Inversion of converted PS data in the poststack domain for shear impedance

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Summary

Impedance creates a simple quantitative tie between seismic and well log data. Researchers generated some useful models and trends to also qualify these ties. After all, seismic impedance estimation is an interpretation instrument with a wide area of coverage. In this research we investigate one of the methods for impedance estimation. The method is based on an approximation for S-impedance that can be extracted from S-wave component of stacked migrated converted mode PS data in an isotropic environment. Availability of 9-C seismic acquired within a small area at Rulison field provides an opportunity to compare S-impedance results obtained from single mode SS-wave and converted mode PS-wave data. We also introduce a good compatibility between field data and log data estimations.

Introduction

Shear wave found a broad application in reservoir interpretation. Acoustic impedance estimation from compressional PP data is a usual practice for reservoir properties and lithology description. However, P-wave in combination with S-wave data produce a better characterization tool for fluid saturated matrix. Thus, to investigate reservoir parameters and their relationship with seismic data through impedance estimations it is very important to consider both P- and S-impedances.

The industry tends to work more with PS seismic rather than single mode SS data. Through the last years a significant improvement in acquisition and processing techniques made S-wave data more available. The advantage of converted PS mode data over pure shear SS mode is a broader frequency bandwidth and, as a result, higher vertical resolution. Also, in contrast to SS-wave, PS-wave acquisition does not require costly S-wave sources.

Converted mode PS- wave data contain both P- and S-wave legs. The up-going portion of the PS-wave contains information about shear properties of an elastic media. These extracted properties can be utilized for interpretation and characterization of a reservoir.

In this research we consider poststack time domain of PS-wave data. The main advantage of that is better seismic image controlled by higher signal to noise ratio. Trace summation works as a noise suppression tool and assists in increasing seismic resolution.

Methodology

Inversion of PS amplitudes after the trace summation produces impedance estimation within the seismic bandwidth. Notice that this impedance, defined by Valenciano and Michelena (2000) as pseudo $\tilde{S}$-impedance, is proportional to PS reflectivity but not to SS reflectivity.

For further workability the inverted data must contain full bandwidth. Even though the most contribution to the inversion results is made by seismic amplitudes, low frequency part is important for determining absolute impedance values. This was a stumbling block for many years – inability to establish a model for stacked PS data, which would contain low frequency information of impedance inverted results.

The proposed method describes a simple technique that allows one to generate a low frequency impedance model from well log data and obtain full bandwidth impedance inversion of PS data in the poststack domain.

To understand the presented technique, we first need to introduce a new parameter – pseudo density ($\tilde{\rho}$). This quantity when multiplied by shear S-wave velocity produces pseudo $\tilde{S}$-impedance. To compute pseudo density the following equation can be utilized:

$$\tilde{\rho} = \rho^{\left(\frac{1}{4}\frac{V_P}{V_S}+\frac{1}{2}\right)},$$

where
$\tilde{\rho}$ - Pseudo density,
ρ - original density,
V_P – P-wave velocity,
V_S – S-wave velocity.

Complete derivation of the equation can be found in Guliyev (2007).

Pseudo density changes according to velocity ratio Vp/Vs. If the last equals 2, pseudo density is identical to the actual density. Also, the quantity $\tilde{\rho}$ cannot be estimated in the fluids, where shear modulus does not exist.

The parameters involved in the equation can be adopted from well log data, which have broader frequency content than seismic. Velocity ratio Vp/Vs can be calculated from sonic logs. If shear wave velocity is not available, it can be generated by empirical models (e.g. Castagna et al., 1985). The pseudo density log has similar magnitude but lowered absolute numbers than the actual log. As a result, pseudo $\tilde{S}$ -impedance estimations reveal lower values than actual S-impedance.

Figure 1 summarizes log analysis performed on the borehole data registered at Rulison field, Colorado. Calculated from dipole sonic, pseudo impedance log (red curve) mimics normal shear impedance logs (blue curve) but exhibits a shift towards the lower values (figure 1a). The square plot of two calculated logs shown in Figure 1b captures the linear relationship between the results. As seen in Figure 1b, both pseudo and normal shear impedance logs are responsive to gamma ray – the lithological indicator. In this example higher impedance values are indicative of tight sandstones, and therefore, correspond to lower gamma ray (Rojas et al., 2005).

