

# Mopping Up Leftovers in a Matured Basin; Extended Elastic Impedance (EEI) Aiding Subsurface Interpretation

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## ABSTRACT

The need for WRFM (well, reservoir, and facility management) with infill wells cannot be over-emphasized and has become essential for assets maturation and ullage utilization. EEI is the application of angle rotation in the conventional acoustic impedance under certain approximation. It essentially works by projecting intercept and gradient together with different angles which highlights different features. Extended Elastic Impedance (EEI) has proved to be a highly convenient framework for seismic AVO studies. EEI logs can be directly related to the petrophysical properties of interest, and seismic EEI reflectivity volumes can be obtained directly from the prestack data via linear projection in  $\sin^2 \theta$ . In this project, we modelled the "chi" angles from the logs and applied the different chi angles to the prestack seismic dataset. This can be likened to a bandlimited seismic inversion product. The chi angles of the lithology indicators- Share Impedance (SI), MuRho and Density and the fluid indicators- Saturation, Fluid factor (FF) and LamdaRho where derived and applied on the seismic dataset for generate a 3D property distribution map. The input to the EEI inversion is the seismic angle sub-stacks of near (0-10deg), mid (10-20deg) and far (20-30deg) solving the AVA\_2term Shuey AVO fitting function- intercept and gradient only. In some cases where the seismic S/N ratio in the ultra-far angle stack is high, it could be considered for the inversion and would give rise to the 3rd term- curvature, but in our case, it was considered noisy. To ensure stability of the inversion, the substacks were aligned both spectrally and on the waveforms and the seismic dataset was further post-processed. Amplitude maps generation and sculpting was done on the different EEI generated seismic volumes and the result provided insight in the lithology and fluid study at the reservoirs of interest. This has led to FPSO life extension by several years more than design life and is helping to keep xxxkbpd-sized field FPSO full via world class WRFM, infill drilling and growth projects. The EEI result helped in identified new leads and revalidated existing leads aiding well placement.

**Keywords:** Extended Elastic Impedance (EEI), Seismic Inversion, AVO, WRFM.

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## INTRODUCTION

Understanding the subsurface characteristics of rock formations is made possible by an understanding of Extended elastic impedance, a key idea in geophysics seismic exploration. This characteristic connects the seismic reflection coefficients to the acoustic impedance and elastic moduli of the rocks, among other physical characteristics. Extended elastic impedance is essentially based on the typical acoustic impedance (AI) inversion technique, which assumes a P-Wave impedance from the subsurface at a normal incidence angle (Latimar R. B., 2000).

For a CDP gather, this approach works well in limited offset ranges where inversion typically yields dependable results. But as amplitude versus offset (AVO) has developed recently and gained the ability to distinguish hydrocarbon reservoirs from the surrounding shale and cap rock, there has been an increase in the need to analyze non-zero offset seismic data. The idea of elastic parameters from non-zero offset data from the elastic impedance approach was first presented by (Connolly, 1999). Due to its ability to capture significantly more information on lithology and fluid than the traditional acoustic impedance, this approach achieved significant progress in the fields of fluid discrimination and lithology prediction for a variety of reservoir types.

The development of a sophisticated and all-encompassing model that improves the assessment of subsurface rock properties in seismic exploration and reservoir monitoring is the goal of numerous studies on extended elastic impedance. Common goals typically involve developing

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an advanced model that incorporates the identified parameters and takes into account the complexities of subsurface properties, including anisotropy, heterogeneity, fluid effects, and other geologic factors; validating the extended elastic impedance model's performance and reliability using synthetic seismic data with known rock properties; and applying the developed model to real seismic data from difficult reservoir environments or geologically complex areas to show how well it improves resolution and accuracy.

In seismic exploration and reservoir monitoring, a more thorough and precise characterisation of the characteristics of underlying rock is required. This is what extended elastic impedance addresses. Anisotropy, heterogeneity, and fluid impacts are only a few of the many intricate characteristics of subterranean rock formations that the conventional elastic impedance model might not be able to adequately represent. The precise interpretation of seismic data and the estimate of rock attributes are hampered by this complexity. Seismic reflection coefficients may be difficult to forecast with current elastic impedance models, especially in geologically complicated regions or unconventional reservoirs. Advanced modeling methods are required to raise the accuracy and consistency of seismic interpretation.

