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# Determination of Lithology and Pore-Fluid of A Reservoir In Parts Of Niger Delta Using Well-Log Data

Onuoha. Chioma[1], E. D. Uko[2], I. Tamunobereton-ari [3]
[1,2,3]*Department of Physics, River State University,500001, Nkpolu-Orowokwo Port Harcourt, Rivers State, Nigeria*
*Department of Physics, Rivers State University, P.M.B, 5080, Port Harcourt.*
*Corresponding Author: Onuoha.Chioma,*

***Abstract:*** *Lithology and pore fluid determination was effectively carried out using well logs in an Onshore, Niger Delta field. The aim was to use rock physics and petrophysical analysis to distinguish lithology and fluid and to determine hydrocarbon potentials of the field. A suite of geophysical logs comprising gamma ray,resistivity, neutron and density logs from three wells in 'AGBADA' field were used in the analysis. The results reveal that the average porosities of reservoir sands, ranging from 21% to 39%, are very good to excellent indicating good reservoir quality and reflecting probably well sorted coarse grained sandstone reservoirs. The permeability of the field, ranged from 505 mD to 1435 mD, are excellent. Hydrocarbon saturation is high in all the reservoir sands, ranging from 68% to 98%, with corresponding water saturation from 2% to 32%, this indicates that the proportion of void spaces occupied by water is low, consequently high hydrocarbon saturation and production.The net-to-gross ratio ranges from 0.64 to 0.89, which implies the reservoirs contain more sands than other rock types.The crossplot of P-impedance versus* $V_P/V_s$ *distinguishes the reservoirs into gas, oil, brine and shale zones.*

***Keywords:*** *Lithology, Reservoir Characterization, Petrophysical Parameters, Shale Volume*

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## I. Introduction

Lithology Basically Refers To The Types Of Rock In The Earth Crust. These Will Enable Us Identify Those Types Of Rocks That Are Conducive For Hydrocarbon Accumulation, Such Determining Lithology And Pore Fluid Are Key For Effective Exploration And Production Of Hydrocarbon.However Accurate Prediction Of Lithology And Pore Fluid Is, And Will Continue To Be A Key Challenge For Hydrocarbon Exploration And Development [1].

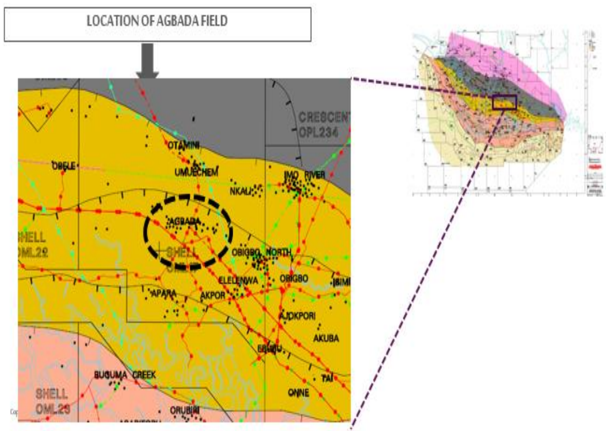



**Figure 1.** Index Map Of Niger Delta, The Inset At The Top Right Hand Corner Shows The Outline Bounding Structural Features.

In The Niger Delta Basin Of Nigeria, The General Lithology Is Mainly Sand And Shale [2]. The 'X Field Lies Between Longitude And Latitude (Northing) Located Within The Region Of The Niger Delta Area. It Contains Only One Identified Petroleum System Referred To As The Tertiary Niger Delta (Akata – Agbada) (Fig 1) Petroleum System. The Niger Delta Basin Is Divided Into Three Formations. The Niger Delta Is The

Sedcementary Structure Formed As A Ccomplex Regressive Offlap Sequence Of Clastic Sediments Ranging From 9000 – 12000 Thickness

[3]. The Three Lithosfacies That Are Basically Identified Are In Regionalformation Namely Benin, Akata And Agbada Formation . However, Several Directional Trends Form An Oil Rich Belt Having The Largest Field And Lowest Gas To Oil Ratio [4]. It Is The Major Petroleum Bearing Unit And Began In The Eocene Continuing Into The Recent. The Formation Which Is 3,700m (12,139ft) Thick Consists Of Paralicsiliclastics And Represents The Actual Deltaic Portion Of The Sequence. The Position Of The Oil Rich Belt To Oil Prone Marine Source Rocks Deposited Adjacent To The Delta Lobes, Suggests That The Accumulation Of These Source Rocks Was Controlled By Pre-Tertiary Structural Sub-Basins, Related To Basement Structures

[5]. The Hydrocarbon Habitat Model Was Constructed For Central Portion Of The Delta, Including Some Of The Oil Rich Belt And These Relates To The Deposition Of Akata Formation To The Sand Or Shale Units In The Agbada Formation [6]. Petroleum In The Niger Delta Is Produced From Sandstone And Unconsolidated Sands Predominantly In The Agbada Formation. Characteristics Of The Reservoirs In The Agbada Formation Are Controlled By Depositional Environment And By Depth Of Burial. Known Reservoir Rocks Are Eocene To Pliocene In Age, And Are Often Stacked [7]. Based On Reservoir Geometry And Quality, [8] Describes The Most Important Reservoir Types As Point Bars Of Distributaries Channels And Coastal Barrier Bars Intermittently Cut By Sand-Filled Channels. The Grain Size Of The Reservoir Sandstone Is Highly Variable With Fluvial Sandstones Tending To Be Coarser Than Their Delta Front Counterparts; Point Bars Fine Upward, And Barrier Bars Tend To Have The Best Grain Sorting. Much Of This Sandstone Is Nearly Unconsolidated, Some With A Minor Component Of Argillo-Silicic Cement [9]. Porosity Only Slowly Decreases With Depth Because Of The Young Age Of The Sediment And The Coolness Of The Delta Complex.

