Correlation of AVO inversion methods with porosity seen on logs and cores: A case study for Mississippian chert reservoir of Oklahoma, USA

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Summary

Inversion of Amplitude Versus Offset (AVO) results are used to derive elastic rock properties. These rock properties can be used for quick determination of lithology and fluid content for exploration/development of reservoirs. The AVO inversion methods such as Elastic Impedance inversion (EI) and LMR (Lambda-Mu-Rho) inversion are used and calibrated with porosity observed on well logs and on core plugs from a field in north-east Oklahoma, USA.

Introduction

Seismic attributes play a critical role in the efforts to reduce risk associated with reservoir prediction and description. Post stack inversion has proven to be a significant tool that allows geologic calibration and a volumetric understanding of the impedance data. When attempting to relate geologic parameters such as lithology, porosity, and fluid type in complex environments, additional parameters related to the rock physics must be utilized. AVO analysis plays an important role to characterize the reservoirs from pre-stack seismic data. The main AVO analysis techniques are 1. Intercept (A) and Gradient (B) method 2. Elastic Impedance (EI) inversion 3. Lambda-Mu-Rho (LMR) inversion.

The study area is from Osage County, north-east Oklahoma. Mississippian chert is the primary target in this area. Chert is an unconventional reservoir rock that is productive in west Texas, northern Oklahoma, south-central Kansas, California and Canada (Rogers and Longman, 2001). Cherts show low resistivity (< 1 ohm-m) and high porosity (15-40%) on well logs. In the present study, we used AVO inversion methods to characterize the high porosity Mississippian chert reservoir.

Elastic Impedance Inversion

Traditional AVO analysis involves computation of the AVO intercept and gradient from a linear fit of P-wave reflection amplitude to the sine square of the angle of incidence. In contrast to the traditional AVO analysis, Connolly (1999) formulated an elastic impedance approach where angle stacks for a range of incidence angles are inverted. Elastic impedance inversion (EI) is based on the elastic impedance formulation of the approximate plane P-wave reflection coefficient for a given angle-of-incidence ϴ. EI is a function of P-wave velocity, S-wave velocity, density and incidence angle.

The pre-stack seismic gathers have been divided into 3 different angle gathers: Near (0-15^0), Mid (15-30^0) and Far (30-45^0); and then stacked. These stacked volumes have been inverted to get elastic impedance volumes using commercial software. Three different wavelets have been extracted from the volumes and an impedance model has been built using the horizons. A model based inversion technique has been applied to obtain the elastic impedance volumes. The inversion results are now dependent on P-wave, S-wave velocities and density. The results indicate not only lithology but respond to fluid effects as well (Cosban et al., 2002).

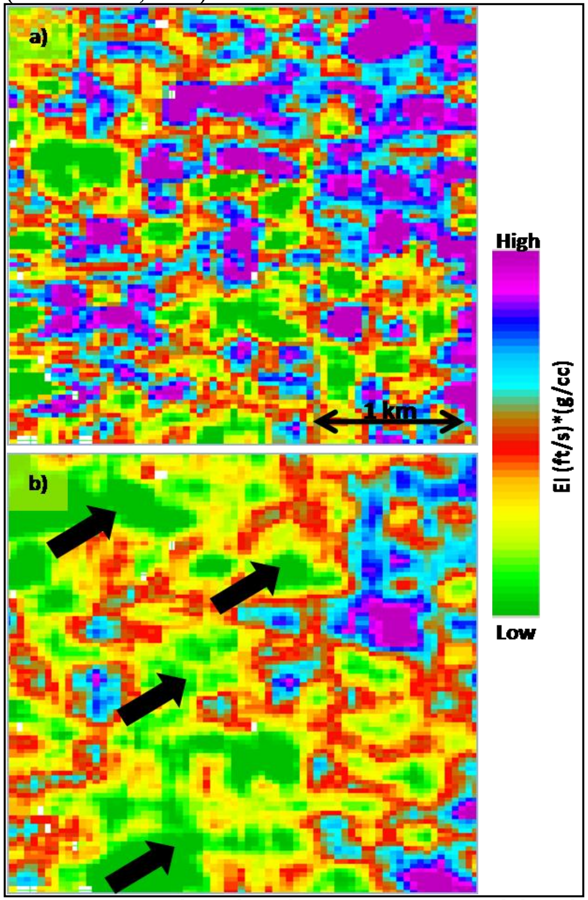

Figure 1: Horizon slices along the Mississippian interval through (a) EI near (b) EI far volumes.

