Cross Plot Analysis of Extracted Seismic Inversion Attributes for Fluid and Lithology Discrimination: A Case Study of K-Field, Onshore Niger Delta Area, Nigeria

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Abstract: ***The use of seismic inversion attributes in reservoir characterization is generally becoming an important factor in integrated reservoir studies, its uses has clearly revolutionize the ways and manners reservoir interpretation is been performed. This paper demonstrates the robustness and advantages of integrating/use of seismic inversion attributes in discriminating the fluid contents and lithology of the reservoir of the case study area. The study involves crossplots analysis of different extracted attributes and their sensitivities to reservoir fluid contents and lithology respectively. The analysis shows that Lambda-Rho (λρ) attribute is more robust in fluid and lithology discrimination than Mu-Rho (μρ) attribute irrespective of the petrophysical parameters of the field considered. The values seismic inversion attributes added to the study includes improved and robust fluid and lithology discrimination.***

Keywords: Cross-plots, Discrimination, Lambda-Rho, Mu-Rho, Attributes, Inversion, Characterization, Lithology, Fluids

1. Introduction

A major problem often encountered in reservoir characterization and analysis is the ability to clearly discriminate the fluid contents and lithology of the reservoir. Seismic inversion products are high resolution data, which are used to constrain and build high fidelity models for reservoir characterization. Reservoir expects often require accurate knowledge of the reservoir geometry, reservoir properties and parameters (especially its porosity, water saturation and permeability volumes) to build reservoir models and compute volumetrics in reservoir studies. Most commonly used attributes are acoustic impedance, shear impedance, Poisson's ratio, Vp-Vs ratio (Goodway et al, 1997), but with the advent of the Lambda-Mu-Rho concepts (λ-μ-ρ), an advanced method of discriminating fluid and lithology was introduced (Russell, 2003; Omodu et. al., 2008).

Therefore seismic inversion attributes can be used to reduce the risk and uncertainty common in integrated reservoir characterization, which are generally use to map sand bodies, building static reservoir modeling, understand the reservoir properties changes, stimulation and production history match.

Seismic inversion generally involves:

- Transforms the reflectivity wavefield to interface or layer properties
- Performing post-stack and pre-stack techniques for evaluation and analysis
- Also deterministic and statistical inversion techniques exist

Some of the possible extractable properties include:

- Acoustic Impedance (AI)
- Velocity
- Poisson's ratio
- Elastic impedance
- Seismic logs

Note that for seismic inversion techniques calibration to log and core data is essential.

2. Theoretical Background

The basic principle of most seismic inversion techniques is the approximation of Zoeppritz equations, which analysis the inverted P-impedance and S-impedance as primary input in inversion techniques (Omodu et al., 2008).

The velocities of P and S waves are commonly expressed as

$$V_P = \sqrt{\frac{K + \frac{4}{3}\mu}{\rho}} \text{ and } V_S = \sqrt{\frac{\mu}{\rho}} \qquad (1)$$

Where ρ = density, K= Bulk modulus and μ = Lame's second parameter.

Although bulk modulus can also be given as

$$K = \lambda + \frac{2}{3}\mu \qquad (2)$$

Where λ is the first Lame's parameter and from equation 1, we can obtain

$$V_P^2\rho = K + \frac{4\mu}{3} \text{ and } V_S^2\rho = \mu \qquad (3)$$

Substituting the above equation and re-arranging the terms, we have

$$\mu\rho = I_S^2 \qquad (4)$$

$$\lambda\rho = I_P^2 - I_S^2 \qquad (5)$$

Equation 5 clearly defines λρ as the difference between the squared P-impedance and scaled squared S-impedance (Olowokere et al., 2010; Omodu et al., 2008).