The necessity of expanding the extended elastic impedance model to include characteristics other than acoustic impedance and elastic moduli, such as porosity, lithology, pore fluid properties, and stress conditions. A more comprehensive picture of the subsurface geology and reservoir properties may be obtained by integrating these data. enhancing the resilience and accuracy of hydrocarbon detection, reservoir characterization, and seismic data interpretation by creating an improved elastic impedance model. The goal of this problem statement is to provide a link between traditional elastic impedance techniques and the sophisticated needs of contemporary geophysical investigation.

Geoscientists and reservoir engineers can improve their capacity to locate prospective hydrocarbon reservoirs, choose the best locations for drilling, and make well-informed decisions about oil and gas exploration and production by tackling these issues and creating an extended elastic impedance model that considers the nuances of subsurface characteristics.

## METHODOLOGY

Extended Elastic Impedance (EEI) is a modification of the elastic impedance (EI) concept introduced to better incorporate the effects of lithology and fluid changes in seismic data. It's particularly useful in rock physics and seismic inversion. The mathematical representation of EEI is derived from the general form of elastic impedance

and involves introducing an angle parameter  $\chi$ , which can vary depending on the specific elastic parameters being studied.

The general form of the Extended Elastic Impedance (EEI) can be written as:

$$EEI(\chi) = E_x \cdot \left(\frac{V_p}{V_{p0}}\right)^a(\chi) \cdot \left(\frac{V_s}{V_{s0}}\right)^b(\chi) \cdot \left(\frac{\rho}{\rho_0}\right)^c$$

EEI( $\chi$ ) is the extended elastic impedance at angle  $\chi$

$V_p$  is the P-wave velocity.

$V_s$  is the S-wave velocity.

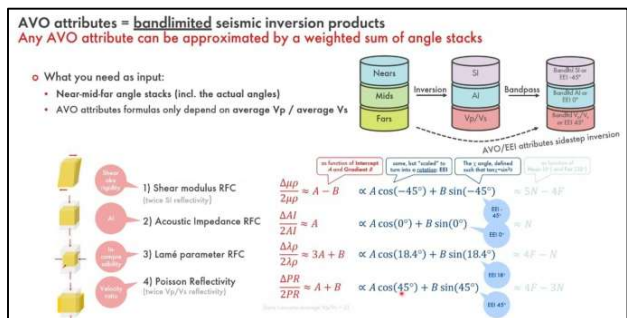
$\rho$  is the density.

$V_{p0}$ ,  $V_{s0}$  and  $\rho_0$  are the reference values for P-wave velocity, S-wave velocity, and density, respectively.

$a(\chi)$ ,  $b(\chi)$ , and  $c$  are functions of the angle  $\chi$  and are derived from rock physics theory.

The angle  $\chi$  is a parameter that can be varied to emphasize different elastic properties.

A key idea in seismic exploration is elastic impedance theory, which links rock characteristics to seismic wave densities and velocities. The significance of comprehending the elastic characteristics of subterranean rocks for precise seismic interpretation has been emphasized by recent research. Elastic impedance has been shown to be a useful tool for determining the lithology, porosity, and fluid content of reservoir rocks. Elastic impedance has been shown to be useful in forecasting lithology changes in carbonate reservoirs by Avseth *et al.*'s research from 2005. Elastic impedance can be used to determine porosity differences in sandstone formations, as demonstrated by Smith *et al.* (2010). The importance of elastic impedance theory in reservoir characterisation and hydrocarbon exploration is highlighted by this research. It essentially works by projecting intercept and gradient together with different angles which highlights different features.



