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Evaluation of the Discriminating Capacity of Rock and Attribute Properties Using Statistical Methods

C.N. Ehirim[1] and K. J. Abia[2]

Geophysics Research Group, Department of Physics, University of Port Harcourt, P.O.Box 122, Choba, Port Harcourt, Nigeria

Abstract: *Statistical rock physics analysis of petrophysical logs for reservoir characterization has been carried out in a Niger delta field. The objective of the study is to determine the discriminating capacity of these rocks and attribute properties in 2-D cross plot space. Classifications were done in terms of Pearson's coefficient of correlation (R^2) of the cross plotted property pairs. Low R^2 value gives the most non-linear data clusters with good separation and highest discriminating capacity, while high R^2 value gives linear and poorly separated data clusters and least discriminating capacity. Results indicates that the discriminating capacity of rock and attribute properties were in the order of ρ, PI, λρ,* Poisson ratio, VpVs ratio, *Zp and Vp for fluid, while ρ, μρ, Zs, Zp, and Vs are for lithology. In all cases of cross plot pairs, ρ appears to have the highest discriminating capacity, while Vs vs VpVs ratio cross plot the least. ρ exhibits* dual property *because of its heightened sensitivity to lithology and pore fill. The relative value of R^2 and the degree of discrimination into distinct lithology units and fluid types for the investigated properties depends on the quality of well log data used in the analysis and the characteristic property of the reservoir parameters.*

Keywords: *Discriminating capacity, Coefficient of correlation, Cross plot, Factor and Variable*

I. Introduction

Evaluating hydrocarbon potentials of reservoirs have continued to attract the attention of researchers and major players in the industry. The main objective is to characterize the reservoir in terms of lithology and fluid content for optimized hydrocarbon production, while minimizing cost and risks.

Rock physics has over the years enhanced reservoir characterization, and rock and attribute properties either logged or modeled has tremendously aided in rock type identification and pore fill saturation through cross plot analysis. Cross plot analysis allows the simultaneous visualization of rock and attributes properties in two or three dimensional space for reservoir characterization.

It has become a powerful and widely used tool in resolving an ambiguous relationship between rock and attribute properties in terms of their sensitivities to lithology and pore fill. Generally, common lithology units and fluid types tend to form distinct clusters in cross plot space, and this helps in making a straight forward interpretation to probable lithology and pore fill saturation.

This approach is adequate only when the data clusters are separated with no overlap. The major drawback of this method is that once there is overlap, it becomes difficult to separate the clusters into distinct anomalous zones by drawing polygons or using cut offs to separate zones of interest [1], and the lack of quantitative measure of cluster separation for reliable and robust property prediction.

Our method accounts properly for overlap and clustering response of the desired property. It quantifies the statistical differences in the clustering of data points in terms of the coefficient of correlation (R^2) for different rock and attribute property cross plots. This implies that on the basis of R^2, the relatedness and discriminating capacity of properties can be accessed.

Low R^2 will tend to loosely group clusters of unrelated properties and give stronger separation, while large R^2 will closely group clusters of related properties and weaker separation. This forms the basis for fluid and lithology discrimination, and provides the criterion for which rock and attribute property cross plot pairs are adjudged with respect to their discriminating capacities ([2], [3]).

This method was applied to determine discriminating capacities of rock and attribute properties in a Niger delta field by rock physics analysis of petrophysical well logs (Fig. 1.0). Investigating the discriminating capacity of rock and attribute properties statistically can inform the choice of the appropriate cross plot pairs for effective and efficient characterization of the reservoir. This is also intended to form the basis for rock and attribute property cross plot template in the field.

Fig. 1.0: The study area within Niger delta of Nigeria

II. Geology of the study area

The Niger delta is a Tertiary sedimentary basin. It is one of the largest regressive deltas in the world with an area of 300,000 km^2 and about 12 km thick in the central part. The basin is divided into three depositional units (Fig. 2.0). These units are distinguished mostly on the basis of sand – shale ratios.
At the base of the delta is Akata Formation formed during the transportation of terrestrial organic matter and clays to deep water areas characterized by low energy and deficient oxygen [4].