3. Location of Study Area

The study area is situated in the coastal Eastern Niger Delta, in the coastal swamp depobelts of the Delta petroleum system, it is a prograding system of alternating regressive and transgressive cyclic sequence and the reservoirs are Eocene to Miocene tertiary sands (Ogundipe et al, 2010). The K-Field is located incoastal swampof the Basin (Figure 1), which is about 40km south-west of Port Harcourt. The Niger Delta Basin of Nigeria is located in the west coast of Africa at the apex of the Gulf of Guinea between latitude 4^0N and 6^0N and within Longitudes 3^0E and 9^0E

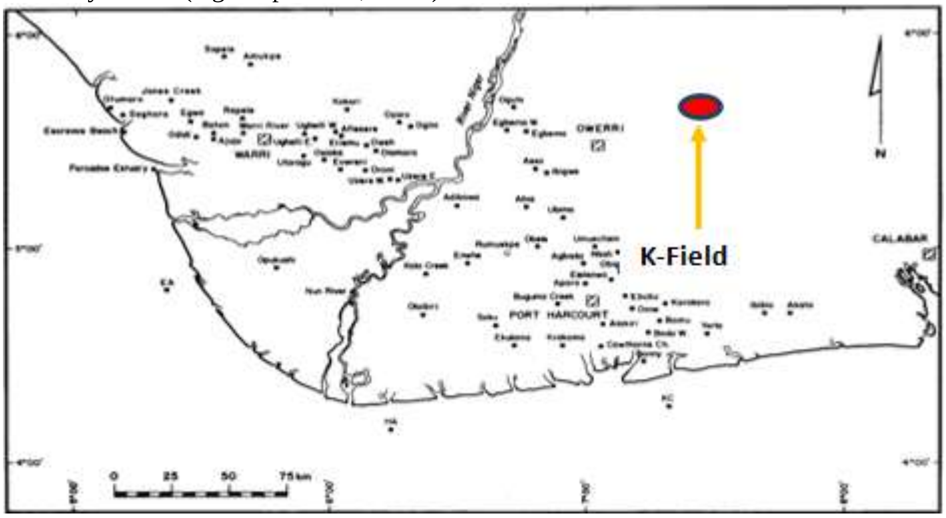


Figure 1: Map of Niger Delta showing location of Study Area (K-field)

Well Data

This study was conducted using 3-D seismic data and well log data obtained (recorded) from K-field, onshore Niger Delta Area (study area). Some of the available log data of the suiteare Gamma ray (GR) log, Neutron-Porosity (NPH) log, Density log, Resistivity log, Caliper log, Sonic log (Compressional P-wave) and Slowness (S-wave) logs. The depth of investigation ranges from 9000 to 12500ft measured depth for the vertical wells whiledepth of investigation for the deviated well is 12000 to 13500ft measured depth.While the checkshot data, well headers information and Post-stacked 3-D Migrated Seismic volume of the field were used for process.The seismic data covers an area of approximately 540 km^2, within which the 3 available wells are situated. The data has 1062 in-lines and 592 cross-lines, with 25ft spacing between each. The time range is between 0 – 6000ms

Method

Data from three hydrocarbon producing wells were used in this study. The wells include: Well-13, Well-26 and Well-30. Well-13 is a deviated well while Wells-26 and Well-30 are vertical wells (Figure 2).The wells were correlated using the Gamma ray and Resistivity logs from the log suites. The logs (Gamma ray and Resistivity) were used to identify the hydrocarbon bearing sand (reservoir) in the wells of the field (K-field). Sand bodies (zones) in the wells with low gamma ray values and high resistivity values were classified as hydrocarbon bearing sands while zones with high gamma ray values and low resistivity values were classified as non-hydrocarbon bearing sand using the shale as the marker beds in each case. In each well, four reservoirs sand bodies were delineated for this work and correlated across the field.

