Journal of Multidisciplinary Engineering Science and Technology (JMEST)
ISSN: 2458-9403
Vol. 7 Issue 1, January - 2020

Hydrocarbon Discrimination in Sedimentary Delta Basin Using Extended Elastic Impedance (EEI) from Modified Zoeppritz Equations

Balogun, A.O.
Geoscience Research Group
Department of Physics,
University of Port Harcourt,
Rivers, Nigeria.
ayomide.balogun@uniport.edu.ng

Sofolabo, A.O.
Geoscience Research Group
Department of Physics,
University of Port Harcourt,
Rivers, Nigeria.
adekunle.sofolabo@uniport.edu.ng

***Abstract*—Hydrocarbon discrimination of the sedimentary basin is performed using derived Extended Elastic Impedance (EEI) attributes from modified Zoeppritz equation, which uses the relations between elastic impedance constants and velocities. Several attributes like MuRho, Shear Impedance (SI), Vp-Vs ratio and Gradient Impedance (GI) were obtained from the Extended Elastic Impedance logs ranging from chi angles (χ) - 90^0 to + 90^0. These attributes were validated by comparing them with established attributes produced by Connolly and Whitcombe. The log correlation of the Extended Elastic Impedance (EEI) attributes corresponding to chi angles -51°, 12°, 45° and 90° were derived, with each corresponding to the MuRho, Shear Impedance (SI), Vp-Vs ratio and Gradient Impedance (GI) parameters respectively. The attributes derived were used to discriminate the reservoir and the results obtained clearly delineate the lithology of the field and the fluid contents in the reservoir (fluids discrimination).The result shows the sensitivity of chi angles -51° and 12° respectively, corresponding to the results obtained for MuRho and Shear Impedance (SI), which shows a cluster of points away from the shale background trend for lithology at medium to high values indicating hydrocarbon bearing sand when Gamma ray was used as the plot indicator, the result gave a distinct demarcation of the lithology. The result for chi angles 45° and 90° corresponds to the results obtained for Vp-Vs ratio and Gradient Impedance (GI), which shows low values for hydrocarbon reservoir sands and fluid contents within the reservoirs, there was a clear discrimination of the properties when resistivity was used as the indicator. The results support the idea that derived Extended Elastic Impedance (EEI) attributes corresponding to varying chi angles are robustly and successful parameters in identifying, delineating and discriminating hydrocarbon reservoir for Sedimentary Delta formation**

***Keywords*— Hydrocarbon discrimination; extended elastic impedance; log correlation; crossplots; sedimentary delta formation; chi angles**

I. INTRODUCTION

The results of seismic exploitation and exploration using imaging techniques which required measurements of the travel times of elastic waves that were reflected off boundaries in the Earth layers and their attributes, has produced both successes and failures especially in zones with the same acoustic energy response which gives a zero angle of incidence.

The variation of the angle (ANA) or offset (AVO) which is rooted in Zoeppritz equation describes the zero and nonzero angle of incidence. The Zoeppritz equations expresses the reflected compressional (P) wave and shear (S) wave amplitudes with that of the transmitted compressional (P) wave and shear (S) wave amplitudes when a primary wave strikes the interface between two elastic media. The corresponding coefficients of reflectivity and transmissivity are dependent on the incident angle as well as the material of elastic parameters of both layers [1].

Reference [2] put forward the concept of Elastic Impedance (EI), which takes into account the dependence of the P-wave reflectivity on the incident angles and it is a function of shear wave velocity (V_S), incident angle (θ), density (ρ) and compressional wave velocity (V_P) [3-6].

$$\mathrm{EI}(\theta) = \mathrm{V_P}^{(1+\tan^2\theta)}\mathrm{V_S}^{(-8\mathrm{K}\sin^2\theta)}\rho^{(1-4\mathrm{K}\sin^2\theta)} \quad (1)$$

A major constraint in the Elastic Impedance (EI) concepts is that the various angles dimensional analysis values were not correctly scaled [6-8]. To overcome the limitation in Elastic Impedance (EI) equation, the equations were modified by introducing the following constant parameters namely the average density (ρ_0), shear wave velocity (V_{S0}) and the compressional wave velocity (V_{P0}) to normalize the equation over the zone of interest [6-9].

