



Petrophysical Analysis of Well Logs Data for Sandstone Reservoir Hydrocarbon Evaluation In Niger Delta Sedimentary Basin.

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ABSTRACT

The primary function of petrophysics is to provide the necessary parameters for an accurate establishment of reservoir model, petrophysical analysis is considered as one of the critical factors in reservoir evaluation. Hydrocarbon exploration in Niger delta province has been ongoing for many decades with the exercise now been gradually shifted to the deep offshore, to exhaust the basin petroleum potential, the sand channel within the deep sea is now targeted as the main exploration point. This research work reiterated the relevance of petrophysical analysis of open-hole wireline data as the primary step in establishing the concept of reservoir evaluation during hydrocarbon exploration, reservoir petrophysical properties of subsurface sedimentary layers were studied using wireline logs data from three selected wells in Niger Delta Basin. The electronic copies (LAS file) of the wireline logs data were obtained for this research work, the quality checks, accuracy, content policy and confidentiality remained the right of Department of Petroleum Resources (D.P.R.) Nigeria. The wireline logs data comprised of gamma ray, resistivity (deep), sonic, and neutron logs integrated with calculated field curves; Archie's water saturation (S_w), total porosity (PHIT), bulk-volume water (BVW) and shale volume (V_{sh}). Computer based data interpretation was conducted using Schlumberger's PETREL E&P software 2013. The results of the petrophysical analysis were presented in bi-plots and log Vs depth format (log tracks) for convenient interpretation. The various hydrocarbon bearing zones across studied wells were quantitatively categorized into three distinctive reservoirs. Reservoir AA, encountered between intervals 2610ft and 3068ft, has an average pay thickness of 40.4ft and laterally extends to across all the five wells. Reservoir BB, encountered along interval 4011ft to 4690ft has an average pay thickness of 16ft. The deepest reservoir encountered between interval 5305ft and 6930ft, has an average pay thickness of 61ft. The average hydrocarbon saturation, effective porosity and bulk-volume water for reservoir AA, BB and CC, are 50%, 30% and 0.0571; 33%, 26% and 0.2085; and 40%, 20% and 0.1565 respectively. Due to the limited availability of wireline logs data only two types of fluids; water and hydrocarbon were delineated, the values of effective porosity and hydrocarbon saturation calculated for the hydrocarbon bearing zones are good enough for commercial accumulation and production of hydrocarbon. The direct correlation between facies and gamma log shapes relationship has evidently supported the tentative interpretation of paleo-depositional environment of the Niger Delta Basin.

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1.0 Introduction

Oil and gas industry covered almost everything in the general consumer usage and has become the powerhouse of almost all activities on the earth crust, the increasing nature of the world population at the same advancement in technology and infrastructural development, has heighten exploration, exploitation and production thus becoming more complex to handle. These have necessitated the stakeholders to handle it in an explicit and cost-effective manner, develop strategies for best practices (Badiru and Osisanya, 2013). Furthermore, the heterogeneity nature of the subsurface that harbored hydrocarbon reservoir rocks has led to a great deal of uncertainty in oil and gas exploration and production exercise, more attentions must be rendered in every stage of the project The task of producing hydrocarbon is flanked by series of complex exercises, huge capital are involved (cost and revenue), volatile global economy, and dynamic subsurface. There is continuous need for improvement in understanding the various exercises involved in petroleum exploration and production, also extra efforts must be rendered in utilizing strategies in meeting promised and targeted outcomes (Badiru and Osisanya, 2013). Additionally due

to complexity of the subsurface materials, limited information is available for accurate description of the reservoir and understanding the real situation is based on estimates. (Jahn et al., 2008).

Reservoir characterization and subsurface geological mapping are the most important tools used to explore for undiscovered hydrocarbons and to develop proven hydrocarbon reserves (Oyedele, 2013). Petrophysical analysis is as one of the critical exercises in petroleum exploration, it serves as a primary source of data for reservoir characterization, there is explicit need of subsurface data for any successful hydrocarbon reservoir evaluation. Data acquisition for subsurface evaluation involves numerous geophysical techniques: Ground penetrating radar, Electromagnetic, Magnetic, Seismic, Gravity, Ground motion monitoring and Wireline logging method. Wireline logging has aided the geoscientist with outstanding ideas on the subsurface rock properties, by providing a continuous recording over a considerable length of depth of the underlying formation rocks. It serves as a medium for partial or complete acquisition of data and valuable information for a detailed reservoir study (Moore et al., 2011), also hydrocarbon estimates can only

be made through data collection and interpretation of different petrophysical parameters of the host rock and fluid content (Parasnis,1997). Well data provides a variety of information describing the lithology (including the mineralogy, porosity, and perhaps even the morphology of the pore spaces), the fluid content (sometimes related to logged conditions, in virgin reservoirs conditions), and detailed depth constraints on geologic horizons (Weber and Daukoru, 1975).

Reservoir resources estimation start with a proper characterization of the resource play in a sequential manner, this start with a determining a well-defined gross formation extent, followed by selective identification of the hydrocarbon generation together with the storage capacity all within the targeted formation and lastly defining the dynamics controlling the production of hydrocarbon in the reservoir, the reserves estimate is generally based on the availability of data and proven geologic interpretation (Lyons Plisga, 2005). Eyvazzadeh et al., (2007) stressed on the need for improvements in accuracy for all petrophysical analysis, describing it as critical for every successful formation studies. Reservoir heterogeneity and errors inherent in core measurements and log data

frequently affect petrophysical analysis results, in terms of accuracy and precision (Adel et al., 2004). These errors can lead to underestimation or overestimation of pay zones, fluid saturations and hydrocarbon recovery, prompting the cost of additional testing. Furthermore, poor management of the petroleum resources has led to socio-economic, socio-political and complex interaction problems involving the people, economic development, and the environment. Despite massive influxes of oil revenues, Nigeria seems to suffer from the “oil curse” or the “natural resource curse” due to poor governance, lack of effective environmental and sustainability awareness. The need to proliferate the standard of basic wireline logs in oil exploration becomes inevitable, with low oil prices causing the re-evaluation of mature oil fields.

This research executed with the application of modern software in petrophysical analysis of wireline data to delineate hydrocarbon bearing intervals in Niger Delta Basin, it aims to understand the petrophysical parameters, which in turn are the most useful characteristics of subsurface reservoir evaluation. The study will tend to achieve the following research objectives.

- To identify hydrocarbon bearing zones and examine the formation properties based on well logs information from five open wells.
- To characterise the reservoir units in the studied wells using composite well logs data.
- To convert the raw log data into estimated quantities of hydrocarbon and water in the wells.
- To determine the reservoir porosity, fluid saturation, net pay thickness, and lithology.
- To determine the reservoir depth and thickness across the studied oil wells.