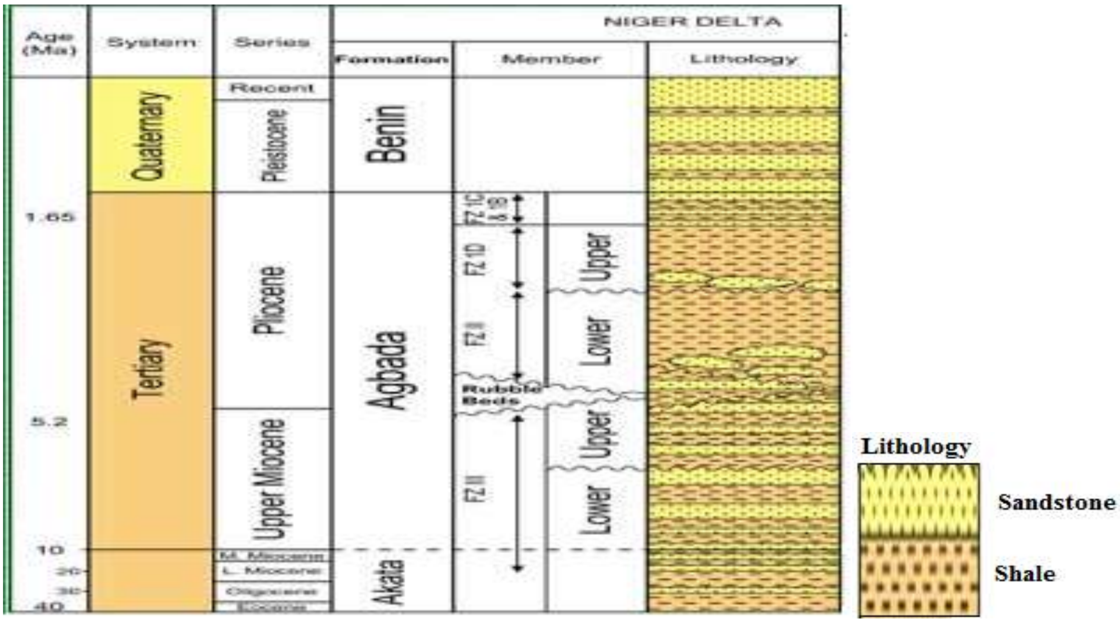

Fig. 2.0: Geologic and Stratigraphic map of the area

It is composed of thick shale sequences which are potential source rocks, turbidite sand (potential reservoirs in deep water) and minor clay and silt [5]. This formation is generally overpressured.

Overlying the Akata Formation is the Agbada Formation consisting alternating units of sandstone and shale. The sands are under-compacted due to high rate of sedimentation and hydrocarbon bearing with transgressive-sealing shale readily influenced by faults, which provides pathway for hydrocarbon migration. This forms structural traps, which combines with stratigraphic traps to accumulate hydrocarbon in this stratigraphic unit [4].

Overlying the Agbada Formation and the uppermost continental deposit of the delta is the Benin Formation. Relatively coarse sand in this formation is deposited as point bars, while finer grains and shale are deposited in back swamps and oxbows. Benin Formation is generally water bearing, hence it is the main source of portable water in Niger delta [6].

III. Methodology

A clustering analysis classification scheme aided by statistical package for social sciences (SPSS) was performed on well log data in the Niger delta field. It has as its input well logs referred to as variables and output lithology and fluid as factors responsible for the variability in data clusters in the cross plot space.

The input logs are comprised of Density (ρ), Gamma ray (γ), Resistivity (R), and Sonic (Vp), were edited and de-spiked using median filter (Fig. 3.0). Shear (Vs), VpVs ratio, Poisson ratio, Poisson impedance (PI), Lambdrho ($\lambda\rho$), Murho ($\mu\rho$), Acoustic impedance (Zp) and Shear impedance (Zs) logs were modeled from appropriate rock physics empirical relations using Hampson Russel (HR) soft ware package. These logs constitute the rock and attribute properties used in the cross plot analysis.

