecting for bypassed oil and gas) of WABI Field in the Niger Delta Basin of Nigeria. The objectives are to delineate the hydrocarbon-bearing reservoirs and fluid differentiation using density/neutron log combination and cluster analysis.

## 2. GEOLOGY OF THE STUDY AREA

The study area Wabi field (Figure 1) is positioned in the Upper Ughelli north central of the Niger Delta Basin. The Tertiary Niger Delta covers an area of approximately 75,000 $km^2$ within the Gulf of Guinea in West Africa, but mostly in Nigeria. The modern Niger delta complex was formed in the early Tertiary when sediments deposit began to accumulate during Mesozoic rifting which was associated with the drifting apart of the African and South American continents (Weber and Daukoru 1975; Doust and Omatsola, 1990).The delta complex has an arcuate-lobate shape and it is formed by destructive and wave dominated type. The Cenozoic Niger delta complex was developed as a regressive offlap sequence. These clastic sequences reach a maximum depth thickness of 9000–12,000 m (Evamy et al., 1978). Sediments deposition were built up by superposition of various offlap, these depositions in an ascending order started with Marine clays under-compacted, which is overlain by paralic deposits and the continental sands deposits (Weber and Daukoru 1975). These deposits are characterized by a series of depobelts that transverse through north-west, sub-parallel to the present shoreline. The stratigraphy of the Niger Delta consists of three diachronous lithostratigraphic units. The recent in age is the continental top facies (Benin Formation), the paralic delta front facies (Agbada Formation) and the Akata Formation which forms the prodelta facies. The Benin formation is of Miocene to recent. It is a continental deposit of probable upper deltaic depositional environment. The overall thickness varies but do not generally exceeds 6000ft.Various structural units, points bars, channel fills, natural leaves, back swamp deposits, oxbow fills are identifiable within the formation. The Agbada Formation is a paralic sequence that overlies Akata Formation and underlies the Benin Formation. It is of Eocene to Pliocene in age. It occurs throughout Niger Delta clastic wedge and has thickness over 10,000ft. It outcrops around Ogwashi and Asaba, southern Nigeria (Doust and Omatsola, 1989). The Agbada formation is characterized by sequence of sandstones and shale that is it consists of predominantly sandy unit and the base is of significant sandstone unit with minor shale intercalations (Short and Stauble, 1967). It is defined by progressive upward changes in grain size and bed thickness. The strata are generally interpreted to have been formed in fluvial-deltaic environment. The Akata Formation is a marine sedimentary succession that was laid in front of the advancing delta. It is composed of mainly marine under compacted shales with sandy and silty beds lenses though to have been deposited as turbidite and continental slope channel fills (Schlumberger, 1985). It is characterized by dark grey, sandy, silty shale with plant remains at the top. Sandstone lenses occur near the Agbada Formation (Doust and Omatsola, 1989). Planktonic foraminifera may account for over 50% of the rich micro fauna and the bentonic assemblages indicating shallow marine shelf depositional environment. The top of the Akata Formation is the economic basement for oil. Therefore, the Akata Formation is the main source rock of the Niger Delta (Short and Stauble, 1967). It is over 1000ft thick however; it depends on the shale diapirism and flowage. The Niger delta basement faulting affects the development of delta and destruction of sediments thickness. Growth fault associated with rollover structure in the paralic interval trapped hydrocarbons and play a vital role in distribution of hydrocarbon. It also functions as the paths from over-pressured Akata shales. The depositional environments of reservoir sands strongly control well production as well as recovery efficiency (Weber and Daukoru, 1975).