2.0 Petroleum Geology and Exploration in Niger Delta Basin

Niger Delta Basin overlain a thick deltaic deposits of tertiary age, it covers about 103,599 square kilometers. The deltaic deposits are subdivided into; Benin Formation (continental sand), transitional Agbada Formation (alternating sands and shale) and Akata Formation (marine shale). Early studies of the Niger Delta Basin by Short and Stauble, in 1967 subdivided the basin into three formations namely the Akata (base), the Agbada (middle), and the Benin (top) Formations. These formations

represent the prograding depositional facies that are distinguished mostly because of their sand-shale ratios. The Akata Formation comprises mostly marine shale sequences and lowstand turbidite sand. The Agbada Formation comprises alternating sequences of sandstone and shale and is interpreted as a cyclic paralic sequence comprising marine and fluvial deposits. The Benin Formation comprises continental, massive sands with clay intercalations (Short and Stauble, 1967). The Akata Shale as the source rock and the Agbada Formation as the reservoir sequence (Adedapo et al., 2014, Jubril and Amajor, 1991), also Ako et al, (2004) reported that Akata and lower Agbada Formations constitute the major source rocks of the Niger Delta. Oil is stored in sandstone facies within the Agbada Formation, however, turbidite sand in the Upper Akata Formation is a potential target in deep water offshore and possibly beneath currently producing intervals onshore (Underdown and Redfern, 2008). Traps in Niger Delta fields are structural although stratigraphic traps are not uncommon, structural traps developed during synsedimentary deformation of the Agbada paralic sequence (Ajaegwu, 2012). The primary seal rock in the Niger Delta is the interbedded shale within the Agbada

Formation, although other mechanism such as flank of a rollover may have contributed to hydrocarbon accumulation (Waples and Ramly, 2001). The alternating sandstone and shale vary in thickness between 100ft to 1500ft, Sand is mainly the hydrocarbon reservoir with shale providing lateral and vertical seal (Short and Stauble, 1967).

The principal Hydrocarbon discoveries were made within the transitional Agbada Formation. Seismic surveys revealed that, oil accumulation are structurally controlled by roll-over anticlines and growth faults. Hydrocarbon exploration exercise conducted mid-1956 was successful and out of 261 wildcats well established, 136 discoveries were made. Okan was the first commercial field in the offshore, where as along the onshore, Bomu field was the most productive. Both the reservoir in Bomu and Okan are water drive. Exploration activities in Niger Delta remained a continuous process with a greater magnitude even beyond the province but also extended to the basins bordering the actual delta (Franki and Cordry,

1967). Hydrocarbon exploration in Niger Delta province has developed since 1961, the oil sector has continued to witness increasing number of oil companies and increased exploration activities and hydrocarbon production for decades, predominantly in the onshore area and recently extended to the offshore. Nigeria ranked sixth in OPEC and fourteenth globally amongs the oil producers with 2.2% and 1.2% of world discovered oil and ges respectively, it has a reserve estimate of about 70 bboe. Presently, about 1,300 exploration wells were drilled, however, exploration in the basin is facing major set back due to community-related disturbances (Ejedawe, 2012). Well logs data revealed different information about the sedimentary processes occurring within the basin. Sediment traced to different paleoenvironment shows some distinctive log motifs, as such sedimentary facies correlation and evaluation can be achieved with interpreted well logs (Weber, 1971).

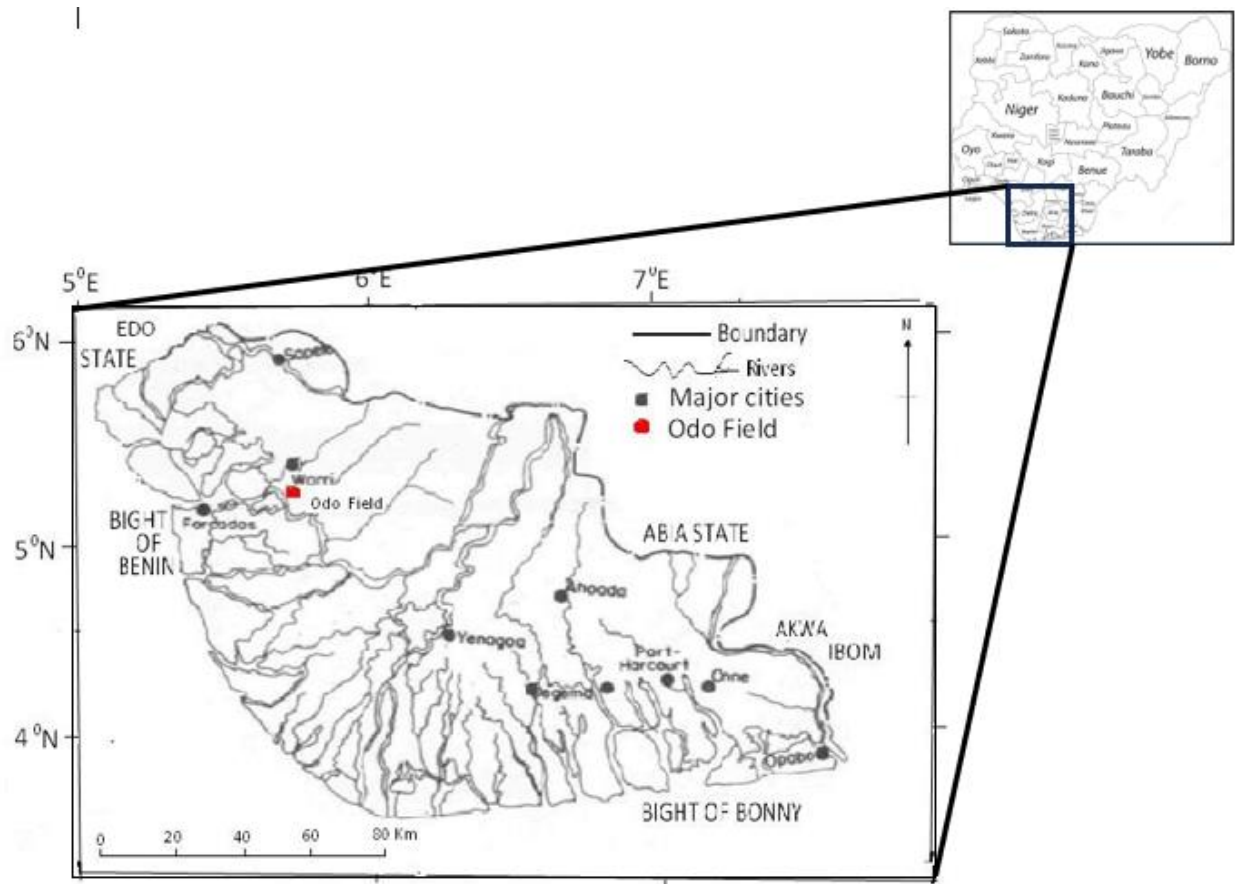


Figure 1.1: A location map showing Niger Delta Basin where the oil wells were drilled modified after Obiekiezie 2014.

3.0 Methodology

3.1 Data Availability

The data used in this research work was based on obtaining an electronic copy (LAS file) of the wireline logs. The quality checks, accuracy, content policy and confidentiality remained the right of Department of Petroleum Resources (D.P.R.) Nigeria. A detailed petroleum geology and petrophysical review of the entire Niger basin was periodically undertaken based on

request and approval of Federal Republic of Nigeria.

3.2 Data Collection

The research data consists of a set of wireline logs across five different wells conducted on a sand reservoir within the Niger Delta basin. The suite of field well logs includes, Gamma ray, Resistivity (deep), Sonic, and Neutron logs. Moreover, the calculated field curves used in this research work are; Archie's Water saturation (S_w), Total porosity (PHIT),

Bulk-volume water (BVW) and Shale volume (V_{SH}). Hence, the Hydrocarbon potential of the reservoir could be evaluated (Ishwar and Bhardwaj, 2013).

