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Evaluation of Seismic Attributes Generated from Extended Elastic Impedance for Lithology and Fluid Discrimination

Balogun A. O[1], Ebeniro J. O[2]

Geophysics Research Group Department of Physics University of Port Harcourt

Abstract: ***Seismic attributes are essential in interpretative purposes for accurate discrimination of lithology and fluid especially in areas where the values of acoustic impedance for shale and gas-saturated sands are approximately equal. The extended elastic impedance (EEI) used in this study was generated from a modified Zoeppritz equation which was derived in terms of shear modulus, Psuedo-Poisson's ratio, and density. The results show that the two seismic attribute volumes α / β ratio and shear impedance (SI) generated from the extended elastic impedance equation and their respective horizon slices help to show a better characterization of the reservoir and hence, shear impedance (SI) attribute volume and horizon slice shows the determination of the reservoir's lithology and α / β ratio attribute volume and horizon slices predicts its pore-fluid type. The cross-plot of seismic attribute generated facilitated the discrimination of gas sands from brine filled sands as well as the discrimination between sands and shales. The results show that extended elastic impedance (EEI) is worthy effort to highlight the difference between reservoir and non-reservoir to identify hydrocarbon area.***

Keywords: Seismic Attributes, Modified Zoeppritz Equation, Extended Elastic Impedance, α / β ratio, Shear Impedance

1. Introduction

According to [1], Imaging of the subsurface through seismic exploration is the principal method used by the petroleum industry to identify and exploit hydrocarbon prospects. Successful modeling of the subsurface can allow the physical properties of these prospects to be determined more accurately, and hence significantly improve the efficiency of the hydrocarbon exploitation process. The increasingly accurate interpretation resulting from subsurface modeling has the potential to save the petroleum industry millions of dollars annually, which will in turn enhance the state of the economy as a whole.

In an attempt to enhance understanding of seismic responses and prediction of fluids and lithologies, a modified form of the [2] is derived using relations between elastic constants and velocities. This modified equation was used to generate an Extended Elastic Impedance (EEI) volume, through a multi-attribute inversion process employing the neural network algorithm. Data slices of the elastic rock parameter volumes were then used to study the characteristics of hydrocarbon bearing intervals.

Extended elastic impedance (EEI) is an extension of the elastic impedance and it is the optimum projection for a noise free, isotropic environment. EEI allows arbitrarily large positive or negative values of $sin^2\theta$ and it also approximates several elastic parameters which include bulk modulus, shear modulus and Lamé's parameters [3]. EEI allows the use of a range of physically non-meaningful incident angles by substituting tanχ for $sin^2\theta$ in the two-term reflectivity equation. Thus, the primary variable now becomes χ rather than θ and it is varied from -90 to 90° [3].

2. Materials and Method

A 3D pre-stack migrated seismic data acquired from a field in the Niger Delta. The seismic data comprises 510 In-lines, 243 Cross-lines, with signals extending to a depth of approximately 6 seconds and covers an area of about 79.5 km^2. All the wells have the fundamental log suite required for a basic petrophysical evaluation project, including; the gamma ray log, sonic (P-wave velocity) log, resistivity log, density log, caliper log and neutron porosity log.

From the [4] approximation written in three terms, the first term involving P-wave velocity, the second term involving S-wave velocity, and the third term involving density, the new equation is reformulated in terms of Pseudo Poisson' ratio reflectivity, $\Delta q/\text{q}$, rigidity reflectivity, $\Delta\mu/\mu$, and density reflectivity, $\Delta\rho/\rho$ as:

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

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. These parameters are lithology and fluid indicators.

