

Estimation of Effective Porosity and Saturation Volume by Extended Elastic Impedance Approach: A Case Study*

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Abstract

The study area is a gas field situated in the deepwater of the east coast of India. The depositional setting is a channel-levee complex. From seismic, many smaller episodes of paleo-channel flow have been distinguished within major channel-levee complexes. The smaller episodes of channels cut-fill and migrate, grow younger from bottom to top, depositing vertically offset sand bodies. Clean-thick channel sands, thinly laminated sands, splay sands and mudstone/shale are the major facies. In this complex geological setup, both horizontal and vertical heterogeneity has been observed. Therefore, the challenge in this field is to capture the reservoir heterogeneity efficiently. Any direct method of determining the reservoir property using transform based on single property viz., amplitude, sweetness, P-Impedance generates only an average outcome, which is devoid of finer details.

Effective porosity and saturation are the key reservoir parameters, which play a vital role in reserve estimation and planning production operations. In the present study, extended elastic impedance approach has been adopted for obtaining effective porosity and saturation (Arsalan et al, 2009). Results show that the EEI approach is an effective way of deriving petrophysical properties. The output of this study can be effectively used for static model building and volumetric calculation; hence helpful in further field development.

Theory

Two-term linearization of Zeoppritz equation for reflectivity (Aki & Richards 1980),

$$R=A+B\sin^2\theta \quad (1)$$

replacing $\sin^2\theta$ by $\tan \chi$ in the two-term AVO equation, allows angle to vary form -90° to $+90^\circ$,

$$R(\chi) = A + B \tan\chi \quad (2)$$

Whitecombe et al. (2002) extended the concept of elastic impedance (Connolly, 1999), that can be used for fluid and lithology mapping. EEI is defined as

$$EEI(\chi) = \alpha_0 \rho_0 \left[\left(\frac{\alpha}{\alpha_0} \right)^p \left(\frac{\beta}{\beta_0} \right)^q \left(\frac{\rho}{\rho_0} \right)^r \right] \quad (3)$$

where α = P-wave velocity, β = S-wave velocity, ρ = density, $p = \cos \chi + \sin \chi$, $q = -8K \sin \chi$, and $r = (\cos \chi - 4K \sin \chi)$, α_0 , β_0 , and ρ_0 are the average of the respective property used as normalization factors for P velocity, S velocity, and density, respectively. K is the average of $(VS/VP)^2$ in the time/depth interval.

Methodology

In the present study, petrophysical properties (effective porosity and saturation) estimation was done in the sequence employed by Arsalan et al, 2009. In the first step, EEI was computed at different angles (χ) using equation (3), taking P Sonic, S Sonic and density logs as input. Further, angle χ_ϕ (and χ_{Sw}) against maximum absolute correlation of computed EEI log and effective porosity (ϕ_{eff}) (and saturation (Sw)) log was determined. The next step was to compute AVO intercept (A) and gradient (B) from seismic gather. Further, equivalent seismic volumes were calculated using equation (2) at angles χ_ϕ and χ_{Sw} , which have been obtained in the first step. These equivalent seismic volumes were inverted using constrained sparse spike inversion algorithm. The inversion products are EEI volume

corresponding to porosity and saturation at χ_ϕ and χ_{Sw} angles respectively. These were then scaled to derive porosity and saturation volumes.

Result

Correlations between effective porosity log and saturation log with EEI log for various angles are obtained and plotted in [Figure 1a](#) and [Figure 1b](#). EEI corresponding to $\chi = 27.5^\circ$ gives the maximum correlation ($\approx 93\%$) with log-derived effective porosity. The optimum χ and the corresponding correlation values for effective porosity and saturation log are given in [Table 1\(a\)](#) and [Table 1\(b\)](#).

[Figure 2a](#) and [Figure 2b](#), compares pseudo-petrophysical property logs (ϕ_{eff} and S_w) derived from EEI and corresponding actual petrophysical logs (ϕ_{eff} and S_w). A very good match, except for a scaling factor, indicates that the petrophysical volumes derived from seismic data through EEI can be used for quantitative interpretation.

[Figure 3a](#) and [Figure 3b](#), shows the section view of generated EEI petrophysical properties, ϕ_{eff} and S_w respectively through the well. Actual well log overlaid on the section indicates their match at the well and the property distribution away from the well. Thus, the EEI-derived volumes help in mapping the character of reservoir sand in 3D space and further quantitative reservoir characterization.