$$\mathrm{EI}(\theta) = \mathrm{V_{P_0}}\rho_0\left[\mathrm{V_P}^{(1+\tan^2\theta)}\mathrm{V_S}^{(-8\mathrm{K}\sin^2\theta)}\rho^{(1-4\mathrm{K}\sin^2\theta)}\right] \quad (2)$$

Thereafter, [8] changed the variable θ to χ and replaced $sin^2\theta$ by tanχ to give the Extended Elastic Impedance (EEI) equation which can be varied from -90° to +90°. Equation (3) is the expression for the Extended Elastic Impedance (EEI).

$$EEI(\chi) = V_{P_0}\rho_0\left[\frac{V_P}{V_{P_0}}\right]^p\left[\frac{V_S}{V_{S_0}}\right]^q\left[\frac{\rho}{\rho_0}\right]^r \quad (3)$$

Where

$$p = cos(\chi) - sin(\chi),$$
$$q = -8Ksin(\chi) \text{ and}$$
$$r = cos(\chi) - 4Ksin(\chi) \quad (4)$$
$$K = \left(\frac{V_S}{V_P}\right)^2 \quad (5)$$

The aim of this work is to use the derived Extended Elastic Impedance to discriminate the fluid contents and lithology of a sedimentary reservoir (K-field) in Niger Delta basin by generating several well based attributes [MuRho, Shear Impedance (SI), V_P/V_S ratio and Gradient Impedance (GI)], which are used to enhance fluid characterization and lithology discrimination.

The study area is situated in the coastal Eastern Niger Delta of the basin, 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 [10]. The K-Field is located in coastal swamp of the Basin which is about 40km south-west of Port Harcourt [11] (Figure 1).

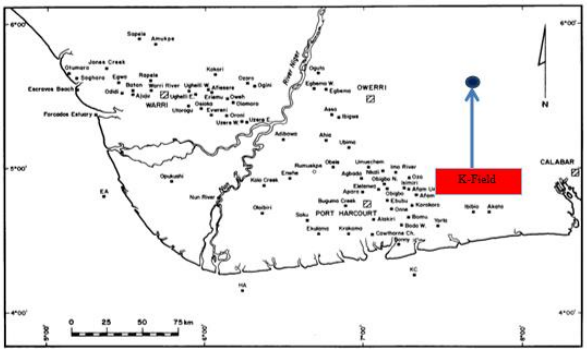

Figure 1: Niger Delta Map showing oil prospect locations in Niger Delta and Study Area location [11].

II. MATERIALS AND METHODS

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 (inputted) data are the well log suite, which comprises of Gamma ray (GR) log, Neutron-Porosity (NPH) log, Density log, Resistivity log, Compressional (P-wave) and Slowness (S-wave) logs, Checkshot data, Well headers information and Post-stacked 3-D Migrated Seismic volume of the field.

[12-13] carried out a modification of the Zoeppritz equations to derived modified Elastic Impedance and Extended Elastic Impedance equations by reformulating [14] in terms of Pseudo Poisson' ratio reflectivity, $\Delta q/\text{q}$, rigidity reflectivity, $\Delta\mu/\mu$, and density reflectivity, $\Delta\rho/\rho$ which are interface properties for hydrocarbon discrimination [15].

Thus, the modified Zoeppritz Equation is given as,

$$\frac{1}{2}\frac{\Delta q}{q}(1+\tan^2\theta)+\frac{1}{2}\frac{\Delta\mu}{\mu}\left(\frac{\sec^2\theta}{2}-4\left(\frac{V_S}{V_P}\right)^2\sin^2\theta\right)+\frac{1}{2}\frac{\Delta\rho}{\rho}\left(1-\frac{1}{2}\sec^2\theta\right) \quad (6)$$

This modified Zoeppritz equation is used to generate Extended Elastic Impedance (EEI) attributes using the same derivation procedure as in [2, 8].

$$EEI(\chi) = [36q_0^2\mu_0\rho_0]^{0.5}\left[\frac{q}{q_0}\right]^r\left[\frac{\mu}{\mu_0}\right]^s\left[\frac{\rho}{\rho_0}\right]^t \quad (7)$$

Where P-wave velocity ($V_P$or α), S-wave velocity ($V_S$or β), density (ρ), shear modulus (μ) and (q) is Pseudo-Poisson's ratio [12-13].