Jun Yan 2001 Estimated Reservoir Parameters Of North Sea From Well Log Data, He Integrated Well Log Data With Core Data Such That Porosity, Permeability, Shale Volume, Clay Content And Fluid Saturation, He Used Calibration Method On The Data Before Edition And Correction. Linear And Non Linear Regression Was Used To Identify The Above Parameters, On Confirming His Prediction He Performed Error Analysis On The Data. [10] Successfully Used Neural-Network Prediction Of Well-Log Data In Characterizing The Reservoir Based On Lithology.

## II. Methodology

Well Log Data From An Onshore Niger Delta Oil Field Was Used, The Data Consist Of Suites Of Well Logs From Four Wells (Agbada 1, 2, 3 & 4). However Due To The Gaps And Null Values In Agbada 4, It Was Not Used In The Analysis. These Data Were Analyzed In A Workstation Using Rokdoc Software Version 6.1.4.1089. The Logs Consists Of Gamma Ray, Calliper, Resistivity, Neutron And Density Logs Which Will Be Used In Evaluating Petrophysical Properties Such As Fluid Saturation, Porosity, Net-To-Gross, Volume Of Shale, Permeability Etc. Also, We Shall Delineate Fluid-Water And Oil Water Contacts. The Following Are The Various Log Data Used For This Study.

### 2.1 Reservoir Delineation

The First Step Involved Well-Log Editing And Conditioning, This Step Aided In The Filtering Of Data To Attain Proper Presentation, Delineating The Reservoir And Interpreting Thepetrophysical Properties Including Lithology, Shale Volume, Fluid Saturation, Net-To-Gross, Porosity And Permeability Among Others Of The Field Under Study Were Carefully Carried Out

The Second Step Involved The Application Of Well-Log And Crossploting Of The Data Set And Stratigraphic Interpretation. Cross Plots Are Visual Representations Of The Relationship Between Two Or More Variables, And They Are Used To Visually Identify Or Detect Anomalies Which Could Be Interpreted As The Presence Of Hydrocarbon Or Other Fluids And Lithologies. Cross Plot Analysis Are Carried Out To Determine The Rock Properties / Attributes That Better Discriminate The Reservoir

[11]. The Goal Of This Rock Physics Analysis Is To Determine The Feasibility Of Discriminating Between Reservoir Fluids.

To Illustrate This Point, The Cross Plot Of $V_P/V_S$ Ratio Against Acoustic Impedance (AI) Shows Fluid As Well As Lithology Discrimination Along The Acoustic Impedance Axis. It Describes The Conditions In Terms Of Lithology And Fluid Content Than $V_P/V_S$ Ratio. P-Impedance And $V_P/V_S$ Ratio Relationship Discriminate Both Fluid And Lithology. The $V_P/V_S$ Ratio Is A Fluid Indicator Because Compressional Waves Are Sensitive To Fluid Changes, Whereas Shear Waves Are Notexcept In The Special Case Of Very Viscous O. P-Impedanceshows A Better Discrimination Which Can Better Describe The Reservoir Conditions In Terms Of Lithology And Fluid Content Than The $V_P/V_S$ Ratio.

### 2.2 Data Set

The Agbada Oilfield Where The Data Set Were Collected Is Managed And Owned By Shell Petroleum Development Company, In Line With The Current Practice By The Petroleum Industries In Nigeria The Precise Location Was Not Disclosed, Below Are The Data Set And Base Map Used For This Work.

| Data | Agbada 1 | Agbada 2 | Agbada 3 | Agbada 4 |
|---|---|---|---|---|
| **Resistivity** | ● | ● | ● | ● |
| **Spontaneous Potential** | | | ● | ● |
| **P-wave log** | ● | ● | ● | ● |
| **S-wave log** | | ● | | |
| **Caliper** | ● | ● | ● | ● |
| **Density** | ● | ● | ● | ● |
| **Gamma Ray** | ● | ● | ● | ● |

**Figure 2** The table above shows the various well-log data presence in the various reservoirs

The Reservoirs Tops Are Used In Recognizing The Probable Reservoir Within The Wells. In Practice, Well Logs Contain Several Intrinsic Problems Particularly Problems Of Noise, Gaps And Spikes. Prior To Its Usage, An Attempt Is Made To Carefully Check For Quality And Completeness In The Petrophysical Analysis. Precisely, The Logs Shall Be De-Spiked, Filtered, Edited To Remove Spurious Events Reduce The Scatter In The Lithology And Petrophysical Analysis. A Filter Shall Be Applied Iteratively To The Logs In Order To Remove High Frequency Noise From The Well Logs Without Increasing The High Frequency Geologic Component Of The Surface. Spurious Spikes That May Affect The Trend Were Removed Prior To Trend Fitting To Ensure Quality Results. This Was Done On Rokdoc Using A De-Spiking Script With A Filtering Frequency Of 30Hz.