This modified Zoeppritz equation is used to generate Extended Elastic Impedance (EEI) attributes for effective fluid and lithology discrimination. Using the same derivation procedure as in [5], the new elastic impedance in terms of shear modulus, Pseudo-Poisson's ratio, and density are derived.

$$EEI(\chi) = \text{B}_0\left[\frac{q}{q_0}\right]^r\left[\frac{\mu}{\mu_0}\right]^s\left[\frac{\rho}{\rho_0}\right]^t \quad (2)$$

Where,

$$\text{B}_0 = \left[36q_0^2\mu_0\rho_0\right]^{0.5}$$
$$r = cos\chi + sin\chi$$
$$s = \frac{1}{2}cos\chi + \frac{1}{2}sin\chi(1-8K)$$
$$t = \frac{1}{2}(cos\chi - sin\chi) \quad (3)$$

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$$K = \left(\frac{\beta}{\alpha}\right)^2 \quad (4)$$

$$EEI(\chi) = \left[36 q_0^2 \mu_0 \rho_0\right]^{0.5} \left[\frac{q}{q_0}\right]^r \left[\frac{\mu}{\mu_0}\right]^s \left[\frac{\rho}{\rho_0}\right]^t \quad (5)$$

B_0, q_0, μ_0, and ρ_0 are references values of P-impedance, Pseudo-Poisson ratio, shear modulus and density, respectively.

3. Results and Discussion

The results show the cross-plot and seismic inversion volume of seismic attribute generated from the extended elastic impedance.

3.1 Crossplot Results

It is apparent from the illustration of these figures that, apart from the scaling factor (EEI log units are impedance); the EEI curves show reasonable similarity with well log curves particularly in the zone of interest. Figure 1, shows the high correlation is with the α / β ratio and SI in the zone of interest (ZOI) which confirms the capability of the EEI log derived from the modified Zoeppritz Equation at these angles. With these results we use petrophysical volumes derived through EEI approach for quantitative interpretation. Figure 2 – 5, shows the cross plots of α / β ratio and SI, against density and porosity logs respectively with cluster covering the hydrocarbon sand reservoir.

Cross plots enables us to enhance recognition of zone of interest and layer properties and in turn could be useful to better understanding and definition of hydrocarbon reservoir.

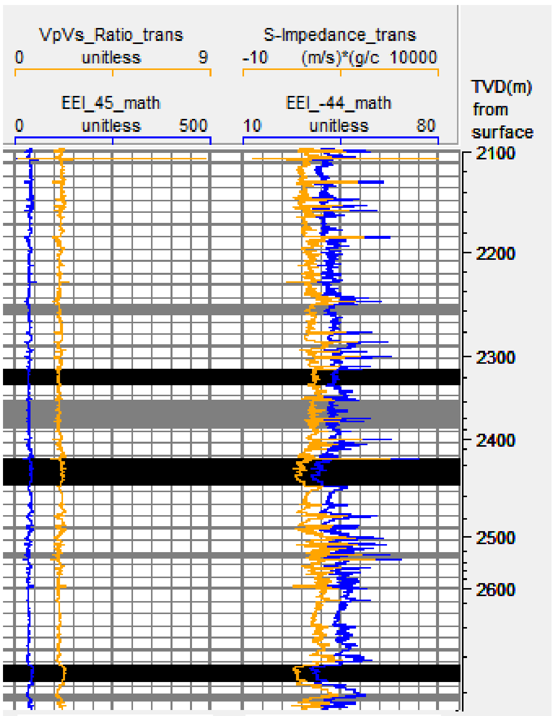

Figure 1: Correlation between EEI 45 and / β , and EEI -44 and S-Impedance.