Discussions

Close observation of EEI, effective porosity, P-sonic, density and resistivity logs ([Figure 3a](#), [Figure 3b](#), [Figure 4a](#), [Figure 4b](#), [Figure 5a](#), [Figure 5b](#)) shows that the first, second and the forth zone of sand are clearly indicated by low EEI value on the log, and in the third zone the upper sand is giving low EEI value but the lower portion of this although having a good effective porosity, is unable to be captured in EEI log. The most likely reason is that the zone 1, 2 and 3 are channel sand with minimal laminations of shale, whereas the lower portion of third zone is mostly laminated sand of levy area. The thickness of the laminated sands is beyond seismic resolution for the bandwidth of the available seismic data.

Selected References

Arsalan, S., and A. Yadav, 2009, Application of extended elastic impedance: A case study from Krishna-Godavari Basin, India: The Leading Edge, v. 28/10, p. 1204-1209.

Connolly, P., 1999, Elastic Impedance: The Leading Edge, v. 18/4, p. 438-452.

Whitecombe, D., P. Connolly, R. Reagan, and T. Redshaw, 2002, Extended elastic impedance for fluid and lithology prediction: Geophysics, v. 67/1, p. 63-67.

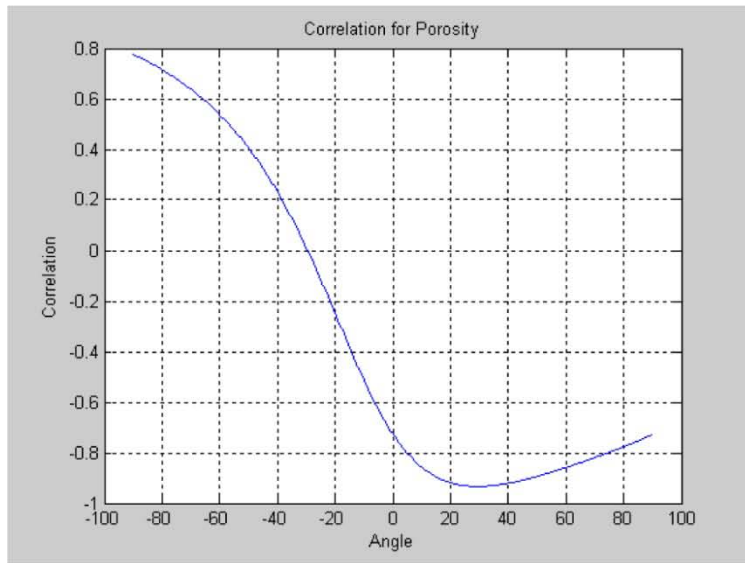
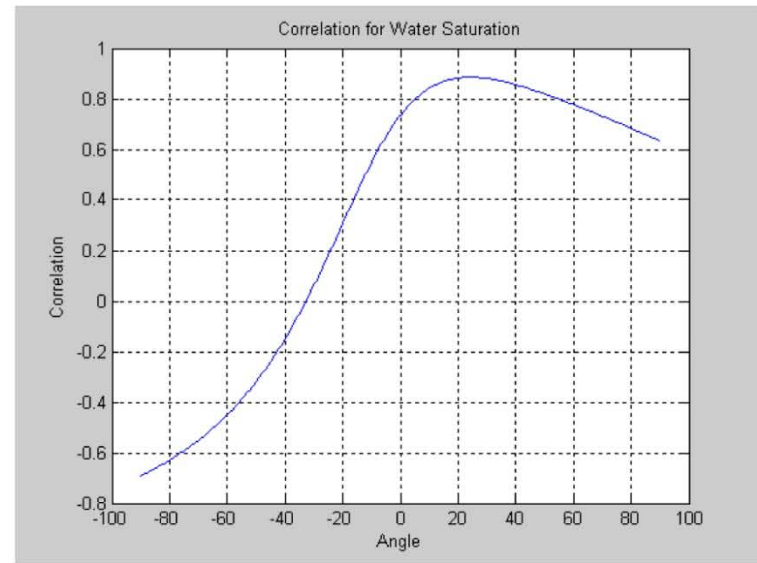


Figure 1. A) Correlation for effective porosity (ϕ_{eff});



B) correlation for saturation (S_w).