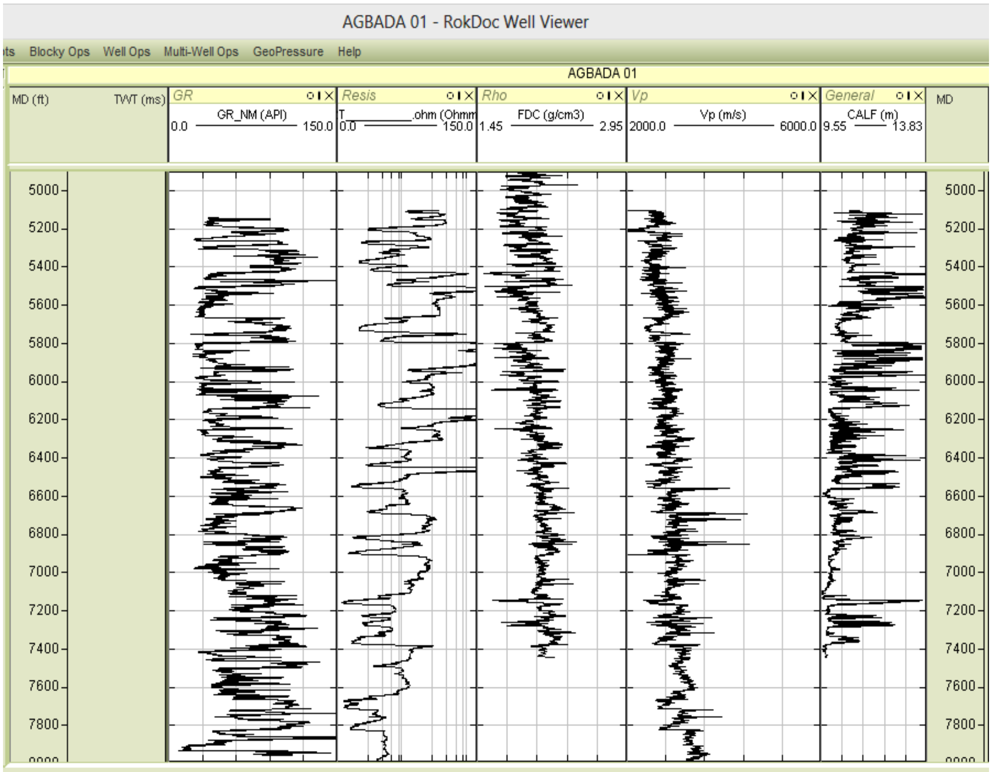


**Figure 3**Wireline Log Data for Agbada 1

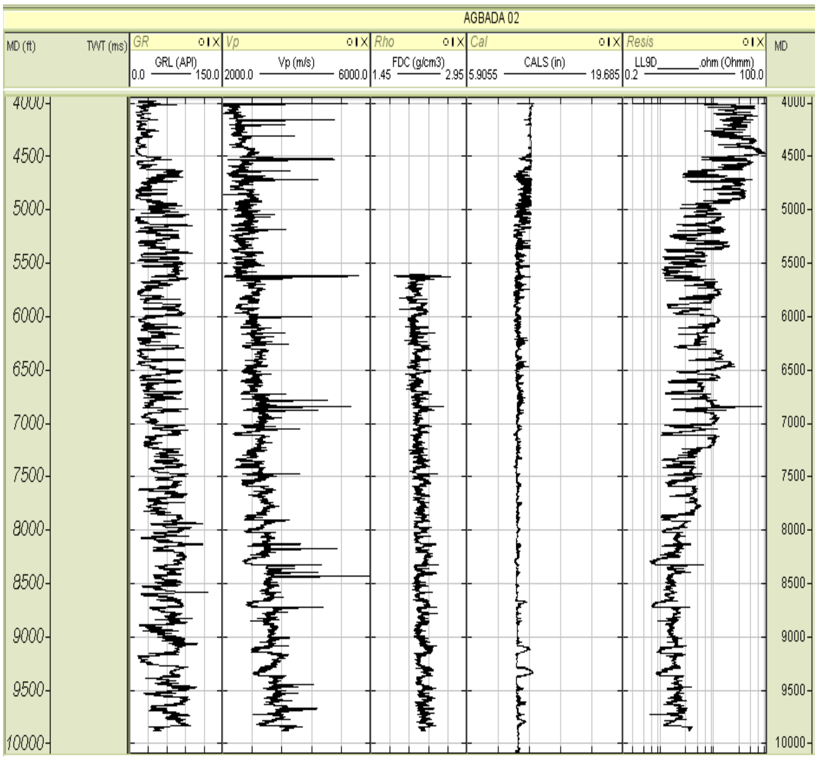



**Figure 4** WirelineLog Data for Agbada 2

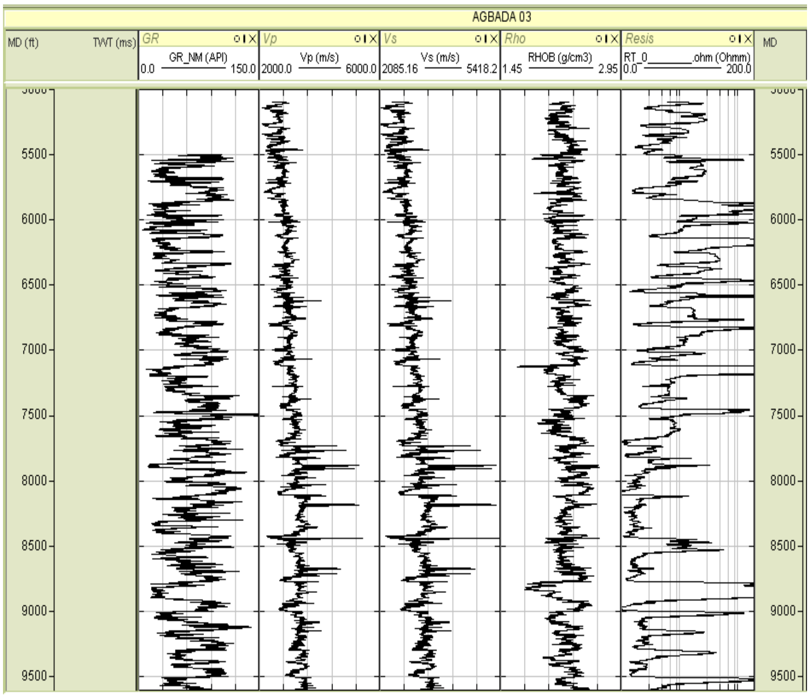



**Figure 5** Wireline Log Datafor Agbada 3

The Figures Above Shows The Complete Wire Line Log Representing The Various Reservoirs And Its Useful Content, These Logs Are Used To Evaluate And Analyze The Petro physical Properties Such As Hydrocarbon Saturation (*Sh*), Porosity (Φ), Permeability (K), Water Saturation (*Sw*), Water Resistivity ($R_W$), Etc

## 2.3 Estimation of Petro physical Parameters

Petro physical Properties Of A Reservoir Of The Field In Study Was Obtained Using The Parametric Equations Below For The Estimation Of Shale Volume,Porosity, Permeability, Water/Hydrogen Saturation,

## Shale Volume

$$I_{GR} = \frac{(\mathrm{Gr\,log} - \mathrm{Gr\,min})}{(\mathrm{Gr\,max} - \mathrm{Gr\,min})} \qquad 2.1$$