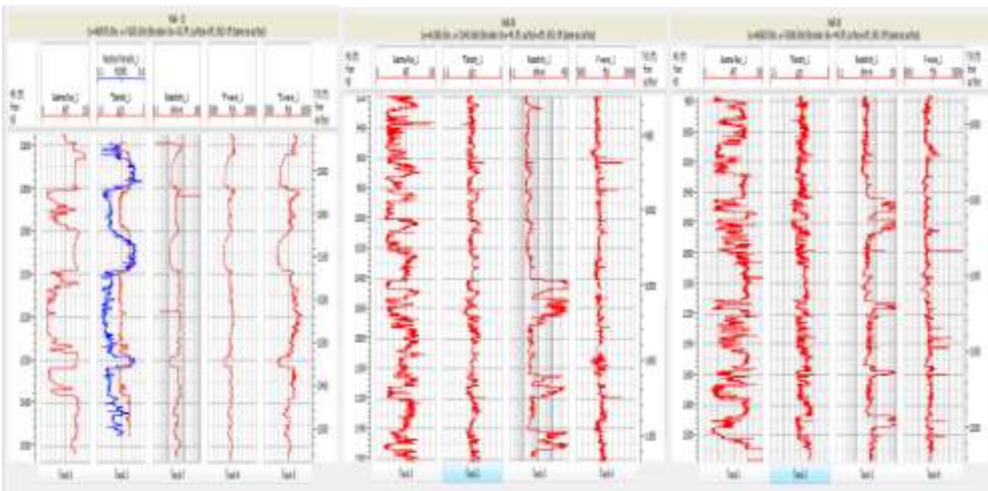


Figure 2: Log section of the Wells from the study area

Probable hydrocarbon reservoirs were mapped (identified) in the wells, using the gamma ray, resistivity, density and porosity logs. The gamma ray log mainly identifies lithology, giving high values for shales and lower values for sands. Only probable sand and shale intervals were identified in all the wells.

For each of the identified permeable or sand intervals in the wells, the resistivity logs were used to discern whether hydrocarbons are probably housed in them, because resistivity values for hydrocarbon charged reservoirs are generally high owing to the non-conducting nature of hydrocarbons. Also using the combination of the bulk density and neutron porosity logs inversely plotted on the same track, a confirmation of the saturating fluid is obtained, as the size of the overlap bubble between the logs indicates what the saturating fluid is: Very large separation bubble indicates gas saturation, large to moderate bubble indicates oil, while small or no separation indicates brine and shales. In the absence of the neutron porosity log as is the cases for wells 26 and 30, the resistivity log was relied upon to identify probable hydrocarbon charged reservoirs.Using the above described technique, three probable hydrocarbon reservoirs were mapped in well 13 while four probable hydrocarbon reservoirs were mapped within wells 26 and 30 (Figure 3). A correlation of the wells are shown in Figure 4