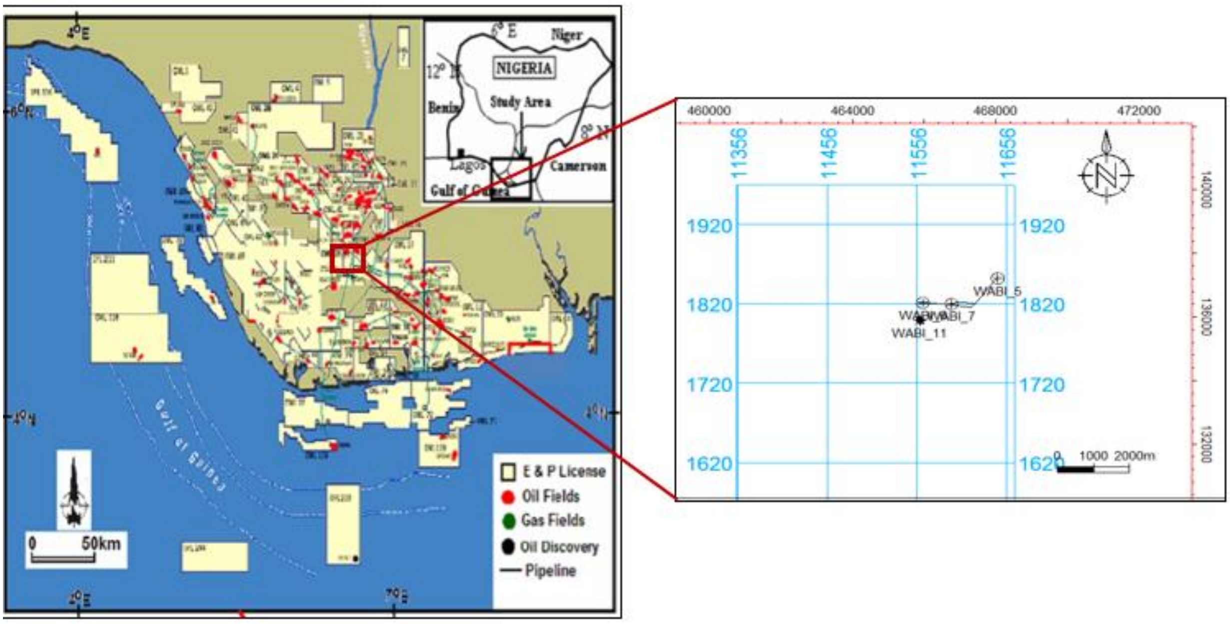


*Figure 1: Map of Niger Delta and enlarged figure of the Base map of the study area.*

## 3. MATERIALS AND METHODS

The data used in this research were obtained from an International Oil Company (IOC) after an approval was given by the Department for Petroleum Resources (DPR). The data consists of suites of well logs consisting of Gamma ray, Calliper, Resistivity, Neutron and Density logs from four wells (WABI 05, 06, 07 and 11), deviation/survey data and checkshot data. These data were analyzed in a workstation using Interactive Petrophysics (IP) Software. The data were utilised in delineating hydrocarbon bearing reservoirs and in fluid/lithology discrimination. The flowchart of the methodology is shown in Figure 2. The methodology can be divided into three parts: Reservoir delineation, fluid/lithology discrimination using density-neutron log combination and cluster analysis.

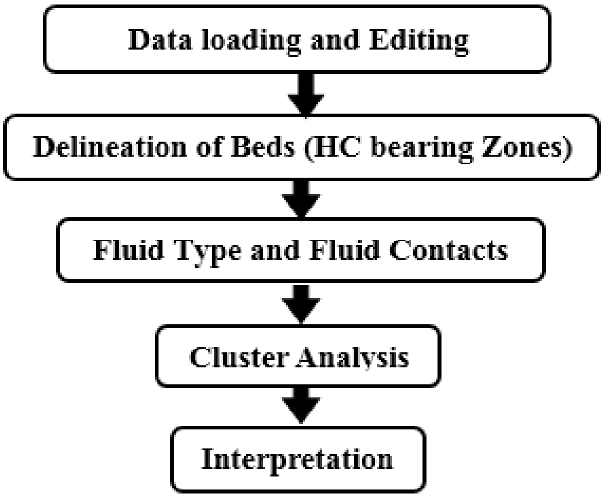


***Figure 2. Flowchart of the methodology***

### 3.1 Data Preparation

A database of 4 wells each with a basic petrophysical QC log suite was compiled in an Interactive Petrophysics (IP) project. In practice, well logs contain several inherent problems, especially problems of spikes. The logs were despised and edited to remove spurious events and reduce the scatter in the lithology and fluid cluster analyses.

### 3.2 Reservoir Delineation

The next step was to evaluate the well logs to determine reservoir zones with considerable hydrocarbon saturation. This is based on the fact that logs respond to different lithologies. The gamma ray (GR) log is principally useful for defining shale beds. GR log reveals the proportion of shale and, in many regions, can be used quantitatively as a shale indicator. High gamma ray count indicates shale lithology.

### 3.3 Identification of Oil/Gas Bearing Zones

Combination of Gamma Ray and Neutron – Density Log was used in identification of oil and gas bearing zones. The gamma ray log measures the natural radioactive content of a formation, and functions mainly as a lithology log. Hence, it helps differentiate shales due to its high radioactive counts from sands, carbonates, and anhydrites with low radioactive counts. Porosity logs are density and neutron. The density log measures the electron density in a formation while neutron log is used to measure the amount of hydrogen ions in a formation (Asquith and Gibson, 1982). When these three logs are used together (i.e. combination gamma ray, neutron-density log), lithology and fluid can be determined. Density-neutron log overlay each other on the same log track plotted on compatible scale. In a gas bearing zone, density and neutron curves separate. Density increases and neutron decreases in the presence of lighter hydrocarbons. This effect is called "gas cross-over effect" or the "butterfly effect". Density of gas is lower when compared to water resulting in lower formation density. Neutron reads lower hydrogen index. For oil bearing zone, the separation between density-neutron will be in between gas and water responses.