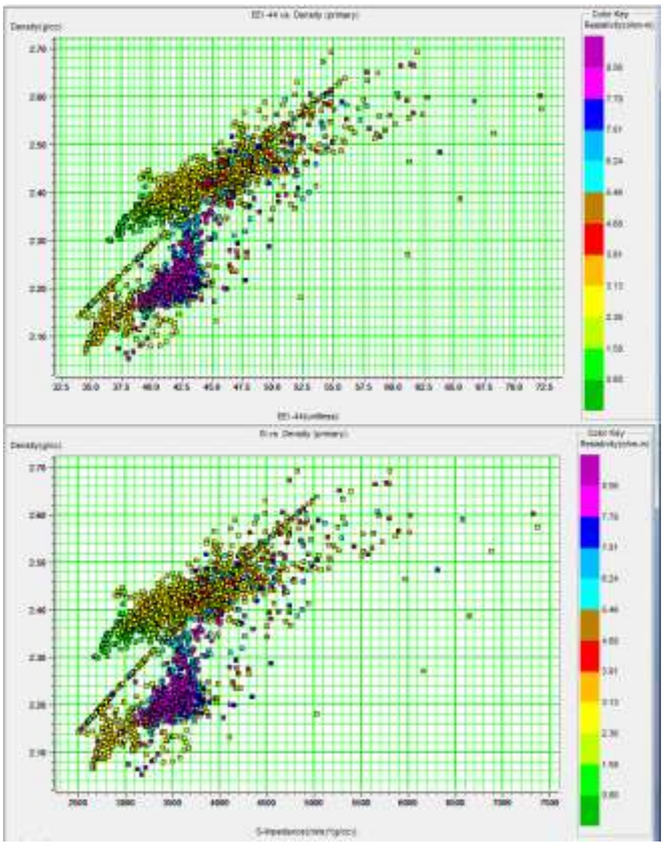

Figure 2: Comparison between EEI -44 (S-Impedance) versus Density and S-Impedance versus Density cross plot for all target zones with Resistivity as colour code.

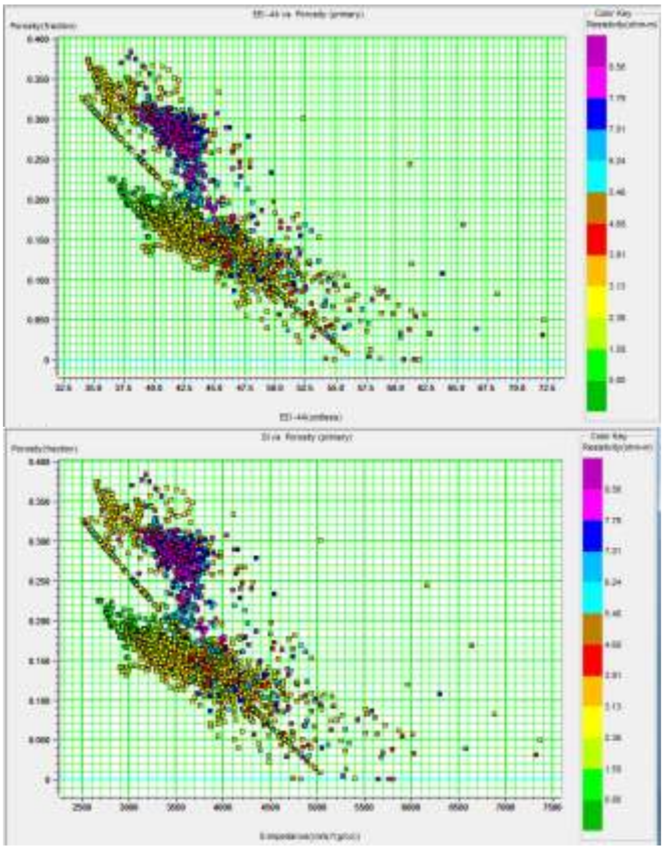

Figure 3: Comparison between EEI -44 (S-Impedance) versus Porosity and S-Impedance versus Porosity cross plot for all target zones with Resistivity as colour code.