Further, availability of P-wave, S-wave and density logs allows one to build an impedance model. Extrapolated product of S-wave log and computed pseudo density log reveals a series of layers with variable velocity, density, and thickness. To distinguish missing by seismic low frequencies, the model is further filtered to the required bandwidth. Afterwards, the generated impedance reproduction contains low frequency information and must be added to the final seismic amplitudes inversion results to obtain full bandwidth of impedance estimations.

We must recall that the outcome from inversion in this case is not the actual S-impedance but some pseudo quantity we assign for PS reflectivity. To convert pseudo $\tilde{S}$ -impedance to the actual S-impedance some corrections are needed to be applied. These corrections can be derived directly from log data.

Field Example

We applied the described methodology on 3-D multicomponent seismic data registered at Rulison field. The area of investigation is about 2.5 sq. miles. Three sections shown in Figure 2 represent time migrated PP-, PS- and SS-wave data within the interval of interest. The reservoir consists of gas charged tight sandstone lenses, forming a large depth interval of about 1,000ft. The productive interval is bounded by geological marks – KMV on the top and CAMEO on the bottom. Seismically, we can confidently define only the above KMV depositions of shale called UMV. Complex geology lowers impedance contrast and complicates reservoir characterization. However, absolute impedance numbers estimated through amplitudes inversion provide an

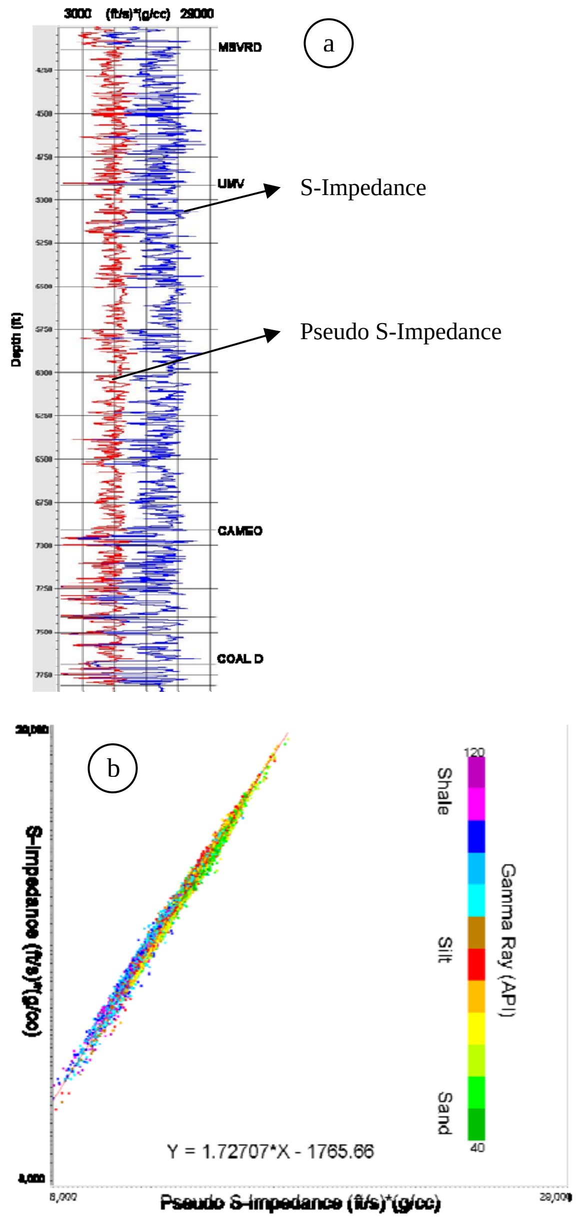

Figure 1: (a) Comparison of shear impedance (blue) with pseudo shear impedance (red) logs in depth. Shear impedances are slightly higher than pseudo shear impedances. (b) Crossplot of shear impedance versus pseudo shear impedance log color-coded by gamma ray log. As expected from the geological settings, higher impedance is corresponding to sand while lower – to shale. The derived from the plot regression line is used to estimate the corrections for pseudo shear impedance inverted results.

important tool for lithology description and reservoir delineation.

Impedance inversion of stacked PS data within the seismic bandwidth can be done by applying any of the algorithms for acoustic impedance estimations implied in commercial software packages.

For the seismic inversion of PS data we generalize two assumptions:

- Environment is isotropic and there is no reflected energy at zero offset.
- Summed near and far offset PS traces accurately replicate amplitudes at zero offset.

The first assumption is necessary to exclude the possible existence of reflectivity at zero offset point, which complicates the computations and is beyond the scope of the presented research. This assumption is reasonable because the anisotropy parameters estimated by Franco (2006) within the reservoir at Rulison field indicate the presence of a weakly anisotropic environment.