### 3.4 Cluster analysis

Cluster analyses are the most important tools employed in the Petroleum industry for the studies of depositional environment and sedimentological investigation of hydrocarbon bearing rocks. In the absence of core or drilling cuttings where wireline log is the only available and reliable data source. Cluster analysis of wireline logs give visual representations of the existing relationship between two or more variables to quantify the desired characteristic of reservoir features (Rider, 1986). Therefore, neutron versus density cross-plots are interpreted for the presence of hydrocarbon and used to discriminate lithologies as well as fluid types.

## 4. RESULTS AND DISCUSSIONS

### 4.1 Reservoir Delineation

Neutron and Density logs have been used mainly for recognition of lithology and hydrocarbon-bearing zones. A total of eight (8) hydrocarbon-bearing zones were identified from wells WABI 05, 06, 07 and 11, using conventional log analyses. The tops and bases of the other identified reservoirs are shown in Table 1. The wells display a shale/sand/shale sequence which is typical of the Niger delta formation. Figure 3 shows Reservoir WABI A and B in well WABI 06, which is the well shown for illustration. The well was analyzed in terms of lithology from gamma ray, resistivity, density and neutron logs. Low gamma ray and high resistivities are sand lithologies. Shale lithologies were delineated by the high gamma ray counts. Gamma ray logs measure the radioactivity of formations in the well which is connected to clay mineral, oil source rock, organic matter and shale in reservoir rocks (Schlumberger, 1972). Shale-free sandstones and carbonates normally possess low radioactive concentrations, representing relatively low gamma ray response. Resistivity describes the property of a material or substance to resist the flow of electric current (Schlumberger, 1972). Three types of resistivity log are available which are flushed zone resistivity (micro spherically focused, MSFL), shallow resistivity (laterolog shallow, LLS) and deep resistivity (laterolog deep, LLD). LLD and LLS logs show high value than MSFL logs in hydrocarbon-bearing zones. The deep resistivity log responses against hydrocarbon-bearing zones as observed from the reservoirs were relatively high.

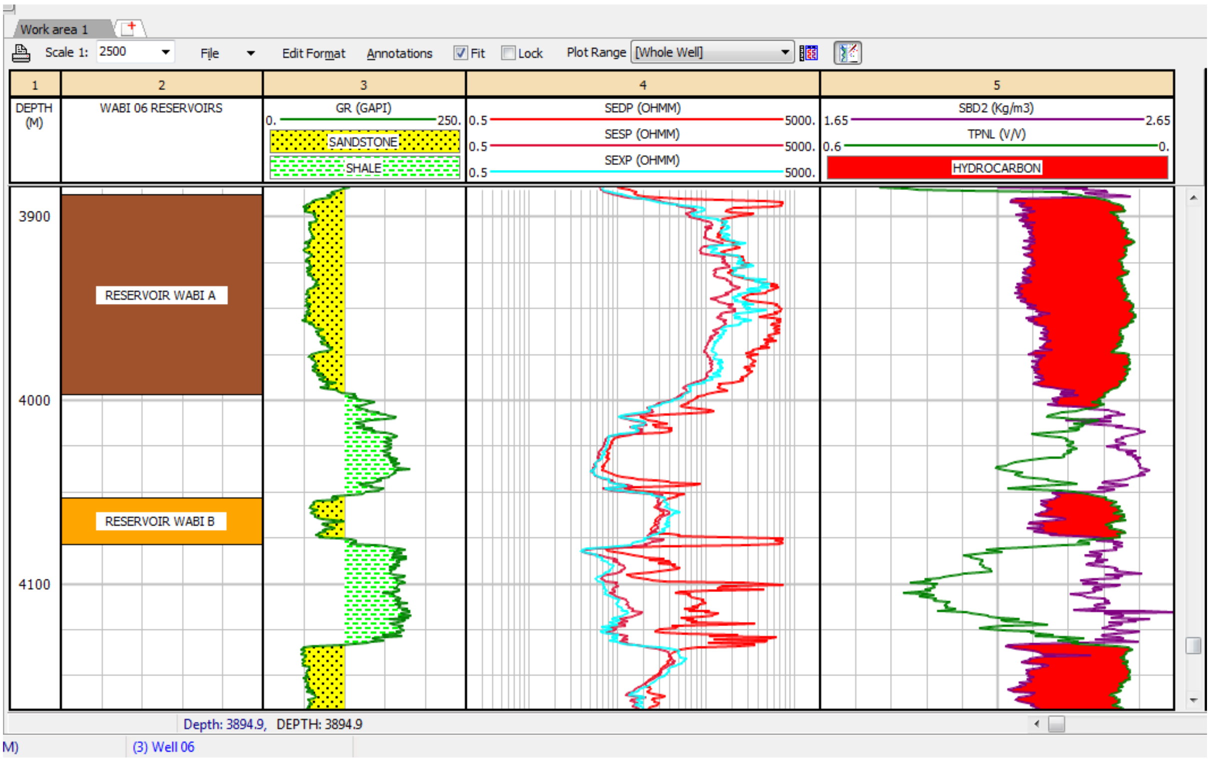


*Figure 3: Reservoir WABI A and B in well WABI 06 showing gamma ray, resistivity, density and neutron logs*

