Estimation of VP/VS ratio and Water saturation volumes by Extended Elastic Impedance approach: A case study

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ABSTRACT
There are different objectives in performing seismic reservoir characterization studies but among all of them lithology and Pore fluid prediction are two of the most important ones. In seismic reservoir characterization, different techniques are applied to extract the most valuable results from the available seismic data, especially in places with limited well control and low quality seismic data. Extended elastic impedance (EEI) inversion is a technique that provides a simple robust means of deriving lithological and fluid sensitive seismic impedance volumes by defining an angle called Chi angle (χ) and using this angle as a rotation in intercept-gradient space, to compute the volume to be inverted. EEI at various Chi angles is proved to be proportional to numerous elastic and petro-physical properties such as density, S-impedance, V_P/V_S ratio, shear modulus, clay volume, porosity and water saturation. In this case study EEI analysis is performed to estimate V_P/V_S ratio and water saturation cubes to evaluate an oil producing reservoir. After determination of the proper Chi angles, the EEI reflectivity data were generated by integration of A (Intercept) and B (Gradient) volumes (estimated from AVO analysis). Then LP Sparse spike inversion procedure was performed to generate desired cubes. Generated V_P/V_S ratio cube in addition to well log data, was compared with the corresponding VP/VS ratio cube acquired from pre-stack seismic inversion. The results revealed a proper match at well location and also at places far from the well control. Generated water saturation results were also compared with available log data that again good match was observed. The outcomes of this fast seismic reservoir characterization method can help to rank previously defined drilling locations and also determine new potential locations.

Keywords: V_P/V_S ratio, Water saturation, AVO analysis, Extended elastic impedance (EEI).

1 INTRODUCTION
The main idea of this research is to use application of extended elastic impedance inversion (EEI) to improve reservoir characterization and enhance lithology and fluid discrimination. In 1999, Connolly drew up the elastic impedance formula (EI) by two and three Zoeppritz linear equations, which retained the seismic data of AVO information and made the AVO inversion feasible and effective (Connolly, 1999). In 2002, Whitcombe modified the number of variable dimensions and the Connolly formula by introducing the 3 parameter variable. It normalized impedance value of all angles, so that the elastic impedance and post stack impedance are in the same magnitude (Whitcombe, 2002). In the same year, Whitcombe revised the elastic impedance equation normalization and proposed the extended elastic impedance inversion (EEI) concept as a pre-stack seismic attribute for fluid and lithology discrimination. In this method integration of intercept and gradient (extracted from AVO analysis) with various Chi (χ) angles (varying between -90º and 90º angles) highlights different reservoir parameters. EEI equation is a linearized form of the Aki and Richards (1980) AVO equation introduced by Shuey (1985), where $\sin^2(\theta)$ is replaced with $\tan(\chi)$ for extrapolation beyond physically observed range of theta. (Whitcombe et al., 2002). So far, numerous authors have studied extended elastic impedance technique, and proved its ability to predict fluid and lithology types which

some the recent studies are as follow; Awosemo, O. O. 2012, Gharaee Shahri, S. A. 2013, Shi et al. 2014
Mirzakhanian et al. 2015. We applied the extended elastic impedance (EEI) method to predict V_P/V_S ratio and Water saturation cubes that the prediction results are in good agreement with the actual drilling data.

2 AVAILABLE DATA

In this study, the available pre-stack seismic data were 4 angle stacks ranging from 3 up to 32 degrees passing through 5 wells located in an Iranian Oil field. Well logging data, in particular P and S sonic and density logs (Essential logs for EEI log prediction), in addition to interpreted logs such as water saturation, angle stack seismic data and interpreted seismic horizons were main inputs. The target reservoirs in this study were the Burgan member and Dariyan formation which consist dominantly of Carbonate and sandstone with interbedded shale layers.

3 METHODOLOGY

In brief, inversion takes an actual seismic trace, removes the seismic pulse and delivers an earth model for that trace location. In conventional post stack acoustic impedance inversion seismic reflection amplitudes are converted to Acoustic impedance values while in the EEI method at first reflectivity of the desired parameters are created using the A and B volumes rotated with chi angle and then similar to post stack inversion the initial low frequency models are created and the reflectivity cubes are inverted to the desired log parameters.
In this study to perform EEI analysis, at first available partial angle stack volumes were converted to Angle gather data to be able to calculate intercept (A) and Gradient (B) volumes through AVO analysis. Then a series of EEI curves with a series of Chi angle from -90° to 90°, differing by an increment of 1° are calculated and correlated with V_P/V_S ratio and Water saturation logging data. At approximate angle of 45°, the correlation coefficient function of Chi reaches its maximum value, which means that EEI at angle 45°is a representative of V_P/V_S ratio (Figure 1-left). Similarly, EEI log at Chi angle of 40° is selected as the best indicator of the Water saturation data (Figure 1-right).