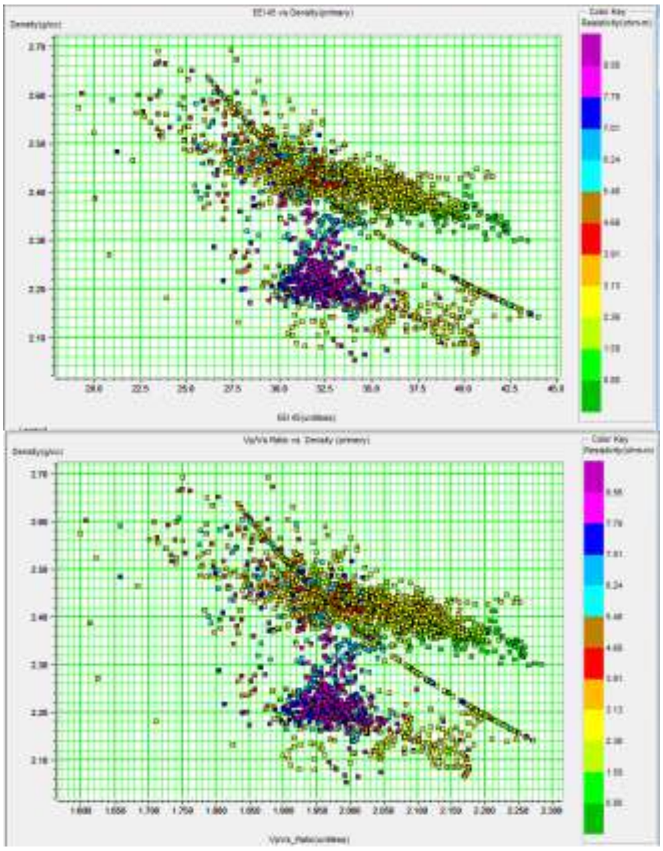

Figure 4: Comparison between EEI 45 (α / β) versus Density and (α / β) versus Density cross plot for all target zones with Resistivity as colour code.

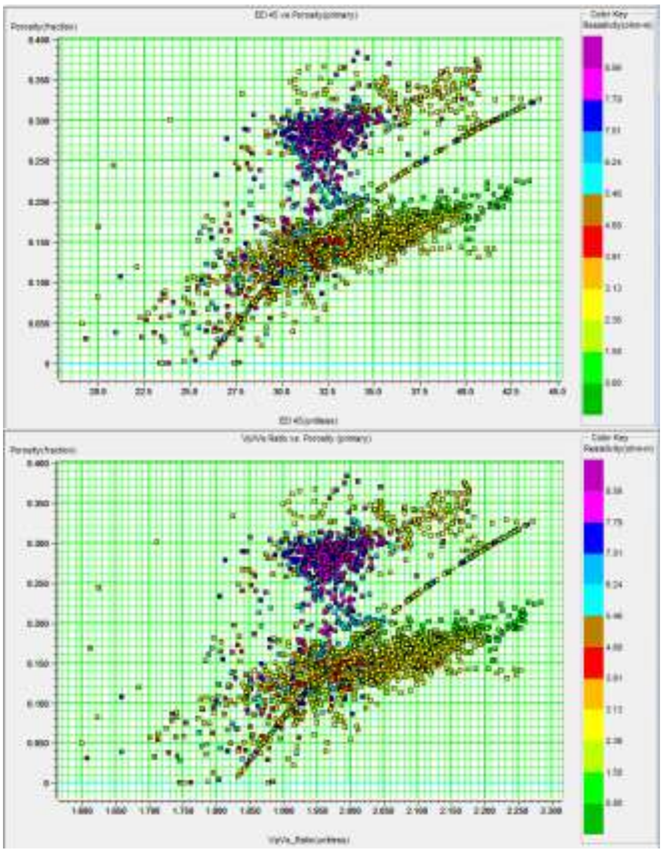

Figure 5: Comparison between EEI 45 (α / β) versus Porosity and (α / β) versus Porosity cross plot for all target zones with Resistivity as colour code.

3.2 Inversion Results

Figure 6-11 shows the EEI volumes inversion equivalent to different elastic and petrophysical parameters such as (α / β) ratio and SI generated. The results indicate that chi angles obtained in cross correlation study can provide good separation between fluid and lithology on the zone of interest. The present results are well defined and delineate difference between reservoir and non-reservoir to identify hydrocarbon area.