*Table 1: Summary of identified reservoirs in WABI field*

| Wells | | Reservoirs | Top MD (m) | Bottom MD (m) | Thickness (m) |
|---|---|---|---|---|---|
| WABI 05 | 1 | Reservoir WABI A | 3158.795 | 3228.899 | 70.104 |
| | 2 | Reservoir WABI B | 4000.043 | 4045.763 | 45.720 |
| WABI 06 | 3 | Reservoir WABI A | 3887.862 | 3997.286 | 109.424 |

| | | | | | |
|---|---|---|---|---|---|
| | 4 | Reservoir WABI B | 4053.216 | 4078.972 | 25.756 |
| WABI 07 | 5 | Reservoir WABI A | 2915.260 | 2984.144 | 68.884 |
| | 6 | Reservoir WABI B | 3340.760 | 3429.610 | 88.850 |
| WABI 11 | 7 | Reservoir WABI A | 2887.661 | 2962.185 | 74.524 |
| | 8 | Reservoir WABI B | 3513.263 | 3591.597 | 78.334 |

### 4.2 Fluid Type and Fluid Contacts

Conventional method for fluid contact identification includes interpretation of pressure gradients due to fluid density differences in the reservoir hydrostatic column. The tables 2 to 5 show the various fluid types and contacts for the four wells (WABI 05, 06, 07 and 11) in the study area. Density log is strongly affected by the presence of gas and records the lowest density values. Neutron porosity tool accounts for the amount of hydrogen present in the formation. In clean sandstone formations that is shale-free, where the porosity is filled with water or oil, the neutron log measures liquid filled porosity. Neutron log response becomes high in shale because of presence of capillary and clay-bound water; whereas it shows very low value in gas saturated sand. The separation between neutron and density termed as crossover is an identification for gas-bearing zones in clean sand (Bateman, 1985). Gas-bearing zones are characterized by low gamma ray, high deep resistivity and cross-over between neutron and density logs. The cross-over becomes close to each other, indicating signature of oil saturated sand and when they are overlaid with each other representing water saturated sand (See figures 4-6).

In reservoir WABI A of WABI 05, for example, the reservoir is basically made up of gas and water with the Gas – Water Contact at 3181.2m. Gas-bearing zones are characterized by low gamma ray, high deep resistivity and cross-over between neutron and density logs. The cross-over separation between neutron and density for gas is large and creates a balloon effect; whereas for brine, the logs are overlaid with each other. In reservoir WABI A of WABI 05, the reservoir is a combination of oil, gas and brine. The Gas – Oil Contact is at 4009.492M and OWC is at 4030.066M. In the case of WABI 06, the reservoirs are basically gas reservoirs and there is quite a large cross-over between the neutron and density logs. Table 3 shows the summary of WABI 06 for the fluid type and contacts, two reservoirs identified have gas as their fluid type, at depths 3887.862m and 4053.210m respectively. The summary of the fluid type and contact for WABI 07 is shown in Table 4; two reservoirs were identified which have Gas-Water contact at 2931.9m for the top reservoir and 3364.078m for the bottom reservoir. Table 5 shows the summary of fluid type and contact of two reservoirs in the WABI 11. The two identified reservoirs are Gas reservoir at a depth of 3513.263m and Gas-Water contact reservoir at a depth of 2917.379m.

***TABLE 2: Summary Table for WABI 05 showing Fluid Type and the Fluid Contacts***

| WABI 05 | | | | |
|---|---|---|---|---|
| Reservoirs | Top MD (m) | Base MD (m) | Hydrocarbon Fluid Type | Fluid Contact |
| Reservoir WABI A | 3158.795 | 3181.198 | GAS | GWC @ 3181.198M |
| | 3181.198 | 3228.899 | WATER | |
| Reservoir WABI B | 4000.043 | 4009.492 | GAS | GOC @ 4009.492M OWC @ 4030.066M |
| | 4009.492 | 4030.066 | OIL | |
| | 4030.066 | 4045.763 | WATER | |