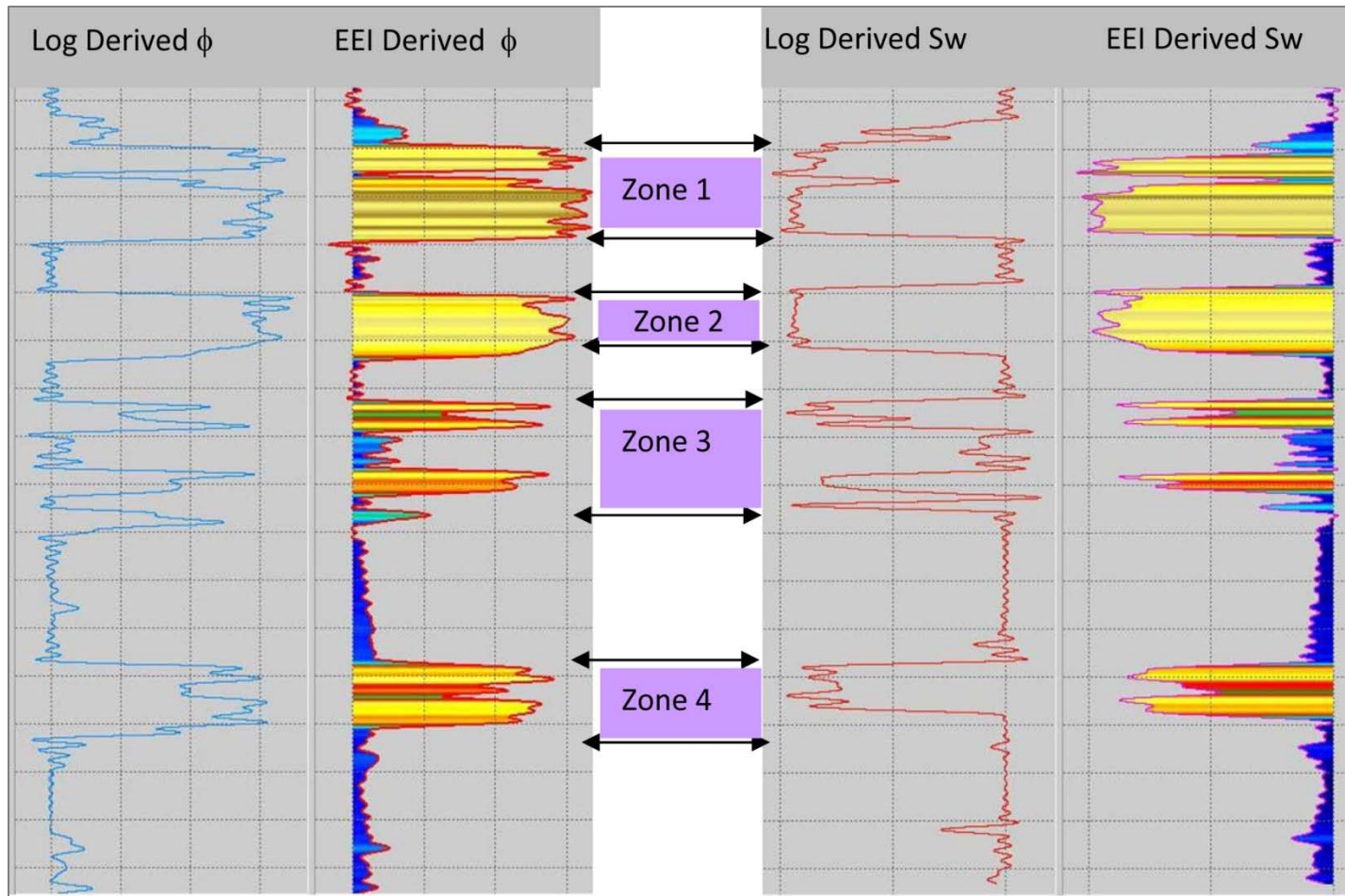


Figure 2. A) Comparison of log derived and EEI derived effective porosity;

B) comparison of log derived and EEI derived saturation.

