



Application of Extended Elastic Impedance (EEI) for Estimation of Reservoir Properties-A case study from Upper Assam Basin, India

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Keywords

Extended Elastic Impedance (EEI), Reservoir Properties

Summary

Upper Assam Basin, situated in north-east part of India is a proven sedimentary basin and several hydrocarbon fields are discovered historically in this region. The study area is in central basement high over a mature field (Figure-01) and producing hydrocarbon primarily from Oligocene (Barail) & Lower Tipam (Early Miocene) formations. In recent past, few prospects are discovered in shallower formations i.e. Upper Tipam (Mid Miocene) and indications of hydrocarbon presence is seen in Girujan (Late Miocene) formation as well. However, sand connectivity and extension of these thin discrete reservoirs is not well known. Static model building & volumetric calculations for these reservoirs requires quantitative estimation of key reservoir properties viz. shale volume (V_{CLAY}), effective porosity (ϵ_{EFF}) and water saturation (S_w).

In order to estimate reservoir properties, elastic parameters viz. P-wave velocity (V_P), S-wave velocity (V_S) & density (ρ) are obtained from analysis/inversion of seismic amplitude. These elastic parameters and their derived attributes discriminates lithology and fluid very efficiently. However, quantitative estimation of reservoir properties cannot be done directly from these attributes. A no. of approaches can be adopted to estimate reservoir properties by incorporation of well information and seismic derived attributes. Extended Elastic Impedance (EEI) is one of such attributes which is an extension of Elastic Impedance beyond the range of physically meaningful angles. EEI provides a framework to work with pre-stack AVO in terms of impedance instead of reflectivity.

In the present study, an attempt has been made for estimation of key reservoir parameters (Shale volume, effective porosity and water saturation) by using extended elastic impedance (EEI) approach.

Introduction

The reflectivity (R) for normal incidence (at 0° incidence angle) can be written in terms of acoustic impedance ($AI = V_P * \rho$) as,

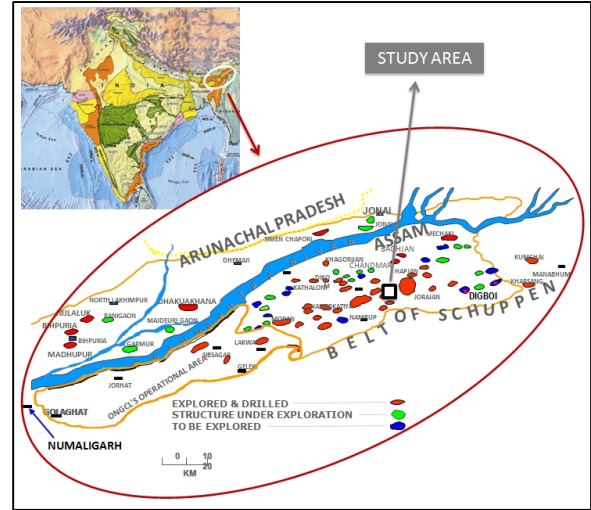


Figure-01: Indicative location map of study area

$$R(0) = \frac{AI_{i+1} - AI_i}{AI_{i+1} + AI_i} \tag{1}$$

For any non-normal incidence, due to mode conversion at the interface, reflectivity varies with incidence angle. A no. of linearization approximations of Zoeppritz equation are derived for non-normal reflectivity. The most widely used approximation i.e. AVO equation (Aki & Richards, 1980) is written as,

$$R(\theta) = A + B \sin^2(\theta) \tag{2}$$

Where,

$$\text{Intercept, } A = \frac{1}{2} \left(\frac{d(V_P)}{V_P} + \frac{d(\rho)}{\rho} \right),$$

$$\text{Gradient, } B = \frac{d(V_P)}{2V_P} - 4 \frac{V_S^2}{V_P^2} \frac{d(V_P)}{2V_P} - 2 \frac{V_S^2}{V_P^2} \frac{d(\rho)}{\rho}$$

And θ is the average of incident & transmitted angle, whereas V_P , V_S & ρ are the average respective properties across the interface.