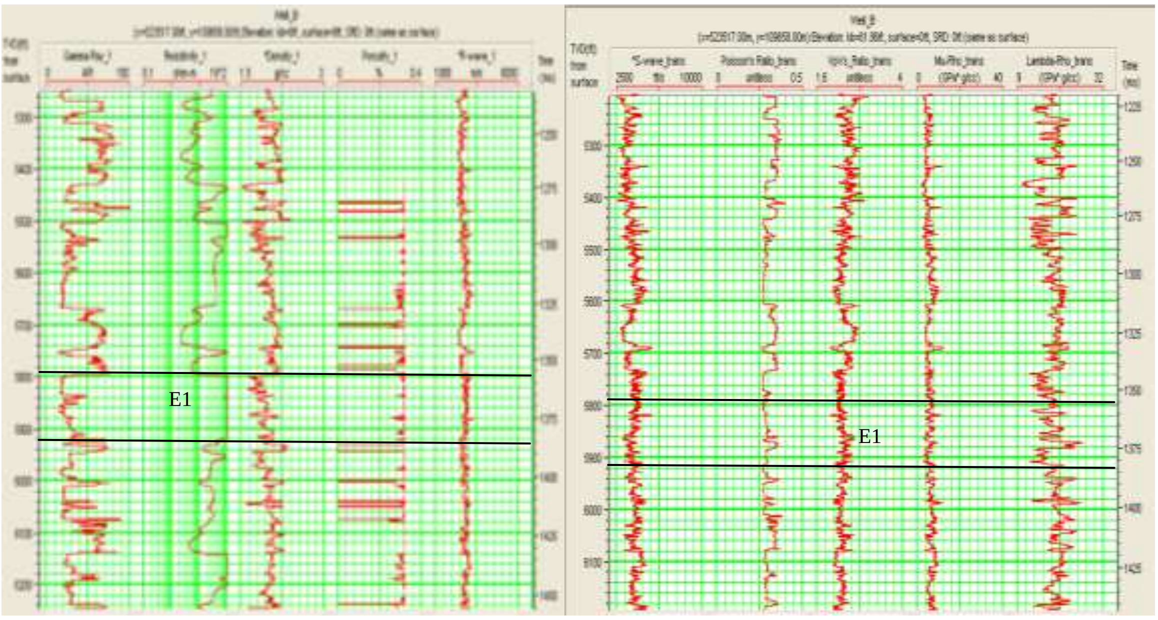

Fig. 3.0: Typical logs used in the analysis for well B reservoir E1

A hydrocarbon reservoir zone was delineated in the well by low gamma ray, density and sonic and high resistivity values. This reservoir interval with the logs were imported into the statistical package and subjected to analysis using varying combinations of rock and attribute property cross plot pair in 2D space. The coefficients of correlation (R^2) were computed for each cross plot pair from the clustering pattern of the data points in the cross plot space.

The resulting pattern of correlations and the accompany correlation coefficients (R^2) were evaluated for each cross plot pair to determine their discriminating capacities.

IV. Result Presentation

The coefficient of correlation (R^2) of ten (10) commonly logged-derived cross plotted rock and attribute property pairs for lithology and fluid discrimination (Table 1), gives a value of unity along the main diagonal and values less than unity on either side of the diagonal. Results show that values of unity were obtained when a property (variable) is cross plotted with itself (Auto-correlation) and values less than unity when a variable is cross plotted with another (Cross-correlation).

Analysis of results indicates a statistically significant linear relationship between some properties, while a few others exhibits non-linear relationships. The correlation values vary from 0.002 for the least correlated to 1.0 for the most correlated variable. The value of 0.002 signifies a near random relationship, suggesting that there is no linear relationship between the two variables, while a value of 1.0 signifies a perfectly linear relationship between the two variables.

Table1: Pearson's correlation coefficient values (R^2)

Property	ρ	Vp	Vs	VpVs ratio	Poisson ratio	μρ	λρ	Zp	Zs	PI
ρ	1.000	0.002	0.003	0.003	0.002	0.367	0.937	0.687	0.383	0.970
Vp	0.002	1.000	0.996	0.996	0.996	0.660	0.088	0.360	0.660	0.048
Vs	0.003	0.996	1.000	1.000	0.986	0.654	0.091	0.362	0.659	0.051
VpVs ratio	0.003	0.996	1.000	1.000	0.986	0.654	0.091	0.362	0.659	0.051
Poisson ratio	0.002	0.996	0.986	0.986	1.000	0.664	0.084	0.356	0.659	0.046
μρ	0.367	0.660	0.654	0.654	0.664	1.000	0.611	0.893	0.994	0.534
Λρ	0.937	0.088	0.091	0.091	0.084	0.611	1.000	0.885	0.630	0.992
Zp	0.687	0.360	0.362	0.362	0.356	0.893	0.885	1.000	0.908	0.831
Zs	0.383	0.660	0.659	0.659	0.659	0.994	0.630	0.908	1.000	0.553
PI	0.970	0.048	0.051	0.051	0.046	0.534	0.992	0.831	0.553	1.000