The data slice of inverted EEI-45(α / β) amplitude at three horizons with a window of 25ms above with the RMS average shows a lowest values around well locations indicate gas bearing sands, the highest values indicate brine bearing sands. Oil sands, on the other hand, have properties lying between gas and brine properties figure 6-8. This attribute is indicative of fluid type. The data slice of inverted EEI -44 (SI) at three horizons with a window of 25ms above with the RMS average shows a medium to high values around well locations indicate hydrocarbon bearing sands, this attribute in turn is indicative of lithology Figure 9-11.

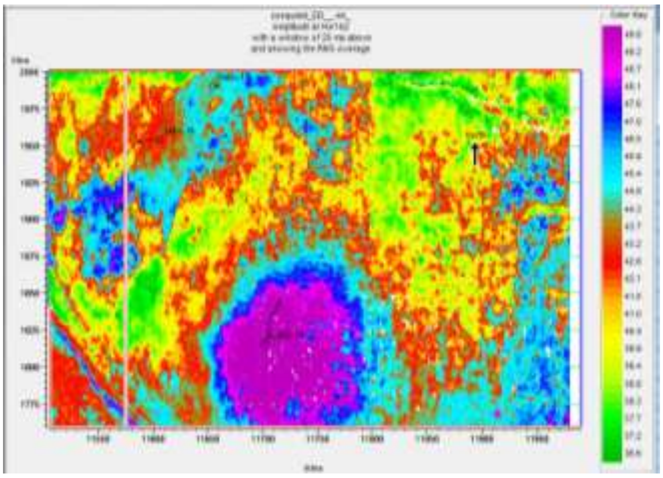

Figure 6: The data slice of EEI -44 (S-Impedance) volume at hor 1b2 with a window of 25ms above and showing the RMS average

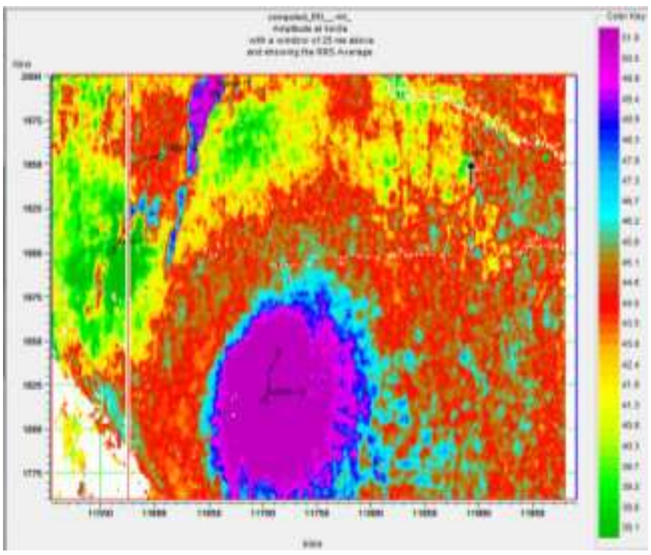

Figure 7: The data slice of EEI -44 (S-Impedance) volume at hor 2a with a window of 25ms above and showing the RMS average

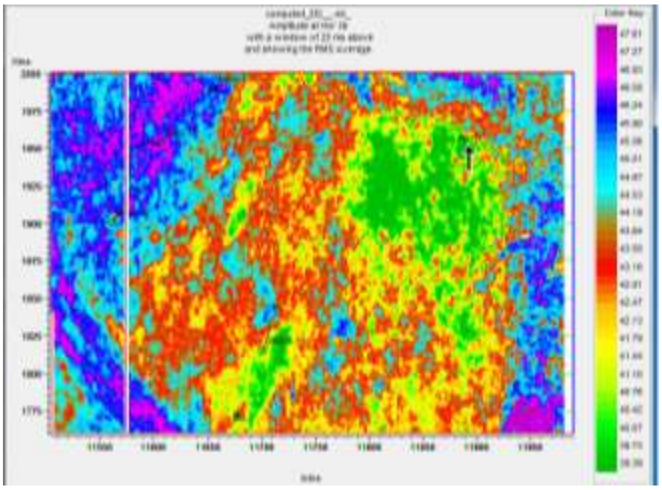

Figure 8: The data slice of EEI -44 (S-Impedance) volume at hor 3b with a window of 25ms above and showing the RMS average.