Where $I_{GR}$= Index Of Gammaray;
$Gr_{log}$ = Gamma Ray Evaluation(Reading) Of The Formation;
$Gr_{min}$ = Ggamma Ray Reading (Minimum Sand Baseline);
$Gr_{max}$ = Gamma Ray Reading (Maximum Shale Baseline)
Larionov's (1969) Volume Of Shale Formula For Tertiary Rocks Was Used.

$$\mathbf{V_{sh} = 0.083^{(23.7*IGR-1)}} \qquad 2.2$$

**Porosity**
Porosity Calculated From Density Log Using The Equation Below:

$$\Phi_T = \frac{\rho_{ma} - \rho_b}{\rho_{ma} - \rho_f} \qquad 2.3$$

Where $\rho_{ma}$ = Matrix Density Which Is Taken To Be 2.65g/Cc For Sandstones.
$\rho_b$ = Bulk Density Read Directly From The Log
$\rho_f$ = Fluid Density, 1 = Gas And 0.87 = Oil.

**Permeability**
Porosity And Permeability Are Somewhat Related

$$K = \left[\frac{250 * \emptyset^3}{S_{Wir}}\right]^2 \qquad 2.4$$

Where $S_{Wir}$ = Irreducible Saturated Water
**Water/Hdrocarbon Saturation**

$$S_W^2 = \frac{F * R_W}{R_T} \qquad 2.5$$

And Formation Factor Is Given As

$$F = \frac{A}{\Phi^M} \qquad 2.6$$

$S_W$ = Saturation Water For Uninvaded Zone
$R_O$ = Formation Resistivity At 100% Water Saturation
$R_T$ = True Resistivity
F = Formation Factor
Φ = Porosity, A = Constant, Which Is Taken As 0.62, M = Cementation Exponent Which Is 2 For Sands.

### 2.4 Cross Plot Analysis For Fluid And Lithology Identification

Cross Plotting Of Rock Properties From Well Logs Is One Very Convenient And Efficient Way To Look At Two Rock Properties And Their Attributes (Combination Of Rock Properties) At The Same Time. It Also Show Quit Decisively Which Rock Properties And Their Attributes Will Be Helpful To Discriminate Gas In A Particular Reservoir.Crossplot Analysis Was Carried Out To Determine The Rock Properties / Attributes That Better Discriminate The Reservoir [5].

## III. Results

The Well Curves Used For The Analysis Are Shown In Figure 3.1 To Figures 3.3. Three Reservoirs Each Were Delineated For Agbada 1, 2 And 3. The Top And Base Of The Identified Reservoirs Of Interest Are Shown In Table 4.1. The Wells Display A Shale/Sand/Shale Sequence Which Is Characteristic Of The Niger Delta Formation. The Wells Were Analysed In Terms Of Lithology From Gamma Ray Log. Shale Lithologies Were Defined By The High Gamma Ray Value. Shale Lithologies Cause The Deflection Of Acoustic Impedance Curve To The Right And Resistivity To The Far Left Due To Its High Conductive Nature. Regions Showing Low Gamma Ray, High Resistivity, And Low Acoustic Impedance Are Mapped As Sandylithologies.