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Conolly (1999) derived equation for non-normal reflectivity analogous to normal reflectivity,

$$R(\theta) = \frac{EI_{i+1} - E_i}{EI_{i+1} + E_i} \quad (3)$$

Here, Elastic Impedance (EI) is the extension of AI for non-normal incidences and it is defined as,

$$EI(\theta) = V_p^a V_s^b \rho^c \quad (4)$$

Where,

$$\begin{aligned} a &= 1 + \sin^2(\theta) \\ b &= -8k \sin^2(\theta) \\ c &= 1 - 4k \sin^2(\theta) \\ &\& k = (V_s/V_p)^2. \end{aligned}$$

Whitecombe et al (2002), extended the concept of elastic impedance by replacing $\sin^2(\theta)$ term by $\tan(\chi)$ in two term AVO equation and allows angle to vary from -90° to $+90^\circ$ (may be referred as rotation angle in Intercept-Gradient Plane).The modified equation in terms of scaled reflectivity is written as,

$$Rs = A \cos(\chi) + B \sin(\chi) \quad (5)$$

The analogous elastic impedance of the scaled reflectivity is termed as Extended Elastic Impedance (EEI), where EEI is defined as,

$$EEI(\chi) = V_{p0} V_{s0} \left[\left(\frac{V_p}{V_{p0}} \right)^p \left(\frac{V_s}{V_{s0}} \right)^q \left(\frac{\rho}{\rho_0} \right)^r \right] \quad (6)$$

Where,

$$\begin{aligned} p &= \cos(\chi) + \sin(\chi) \\ q &= -8k \sin(\chi) \\ r &= \cos(\chi) - 4k \sin(\chi) \end{aligned}$$

And V_{p0} , V_{s0} & ρ_0 are the average of the respective properties used as normalization factors.

The entire spectrum of EEI ($= -90^\circ$ to $+90^\circ$) shows unique characteristic at different rotation angle (χ), and EEI is proportional to different elastic parameters at particular values of χ . Hence, it is expected to come across particular rotation angles (χ) for which EEI should be proportional to particular reservoir properties. This is the basis for estimation of reservoir properties by using EEI approach.

Methodology

The methodology adopted for estimation of petrophysical properties (V_{CLAY} , ϕ_{EFF} & S_w) through EEI approach is described in the following steps.

1) EEI was computed for entire range of angle (-90° to $+90^\circ$) by using measured sonic (V_p & V_s) and densities logs with Equation-6 (Figure-02). The optimum value of for target property that gives maximum correlation with EEI is determined. It is observed that V_{CLAY} shows maximum correlation of 79% with EEI at $\chi = 36^\circ$, whereas ϕ_{EFF} & S_w shows maximum correlation of 74% & 81% at angles 16° & 13° respectively (Figure-03).

2) EEI for target property is calculated for the respective values and compared with the measured target property log. A good correlation between EEI with the target property indicates that EEI preserved the characteristics of target property, except a scaling factor (Figure-04). Thus, EEI can be considered as pseudo-impedance for target property. Further, a scaling equation is obtained through least square regression curve fitting in cross-plot between the target property and respective impedance log. The cross-plot between V_{CLAY} & V_{CLAY} -Impedance (EEI at $\chi = 36^\circ$) is shown in Figure-05.

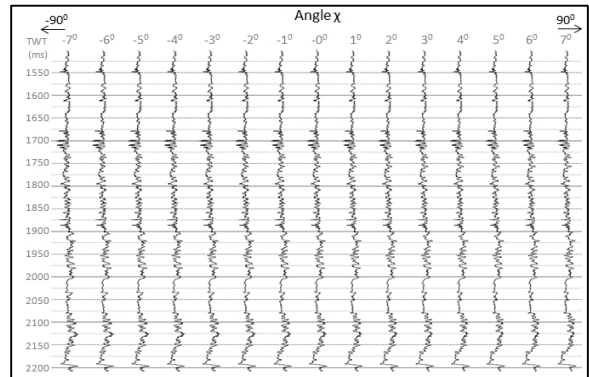


Figure-02: EEI Spectrum (for $\chi = -90^\circ$ to 90°)

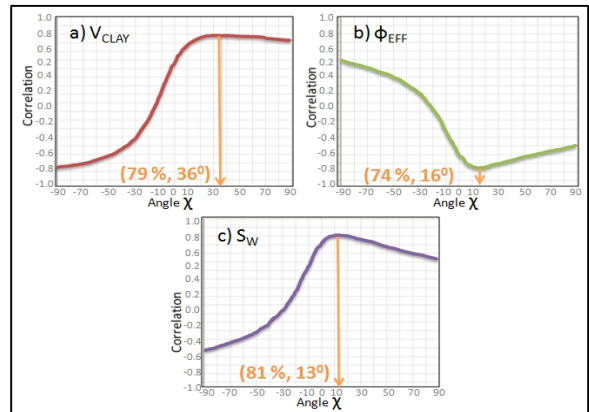


Figure-03: Correlation plot for a) V_{CLAY} , b) Effective porosity and c) Water saturation with EEI calculated at 90° to $+90^\circ$ angle.