$$r = cos\chi + sin\chi$$
$$s = \frac{1}{2}cos\chi + \frac{1}{2}sin\chi(1-8K)$$
$$t = \frac{1}{2}(\,cos\chi - sin\chi\,) \quad (8)$$
$$K = \left(\frac{\beta}{\alpha}\right)^2 \quad (9)$$

B_0 , q_0 , μ_0 , and ρ_0 are references values of P-impedance, Pseudo-Poisson ratio, shear modulus and density, respectively [12-13]. It can be shown when the angle of incidence equals zero that EI(0) from equation above is equal to acoustic impedance [2].

III. RESULTS AND DISCUSSION

Log correlation (Figure 2) of the modeled Acoustic Impedance (AI), Elastic Impedance EI (0) and Extended Elastic Impedance EEI (0) log and Derived Extended Elastic Impedance EEI (0) basically shows similarity between a pair of logs where the orange curve is the Derived EEI (0) curves generated at $\chi = 0^\circ$, the magenta curve is the Model EEI(0) at $\theta = 0^\circ$, the blue curves are the Model EI(0) $\theta = 0^\circ$ from well-log data and the red curve is the AI generated from well log data. The Derived EEI log, Model EEI (0) log and Model EI (0) log at zero degree corresponds to AI. The log correlation validate the derived Exetended Elastic Impedance.

Log correlation of the attributes generated from the derived Extended Elastic Impedance at varying chi angles (χ) angles of -51°, 12°, 45° and 90°, corresponding to well derived attributes such as MuRho, Shear Impedance (SI), $\boldsymbol{V_P/V_S}$ ratio, and Gradient Impedance (GI) respectively (Figure 3).The result of the crossplot analysis (Figures 4 and 5) shows that angles -51° and 12° corresponding to MuRho and Shear Impedance (SI), showing a cluster of points away from the shale background trend for lithology at medium to high values which is an indication of hydrocarbon bearing sand when Gamma ray was used as the indicator, the result gives a distinct demarcation of the lithology. The result for angles 45° and 90° also corresponding to Vp-Vs ratio and Gradient Impedance (GI) respectively (Figures 6 – 9),which shows a low values for hydrocarbon reservoir sands when resistivity was used as indicator, this shows that fluid contents within these reservoirs was clearly discriminated.

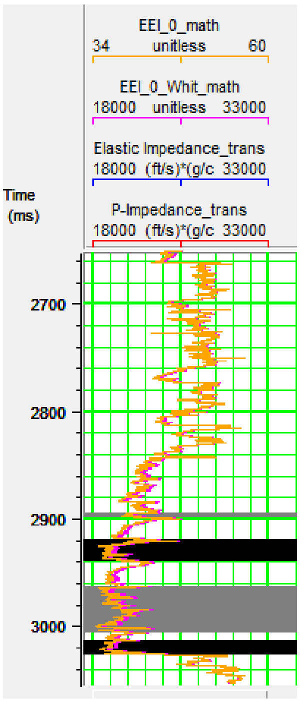

Figure 2: Correlation plots between Modeled AI, EI(0), EEI(0) and Derived EEI(0)log for Well K