3.3 Determination of Lithology from the Wireline Logs

Table 3.1 shows an examples of gamma rays response values of varoius lithological units, while Figure 3.1 shows a direct correlation

between sedimentary facies and gamma ray log response (different shapes). The commonly identified basic log shapes are funnel (coarsening upward), cylinder (blocky) and bell (fining upward), shapes are further subdivided into serrate (interbedded with thin shale) and smooth (relatively homogenous) (Morton-Thompson and Woods, 1992).

Table 3.1: Lithological responses (Morton-Thompson and Woods, 1992)

Lithology	Gamma Ray Values (in API units)
Sandstone (quartz)	15-30 (rarely to 200)
Limestone	10-40
Dolomite	15-40 (rarely to 200)
Shale	60-150
Organic-rich shale	100-250
Anhydrite	8-15
Sylvite (KCL)	350-500
Coal	15-150 (any value possible)

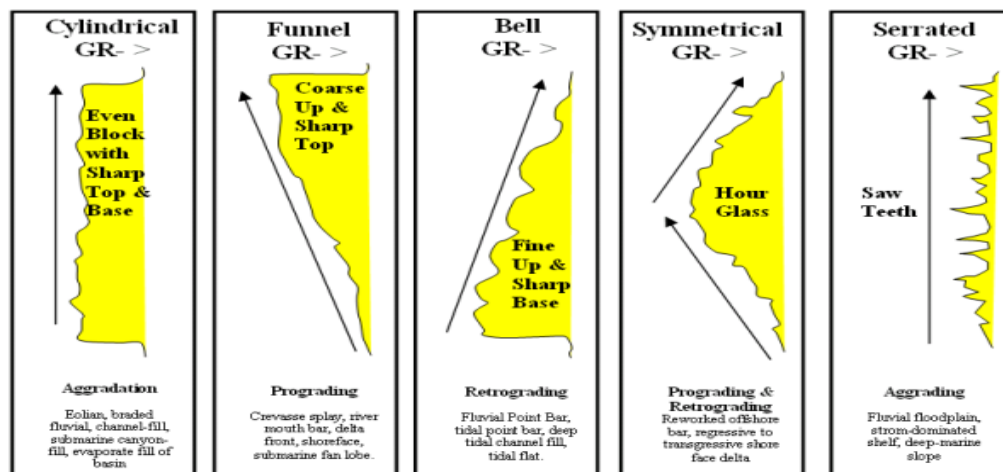


Figure 3.1: Direct correlation between facies and gamma log shapes relationship (Siddiqui et al., 2013).

3.4 Estimation of Petrophysical Parameters

3.4.1 Volume Shale (V_{sh})

The Gamma ray measures the natural radioactivity present in the formation which in turn identifies the formation basic lithology and zones correlation by measuring shale volume.

$$V_{sh} = \frac{GR_{log} - GR_{min}}{GR_{max} - GR_{min}} \dots\dots\dots \text{Eqn. (3.1)}$$

3.4.2 Porosity

Total and effective porosity are derived log value calculated during the analysis from either sonic or neutron porosity log or the combination of sonic and neutron porosity log.

Sonic porosity log is calculated as;

$$\phi_t = \frac{\Delta t_{log} - \Delta t_{matrix}}{\Delta t_{fluid} - \Delta t_{matrix}} \dots\dots\dots \text{Eqn. (3.2)}$$

$$\phi_e = \phi_t \times (1 - V_{sh}) \dots\dots\dots \text{Eqn. (3.2i)}$$

For sandstone formation V_{ma} (ft/sec) is given as 18 or 19.5 while Δt_{matrix} is 55.5 or 51 (us/sec).

3.4.3 Water Saturation (S_w)

S_w is a derived log value calculated based on;

$$\text{Archie's equation } S_w^n = \left[\frac{R_w}{\phi^n R_t} \right] \dots\dots\dots \text{Eqn. (3.3)}$$

Where S_w^n =water saturation, R_w =resistivity of connate formation water, ϕ = porosity from the well log data, R_t is the measured formation resistivity from the well log data, n and m are saturation and cementation exponent respectively (Eyvazzadeh, et'al 2007).

3.4.4 Bulk-Volume Water (BVM)

Bulk-volume water is a derived log value which represent the amount of water in a given formation. It is presented quantitatively as the product of water saturation and porosity;

$$BVW = \phi \times S \dots\dots\dots \text{Eqn. (3.4)}$$

Presented as either fraction or percentage, where S_w = log-derived water saturation and ϕ =log-derived porosity.

3.4.5 Hydrocarbon Saturation (S_H)

Hydrocarbon saturarion cannot be directly measured but inferred from determination of water saturation.

$$S_h = 1 - S_w \dots\dots\dots \text{Eqn. (3.5)}$$

Figure 3.2 shows a diagrammatic process workflow for basin and petroleum system modelling.

3.5 Computer Interpretation

Interpretations of the petrophysical well logs data was achieved using Schlumberger's PETREL E&P software 2013. The petrophysical field data stored in a LAS file was imported to the software as a new project under a new well, well heads information was then added and subsequently well path data was included. Well logs are later imported including the log name, property template, and unit of the desired petrophysical properties uploaded on each track for the varoius logs.

WELL LOG INTERPRETATION WORKFLOW USING PETREL

- Load Petrel.
- Import well log data and well tops.
- Open a new well section window.
- Load data in well section window.
- Open a new well log template.
- On new template define well properties,

Step 1: Insert a new track on template,

Step 2: On the new track insert a well log data, say GR log

Step 3: Define log data limits, say Min 0 and Max 150 units for GR log

Step 4: Define log property (Colour, line type, thickness etc.)

Step 5: Apply cut-off where necessary say 0-70 Sand and 70-150 Shale for GR log,

Step 6: Repeat Process for adding another log data say calliper log on the same track as GR log,

Step 7: Add new track and new well log say Resistivity data and repeat steps 1-6 iteratively till you are satisfied with outcome.

- After editing template we go to the input tab and edit the well cross section from 3D window and arrange wells relative to one another.
- A complete well log section will be displayed in the well section window for all selected wells where we scroll thru to study and identify zones of interest for further studies.

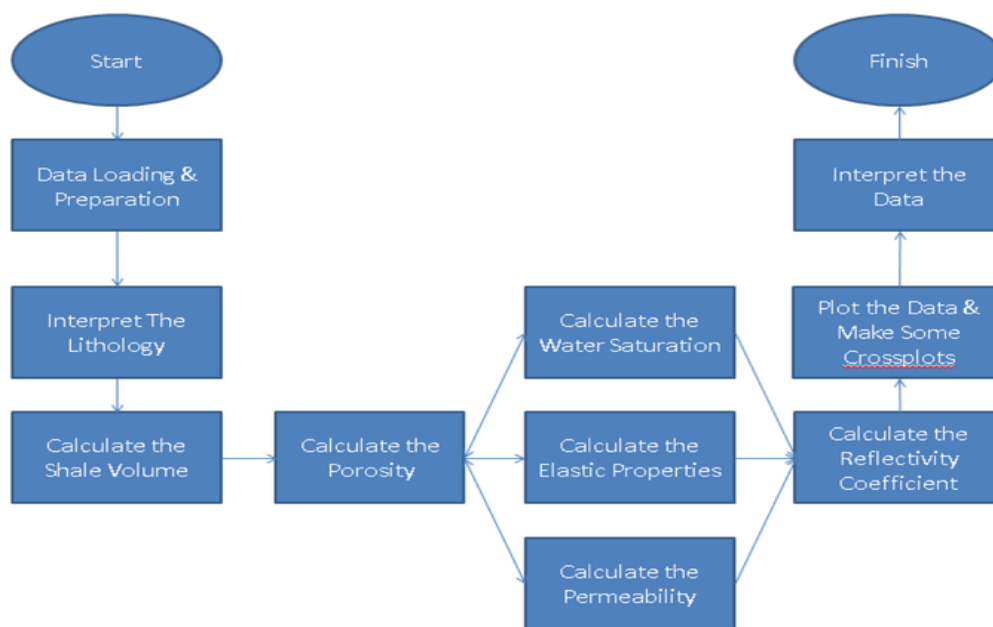


Figure 3.2: Flowchart for general well logs analysis in characterising an oil or gas reservoir.