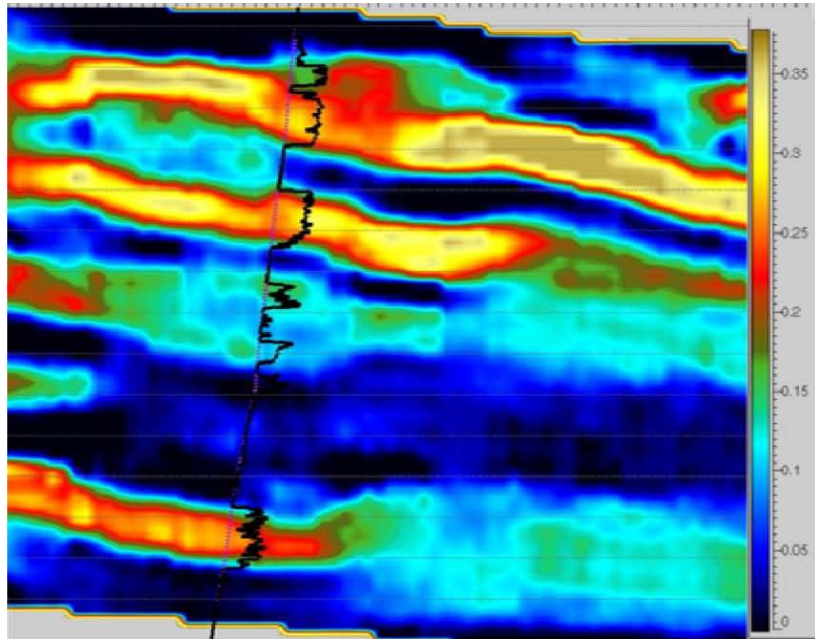
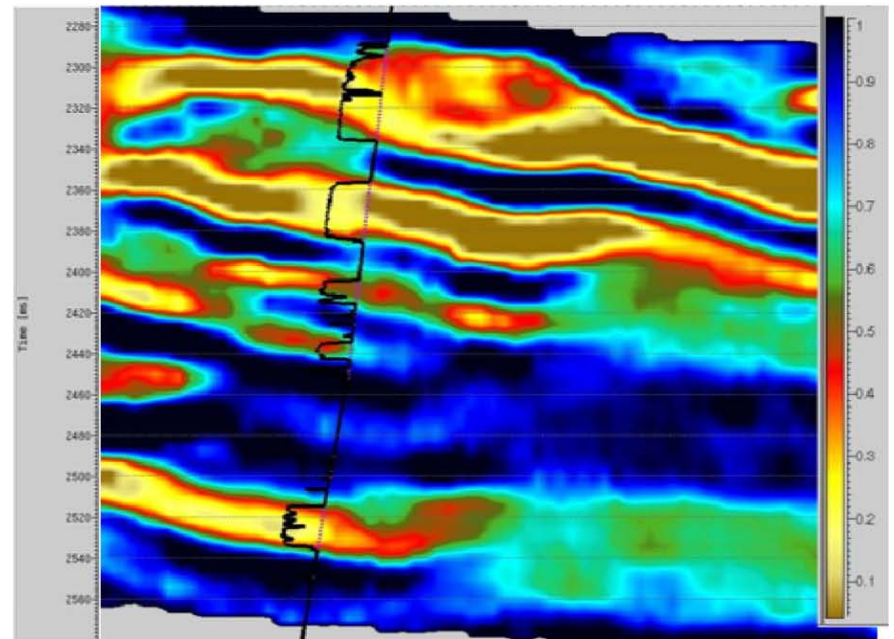


Figure 3. A) Section showing effective porosity;



B) section showing saturation (S_g).