***TABLE 3: Summary Table for WABI 06 showing Fluid Type and the Fluid Contacts***

| WABI 06 | | | | |
|---|---|---|---|---|
| Reservoirs | Top MD (m) | Base MD (m) | Hydrocarbon Fluid Type | Fluid Contact |
| Reservoir WABI A | 3887.862 | 3997.286 | GAS | GDT |
| Reservoir WABI B | 4053.216 | 4078.972 | GAS | GDT |

***TABLE 4: Summary Table for WABI 07 showing Fluid Type and the Fluid Contacts***

| WABI 07 |
|---|

| Reservoirs | Top MD (m) | Base MD (m) | Hydrocarbon Fluid Type | Fluid Contact |
|---|---|---|---|---|
| Reservoir WABI A | 2915.26 | 2931.9 | GAS | GWC @ 2931.9M |
| | 2931.9 | 2984.144 | WATER | |
| Reservoir WABI B | 2915.26 | 2931.9 | GAS | GWC @ 3364.078M |
| | 2931.9 | 2984.144 | WATER | |

*TABLE 5: Summary Table for WABI 11 showing Fluid Type and the Fluid Contacts*

| WABI 11 | | | | |
|---|---|---|---|---|
| Reservoirs | Top MD (m) | Base MD (m) | Hydrocarbon Fluid Type | Fluid Contact |
| Reservoir WABI A | 2887.661 | 2917.379 | GAS | GWC @ 2917.379M |
| | 2917.379 | 2962.185 | WATER | |
| Reservoir WABI B | 3513.263 | 3591.597 | GAS | GDT |

OWC: Oil – Water Contact
GDT: Gas Down- To
GWC: Gas – Water Contact
GOC: Gas – Oil Contact