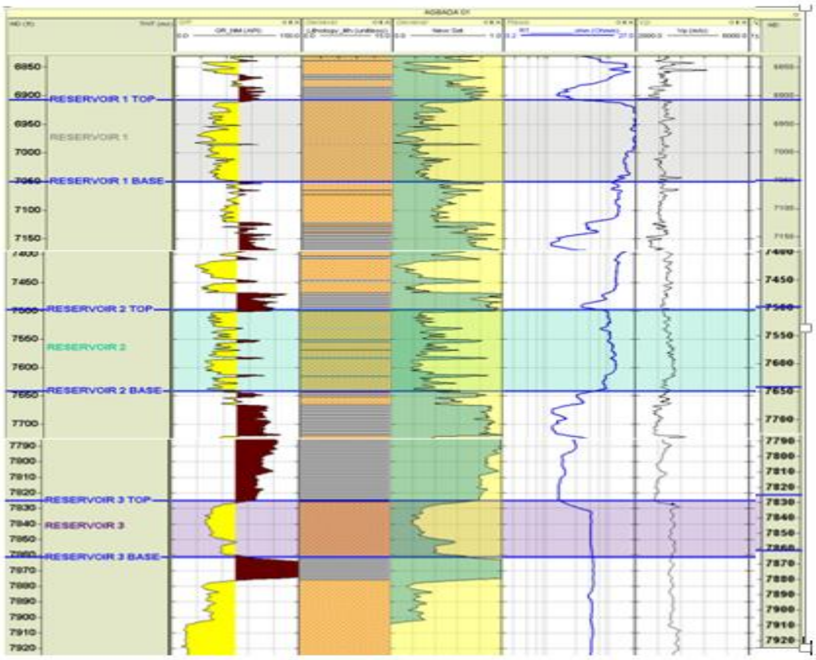



**Figure 6:** Agbada 1 and Suite of Logs Used in the Analysis, (reservoir 1, 2 and 3)

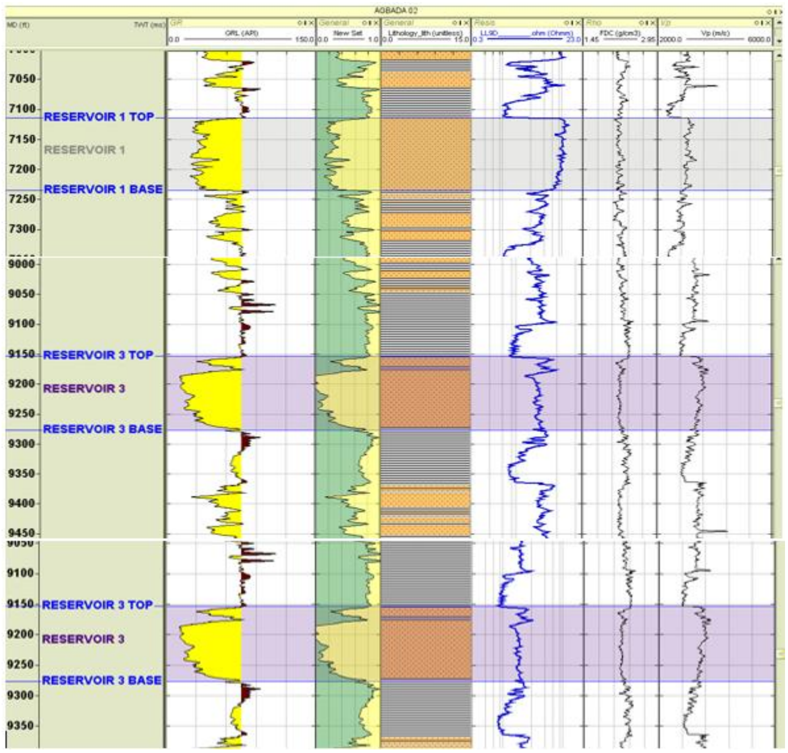



**Figure 7:** Agbada 2 and Suite of Logs Used in the Analysis, (reservoir 1, 2 and 3)

In figures (5 and 7)wells display a shale/sand/shale sequence which is characteristic of the Niger delta formation. The wells were analysed in terms of lithology from gamma ray log. Shale lithologies were defined by the high gamma ray value. Shale lithologies cause the deflection of acoustic impedance curve to the right and resistivity to the far left due to its high conductive nature. Regions showing low gamma ray, high resistivity, and low acoustic impedance are mapped as sand lithologies.

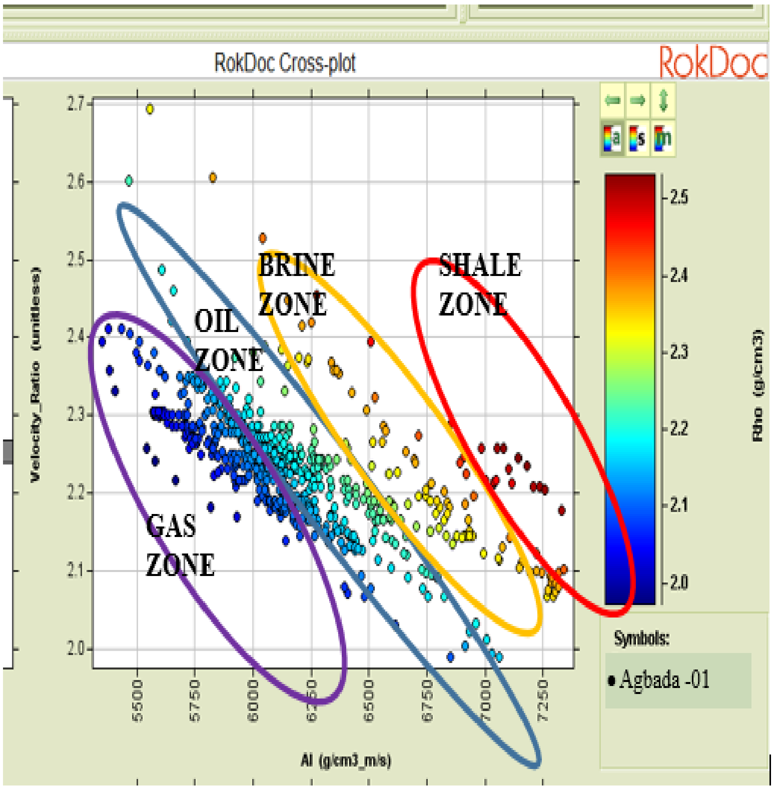



**Figure 8:** Crossplot of $V_p/V_s$ratio versus Acoustic impedance for Reservoir 1, 2 & 3 for Agbada 1

## 3.1 $V_p/V_s$ Ratio Vs Acoustic Impedance (P-Impedance)

The Cross Plot Of $V_p/V_s$ Ratio Against Acoustic Impedance ($Z_p$) (Figure 8), Distinguishes The Delineated Reservoir Sands Into Four Zones Namely; Gas Zone (Purple Ellipse), Oil Zone (Blue Ellipse), Brine Zone (Orange Ellipse) And Shale Zone (Red Ellipse) Which Can Be Validated From The Density Colour Code. This Cross Plot Shows Better Fluid As Well As Lithology Discrimination, Indicating That $V_p/V_s$versus Acoustic Impedance Attribute Will Better Describe The Reservoir Conditions In Terms Of Lithology And Fluid Content. Similar Patterns Are Seen For All The Three Wells.

## 3.2 Shear Impedance ratio and Acoustic Impedance (P-Impedance)

Also In The P-Impedance And S-Impedance Cross Plot (Fig. 7), Hydrocarbon Is Indicated By The Yellow Oval, Which Relates To Low Values Of Both Rock Properties, The Brown Oval Describes Brine Sand, And The Gray Oval Shows The Shale Bearing Zone Of The Formation.