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3) A low frequency model for target property impedance is generated using impedance (EEI) log, measured logs (V_P , V_S &) and horizon-tops.

4) AVO attributes (Intercept 'A' & Gradient 'B') is derived from the pre-stack migrated gathers (Figure-06). Scaled EEI reflectivity for target property is calculated using Equation-5 at the respective value (Figure-07).

5) The derived EEI reflectivity for target property is inverted using full spectrum colored inversion (low frequency added from the impedance model) to obtain impedance volume.

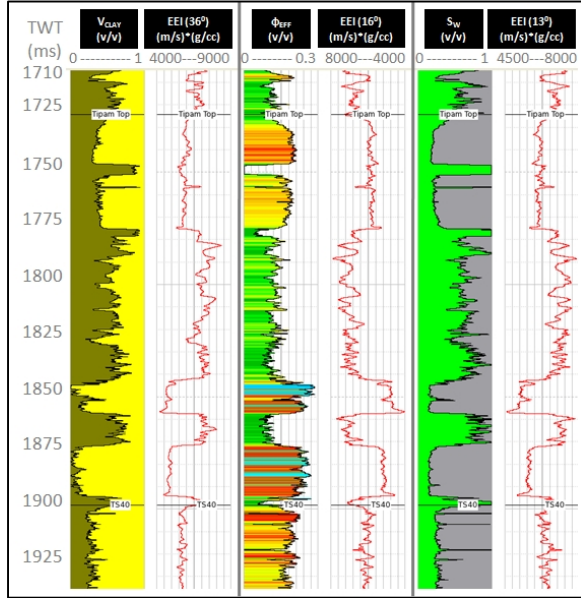


Figure-04: Comparison of Target property (V_{CLAY} , effective porosity & water saturation) with pseudo impedance logs.

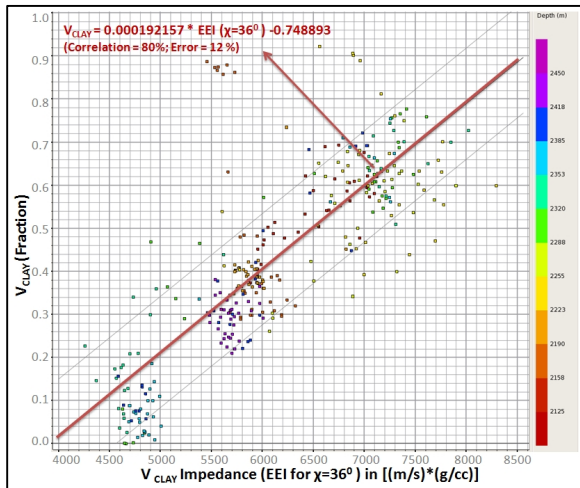


Figure-05: Cross-plot between V_{CLAY} log & pseudo V_{CLAY} -Impedance log (EEI at $= 36^0$).

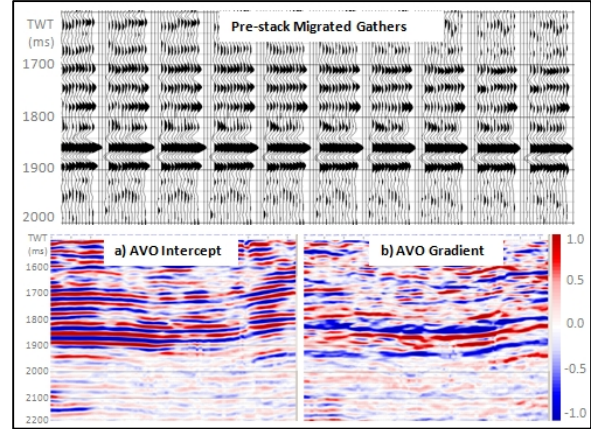


Figure-06: Pre-stack Migrated gathers and derived AVO Intercept (Fig. a) & Gradient (Fig. a).