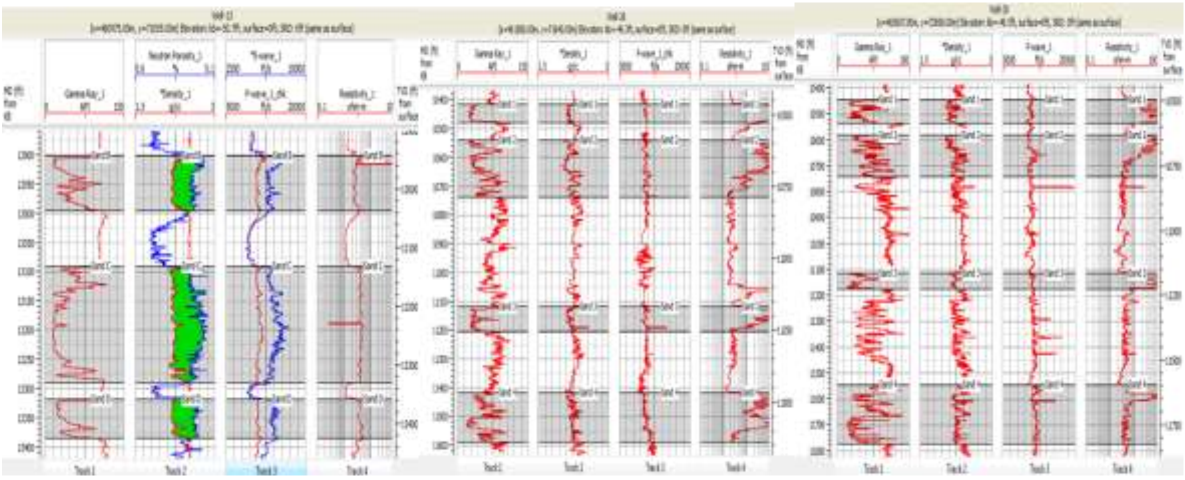


Figure 3: Mapped possible charged hydrocarbon sand units in the wells

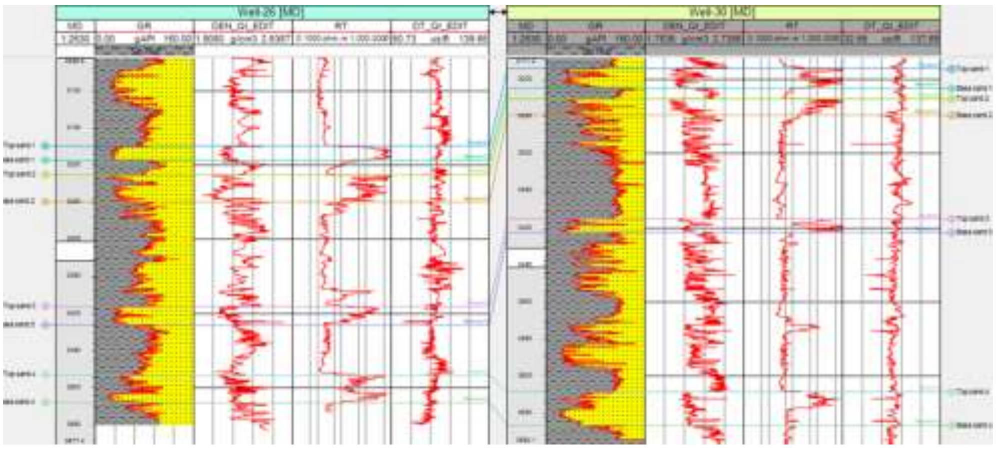


Figure 4: Well correlation panel showing reservoirs correlated within the wells

Having mapped probable hydrocarbon charged reservoirs in the wells using measured well logs, some other reservoir properties/attribute logs, which have relationships with seismic derived properties and are theoretically known to be robust for reservoir fluid and lithology discrimination, were estimated using rock physics models. These estimated attribute logs were evaluated to establish their sensitivity to reservoir fluids and lithologies in this field. The estimated reservoir attribute logs include the acoustic and shear impedances, Vp/Vs ratio, lambda-rho, mu-rho and Poisson's ratio. These attributes were selectively cross plotted using diagnostic reservoir property logs such as the gamma ray log for lithology and the resistivity log for fluid as colour codes. These figures shows the discrimination of the fluid and lithology using Lambda Rho ($\lambda\rho$) against Mu Rho ($\mu\rho$) and the results obtained clearly delineate the lithology of the field and the fluid contents in the reservoir (fluids discrimination). The Figures shows the sensitivity of Lambda-Rho to discriminate the sand bodies from shale bodies, when Gamma ray was used as the indicator, which give a distinct demarcation of the lithology which was not clearly shown in when Mu-Rho were used. The fluid content within the reservoirs was also clearly discriminated in the reservoir when resistivity was used as the indicator. We can deduce that Lambda-Mu- Rho cross plot prove more robust in fluid and lithology discrimination.

Extracted Seismic Attributes of Study Area

The inverted acoustic impedance of the P-wave is used to create the data slices of the seismic volume, which is subsequently used to extract the following seismic inverted attributes in the field and other necessary parameters, such as the two main Lame's parameters, which are found to be sensitive to the structural geology and petrophysical properties of the reservoirs of the study area. The following seismic inverted attributes were extracted from the inverted acoustic impedance of the seismic volume: namely Lambda Rho (rock incompressibility or fluid modulus), Mu-Rho (rigidity modulus), Vp-Vs ratio, P-impedance and S-impedance.

These attributes were selectively cross plotted using diagnostic reservoir property logs such as the gamma ray log for lithology and the resistivity log for fluid as colour codes. These figures shows the discrimination of the fluid and lithology using Lambda Rho (λρ) against Mu Rho (μρ) and the results obtained clearly delineate the lithology of the field and the fluid contents in the reservoir (fluids discrimination). The Figures shows the sensitivity of Lambda-Rho to discriminate the sand bodies from shale bodies, when Gamma ray was used as the indicator, which give a distinct demarcation of the lithology which was not clearly shown in when Mu-Rho were used. The fluid content within the reservoirs was also clearly discriminated in the reservoir when resistivity was used as the indicator. We can deduce that Lambda-Mu- Rho cross plot prove more robust in fluid and lithology discrimination.

4. Results and Discussion

The generated cross plot of the attributes are shown in Figure 5-7, Some selected inverted attributes that are quite sensitive to lithology and fluid discrimination in the reservoir are used for analysis. The Lambda-rho against Mu-rho clearly shows a high level separation of the lithologies as well as the fluid contents ofthe reservoir.The plots of Lambda-Rho versus Mu-Rho, using the petrophysical properties clearly show the distinct discrimination of the probable hydrocarbon zones from the shale zones within each well (Figure 5). From the plots, it was observed that the hydrocarbon sand zones corresponds to low Lambda-rho and high Mu-rho values while the shale or brine zones correspond to high Lambda-rho and low Mu-rho values, the petrophysical properties also clearly indicate the difference between the zones.