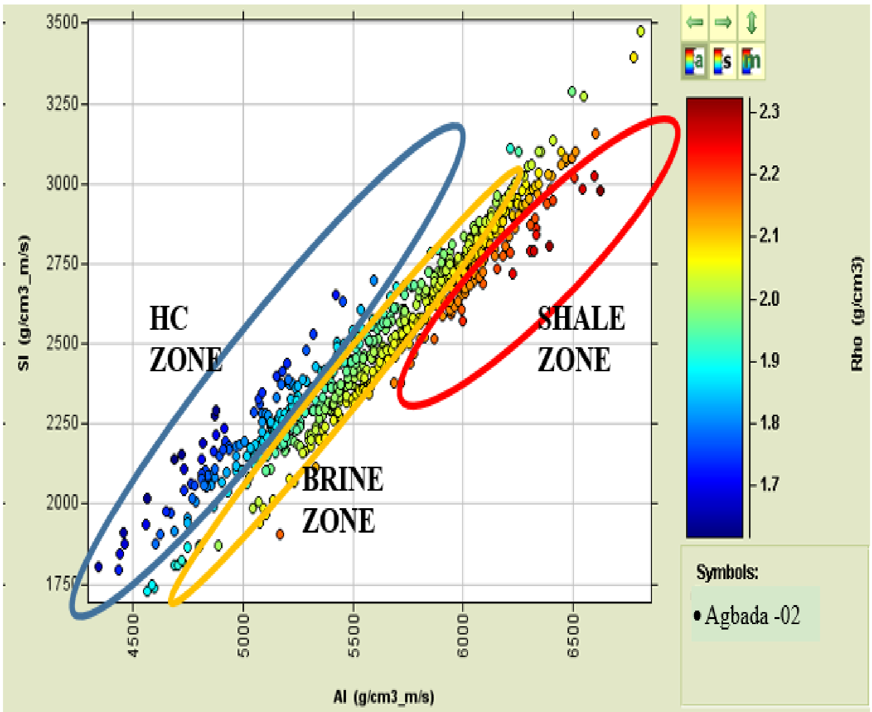



**Figure 9:** Crossplot of Shear impedance (SI) ratio vs. Acoustic impedance

### 3.3 Cross plots of Vp/Vs ratio Versus Porosity

Crossplot Of Vp/Vs Against Porosity Distinguishes The Reservoir Sands Into Four Zones, Inferred To Be Shale (Purple), Brine (Blue), Oil (Red) And Gas (Green). The Lowest Values Of Vp/Vs And Porosiy Associated With Hydrocarbons Are Validated By Low Bulk Density As Observed From The Coulor Code. The Plot Also Indicates That Both Vp/Vp And Porosity, Show Good Discrimination In Terms Of Fluid Content.

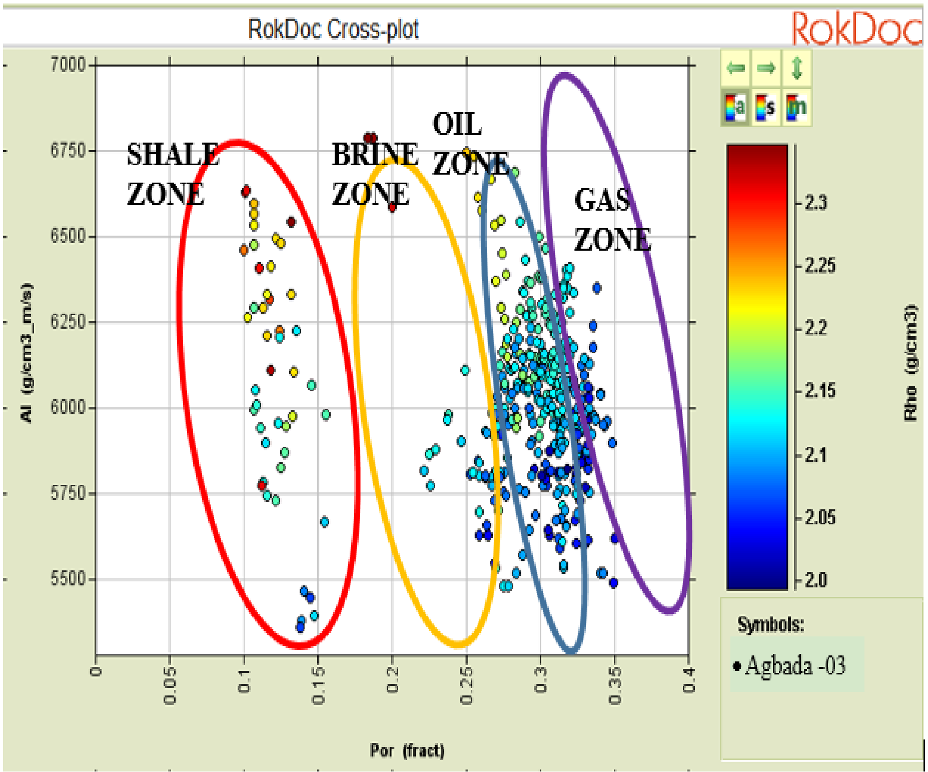



**Figure 10:** Crossplot Of Acoustic Impedance (AI) Ratio Vs. Porosity For Reservoir 1 & 2 For Agbada 3

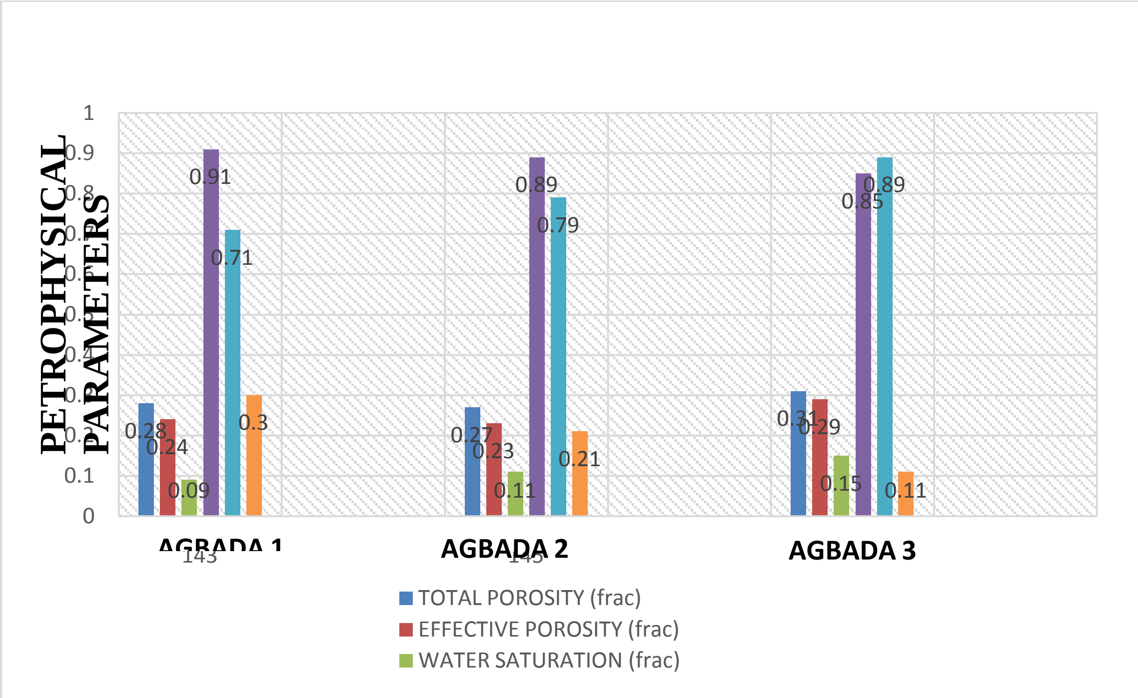
### 3.4 Average Petrophysical Properties