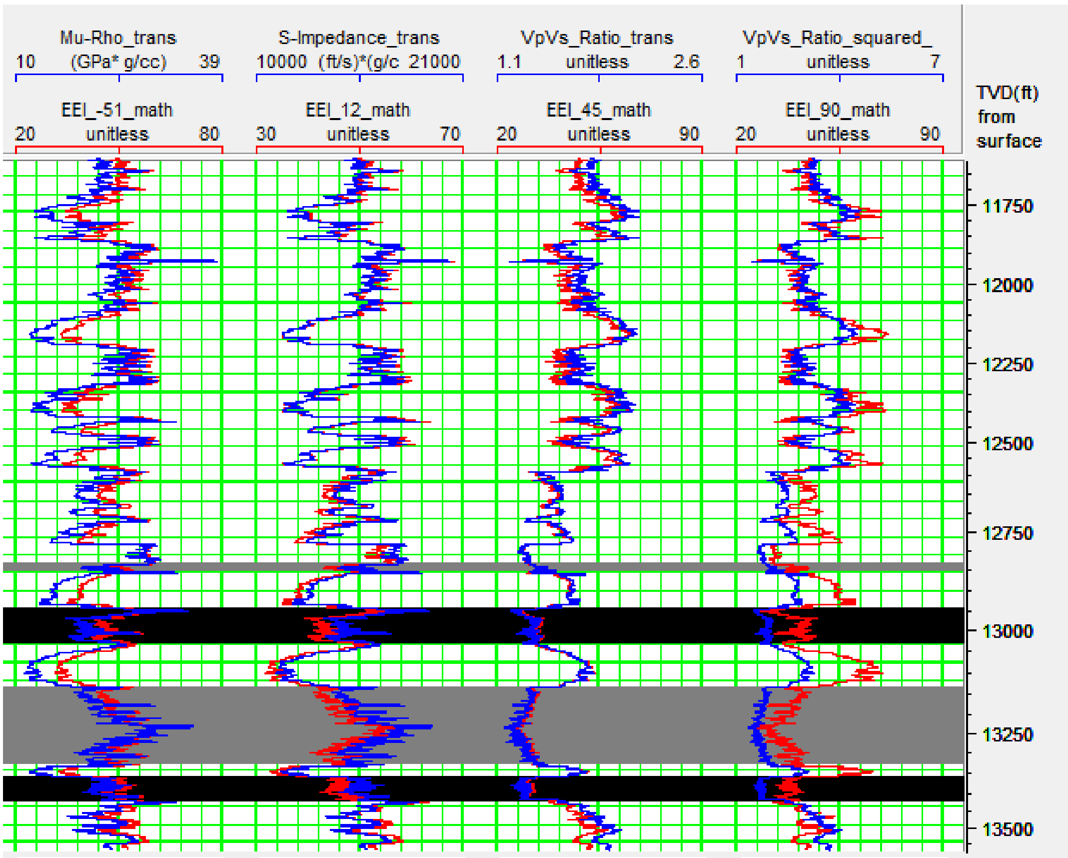

Figure 3: Calculated EEI from modified Zoeppritz equation for target zones in Well K (MuRho, SI, V_P/V_S ratio and GI).

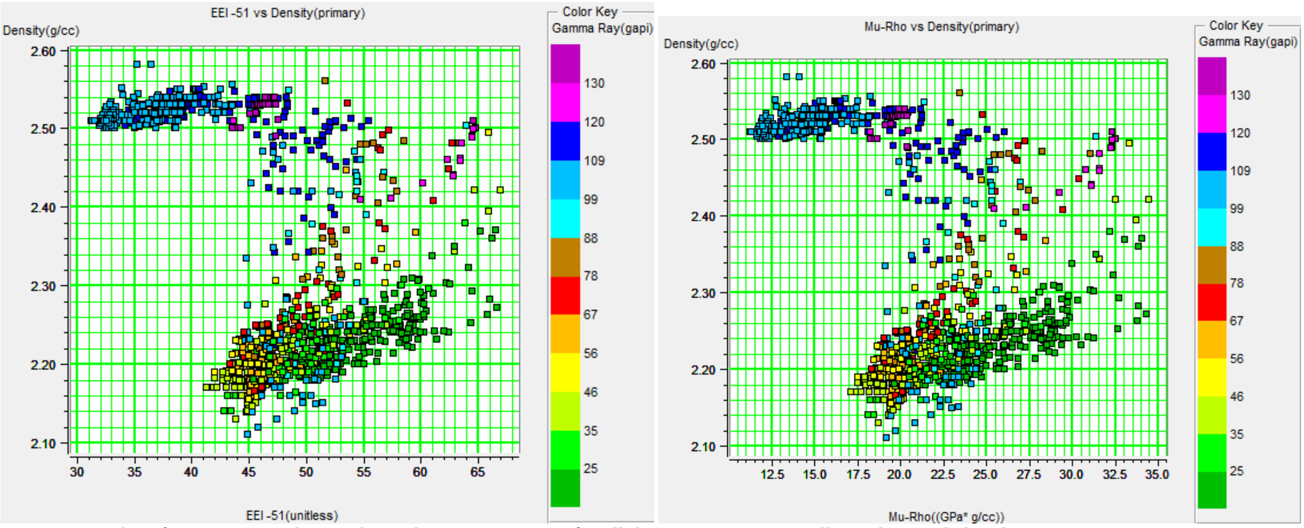

Figure 4: Cross plot of EEI -51(MuRho) and MuRho versus Density for all the target zones in Well K colour coded with Gamma Ray.