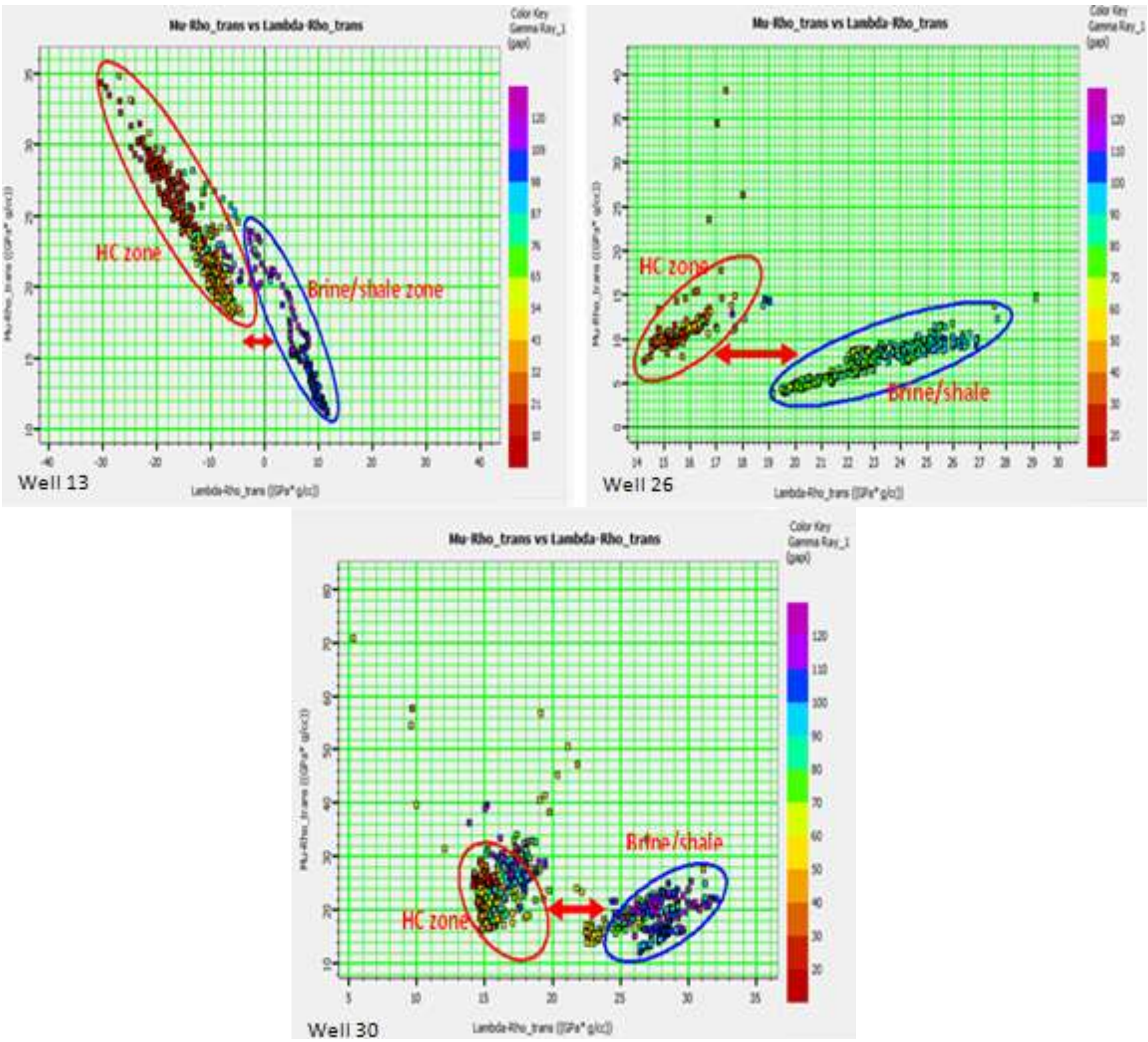


Figure 5: Generated cross plot of Mu-Rho vs Lambda-Rho for specific interval within the Wells