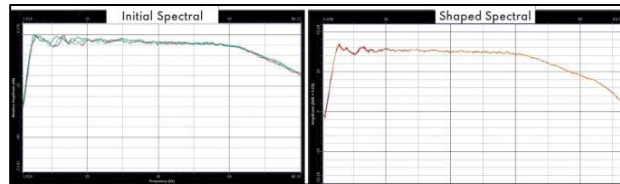
The accuracy and effectiveness of seismic interpretation have increased thanks to recent developments in elastic impedance modeling approaches, such as the application of machine learning algorithms. Researchers have improved reservoir characterization and subsurface imaging by implementing these novel techniques.

A seminal work by Smith *et al.* (2018) examined how

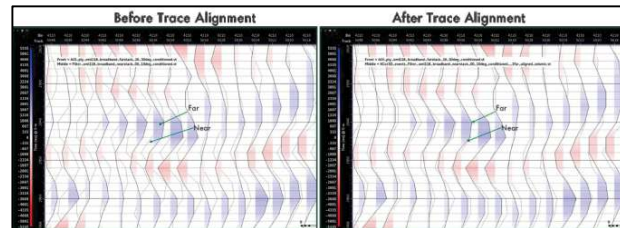
different fluid saturations affected elastic impedance calculations, emphasizing how fluid effects should be considered when interpreting seismic data. The application of machine learning techniques to enhance the prediction of elastic impedance from seismic data was investigated by Jones and Brown (2019), demonstrating the possibility for incorporating cutting-edge technologies into this subject.

**RESULT: Input Preparation**

Because of their potential to improve subsurface imaging and seismic data interpretation, applications of extended elastic impedance have attracted a lot of attention in the geophysics community. The work of Connolly (1999), who developed the idea of Extended Elastic Impedance as a technique for deriving additional information from seismic data beyond conventional impedance inversion, is one of the seminal research projects in this field. The industry has embraced this method extensively for lithology differentiation and reservoir characterisation. Connolly's work established the groundwork for later investigations in this area and shown how crucial it is to use concepts from rock physics to seismic interpretation.

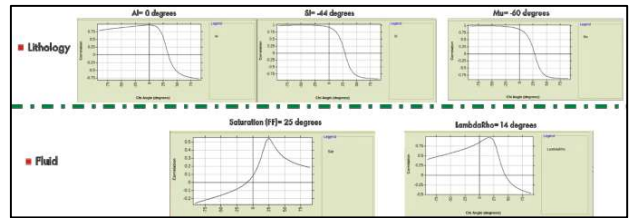


Expanding on Connolly's research, several investigators have investigated the applications of extended elastic impedance in various geological contexts. Smith *et al.* (2015), for instance, applied this method to a carbonate reservoir in the Middle East and showed how well it worked to identify subtle stratigraphic features and predict reservoir properties. This study demonstrated the usefulness of extended elastic impedance in complex geological environments and underscored its potential for streamlining reservoir characterization workflows. Apart from reservoir characterization, extended elastic impedance has also been employed for seismic attribute analysis and seismic inversion. Jones *et al.* (2018) investigated the application of extended elastic impedance as a tool for identifying hydrocarbon indicators in seismic data.



Through the integration of seismic properties and models of rock physics, the researchers were able to identify minute alterations in the subsurface linked to hydrocarbon accumulations. This study serves as an example of how Extended Elastic Impedance can be used in a variety of oil and gas sector applications.

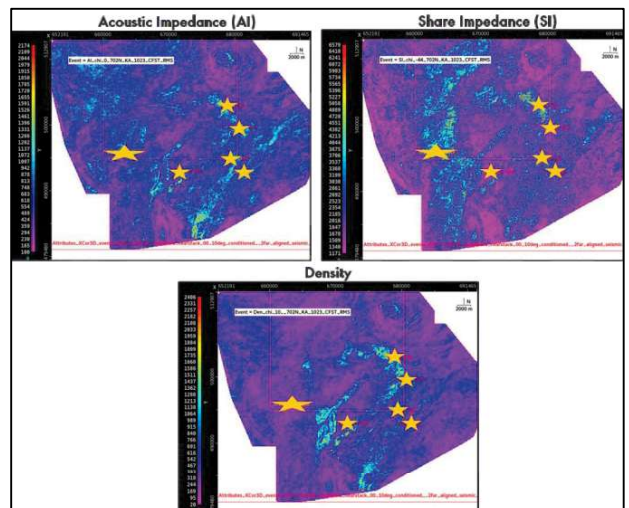
EEI logs can be directly related to the petrophysical properties of interest, and seismic EEI reflectivity volumes can be obtained directly from the prestack data via linear projection in  $\sin^2 \theta$ . Before we proceed with the EEI model proper, it was important to know the chi angles where we expect lithology and fluid responses for the different rock properties. This was modelled using the well dataset on RokDoc. For a check on lithology, chi angle of 0deg for AI, -44 deg for SI, 10 deg for density, and -60 deg for Mu. For the fluid property, chi angles of 25 deg for saturation and 14 deg for LambdaRho where modeled. See below the modelling results.