The discrminant factor chat (Fig. 3.0 a&b) shows the property cross plot pairs with data clusters separated into gas sand (Blue), oil sand (Red), brine sand (Yellow) and shale (Green) zones respectively. The cross plots range from poorly to well separated data clusters. The separation of the data clusters into distinct lithology units and fluid types in each cross plot space is dependent on the relative value of R^2. High R^2 value gives a poorly separated data clusters that are linear, while low R^2 value give well separated data clusters that are non-linear. The main diagonal of the discrimiant chart are empty spaces resulting from the auto-correlation of variables corresponding to unity.

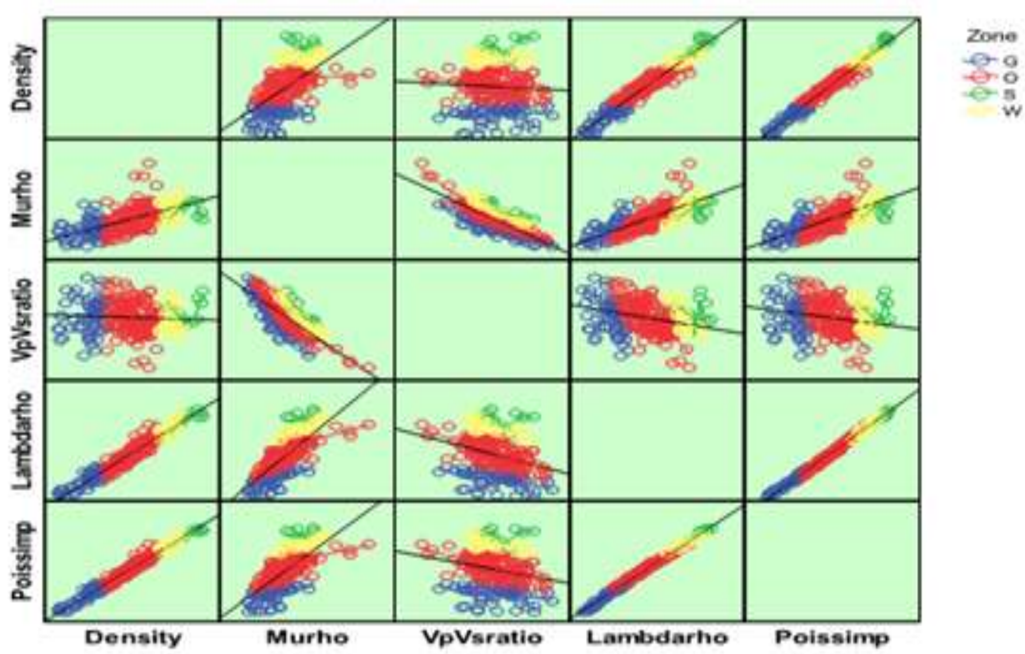

Fig. 3.0a: Discriminant chart for selected cross plotted rock and attribute properties