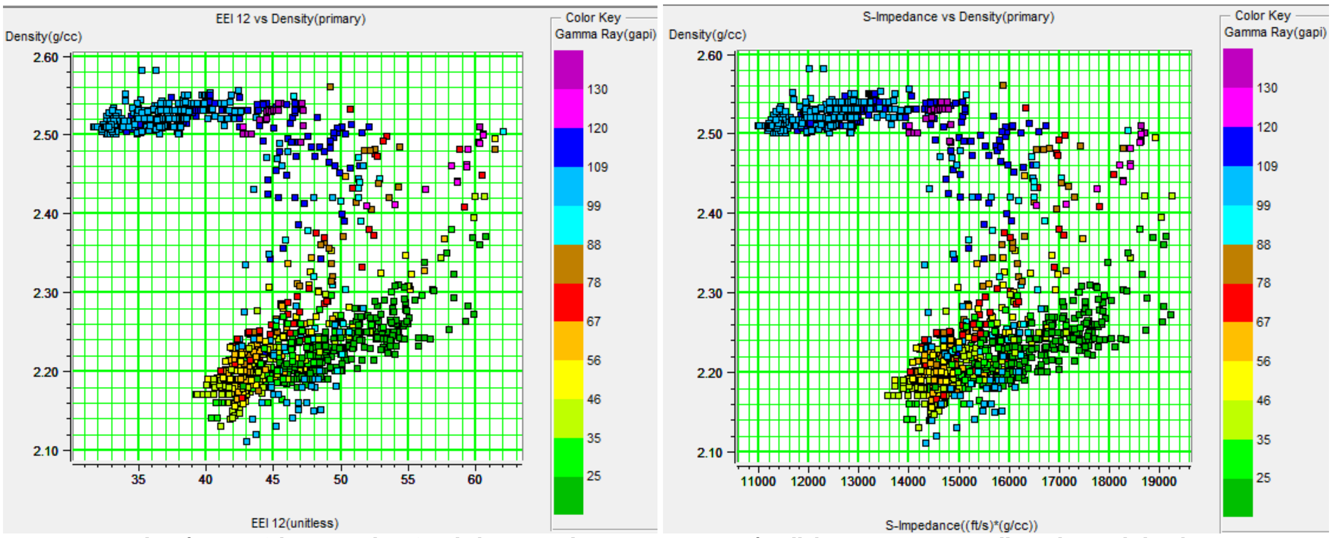

Figure 5: Cross plot of EEI 12 (Shear-Impedance) and Shear-Impedance versus Density for all the target zones in Well K colour coded with Gamma Ray.