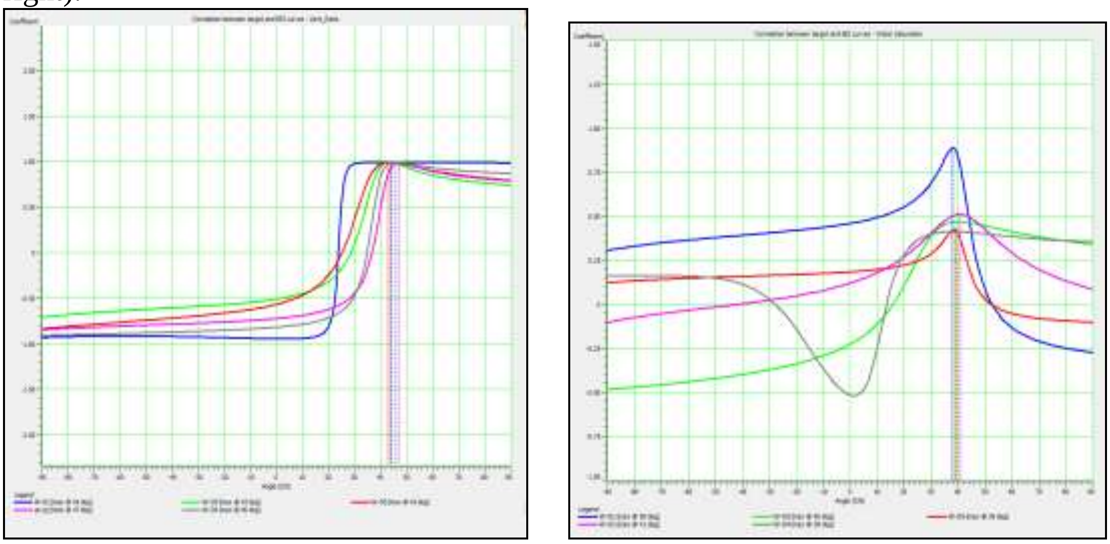

Figure 1) The maximum correlation value of EEI with VP/VS ratio (left) and Water saturation (right) logs Which are approximately at 45 and 40 degrees.

After identification of appropriate χ value for any parameter, the equivalent seismic reflection volume is obtained from combination of intercept and gradient stack volumes through the EEI equation (R (χ)=A+B tan (χ)). Following the same procedure as post-stack inversion, after acquiring the V_P/V_S ratio and Water saturation reflectivity cubes, statistical seismic wavelets are extracted from the each generated reflectivity cubes; then initial EEI models consistent with the regional structural and stratigraphic characteristics are built; and finally EEI volumes are obtained by using LP Sparse spike inversion algorithm.

4 RESULTS AND DISCUSSION

In the following, the results of performing EEI analysis are rendered. Figure 2 presents the result of LP Sparse Spike inversion on EEI reflectivity created at (45) degree (left) and V_P/V_S cubes generated through the Simultaneous pre-stack inversion method (right).As it is obvious V_P/V_S ratio section estimated from EEI analysis section highly represents the V_P/V_S values and indicates good consistency with the pre stack inversion results. In Figure 3, the original VP/VS ratio log and the calculated one through EEI analysis are illustrated in Time domain, which are greatly correlated.

V_P/V_S ratio values are one of the most important data in any seismic reservoir characterization study. Since, V_P/V_S ratio is a good indicator of lithology; for example in shaly-sandy interbeded reservoir that the acoustic impedance values could be similar, Sand reservoir layers are identified with lower V_P/V_S ratio values.

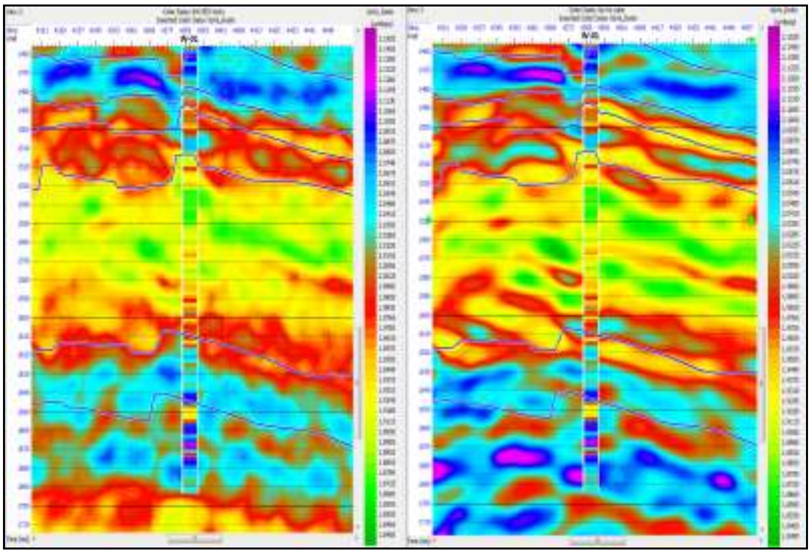

Figure 2) V_P/V_S ratio section estimated from EEI analysis (left) and Pre-stack seismic inversion (right). Original VP/VS logs are inserted.