Table 3.1 Shows The Summary Of The Average Petrophysical Parameters Of Agbada 3, Which Was Delineated To Contain Three Reservoirs Identified (Reservoir 1, 2 & 3) As A Hydrocarbon-Bearing. Porosity, Permeability, Hydrocarbon/Water Saturation, Volume Of Shale. Porosity Of The Well Ranges From 0.25 To 0.39, Water Saturation 0.02 To 0.11, Hydrocarbon Saturation 0.89 To 0.98, Net-To-Gross To And Permeability 730 Md To 1281 Md Were Calcculated. These Results Imply That The Reservoir Is Highly Porous And Permeable And Also Contains High Hydrocarbons Content Which Is Very Viable For Production.

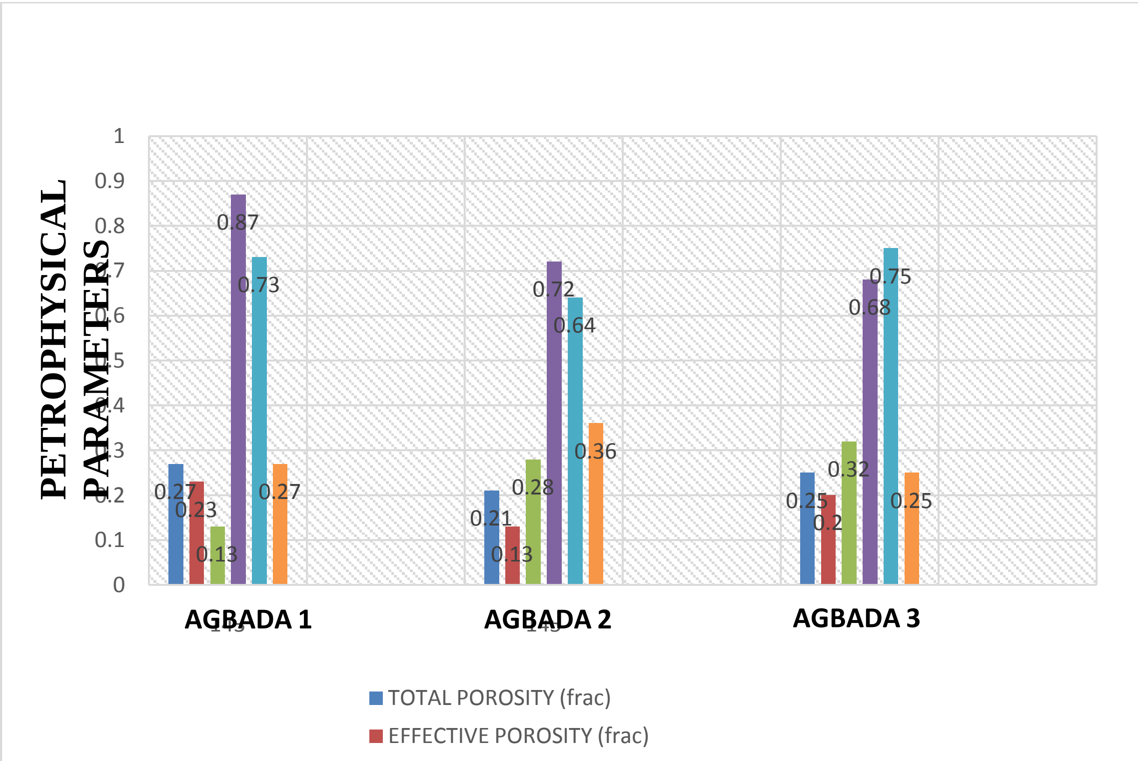
**Table 1:** Average petrophysical properties for Well AGBADA 1, 2 and3

| **AGBADA 1** | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Reservoir name | **Top ft MD** | **Base ft MD** | **Gross Thicknes s Ft** | **Net Thickness ft** | **Net/Gross Thickness Ft** | **Vol of Shale (frac** | **$\Phi_T$ (frac)** | **$\Phi_{eff}$ (frac)** | **$S_w$ (frac)** | **$S_h$ (frac)** | **K (mD)** |
| Reservoir 1 | 6907 | 7050 | 143 | 100.1 | 0.71 | 0.30 | 0.28 | 0.24 | 0.09 | 0.91 | 839 |
| Reservoir 2 | 7497 | 7642 | 145 | 114.6 | 0.79 | 0.21 | 0.27 | 0.23 | 0.11 | 0.89 | 1213 |
| Reservoir 3 | 7825 | 7861 | 36 | 32.0 | 0.89 | 0.11 | 0.31 | 0.29 | 0.15 | 0.85 | 657 |
| **AGBADA 2** | | | | | | | | | | | |
| Reservoir 1 | 7114 | 7235 | 121 | 88.3 | 0.73 | 0.27 | 0.27 | 0.23 | 0.13 | 0.87 | 798 |
| Reservoir 2 | 7699 | 7861 | 162 | 103.7 | 0.64 | 0.36 | 0.21 | 0.13 | 0.28 | 0.72 | 505 |
| Reservoir 3 | 9153 | 9276 | 123 | 92.3 | 0.75 | 0.25 | 0.25 | 0.20 | 0.32 | 0.68 | 691 |
| **AGBADA 3** | | | | | | | | | | | |
| Reservoir 1 | 7120 | 7209 | 89 | 76.5 | 0.89 | 0.14 | 0.36 | 0.23 | 0.63 | 0.97 | 1281 |
| Reservoir 2 | 8780 | 8913 | 133 | 113.1 | 0.85 | 0.15 | 0.39 | 0.27 | 0.02 | 0.98 | 1435 |
| Reservoir 3 | 9500 | 9565 | 65 | 55.2 | 0.68 | 0.32 | 0.25 | 0.13 | 0.11 | 0.89 | 730 |