COMMON ASSUMPTION IN WELL LOGS INTERPRETATION

- Low GR, High density, Low porosity (<0.3)=Limestone.
- Low GR, Very low density, Very high porosity=Coal.
- High GR, Moderate neutron porosity, High density=Shale.
- High resistivity sitting over low resistivity zones against a sand=Oil above water.
- Density Neutron crossover=Gas.

- Cut-off values ($V_{clay}>0.4$, $PHI_e<0.10$, $Sw>0.6$).

5.0 Results and Discussions

5.1 Qualitative Interpretation

The total measured depth of well EMI-01 is 7072 ft. the result shows a total number of eleven hydrocarbon bearing sand intervals namely A to K (Table 4.1 and Fig. 4.1). Sand intervals A, B, E, F, H, I and J are characterized as funnel-shaped curves representing a prograding log expression, while intervals C, D, G and K exhibit the

symmetrical-shape curves representing a prograding and retrograding log expression (Fig. 4.1) (Siddiqui et al., 2013). The intervals encountered are of various thicknesses that ranges between 5ft and 340ft. The direct correlation between gamma ray log shape facies and interpreted curves shows that the environment of deposition is potentially related to barriers bars, fluidal channel, and tidal channel in the delta plain (Siddiqui et al., 2013).

The depth of investigation for EMI-02 well is 6559.7ft (Fig. 4.2). Gamma ray log interpretation revealed some successive subsurface layers of clean sand with alternating shale intervals, pockets, dispersed and laminar clays observed within the sand intervals (Fig. 4.2). Three different sand intervals with good hydrocarbon potentials were identified as zone A, B and C across this well, with various thicknesses of 144ft, 26ft, and 23ft respectively (Table 4.2 and Fig. 4,2). Interval A and B have complete serrated gamma curves showing an aggrading log expression from the gamma log shapes, interval C shows funnel shaped curve, coarsening an upward trend, the funnel shaped and serrated curves are typical examples of beach/barrier bars and fluvial floodplain (Siddiqui et al., 2013).

The well EMI-03 has a total measured depth of 7004 ft. the result shows various subsurface layers of clean sand with alternating shale of different thicknesses, the thickness ranged from 1300ft to 100ft for clean sand intervals, and from 300ft to 10ft for shale (Table 4.3 and Fig.4.3). The analysis identified a total number of three hydrocarbon bearing intervals with high water saturation, fair porosity value and low shale volume; intervals A and B have a thickness of 49ft and 42ft, while interval C has a thickness of 13ft (Table 4.3). Zone A and B displayed a fully serrated gamma log shapes representing an aggrading log expression, this is a typical example of fluvial floodplain deep marine slope, the interval C is characterised as funnel-shaped

curve, expressing a coarsening upward trend, a typical example of beach sand, stream bars and barrier bars (Siddiqui et al., 2013).

The lithology identification from wireline data provides some useful information about the successive subsurface layers identified within a given well (Morton-Thompson and Woods, 1992). The electrical logs examination allows the identification of hydrocarbon reservoir, gamma ray and shale volumes curves showed various sand intervals with alternating shale within the three different studied wells. The sand intervals across the studied wells extended laterally with varying thicknesses at some points showing a somewhat greater depth than the adjacent point, this could be because of basin-wide structural deformation. The alternating sand and shale intervals pattern with corresponding variation in their thicknesses particularly the increase of shale volume with depth, could be attributed to transition between Benin and Agbada formations (Adedapo et al., 2014, Jubril and Amajor, 1991). Analysis from resistivity logs and water saturation curves allowed the delineation of several hydrocarbon bearing intervals across the studied wells, however due to the limited availability of logs, two types of fluids; water and hydrocarbon could be delineated (Eyvazzadeh, et'al 2007 & Craft and Hawkins, 1991). Presence of finer grain size, conductive substances and clays (laminar shale and dispersed clays) could be another reasons for low resistivity pay; this can cause ambiguities in wireline log readings (Eyvazzadeh, et'al 2007). The boundaries (top and base) of hydrocarbon bearing intervals were defined using resistivity curves and water saturation-derived logs, the continuous alternating shale layers to a lateral extend typically observed, is sufficient to act as a baffle for hydrocarbon flow (Short and Stauble, 1967). The lithology of all the evaluated wells appeared broadly similar despite the several distance, thus indicating that the

sand intervals are in communications. The effective porosity for all the encountered zones were calculated with shale volume correction, changes in environmental condition cause lateral variation in porosity across various intervals within the studied wells (Adel et al., 2004). The gamma ray shapes from the gamma ray curves, shows that the sand reservoir bodies across the wells have funnel-shaped, bell-shaped, and symmetrical bodies and are well serrated, thus

representing an aggrading, prograding and retrograding log expression (Siddiqui et al., 2013). Because of the different prograding and retrograding attributes exhibited by lithological units, some of the hydrocarbon reservoir intervals could not be correlated across the entire wells.