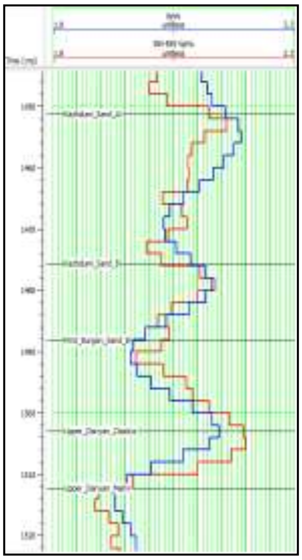

Figure 3) Comparison of the original (in blue) and EEI-estimated (in red) V_P/V_S ratio logs at W-01 well

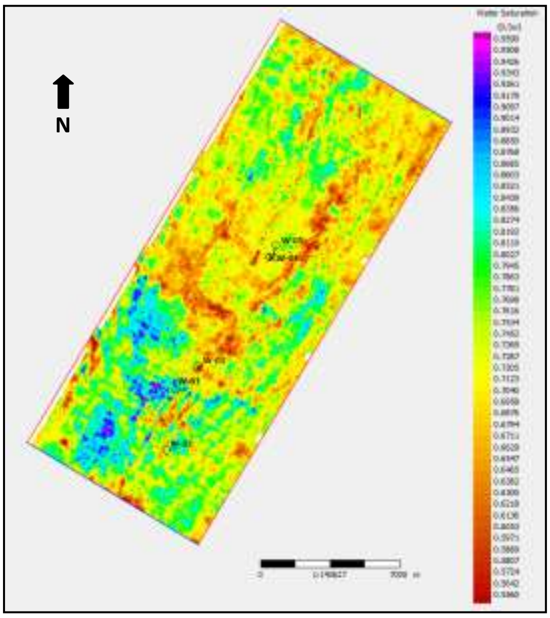

Figure 4) A horizon slice through the Water saturation cube generated by EEI analysis (5ms below the Burgan reservoir)

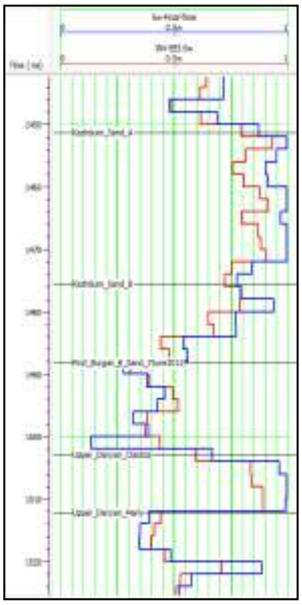

Figure 5) Comparison of the original (in blue) and EEI-estimated (in red) Water saturation logs at W-01 well

A horizon slice at 5 ms below the Burgan reservoir layer through the generated Water saturation cube is illustrated in Figure 4. The water saturation map in addition to porosity map, has a significant impact on defining drilling locations and priority could be given to the locations corresponding to higher porosity and lower water saturation in the seismic volume.

According to this figure south western parts of the field are not suitable for new production well designing due to high values of water saturation (blue color). In order to show the accuracy of the generated water saturation cube, the original Water saturation log and the calculated one through EEI analysis are illustrated in Time domain, which are greatly correlated (Figure 5).

5 CONCLUSION(S)

This pilot study was initiated to determine if attributes generated from partial angle stacks through the EEI inversion method would improve the ability of the seismic to indicate successful drilling locations.

In this case study, EEI analysis was performed on the 3D pre-stack seismic data to predict the V_P/V_S ratio and Water saturation cubes. Log data of five wells have been used for modeling and analysis. After determination of the proper χ angles through the maximum cross correlation of EEI logs (from -90 to +90 degree) and V_P/V_S ratio and Water saturation logs the EEI reflectivity regarding to these angles were generated using Intercept (A) and Gradient (B) volumes. In the next step, LP Sparse spike inversion was performed on EEI reflectivities to derive desired V_P/V_S ratio and Water saturation cubes.

The generated results were checked using well data. The seismically derived V_P/V_S ratio and water saturation data closely matched the well data, adding confidence to the seismically calculated results. V_P/V_S cube generated through the Pre-stack inversion was also used as a validation data and the comparison revealed a very good match between values generated through the Pre-stack and EEI inversion methods. The results of this research support the idea that EEI can enhance interpretability and is a feasible approach to obtain detail reservoir delineation. In other words, EEI can be an excellent precursor for more detailed seismic inversion studies and it is a fast robust method that specially can be used in places that synthetic seismograms are difficult to tie to seismic data.

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