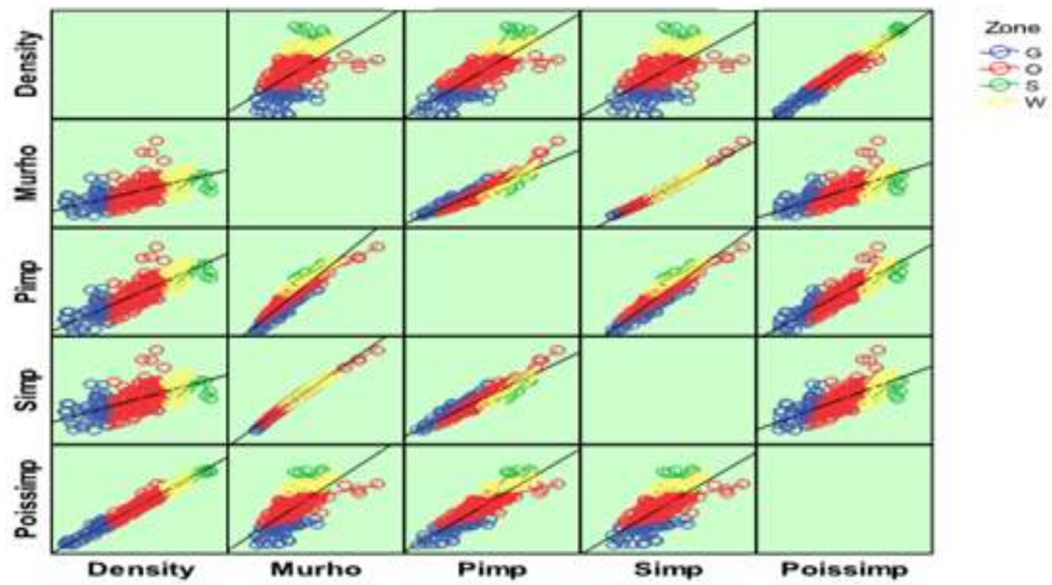

Fig. 3.0b: Discriminant chart for selected cross plotted rock and attribute properties

Cross plots of Zp vs PI, Zp vs λρ, μρ vs Zp, Zs vs Zp, ρ vs λρ, ρ vs PI, λρ vs PI, μρ vs Zs, Vs vs Poisson ratio, Vp vs VpVs ratio, Vp vs Vs, and Vs vs VpVs ratio gives R^2 values ranging from 0.831 to 1.0. These high R^2 values indicate a very strong and positive linear relationship between these variables, suggesting probable sensitivity to the same reservoir factors.

Zp vs Poisson ratio, Vp vs Zp, Vs vs Zp, Zp vs VpVs ratio, ρ vs μρ, ρ vs Zs, μρ vs PI, Zs vs PI, μρ vs λρ, Zs vs λρ, μρ vs VpVs ratio, μρ vs Vs, Vs vs Zs, Zs vs VpVs ratio, Zs vs Poisson ratio, Vp vs Zs, μρ vs Vp, μρ vs Poisson ratio, and ρ vs PI cross plots, have R^2 values ranging from 0.356 to 0.687. This indicates moderate and positive linear relationships, suggesting appreciable degrees of sensitivity to different reservoir factors.

Poor linear relationships are indicated by ρ vs Vp, ρ vs Poisson ratio, ρ vs Vs, ρ vs VpVs ratio, Poisson ratio vs PI, Vp vs PI, Vs vs PI, VpVs ratio vs PI, Poisson ratio vs λρ, Vp vs λρ, VpVs ratio vs λρ and Vs vs λρ cross plots, with R^2 values ranging from 0.002 to 0.091. These properties exhibit very low positive correlation values and are highly sensitive to different reservoir factors.

Result also show that Vp cross plotted with either VpVs ratio, Poisson ratio, or Vs and Zs cross plotted with either Vs, VpVs ratio, or Poisson ratio, have R^2 value of 0.996 and 0.659 respectively, while Poisson ratio cross plotted with either VpVs ratio or Vs has R^2 value of 0.986. Vs and VpVs ratio gives the same R^2 value each time they are cross plotted with any other variable and value of 1.0 when cross plotted with each other. These are strong indications that these rock and attribute properties are strongly linearly related and likely to be influenced by the same or similar factor.

V. Discussion of results

Fluid and lithology discriminating capacities of ten (10) commonly logged-derived rock and attribute properties of a hydrocarbon reservoir zone have been investigated statistically using the clustering analysis classification scheme in a 2-D cross plot space. Classifications were done in terms of the coefficient of correlation of cross plotted properties. This measures the extent to which data points deviate from the best fit line drawn between the clusters. The more the deviation or scatter the lower the coefficient value and the more unrelated the cross plotted properties (variables) and vice versa. Subsequently, the more unrelated these cross plotted properties the higher their discriminating capacities.