**RESULT DISCUSSION**

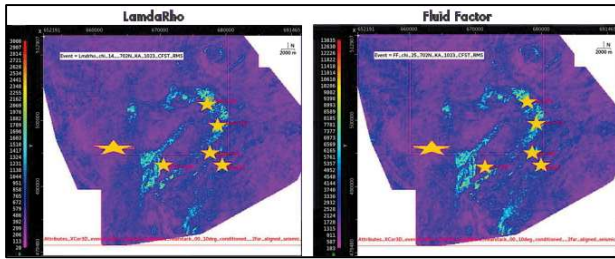
The result showed identified alterations in the subsurface linked to hydrocarbon accumulations by combining seismic characteristics with models of rock physics. The adaptability of Extended Elastic Impedance in many oil and gas sector applications is demonstrated by this study.

The work of Rutherford and Williams (1990), who originally proposed the idea of elastic impedance to integrate seismic and well log data, is one of the important



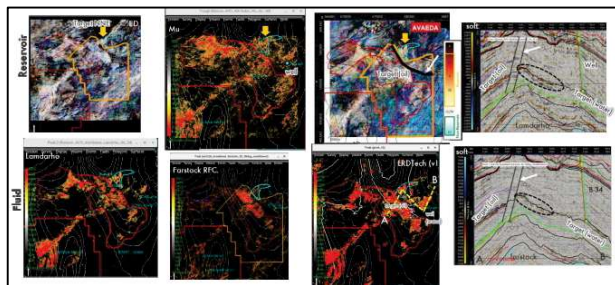
works in this field. The foundation for the advancement of EEI techniques and their use in seismic inversion research was established by this groundbreaking work. Since then, a great deal of research has been done to enhance and improve the precision of inversion techniques based on EEI. Avseth *et al.* (2005), for instance, carried out a thorough investigation on the application of EEI in reservoir characterization, proving its efficacy in forecasting reservoir characteristics like porosity and fluid content.

Their results demonstrated how crucial it is to include rock physics models in the inversion procedure to take lithology and fluid property changes into consideration. In a more recent study, Liu *et al.* (2018) looked at the use of EEI in the detection of small-scale reservoir compartments and subtle stratigraphic characteristics. They were able to attain a high degree of resolution in their inversion results by integrating seismic data with well log information and geological restrictions, allowing a more thorough understanding of the subsurface geology.



**Business Impact**

An essential component of petroleum exploration and production is the characterisation and prediction of reservoirs utilizing extended elastic impedance. To estimate reservoir characteristics including porosity, lithology, and fluid content, this technique integrates seismic data with rock physics models. Geoscientists can make well-informed decisions regarding reservoir development and production methods by comprehending the relationship between rock qualities and seismic response.



This finding has significant implications for the oil and gas industry, as it can help reduce exploration risks and improve reservoir performance.

**CONCLUSION**

In the field of geophysics, the investigation and creation of an extended elastic impedance model mark a substantial improvement in the interpretation of seismic data and subsurface Characterisation. This work has shown how crucial it is to include characteristics other than the conventional acoustic impedance and elastic moduli to adequately represent the intricacies of underlying rock properties. By thoroughly examining current elastic impedance models, determining crucial parameters for expansion, and creating a sophisticated model that considers variables such as anisotropy, heterogeneity, and fluid effects, this study has demonstrated the possibility of improving resolution and precision in the interpretation of seismic data.

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