Consequently, the second assumption is important to assure validity of the stacked PS amplitudes. This can be verified after comparing the multicomponent time sections in Figure 2.

The low frequency model of pseudo $\tilde{S}$-impedance is created by using a single well, where cross dipole sonic tool provides both P- and S-wave velocity information. Small area of investigation and simple horizontal strata justify the application of a single well. Extrapolation guided by the picked horizons exhibits temporarily constant values. This excludes possible local artifacts that may appear due to interpolation between two or more wells.

Summation of log modeled and seismic inverted impedance volumes in frequency domain results in the pseudo $\tilde{S}$-impedance volume. The last can be used to estimate real shear impedances by applying the regression line in Figure 1b.

S-impedance volume was generated by applying similar model based inversion algorithm to the SS-wave data. Figure 3 compares the results of this conversion, S-impedance from SS-wave data on the left and corrected $\tilde{S}$-impedance from PS-wave data on the right. Both results are shown in PP time domain as this is the most used time domain. The sections show similar anomalies, although shear impedances from PS data reveal more detailed picture. The quality of the inversion can be assessed by comparing the results with a filtered shear impedance log at the well location (Figure 4). The log data compare favorably to the seismic derived shear impedance.

Conclusions

Shear impedance is an interpretation and reservoir characterization tool important for lithology delineation. Seismically derived impedance provides a vast area of estimations. However, the product of density and shear velocity information is not always readily available. Expensive SS-wave data rarely satisfies the need and usually are not being registered.

More commonly acquired PS-wave data contain S-wave information but the stacked PS amplitudes cannot be inverted for S-impedance directly. Instead, we propose to estimate pseudo impedance, the quantity proportional to PS reflectivity. The method suggests summation of low frequency pseudo $\tilde{S}$-impedance model and impedance inverted results within the seismic bandwidth. The outcome with applied corrections matches the S-impedance volume estimated from pure mode SS-wave data. Log and seismically derived impedance results also correlate favorably.

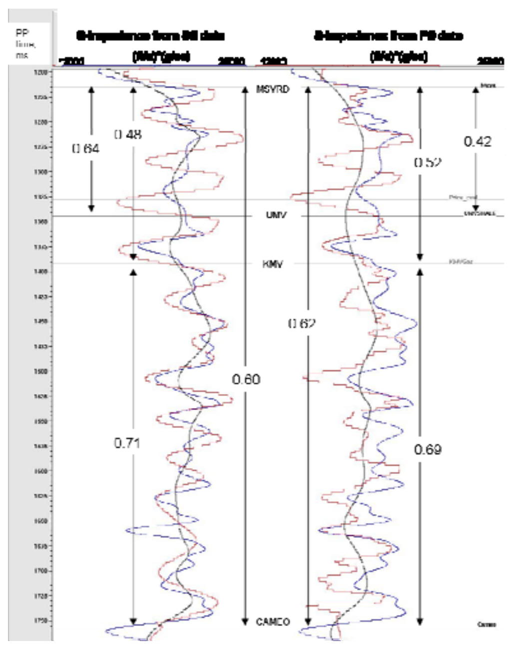

Figure 4: Comparison of seismic derived shear impedance (red) with log shear impedances (blue) at the well location used to create the background model (black). Vertical arrows indicate different intervals where the correlation coefficient between filtered log impedance and interval impedance was calculated.