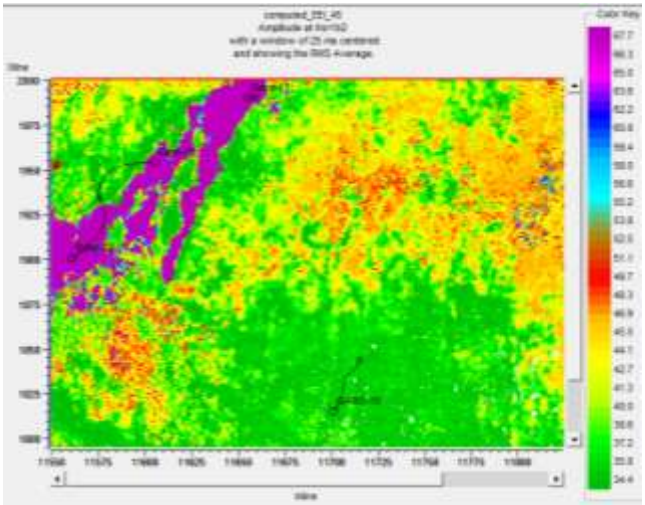

Figure 9: The data slice of EEI 45 (α / β) volume at hor 1b2 with a window of 25ms above and showing the RMS average.

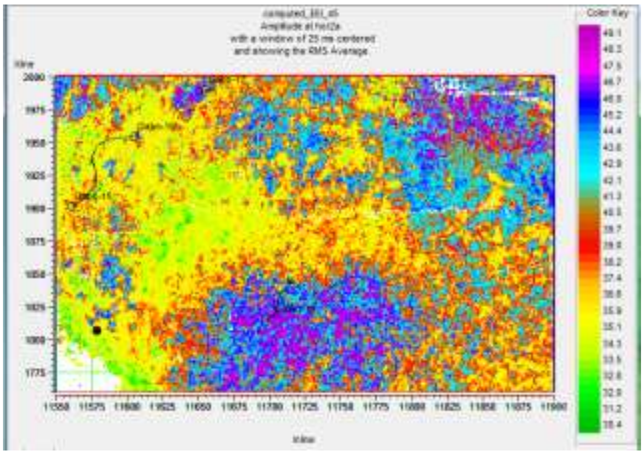

Figure 10: The data slice of EEI 45 (α / β) volume at hor 2a with a window of 25ms above and showing the RMS average.

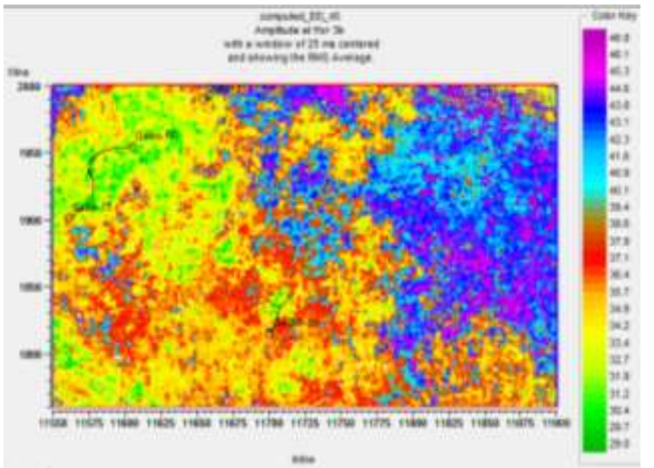

Figure 11: The data slice of EEI 45 (α / β) volume at hor 3b with a window of 25ms above and showing the RMS average.

4. Conclusion

The application of this equation to synthetic and real data show that the inverted results are more stable and less ambiguous than that from conventional procedure, and thus can predict and recover reservoir information very well. This result allows a better distinction between seismic anomaly caused by fluid content (gas, brine and oil) and those caused by lithology (sand and shale).

5. Acknowledgements

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