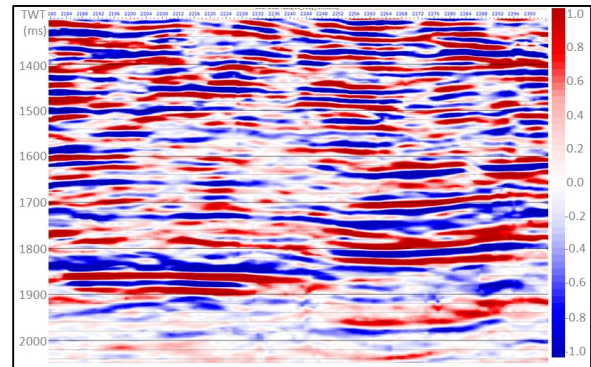


Figure-07: Scaled EEI reflectivity for V_{CLAY} (R_s at $=36^0$).

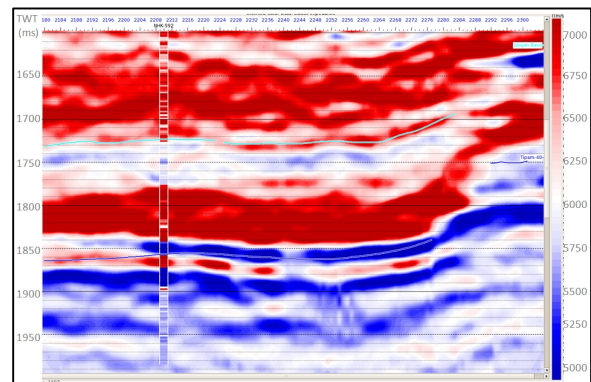


Figure-08: Inverted V_{CLAY} impedance (EEI at $=36^0$)

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The inverted V_{CLAY} -impedance section (EEI at $\chi=36^\circ$) is shown in **Figure-08**. Similarly, pseudo ϕ_{EFF} impedance & pseudo S_w impedance is generated using the respective EEI & EEI reflectivity.

6) The impedance volumes are rescaled using scaling equations and provide the quantitative estimation of target properties viz. V_{CLAY} , ϕ_{EFF} and S_w .

The methodology is summarized in form of a flow-diagram and shown in **Figure-09**.

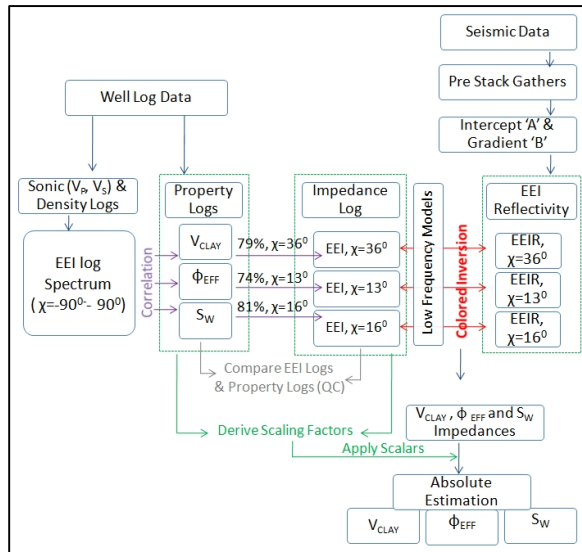


Figure-09: Flow diagram illustrating various steps.

Results & Discussion

EEI derived reservoir properties i.e. shale volume, effective porosity and water saturation along a section passing through the well is shown in **Figure- 10(a), 10(b) & 10(c)** respectively. Two pay-zones in Tipam formation are distinctly visible in all three sections. The estimated V_{CLAY} in upper pay-zone is in between 30-35% whereas lower pay-zone is relatively clean with 20-30% of estimated V_{CLAY} . These pay-zones have 20-22 % effective porosity and estimated water saturation is in between 20-25%. The corresponding reservoir properties measured in the well are overlaid with the section. A very good match between the estimated & measured properties is observed in all the three sections.