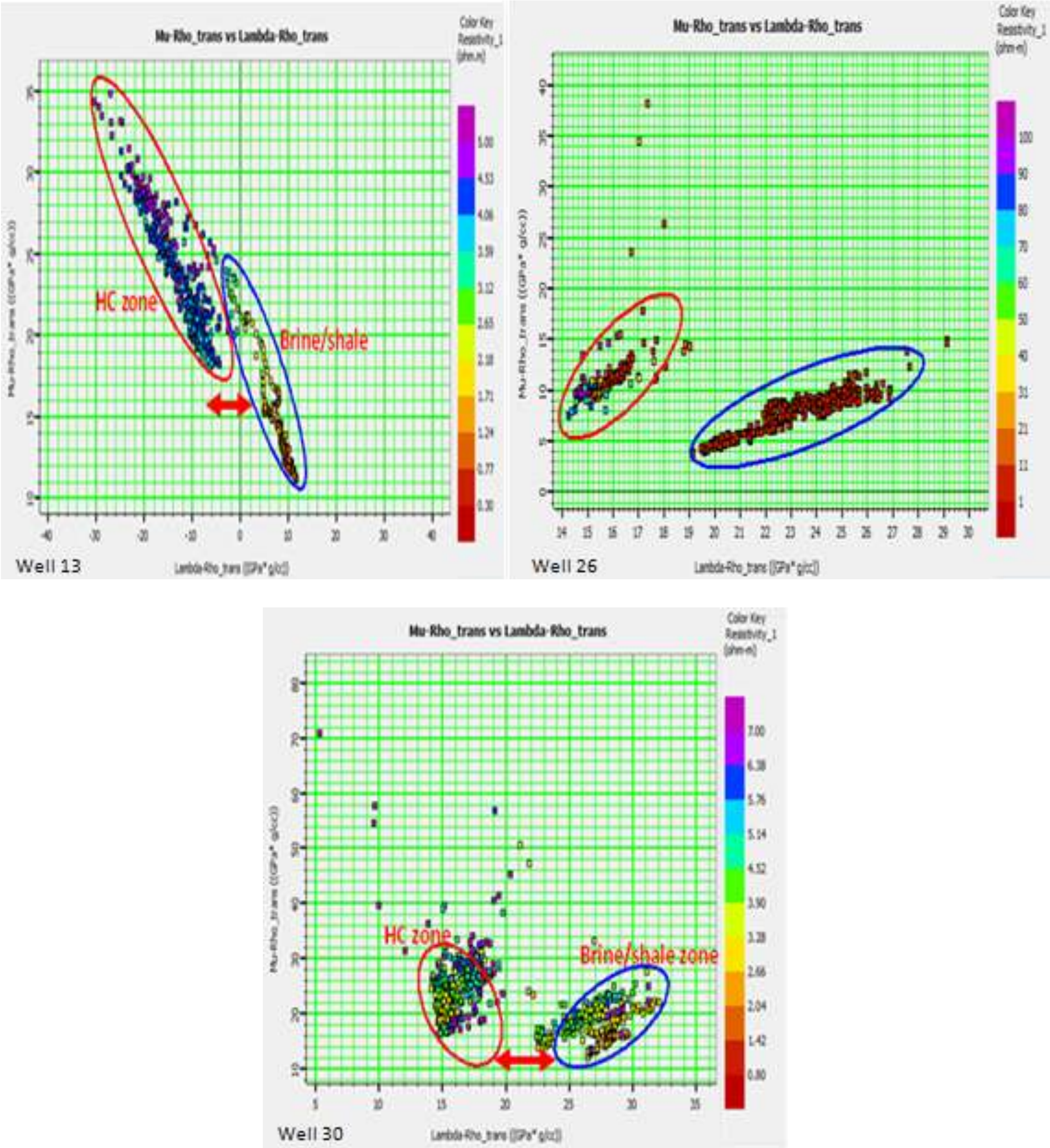
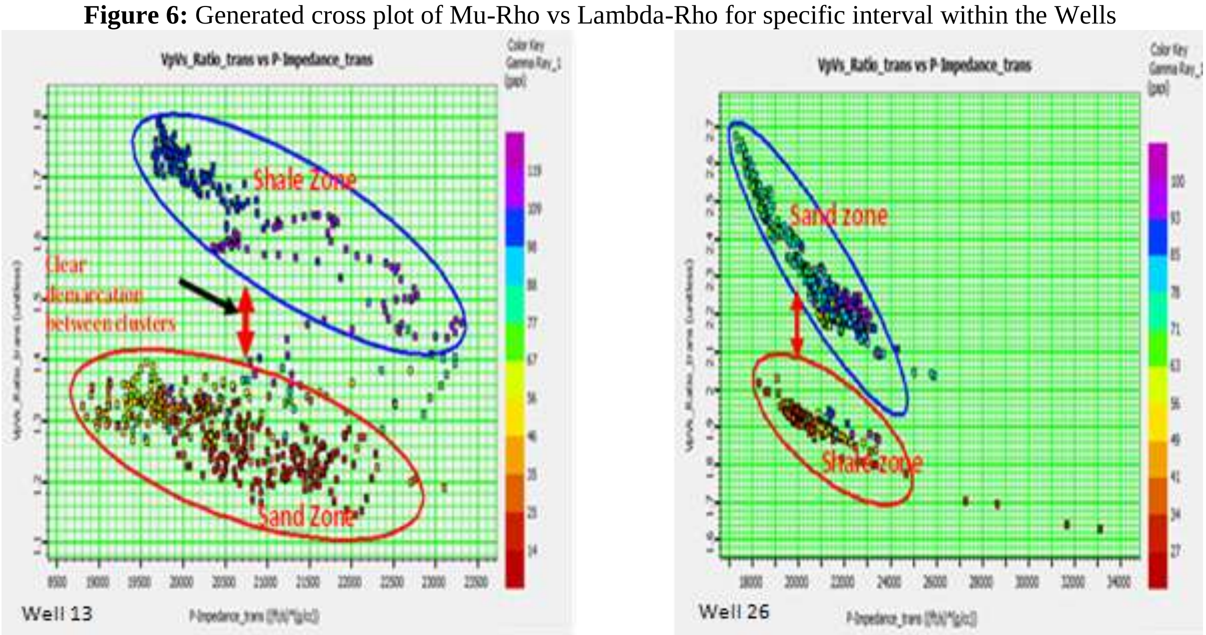