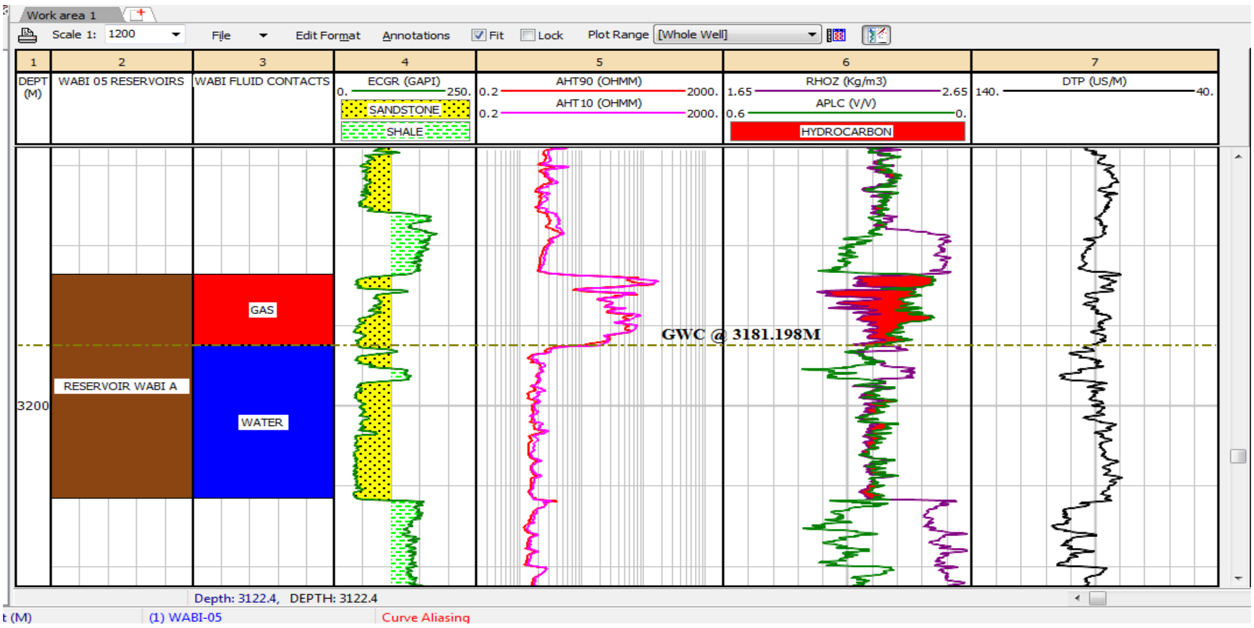

*Figure 4: WABI 05 reservoir WABI A showing the fluid type and contacts*

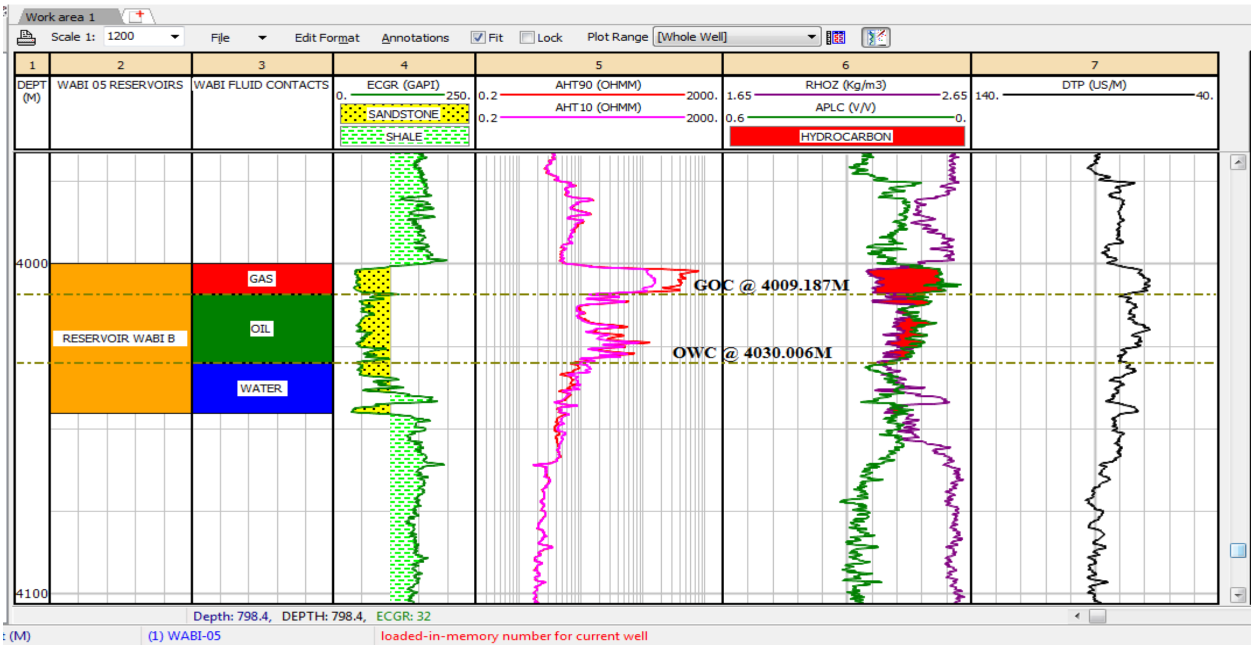

*Figure 5: WABI 05 reservoir WABI B showing the fluid type and contacts*

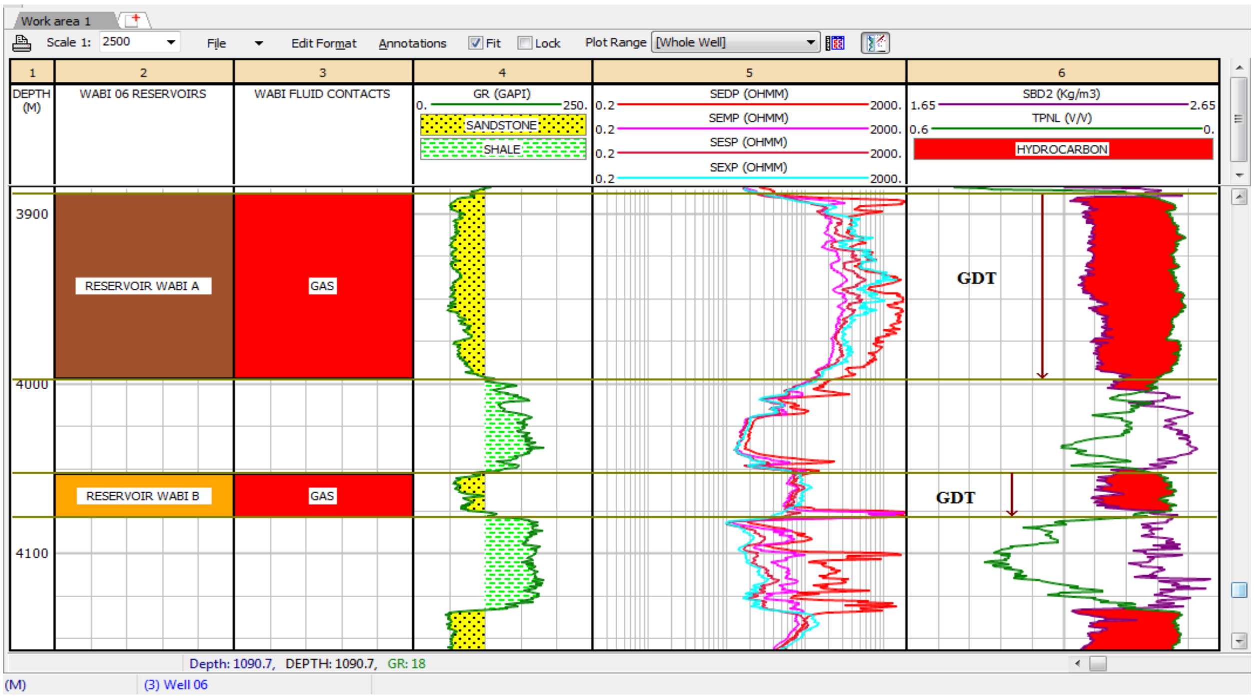

*Figure 6: WABI 06 reservoir WABI A and B showing the fluid type and contacts*

## 4.3. Cluster Analysis

Cross plotting techniques are very robust for identification of lithology and fluid type using log responses. Cross plotting of rock properties from well logs is a very convenient and efficient way to look at two rock properties and their attributes (combination of rock properties) at the same time (Buriank, 2000). It also shows, quite decisively, which rock properties and their attributes will be helpful to