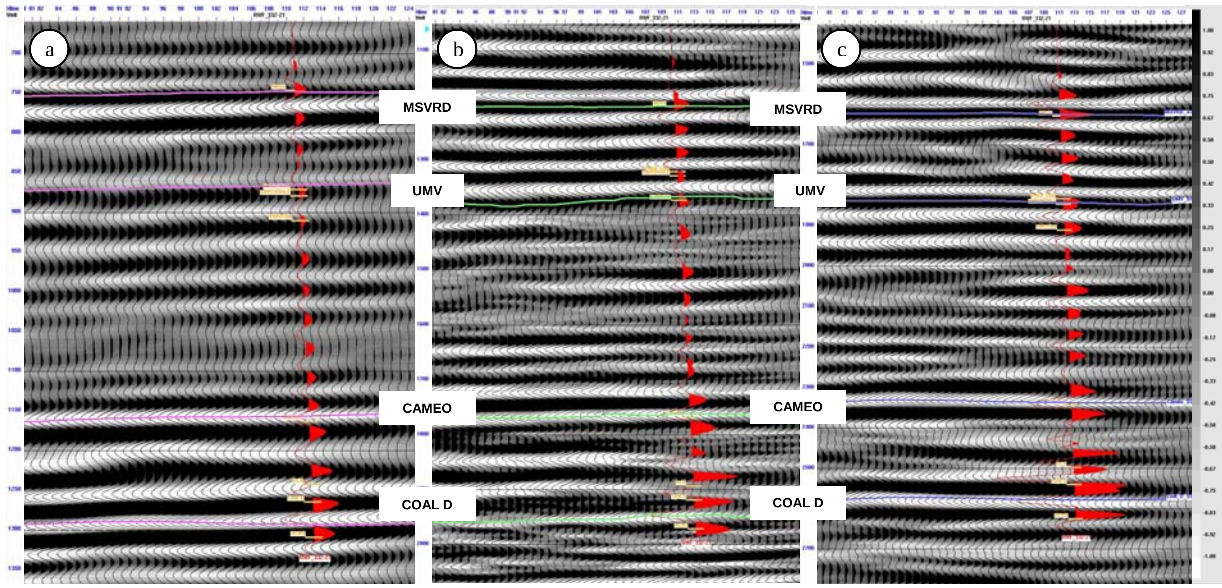

Figure 2: Multicomponent seismic data around reservoir interval. (a) Stacked PP data in PP time. (b) Stacked PS data compressed to PP time for display purposes. (c) Stacked SS data compressed to PP time for display purposes. Synthetic seismograms generated at the well are shown in red. The correlation coefficients for synthetic and field data are: 0.87 for PP data, 0.69 for PS data, and 0.7 for SS data

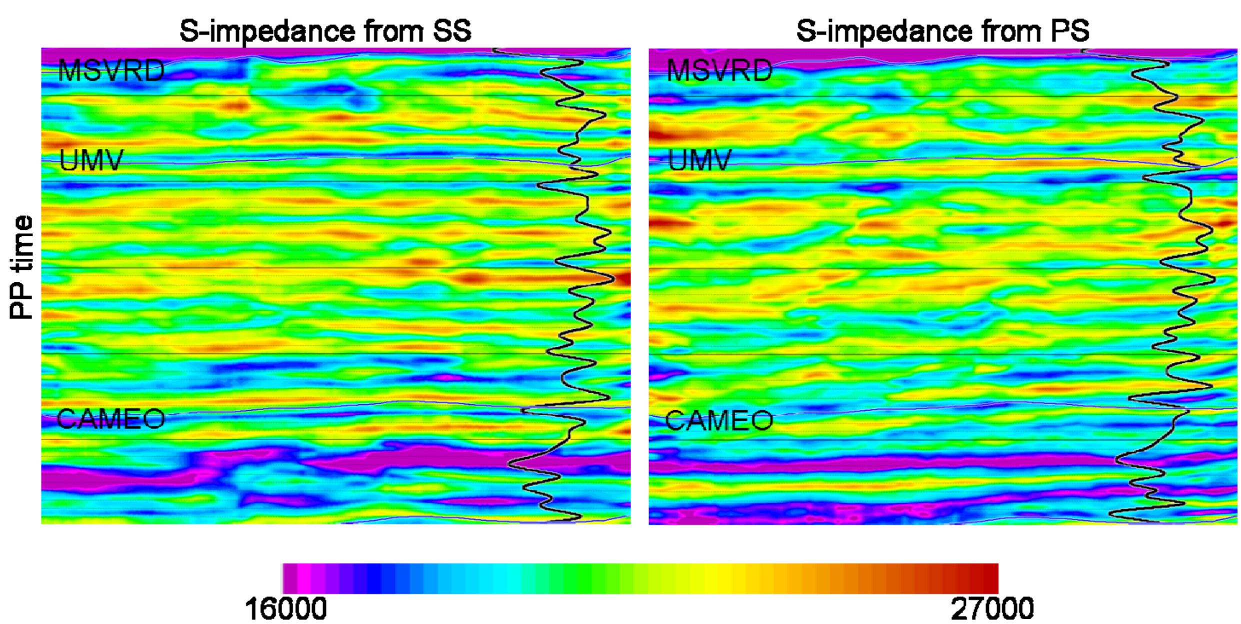

Figure 3: Cross section of shear impedance estimated from SS-wave data (left) and PS-converted wave data (right). Inserted black curve is S-impedance log, calculated from borehole data and filtered down to seismic bandwidth. The log data from this borehole were used to estimate the background model for the inversion algorithm

EDITED REFERENCES

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