Figure 6: Generated cross plot of Mu-Rho vs Lambda-Rho for specific interval within the Wells



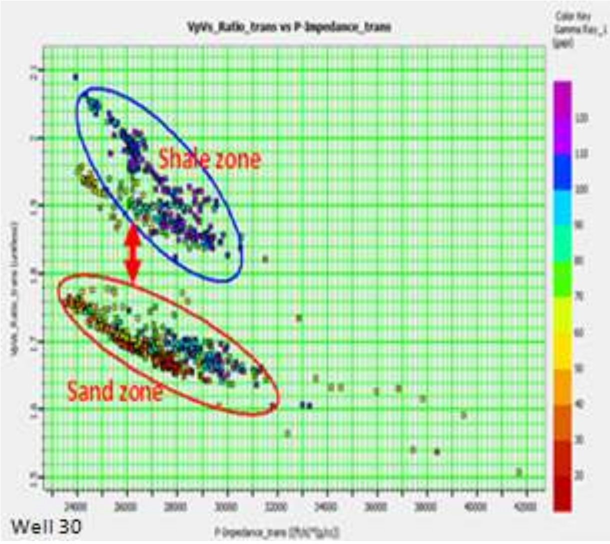


Figure 7: Generated cross plot of Vp-Vs ratio vs P-impedance for specific interval within Wells

The cross plots of the attributes clearly distinguish the probable hydrocarbon bearing reservoirs from non-reservoirs. Mu-Rho (μρ) is generally referred to as the architecture of the rock formation, also known as rock rigidity modulus, while Lambda-Rho (λρ) is generally referred to as the fluid content of the rock, commonly known as incompressibility modulus of the rock formation. The Lambda-Mu-Rho analysis is generally quite sensitive to lithology and fluids discrimination, with clearer delineation using the Lambda-Rho attribute.