Further, shale volume and water saturation was extracted through an arbitrary profile passing through other three nearby wells. **Figure-11, (a) & (b)** represent the V_{CLAY} & S_w sections passing through this profile. A good history

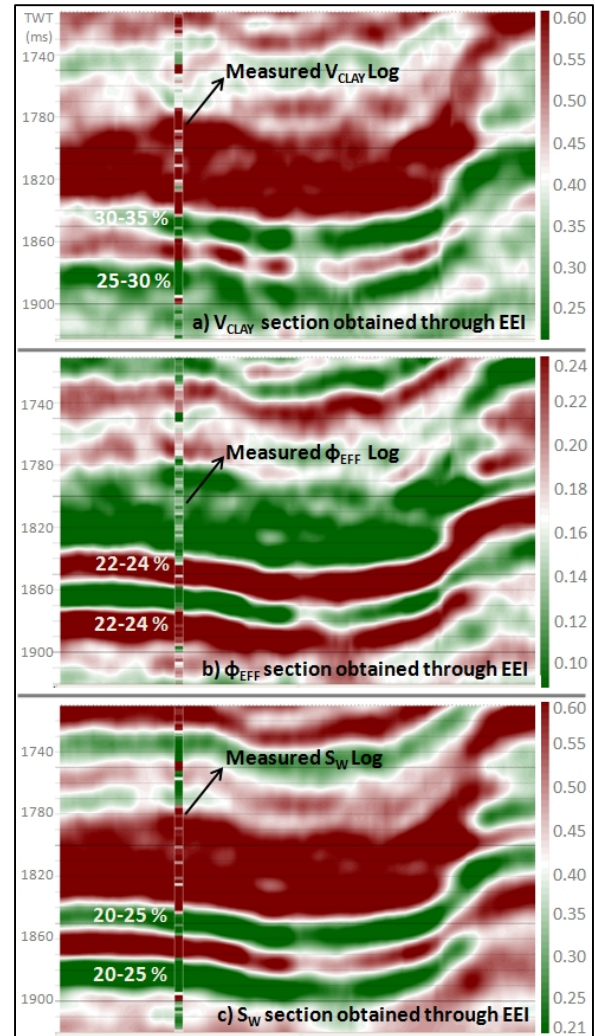


Figure-10: Estimated reservoir property sections.

matching between estimated reservoir properties with the corresponding measured properties is established; Moreover, extension of pay-zones and their connectivity is interpretable from the estimated reservoir property sections.

The study is able to identify presence of hydrocarbon bearing patchy sands within Girujan formation (low V_{CLAY} & low S_w above 1700 ms).

Conclusion

Extended Elastic Impedance is a potential technique for quantitative estimation of reservoir properties. In the present case study, it is observed that estimated reservoir properties viz. Shale volume, Effective porosity & Water

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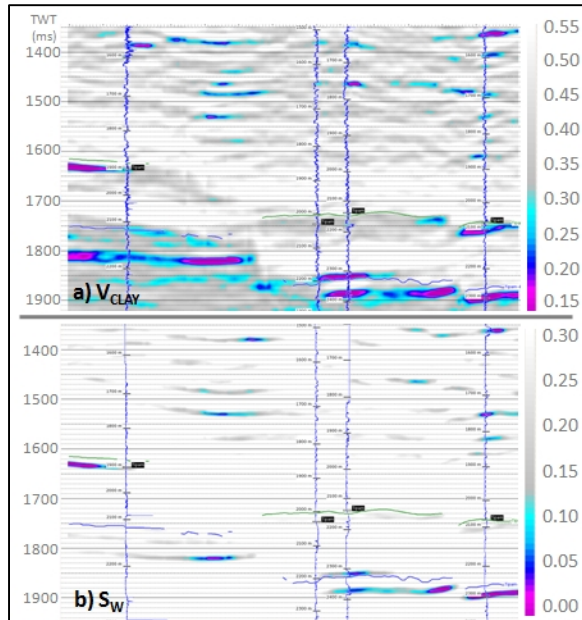


Figure-10: Estimated reservoir property across the wells.

saturation through EEI approach shows a good history matching with the existing geo-scientific data. EEI derived reservoir properties are able to demarcate the sand extension & connectivity of patchy reservoirs.

The estimated properties can be use effectively for improved reservoir characterization which in turn adds value in static geological model building and volumetric calculations.

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