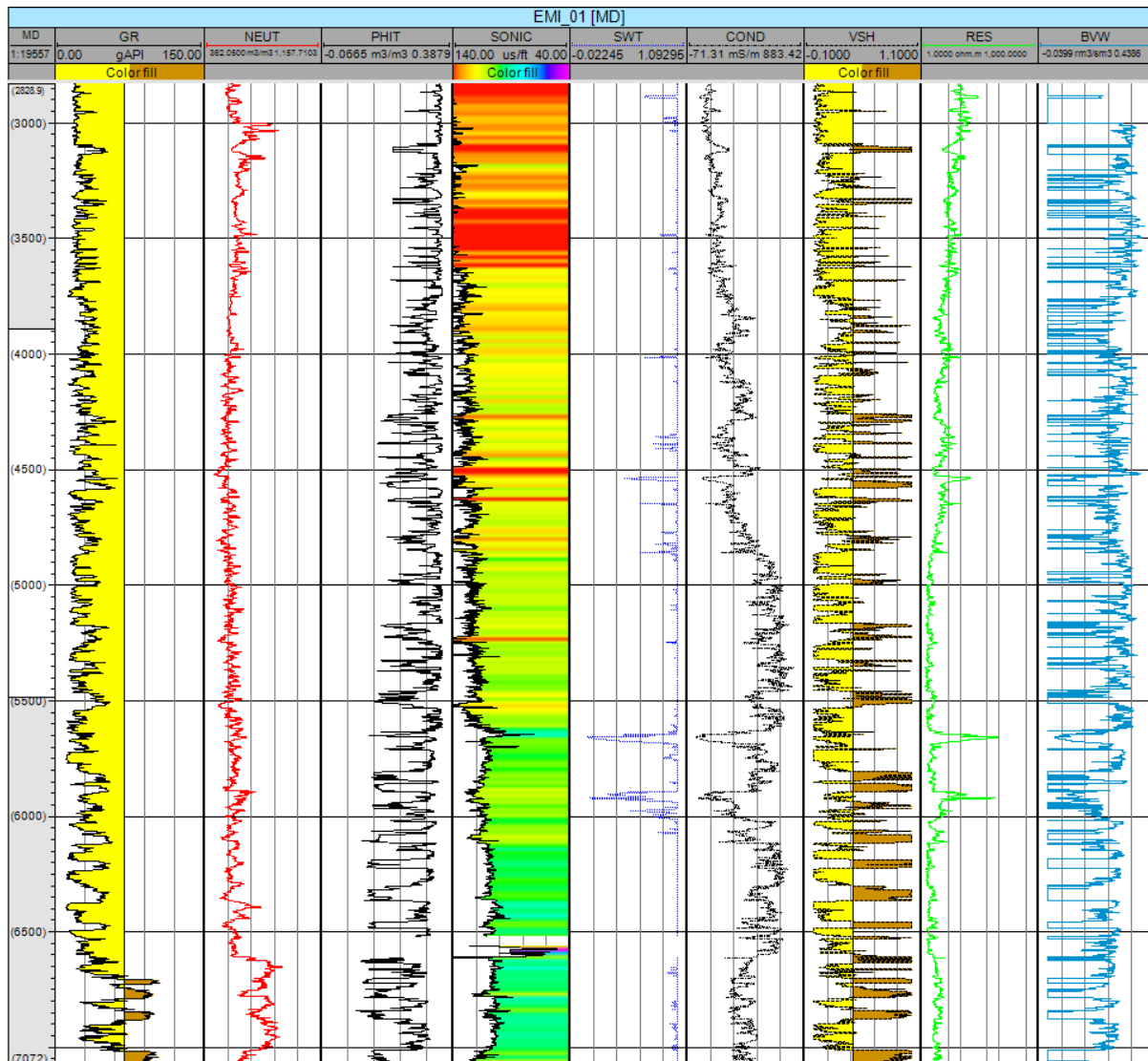


Figure 4.1: Well section showing composite well logging curves across well EMI-01

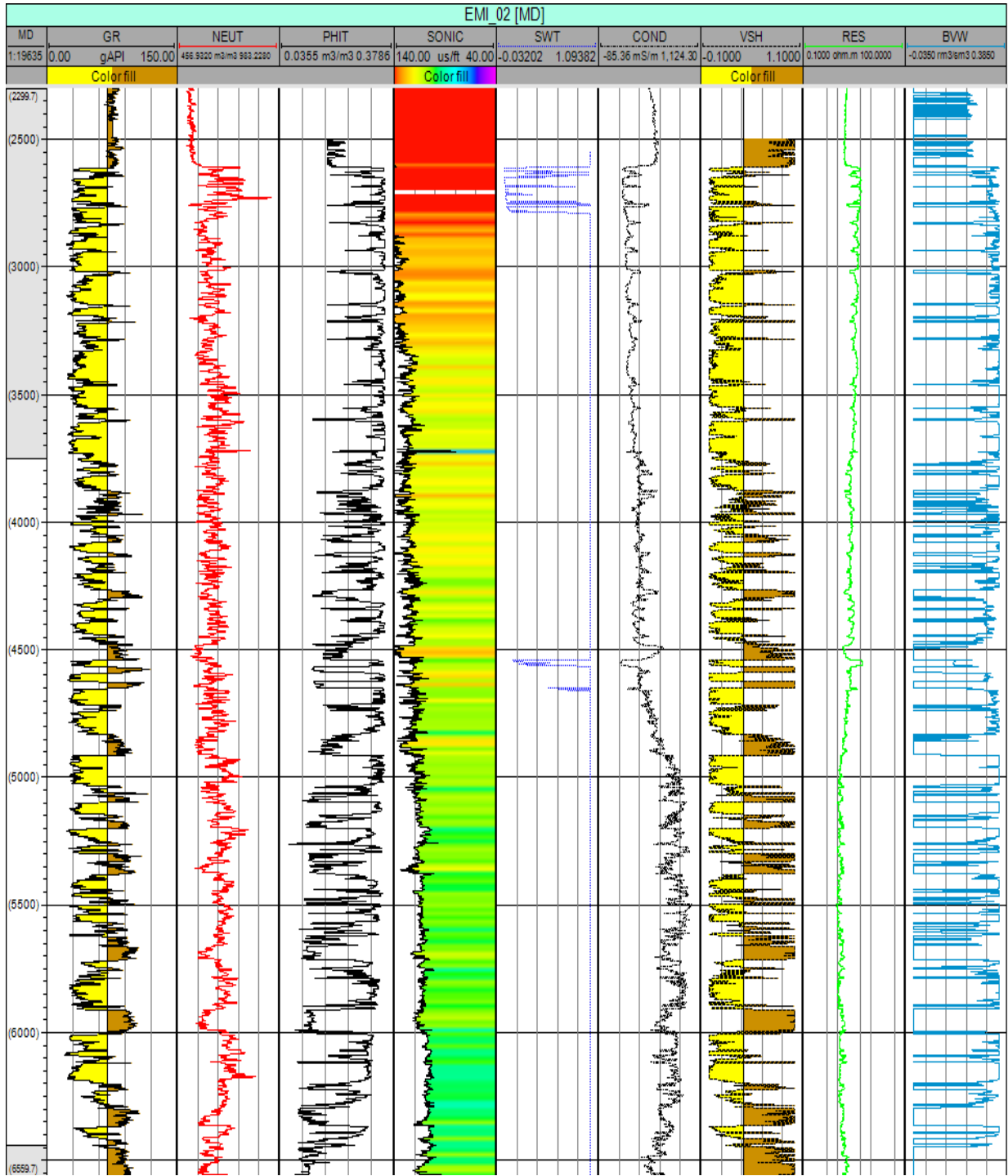


Figure 4.2: well section showing composite well logging interpreted curves across well EMI-02