5. Conclusion

The cross plots of the attributes clearly distinguish the probable hydrocarbon bearing reservoirs from non-reservoirs. Mu-Rho (μρ) is generally referred to as the architecture of the rock formation, also known as rock rigidity modulus, while Lambda-Rho (λρ) is generally referred to as the fluid content of the rock, commonly known as incompressibility modulus of the rock formation. The cross plots also shows the robustness and sensitivity of Lambda-rho (λρ) attribute in fluids and lithology discrimination relative to Mu-rho (μρ) attribute, the Lambda-Mu-Rho analysis is generally quite sensitive to lithology and fluids discrimination, with clearer delineation using the Lambda-Rho attribute

The study has comprehensively show that cross plots of the extracted seismic attributes of the reservoir of the field can be effectively used in delineating lithology and discriminating fluids content of a field.

References

[1] Ako, B.D., Olorunniwo, M.A., Ofuyah, W.N. and Alao, O.A. (2010). Spectral-Pseudo Sections: Seismic Discrimination of Stratigraphy along an arbitrary line for Thin Bed delineation using Discrete wavelet Transform. National Association of Petroleum Explorationists (NAPE) Int'l Bulletin, 22(1), 48-70.

[2] Dillion, L., Schwedersky, G., Vasquez, G. Velloso, R. and Numes, C. (2003).A multiscale DHI elastic attributes evaluation. The Leading Edge, 22, 1024-1029.

[3] Fehintola, T.O., Al-Mandhary, I.R. and Weaver S.(2010). 3-D Close the Loop: Tying the 3-D Static Model to 3-D Seismic Data – A deep water Nigeria case study. National Association of Petroleum Explorationists (NAPE) Int'l Bulletin, 22(1), 1-6.

[4] Folami, T.O., Ayuk, M.A. and Adesida, A.(2008). Identification of Hydrocarbon Reservoir using Seismic attributes and Geocellular Modeling: A case study of Tyke Field, Niger Delta. National Association of Petroleum Explorationists (NAPE) Int'l Bulletin, 20(1), 29-35.

[5] Goodway, B., Chen, T. and Downton, J. (1997).Improved AVO fluid detection and lithology discrimination using Lame Petrophysical parameters; λ, μ and λ/μ fluid stack from P-wave and S-wave Inversion. Presented at 67th Annual International Meeting, Society of Exploration Geophysics (SEG) Expanded Abstract, 183-186.

[6] Ogundipe, O.H. and Ako, B.D. (2010). 3-D Seismic and Well log Integrated Approach to Subsurface Evaluation – A case study of Niger Delta Field. National Association of Petroleum Explorationists (NAPE) Int'l Bulletin, 22(1), 71-73.

[7] Olowokere, M.T. and Ojo, J.S. (2010). Fluid Detections and Lithology Discrimination using Lame Petrophysical Parameters from Simultaneous Inversion – using Northern North Sea, Norway. National Association of Petroleum Explorationists (NAPE) Int'l Bulletin, 22(1), 36-42.

[8] Olowokere, M.T. and Ojo, J.S. (2011).Improved Reservoir Parameters prediction from Seismic Attrinutes using Multivariate Statistics and Neural Networks – A case study of Niger Delta Basin. National Association of Petroleum Explorationists (NAPE) Int'l Bulletin, 23(2), 28 - 38.

[9] Omudu, L.M., Ebeniro, J.O.and Osayande, N. (2008).Cross-plot and Discriptive Statistic for Lithology and Fluid Discrimination – A case study from Onshore Niger Delta. National Association of Petroleum Explorationists (NAPE) Int'l Bulletin, 20(2), 31-37.

[10] Omudu, L.M., Ebeniro, J.O., Xynoglass, M and Osayande, N. (2008).Fluid Discriminator Factor, Moduli Ratio and Reservior Characterization – A Niger

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Delta Experience. National Association of Petroleum Explorationists (NAPE) Int'l Bulletin, 20(2), 38-44.

[11] Russell, B.H., Hedlin, K, Hiterman, F.J and Lines, L.R. (2003).Fluid property discrimination with AVO, A Biot- Grassmann perspective. Geophysics, 68, 29-39.

[12] Yilmaz, O. (2001). Seismic data analysis, processing, inversion and interpretation of Seismic data. Investigations in Geophysics-Society of Exploration Geophysics (SEG), Tulsa, 1: 1-998.

[13] Yilmaz, O. (2001). Seismic Data Analysis: Processing, Inversion, and Interpretation of Seismic Data, Society of Exploration Geophysics (SEG), Tulsa, 2: 1001 – 2024.