discriminate gas in a reservoir. Cross-plot analysis was carried out to establish the rock properties / attributes that better discriminate the reservoir (Omudu and Ebeniro, 2007). The Neutron log versus Density cross-plot colour coded with gamma ray

in figure 7 discriminates the reservoirs into shale, brine sands, oil sands and gas sands. It is obvious that shale shows a very good separation of sand from shaly sand and shale lithology. This separation is due to the fact that shale is denser than sand. Figure 8 shows neutron – density crossplot for gas identification in WABI 06 Well. The gas clusters show low values for both neutron and density.

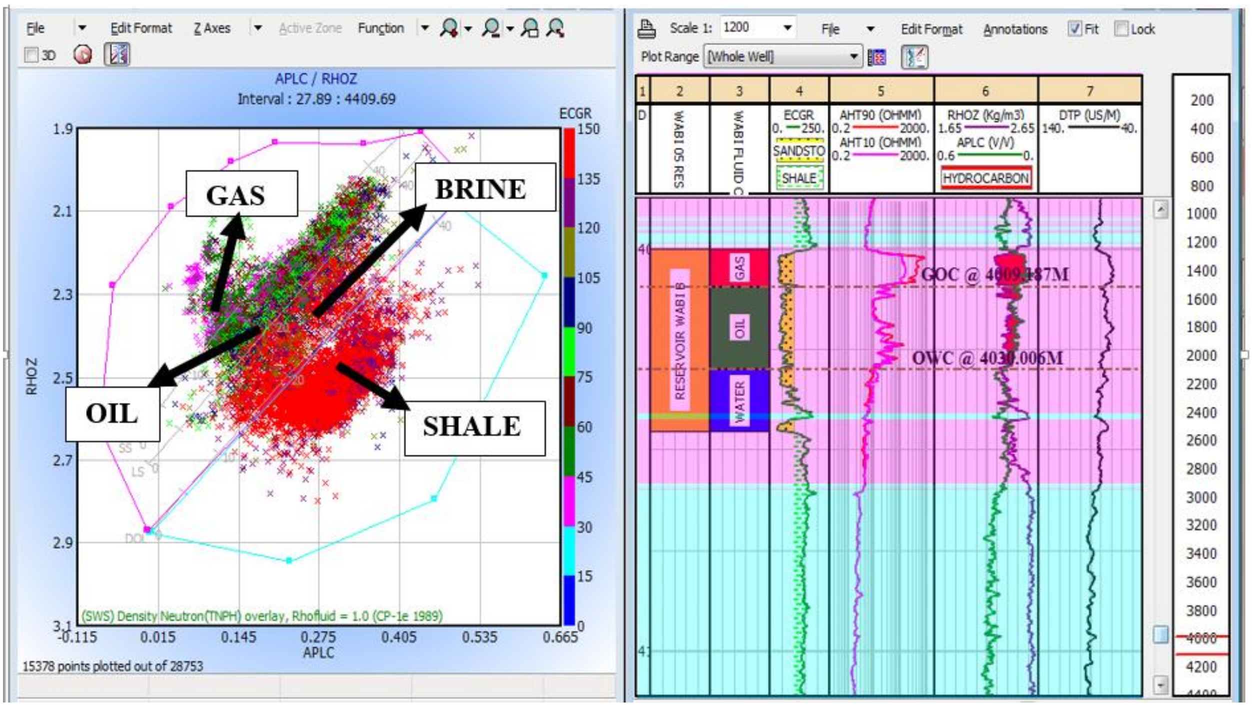


*Figure 7: Neutron – Density Crossplot for fluid and lithology Identification for WABI 05 Well*