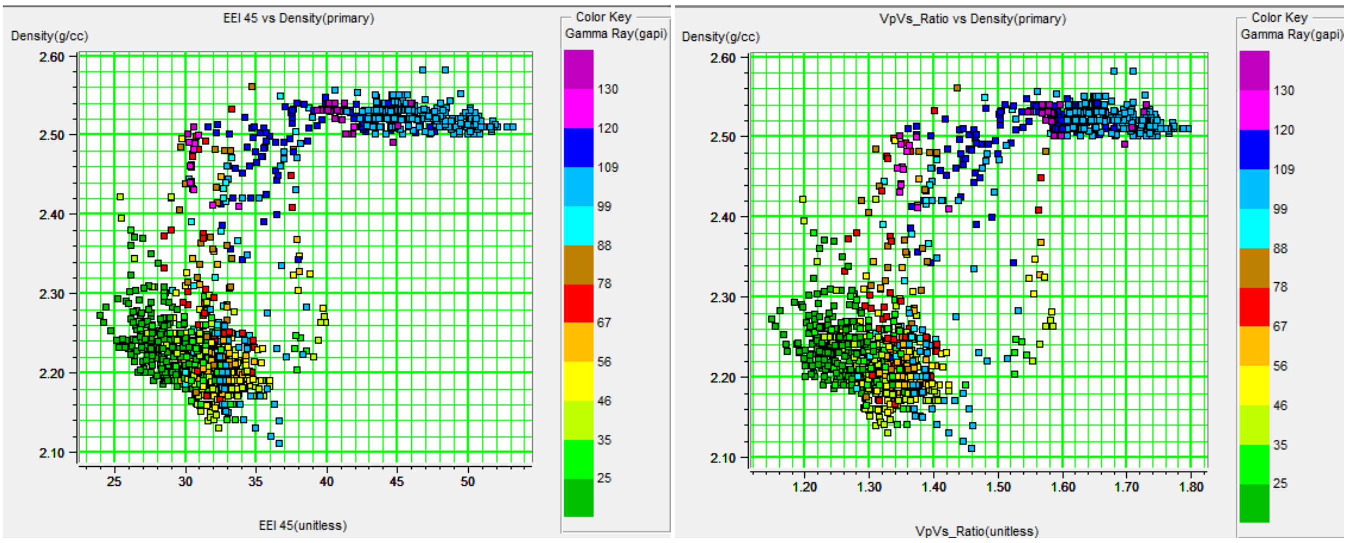

Figure 6: Cross plot of EEI 45 (V_P/V_S ratio) and V_P/V_S ratio versus Density for all target zones in Well K colour coded with Gamma Ray.

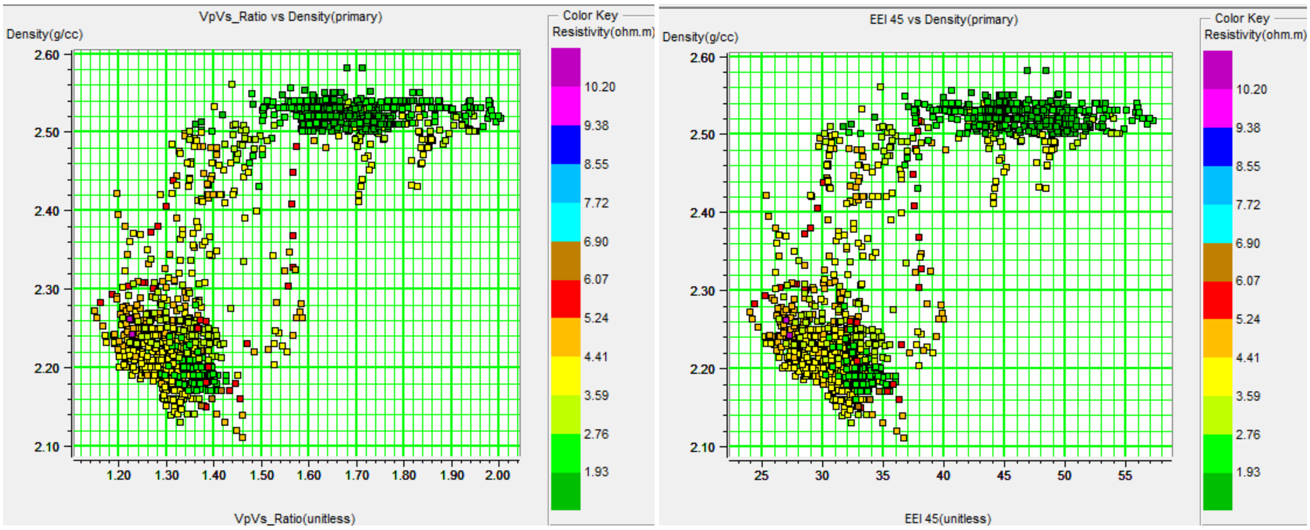

Figure 7: Cross plots of EEI 45 (V_P/V_S ratio) and V_P/V_S ratio versus Density cross plot for all target zones in Well K colour coded with Resistivity