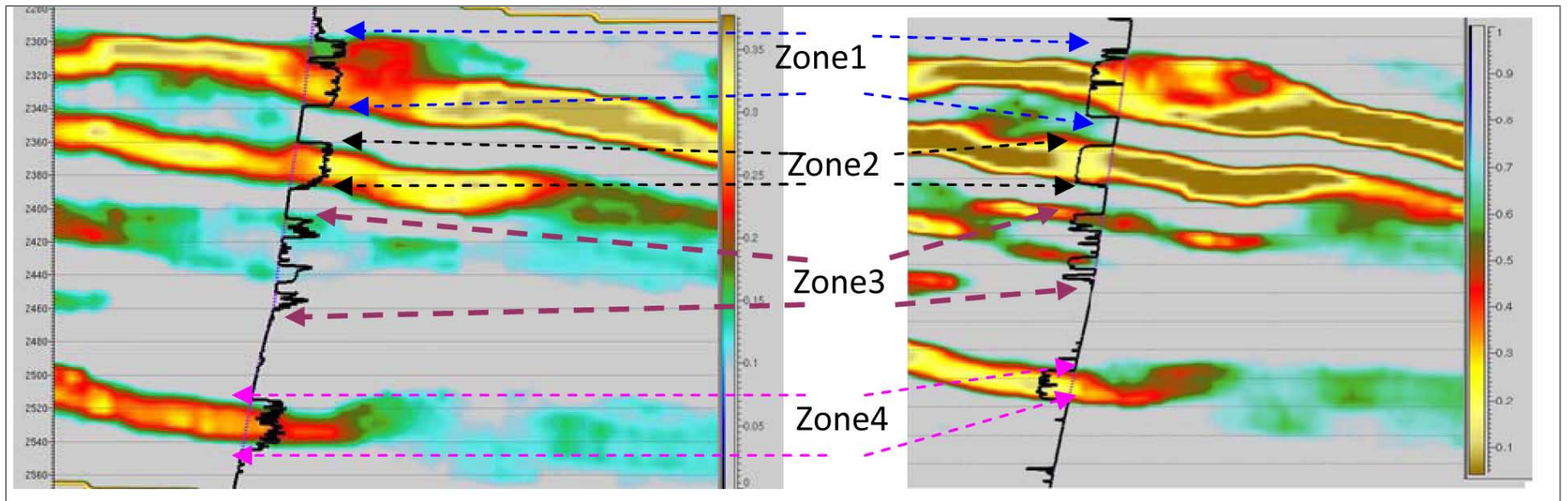


Figure 4. A) Section showing ϕ_{eff} with 10% cut off;

B) section showing S_w volume with 70% cut off.

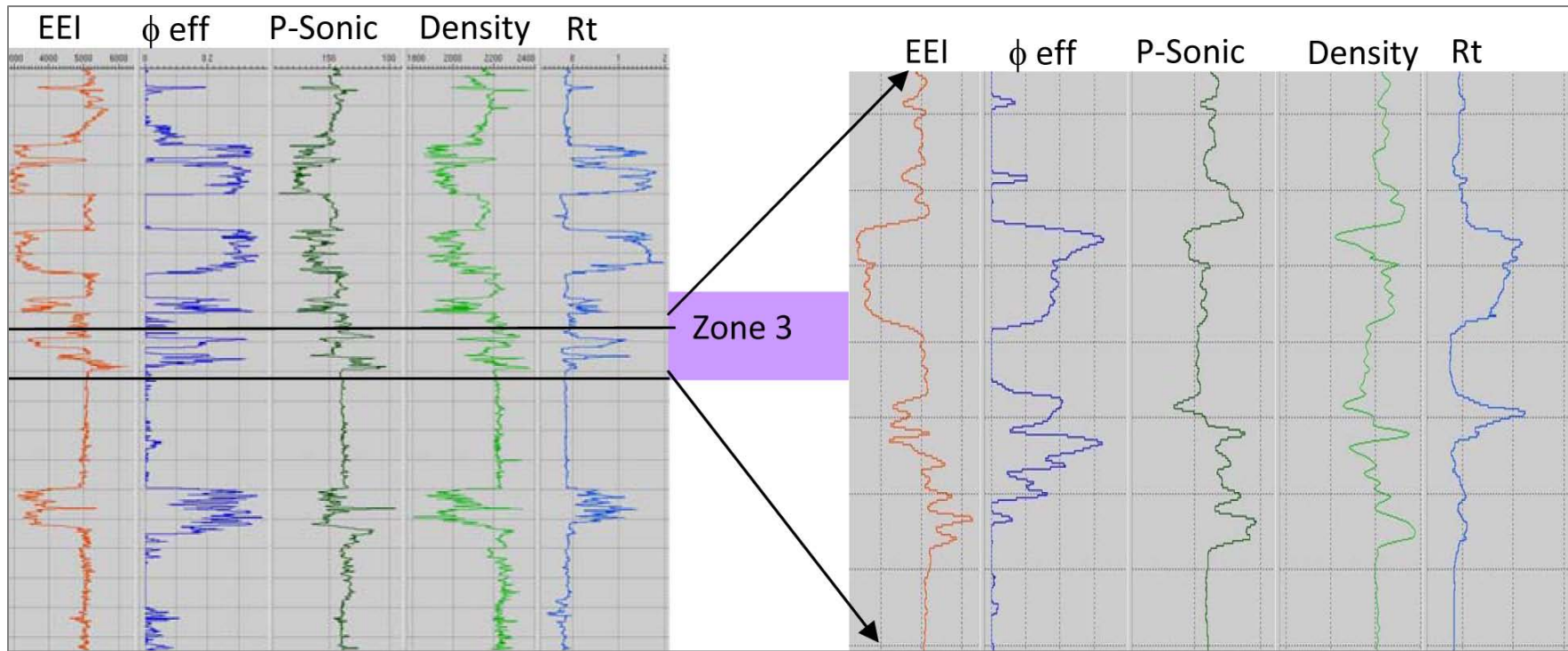


Figure 5. A) Log;

B) zoomed portion of lower part of zone 3.

For Effective Porosity	
Angle $\chi_\phi = 27.5^\circ$	Correlation = 93%

Table 1. A) For effective porosity;

For Saturation	
Angle $\chi_{S_w} = 24^\circ$	Correlation = 89%

B) for saturation.