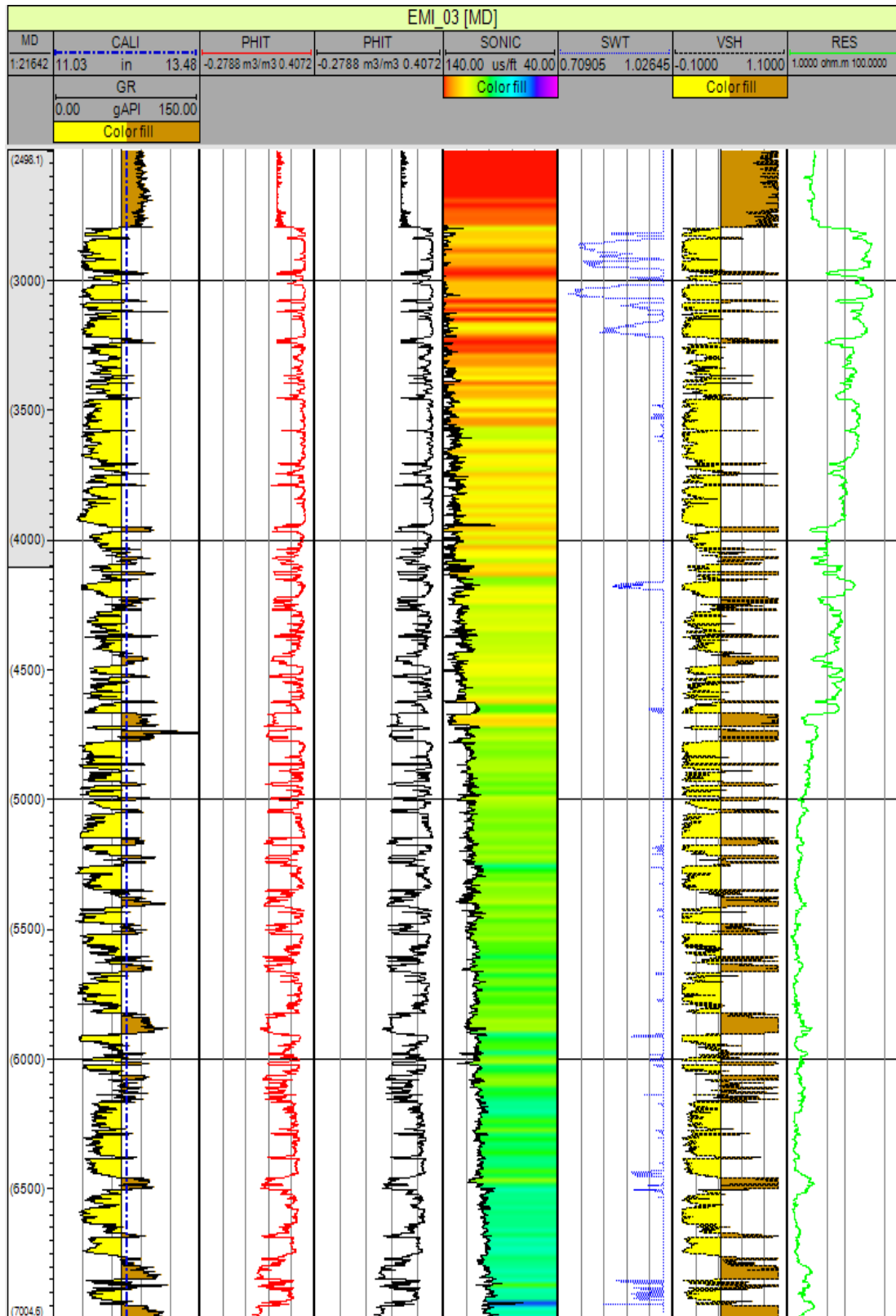


Figure 4.3: well section showing composite well logging curves across well EMI-03

5.2 Quantitative Interpretation

Table 4.1 shows the results of some computed petrophysical parameters for well EMI-01 in hydrocarbon bearing intervals; A – K. As shown in Table 4.1, eleven hydrocarbon bearing intervals were encountered, interval K has the greater thickness with relatively lower hydrocarbon saturation, and the bulk-volume water value is like the shale volume value, thus indicating irreducible water saturation along the interval

(Fig.4.4). The zone with highest percentage of hydrocarbon saturation is interval A, with a good porosity, intervals C, D, F, G and H have relatively lower oil saturation but with fair effective porosity, they could produce a fair amount of hydrocarbon (Table 4.1, Fig.4.4 and Fig.4.5). Zone C, D, F and H have thickness of less than 10ft, however, the formation could be extended interval, and as such the zones could be considered much productive.

Table 4.1: Computed petrophysical parameters for well EMI-01

ZONE	HYDROCARBON RESEERVOIR	PAY THICKNESS	Sw(frac.)	PHiT (frac.)	V _{SH} (frac.)	PHIE (%)	S _H (%)	BVM (frac.)
A.	2708.5 - 2780.5	72	0.1326	0.3377	0.0721	31	87	0.0442
B.	2880.5 – 2893.5	13	0.7631	0.3428	0.0419	33	24	0.2615
C.	4011 - 4016	5	0.8502	0.3424	0.0441	32	15	0.2911
D.	4387.5 – 4392.5	5	0.8433	0.3372	0.07117	31	16	0.2843
E.	4534 – 4549	15	0.6895	0.2960	0.2948	20	31	0.2040
F.	4645.5 – 4651.5	6	0.8278	0.3364	0.0834	31	17	0.2784
G.	4818.5 – 4826.5	8	0.8819	0.3016	0.2507	23	12	0.2659
H.	4854.5 – 4861.5	7	0.8201	0.3162	0.1782	26	17	0.2593
I.	5645 – 5681	36	0.4231	0.2734	0.1081	24	58	0.1156
J.	5893.5 – 5935.5	42	0.5538	0.2984	0.2271	23	45	0.1652
K.	5969 - 6009	340	0.8109	0.2821	0.2515	21	19	0.2287

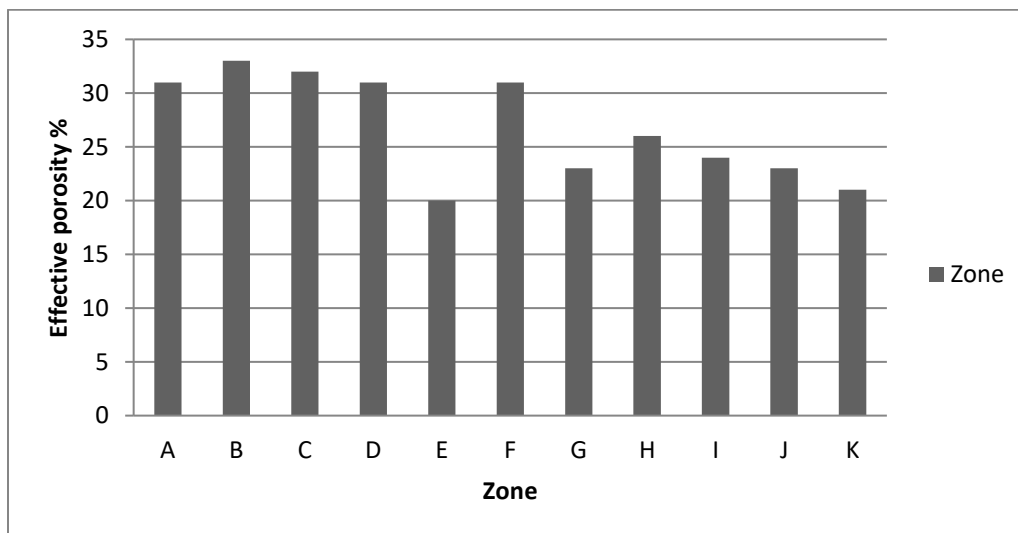


Figure 4.4: Effective porosity for various pay zones encountered along well EMI-01

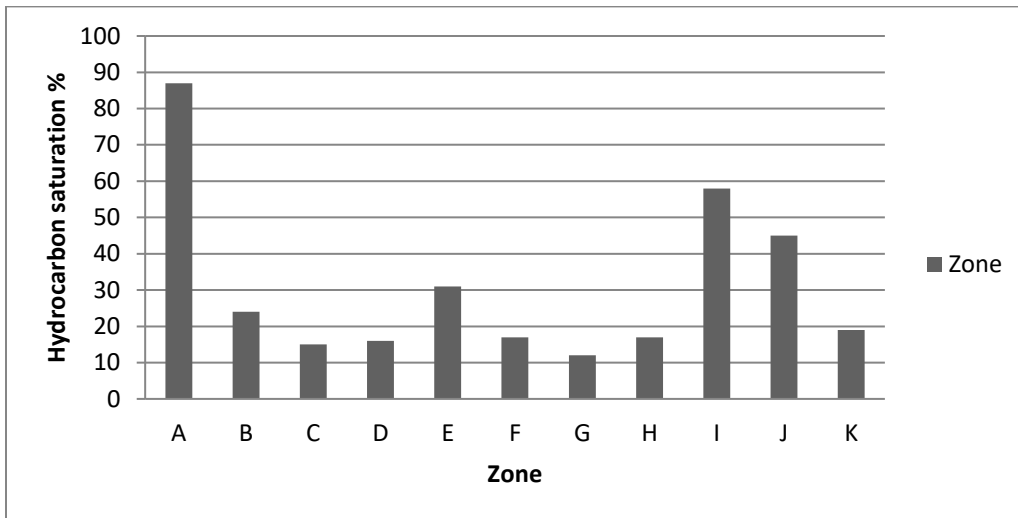


Figure 4.5: Hydrocarbon saturation for various pay zones encountered along well EMI-01