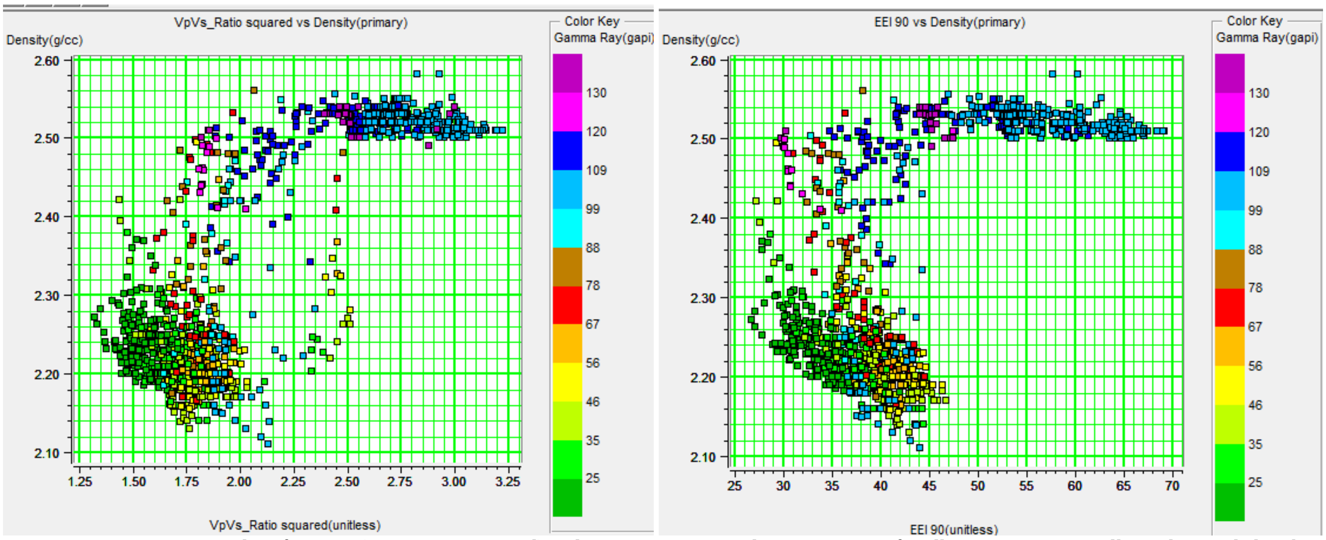

Figure 8: Cross plot of EEI 90 (Vp/Vs ratio squared) and Vp/Vs ratio squared versus Density for all target zones in Well K colour coded with Gamma ray.

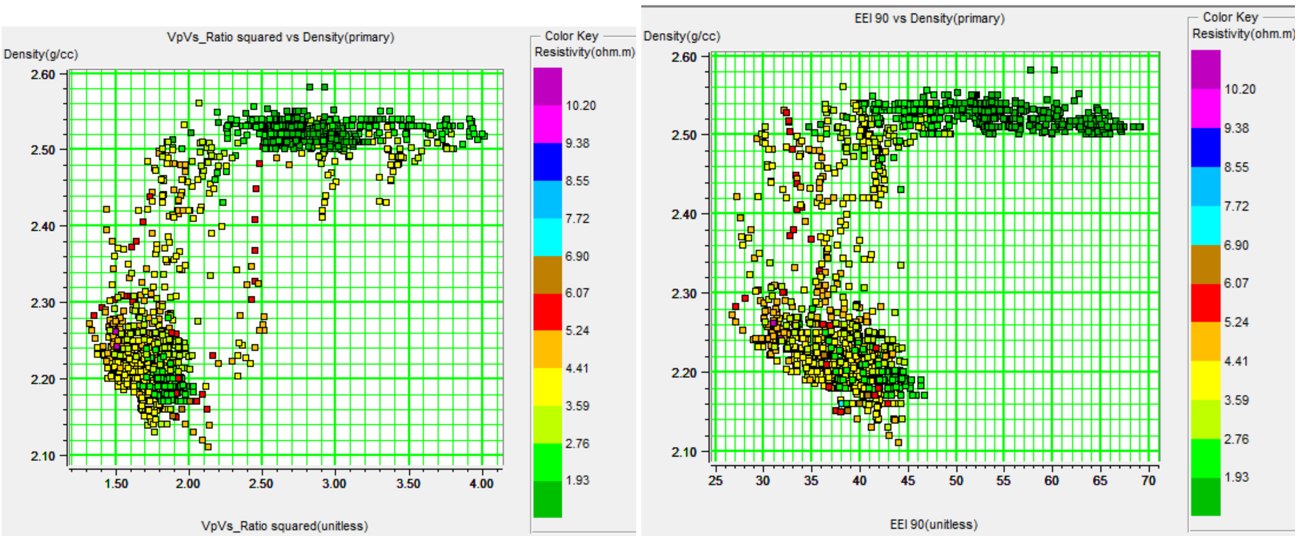

Figure 9: Cross plot of EEI 90 (Vp/Vs ratio squared) and Vp/Vs ratio squared versus Density for all target zones in Well K colour coded with Resistivity.