Velocity and density, and therefore VpVs ratio, Poisson ratio, Zp, Zs, λρ, μρ, and PI are impacted by porosity, sand /shale ratio and pore fill, such that through careful petrophysical analysis, these properties can be directly related to such reservoir parameters as lithology and pore fill.

Among the cross plotted property pairs, ρ exhibits the least coefficient value and highest discriminating capacity. This is followed by PI and λρ. These properties give well separated non-linear data clusters with low R^2 value when cross plotted with either of Vp, Vs, VpVs ratio, and Poisson ratio. When cross plotted with μρ, Zp and Zs fairly separated non-linear data clusters are obtained with moderate coefficient values. These data clusters can be separated into distinct lithology units and fluid types robustly in the earlier than latter cross plots.

It is expected of gas sand to exhibit low values of PI, λρ, VpVs ratio, Poisson ratio and high value of μρ in the reservoir zone when cross plotted. This is however in variance with the result of this study, as gas sand clusters depict low values of PI, λρ and μρ, and high VpVs ratio and Poisson ratio. This is attributed to the fact that the reservoir sand quality may have been compromised due under-compaction and compositional variations with rigidity modulus reduced. This could possibly explain the moderately high coefficient values obtained when these properties are cross plotted.

Vp, Vs, VpVs ratio and Poisson ratio cross plotted with either of μρ, Zp, Zs properties gives fairly separated non-linear data clusters which can be separated into distinct lithologic units and fluid types fairly well with moderately high coefficient values. This moderately high coefficient values are indications that these properties are likely to be influenced by almost similar reservoir factors.

Cross plots of ρ vs PI, ρ vs λρ, Vs vs Vp, Vp vs VpVs ratio, Vs vs VpVs ratio, Vp vs Poisson ratio, VpVs ratio vs Poisson ratio, μρ vs Zs, μρ vs Zp, λρ vs Zp, λρ vs PI, Zp vs PI, gives linear data clusters with high coefficient values. Highest coefficient values are obtained when Vs vs VpVs ratio are cross plotted. In these cross plots pairs, separation into distinct lithologic units and fluid types are very minimal. This revelation strongly suggests that these properties are influenced by the same or similar reservoir factors, and cannot be cross plotted for distinct discrimination of lithology units and fluid types in the reservoir.

Most revealing in this study is that Vs and VpVs ratio gives the same value of R^2 each time they are cross plotted with any other property. When cross plotted with each other, a maximum R^2 value of 1.0 is obtained. This is a strong indication of the relatedness of the two properties. This result is true considering the fact that VpVs ratio is a function of Vp and Vs. Its sensitivity is dependent mostly on the response of Vs to lithology and pore fill in the reservoir.

On the basis of the coefficient values and the relative scatter of clusters in the 2D cross plot space, these investigated properties are classified in the order of their discriminating capacities into fluid and lithology sensitive properties. Fluid sensitive properties are ρ, PI, λρ, Poisson ratio, VpVs ratio, Zp and Vp, while lithology sensitive properties are ρ, μρ, Zs, Zp, and Vs.

Robust lithology and fluid discrimination is obtained when a highly sensitive lithology and fluid property pair is cross plotted. This is a necessary requirement for reservoir characterization and optimized hydrocarbon production using well log data.

VI. Conclusion

The discriminating capacity of ten (10) commonly used logged- derived rock and attribute properties was investigated statistically using the clustering analysis classification scheme in a 2-D cross plot space. Results show that on the basis of the coefficient values and relative scatter of clusters, these investigated properties can be classified into lithology and fluid sensitive properties in the other of their discriminating capacities.

The fluid sensitive properties are ρ, PI, λρ, Poisson ratio, VpVs ratio, Zp and Vp, while lithology sensitive properties are ρ, μρ, Zs, Zp, and Vs. In all cases of cross plot pairs, ρ appears to be the most robust property for both lithology and fluid discrimination. This is followed by PI and λρ for fluid, and μρ and Zs for lithology. Vs vs VpVs ratio is the least cross plot pairs for discrimination.

The relative value of R^2 and the degree of discrimination into distinct lithology units and fluid types for the investigated properties depends on the quality of well log data used in the analysis and the characteristic property of the reservoir parameters.

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