Table 4.2: Computed petrophysical parameters for well EMI-02

S/N	ZONE	HYDROCARBON RESERVOIR INTERVAL (ft)	PAY THICKNESS (Ft)	S_w (frac.)	PHIT (frac.)	V_{SH} (frac.)	PHIE (%)	S_H (%)	BVM (frac.)
1.	A.	2610 – 2754	144	0.2226	0.3257	0.1428	28	78	0.0725
2.	B.	2761 – 2787	26	0.1840	0.3405	0.0553	32	82	0.0626
3.	C.	4540 - 4563	23	0.3602	0.3283	0.0703	30	64	0.1182

The interpretation of wireline logs across Well EMI-02 shows three intervals A-C with hydrocarbon potentials (Table 4.2). Both the three zones have good thickness, porosity

and oil saturation (Fig.4.6 and Fig.4.7). Along zone B the BVM curves relatively conform to the volume shale curves; this could be irreducible water saturation (Table 4.2).

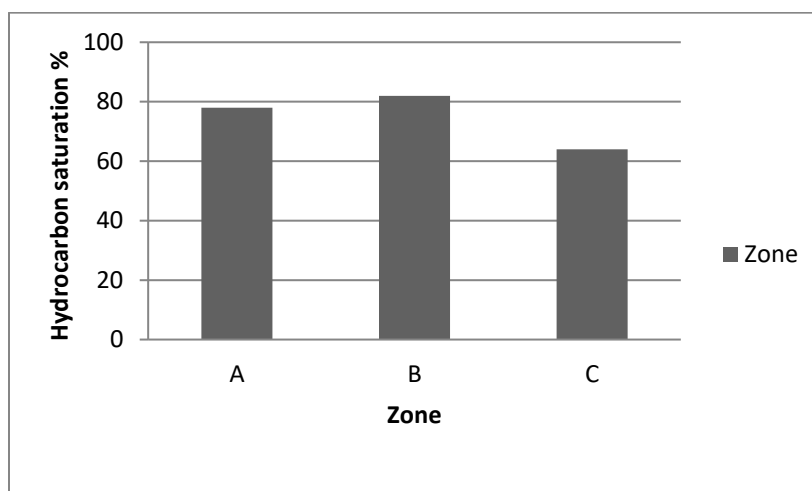


Figure 4.6: Hydrocarbon saturation for various pay zones encountered along well EMI-02

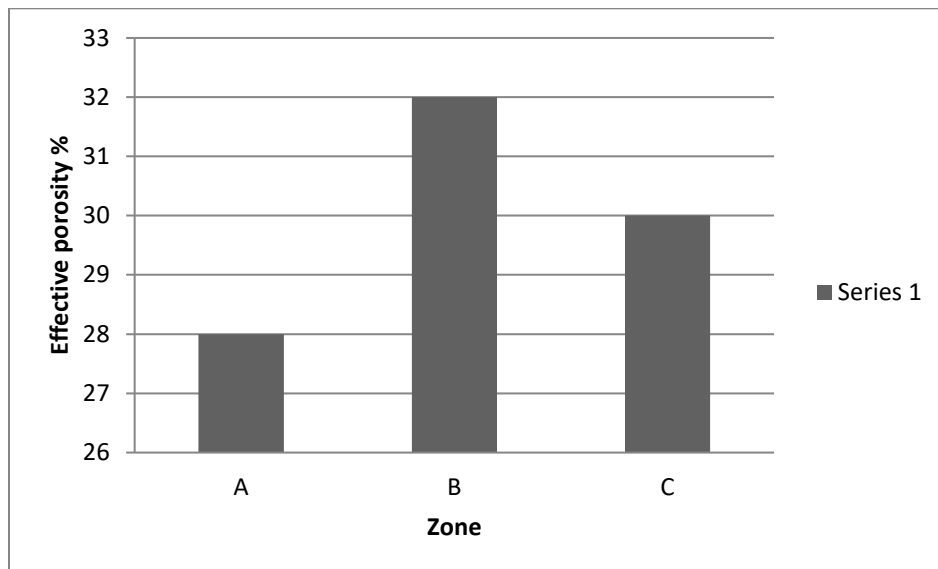


Figure 4.7: Effective porosity for various pay zones encountered along well EMI-02

Table 4.3: Computed petrophysical result of well EMI-03

SN	ZONE	HYDROCARBON RESERVOIR INTERVAL	PAY THICKNESS (Ft)	S _w (frac)	PH _i T (frac)	V _{SH} (frac)	PH _i E (%)	S _H (%)	BVM (frac)
1	A	2857 – 2906	49	0.8114	0.3456	0.02561	34	19	0.2804
2	B	3026 – 3068	42	0.7814	0.3469	0.0179	34	22	0.2710
3	C	6917 - 6930	13	0.9427	0.2716	0.1217	23	6	0.2560

Based on the petrophysical analysis of the log data and the interpretation curves, three hydrocarbon bearing zones A, B, and C were identified within well EMI-03 with a depth range between 2857ft and 2906ft: 3026ft and 3068ft, 6917ft and 6930ft and thicknesses of 49ft, 42ft and 13ft respectively

(Table 4.3). The porosity and hydrocarbon saturation for these three identified zones are 34% and 19% for zone A, 34% and 22% for zone B and 23% and 6% for zone C (Fig.4.8 and Fig. 4.8). The contrast between shale volume fraction and bulk-volume water fraction is a clear indication of movable water (Table 4.3).

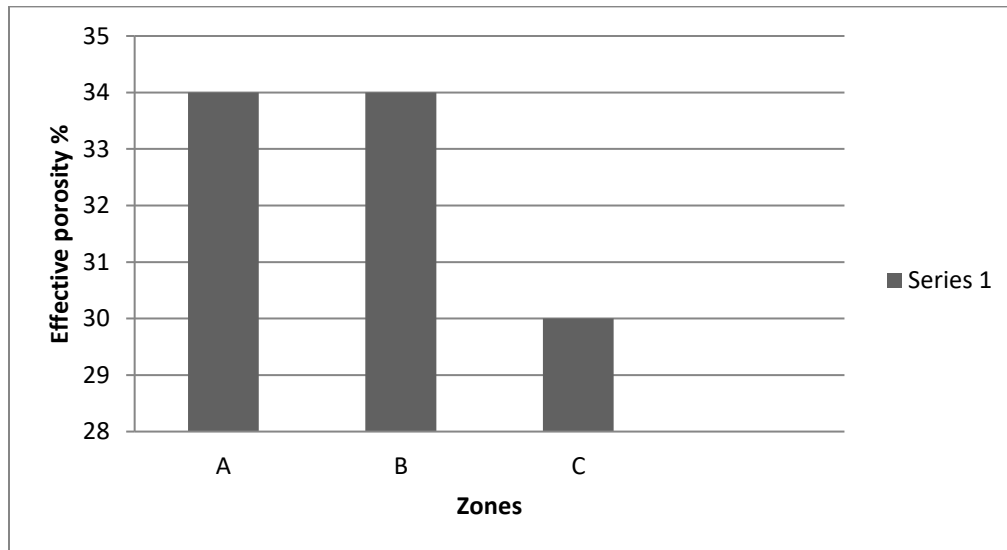


Figure 4.8: Hydrocarbon saturation for various pay zones encountered along well EMI-03