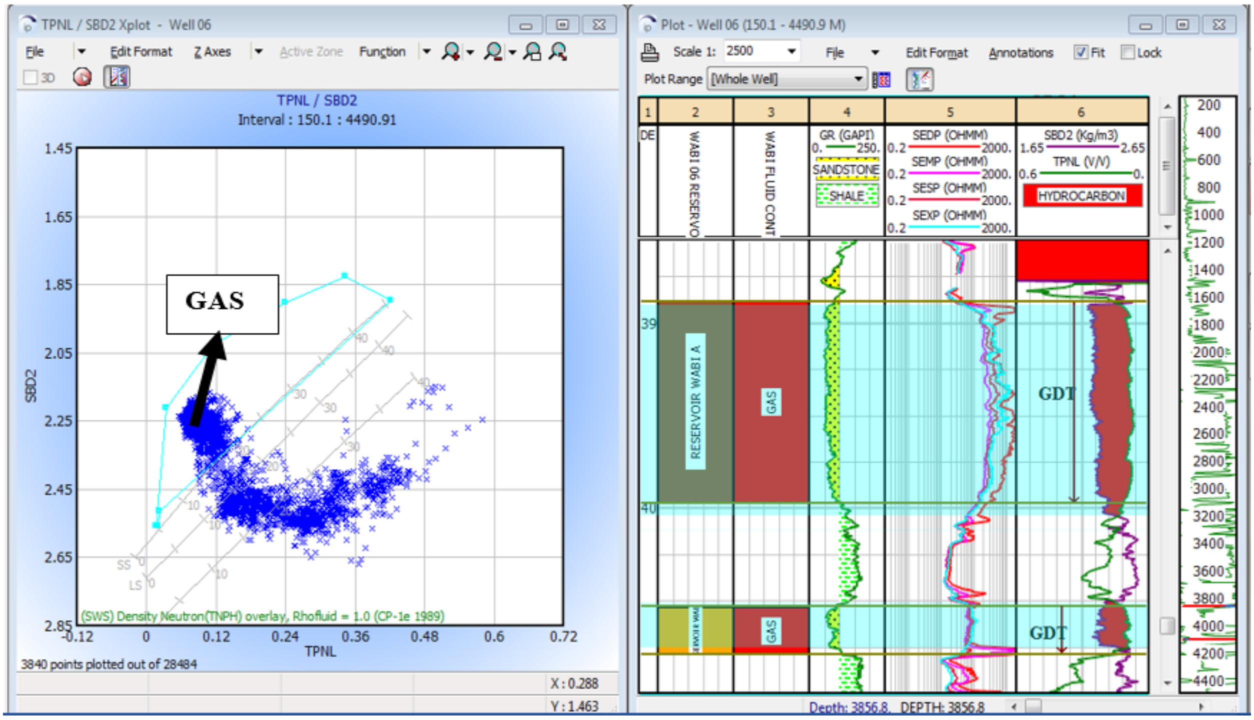


*Figure 8: Neutron – Density Crossplot for fluid and lithology Identification for WABI 06 Well*

## 5. CONCLUSION

Formation evaluation analysis and log-facies classification are powerful tools employed by the Petroleum industry for identification and assessment of hydrocarbon-bearing zones. In this paper, petrophysical evaluation of well log data from a suite of four wells (WABI 05, 06, 07 and 11) in the study area was carried out by integrating conventional log analysis and cluster analysis of some reservoirs in WABI field of Niger Delta basin, Nigeria. The analyses methodology was based on conventional formation evaluation models and cluster analysis techniques using interactive petrophysics. Cluster analysis of different log properties are generated to identify the lithology variability and pore-fluid type, and to establish likely distinction between the hydrocarbon-bearing sands, brine sands and shale. The final output is the set of petrophysical curves, fluid Type and Fluid Contacts and

Neutron – Density cluster analysis. Eight reservoirs are delineated and found to be primarily sandstone intercalated with shale. Neutron – Density cross-plot analyses revealed the presence of oil, gas or brine in all wells. Gas-bearing zone showed very big cross over for neutron-density curves and is also confirmed by very high resistivity. The Neutron log versus Density crossplot colour coded with gamma ray in WABI 07 discriminates the reservoirs into shale, brine sands, oil sands and gas sands. Some reservoirs are made up basically of gas. From the results, the reservoirs are prolific and feasible for hydrocarbon production. Out of the eight reservoirs, four are Gas-Water; three, Gas only and one Gas-Oil-Water. From the study, the Gas reservoirs are mostly shallow as compared to Gas-Water and Gas-Oil. The Largest reservoir is WABI 06, reservoir WABI A, with a pay thickness of 110m, while reservoir WABI B, WABI 06, has the lowest pay thickness of 25m; it is also a gas reservoir. The Gas-Oil-Water reservoir has pay thickness of 45m, while the highest pay thickness for Gas-Water reservoir is 65m.This study has shown that the integration of conventional log analysis and cluster analysis is a robust method in the determination of the production potential of hydrocarbon reservoirs.

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