IV. Conclusion

The result of crossplots of Extended elastic impedance attributes generated, shows cluster of points away from the shale background trend for lithology which correspond to sand formation identification and also shows that the anomalous data points corresponds to a hydrocarbon bearing interval which correspond to fluid identification.

The results support the idea that the derived Extended Elastic Impedance (EEI) attributes corresponding to varying chi angles are robustly and successful parameters that can be used in identifying, delineating and discriminating hydrocarbon reservoir for Sedimentary Delta formation

The study provided most evident that EEI results can be used to generate several well based attributes such as MuRho, Shear Impedance (SI), V_P/V_S ratio and Gradient Impedance (GI) which in turn can be used in hydrocarbon differentiation, however, it is important to note that other methods are needed to verified the results obtained in the reservoirs.

Acknowledgment

We acknowledge the assistance of Shell Petroleum Development Company (SPDC) and Total E&P Nigeria for graciously releasing the data used for this work. We acknowledge CGG for their software support.

References

[1] G. Mavko, T. Mukerji, and J. Dvorkin, The Handbook of Rock Physics. Cambridge University Press. United Kingdom, 1998
[2] P, Connolly, "Elastic Impedance," The Leading Edge, pp 438-452, April 1999
[3] R.G. Keys, and D.J. Foster, Comparison of Seismic Inversion Methods on a Single Real Data Set, Society of Exploration Geophysicists P. O. Box 702740, Tulsa, United States of America, 1998.
[4] J. Washbourne, and E.F. Herkenhoff, Optimizing amplitude inversion utilizing statistical comparisons of seismic to well control data, Chevron U.S.A. Inc, 2008.
[5] O.O. Awosemo, Evaluation of Elastic Impedance Attributes in Offshore High Island, Gulf of Mexico, Msc. Thesis, Department of Earth and Atmospheric Sciences, University of Houston, 2012
[6] S.A. Gharaee Shahri, Application of Extended Elastic Impedance (EEI) to improve Reservoir Characterization: Master of Science in Petroleum Geosciences, Department of Petroleum Engineering and Applied Geophysics, Norwegian University of Science and Technology, June 2003.
[7] D.N. Whitcombe, "Elastic impedance normalization," Geophysics, vol. 67, pp. 60 – 62, 2002
[8] D. Whitcombe, P. Connolly, R. Reagan, and T. Redshaw, "Extended Elastic Impedance for Fluid and Lithology Prediction," Geophysics, vol. 67(1), pp. 63-67, 2002
[9] D.A. Zhang, Applications of VP/VS and AVO modeling for monitoring heavy oil cold production (Masters Thesis). University of Calgary. Canada, 2007
[10] O.H. Ogundipe, and B.D. Ako, "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, vol. 22(1), pp. 71-73, 2010
[11] B.D. Evamy, J. Haremboure, P. Kamerling, W.A. Knaap, F.A. Molloy, and P.H. Rowlands, "Hydrocarbon habitat of the Tertiary Niger Delta," American Association of Petroleum Geologists Bulletin, vol. 62, pp. 1 – 39, 1978
[12] A.O. Balogun, and J.O. Ebeniro, "Evaluation of Seismic Attributes Generated from Extended Elastic Impedance for Lithology and Fluid Discrimination," International Journal of Science and Research (IJSR), vol. 6(9), pp. 776 – 779, September 2017
[13] A.O. Balogun, and C.N. Ehirim, "Lithology and Fluid Discrimination Using Bulk Modulus and Mu-Rho Attributes Generated From Extended Elastic Impedance," International Journal of Science and Research (IJSR), vol. 6(10), pp. 639 – 643, October 2017
[14] K.I. Aki, and P.G. Richards, Quantitative seismology - Theory and methods,: W. H. Freeman and Company, San Francisco. 1980, (1), 5.2
[15] S. Pengyuan, L. Xiuli, L. Yanpeng, Y. Yuanyuan, and C. Haifeng, "Elastic parameter AVO approximations and their applications," BGP, CNPC SEG Las Vegas Annual Meeting, pp. 523-527, 2008