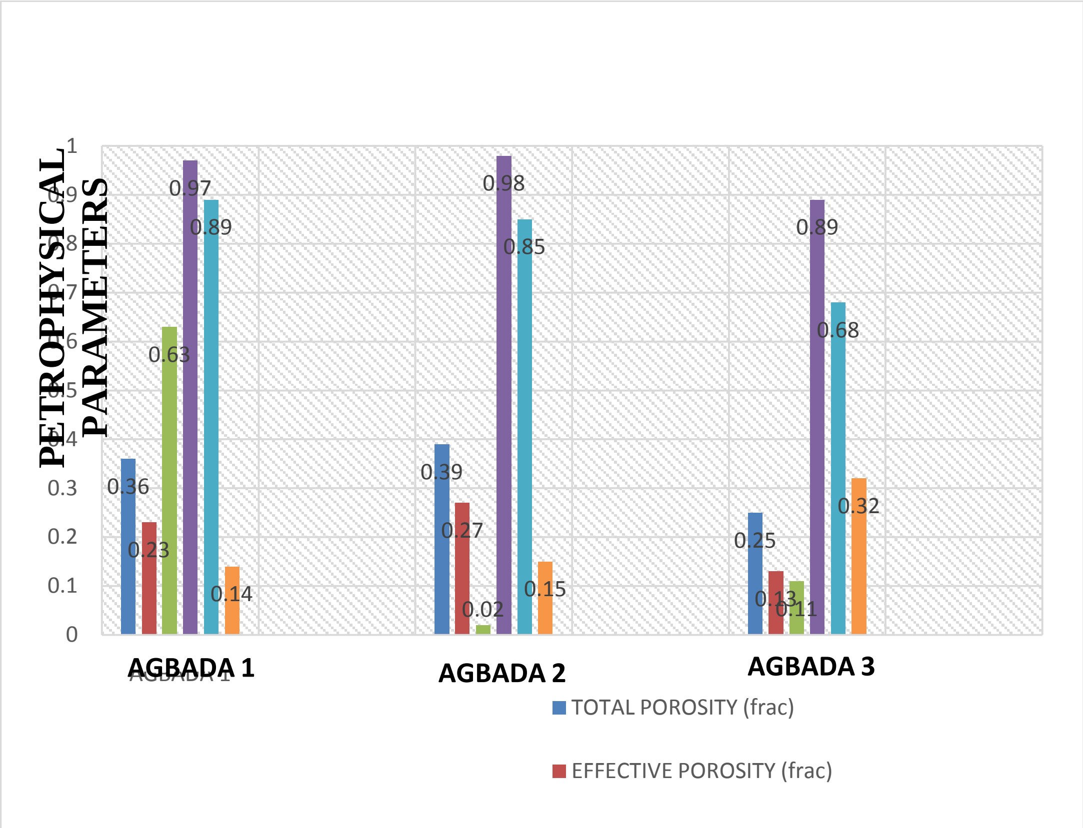
The Various Petrophysical Properties Were Plotted Across The Nine Reservoirs Studied. Combined Bar Chart Showing Variations Of Reservoir Properties In Agbada 1, 2 And 3 Are Shown In Fi Respectively. The Results Gives At A Glance Which Well Has The Best Hydrocarbon Content And Which Is Most Prolific Than The Other. The Results Obtained Reveals That The Average Porosity Of Reservoir Sands, Ranging From 21% To 39%. The Permeability Of The Field, Which Range From 505 Md To 1435 Md, Are Very Good And Excellent. Hydrocarbon Saturation Is High In All The Reservoir Sands, Ranging From 68% To 98%, With Corresponding Water Saturation From 2% To 32%.The Net-To-Gross Ratio In The Field Ranges From 0.64 To 0.89. In All The Reservoir 2 Of Agbada 3, Is The Most Prolific In The Agbada Field Because Of The Excellent Values Of Porosity, Permeability And Hydrocarbon Saturation?




**11: Combined Bar chart showing Variations of Reservoir Properties in Agbada 1**




**12: Combined Bar chart showing Variations of Reservoir Properties in Agbada 2**




**13: Combined Bar chart showing Variations of Reservoir Properties in Agbada**

## IV. Conclusion

This Research Shows In Details How Various Petrophysical Properties Like Porosity, Permeability, Water Saturation Etc, Was Obtained In Order To Estimate The Field's Hydrocarbon Prospective. It Also Show How Cross-Plots Analysis Was Used To Investigate The Sensitivity Of The Rock Properties To Fluid And Lithology In Cross-Plot Space The Theories Of Well Logging, Relevant Petrophysical Equations And Software (Rokdoc And Excel) Were Applied Successfully To Wireline Log Data From Three Wells Obtained In An Onshore Niger Delta Field (AGBADA FIELD). The Well Logs Studied Revealed Nine Reservoirs Consisting Of Sand Stone And Shaly-Sand. The Petrophysical Parameters Estimated Included Permeability, Water Saturation, Shale Volume, Hydrocarbon Saturation, Porosity Net-To-Gross, Reservoir Thickness (Pay Zone). These Properties Were Used To Distinguish The Reservoir's Potential Of The Field. In Addition To The Petrophysical Estimates, Charts Of Various Petrophysical Parameters Were Also Plotted To Enable A Quick Look At The Variations Of These Parameters Within The Field. This Helps To Explain The Productivity And Hydrocarbon Potential Of The Field.

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