The methodology as explained in chapter three was chosen for both qualitative and quantitative interpretations of the delineated formations in all the studied wells. Tables 4.1-4.3 represent the analysis results of the interpreted petrophysical parameters for each well. Values are picked from each zone of interest in every well with intermediate calculations for the various parameters. Log-derived total porosity including formation water in the shale layers was corrected with calculation of effective porosity (Tiab and Donaldson, 2012). The log analysis shows that several sand intervals have high porosities, up to 35% with other interval indicating low porosities of 14%

(Tables 4.1-4.3). The minimum hydrocarbon saturation across all the encountered formation was 6% which is below the threshold limit of hydrocarbon saturation in porous media (10%) (Schowalter, 1979). However, the maximum hydrocarbon saturation is 82%. At several intervals encountered, bulk-volume water curves support the shale volume curves, indicating irreducible water saturation (Franklin 2005). These interpreted parameters have been subjected to statistical analysis by computing their values across all the delineated reservoirs encountered across the field boundary.

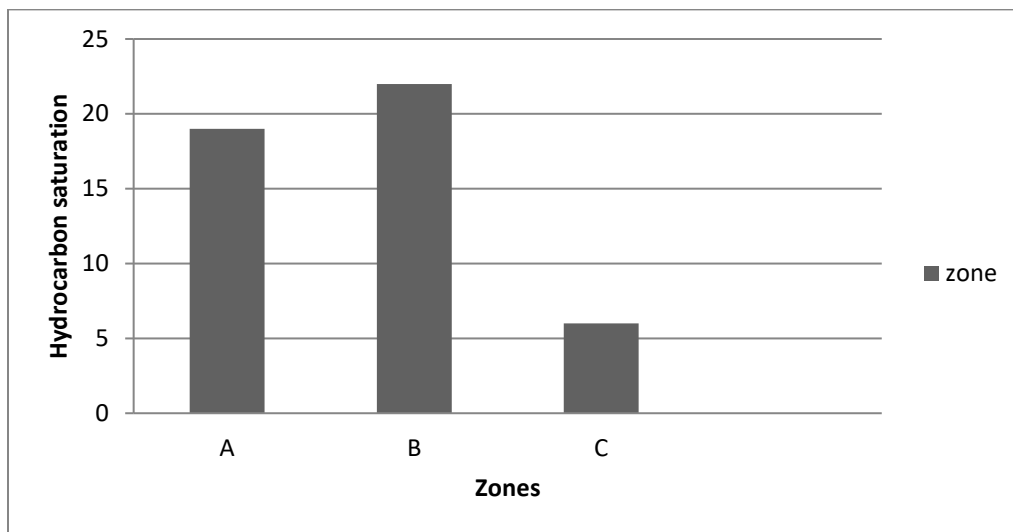


Figure 4.9: Hydrocarbon saturation for various pay zones encountered along well EMI-03

HYDROCARBON RESERVOIR ANALYSIS

Table 4.4: Summary of petrophysical parameters for the identified hydrocarbon reservoirs

Reservoir	Interval (ft.)	Thickness (ft.)	S _h (frac.)	PhiE (%)	S _h (%)	V _{sh} (frac.)	BVM (frac.)
AA	2610-3068	40.4	0.4765	30	50	0.0643	0.0571
BB	4011-4690	16	0.6491	26	33	0.1981	0.2085
CC	5305-6930	61	0.5769	20	40	0.2057	0.1565

These various hydrocarbon bearing zones across the studied wells have been quantitatively categorized into three distinctive reservoirs. These reservoirs, when comprehensively analysed could trace their lateral extent within the oil field where these wells were logged. Reservoir AA, situated between intervals 2610ft to 3068ft, has an average pay thickness of 40.4ft and extended laterally across all the wells (Table 4.4). Reservoir BB, encountered along interval 4011ft to 4690ft has an average pay thickness of 16ft but apparently extended across well 1 and 2 (Table 4.4). The deepest reservoir situated between interval 5305ft to 6930ft has an average

pay thickness of 61ft and extended laterally across well 1 and 3 (Table 4.4). The petrophysical analysis of these reservoirs shows that all the three reservoirs have higher potential of hydrocarbon production. However, the minor contrast between the fraction of shale volume and bulk-volume water across all the reservoirs could be as the result of insignificant movable formation water present. The average hydrocarbon saturation, effective porosity and bulk-volume water for reservoir AA, BB and CC, are 50%, 30% and 0.0571; 33%, 26% and 0.2085; and 40%, 20% and 0.1565 respectively (table 4.4).

The various sand zones encountered across all the wells consist of point bar sandstones with alternating shale continuously interbedded, this lithology is reported to occur within the Agbada formation (Short and Stauble, 1967). The calculated porosity across all the reservoirs shows considerable decrease with depth, and to a lesser extent with depth of burial and varying shale contents, this is agreeing with the reported porosity history of clastic deposits (Tiab and Donaldson, 2012). The average water saturation shows complex variation, as though tend to increase from reservoir AA to reservoir BB, but decreases from reservoir BB to reservoir CC. The average thickness of the pay zones appears to be somewhat randomly varying, as it becomes thinner toward interval 4011ft to 4690ft (16ft) along reservoir BB but reaches 61ft along the interval 5305ft to 6930ft across reservoir CC, which has the thickest sand formation. Understanding fluid saturation is of great importance in all stages of reservoir management and optimization (Craft and Hawkins, 1991). During production reservoir fluid saturation changes significantly with time this is due to either the development of new phase (free gas or condensate liquid) or introduction of some driving fluid (water or gas) in enhancing recovery (Satter et al., 2007).

6.0 Conclusions

The lithology of subsurface sedimentary layer across the studied wells is composed mainly of alternating sequence of sand and shale, these similarities in lithology across the different wells is an indication that the wells are likely in communication within the oil field.

The values of effective porosity and hydrocarbon saturation of the hydrocarbon bearing zones are good enough for commercial accumulation and production of hydrocarbon.

The sand rich layers decrease with corresponding increase in burial depth and shale content, this pattern is commonly associated with compaction and transition particularly in Niger Delta Basin along the Benin Formation and Agbada Formation.

The direct correlation between facies and gamma log shapes relationship has evidently supported the tentative interpretation of paleo-depositional environment of the Niger Delta Basin.

The petrophysical analysis of wireline logs data is useful in reservoir evaluation and delineation of hydrocarbon bearing zones.

Porosity, fluid saturation, bulk-water volume, and shale content are amongst the most important parameters in formation evaluation, reservoir description and characterisation.

Understanding the petrophysical parameters of the subsurface sedimentary layers can serve as a prelude for different fields in explicit oil and gas project but should be considered relevant in basic hydrocarbon exploration exercise.

Information from open hole measurements are not sufficient enough for costly decision in oil and gas project, an integrated approach in formation evaluation involving rock and fluids analysis, well logs and reservoir data remain the ideal tool in hydrocarbon exploration and production.

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