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Figure 1 shows horizon slices extracted within Mississippian interval through elastic impedance near and far volumes. The resolution of the EI_far slice (Figure 1b) is better than the EI_near slice (Figure 1a). The black arrows in EI_far slice show low elastic impedance indicating gas saturated chert reservoir facies.

Figure 2 shows various elastic impedance logs calculated at different angles for the well. Note the impedance low for the gas saturated chert rock within the Mississippian interval. The impedance log range decreases from near angles to far angles may be due to fluid effects.

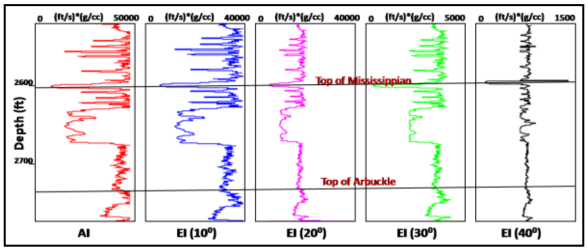

Figure 2: Various elastic impedance logs as a function of angle.

All three elastic impedance inversion angles show low impedance anomalies for the chert reservoir rock. The main challenge is to identify the good chert reservoir facies which have good porosities. To investigate fluid effects, we cross plot the EI_near and EI_far generated at the well (Figure 3). A zone with low EI values on the cross plot correspond to the highlighted zones on the well logs (Figure 3b).

Correlation of EI with porosity from logs

It is important to have a relation between the petrophysical properties with seismic derived properties in order to characterize the chert reservoir rocks. Cherts do show high porosities on the well logs. Impedance inversion is an indicator of lithology and fluid saturation. Chi and Han (2007) have shown the relationship between porosity and AVO attributes (intercept and gradient). An attempt has been made to see the relation between the porosity observed from well log to elastic impedance derived from the pre-stack seismic data.

We correlated the three elastic impedance inversion results with the porosity from the well log. We found that the relation between EI far with the porosity yields good relationship.

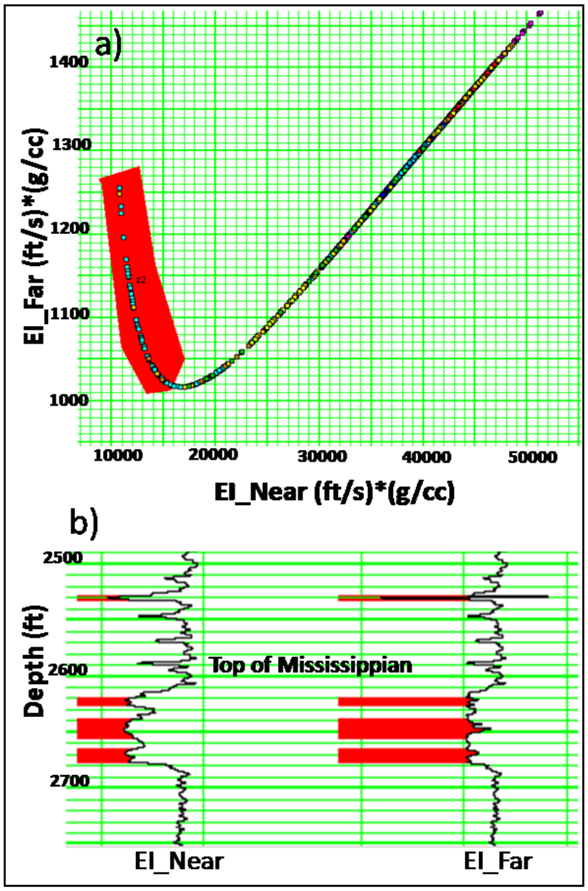

Figure 3: (a) Cross plot between EI_near and EI_far from the well. (b) Correlation of EI logs with the highlighted zones from the cross plot colored in red.

Figure 4 shows the cross plot between EI far and the porosity from the well. A zone (grey colored) with low EI and high porosity has been demarcated in the Figure 4a. The EI far section through the well is shown in the Figure 4b. Porosity log is inserted at the well. The highlighted zone is identified as low impedance value zone within the Mississippian interval from the section.

It is evident from the Figure 4 that the high porous chert reservoir facies have low elastic impedance and far angle EI gives more information about the fluid saturation also.

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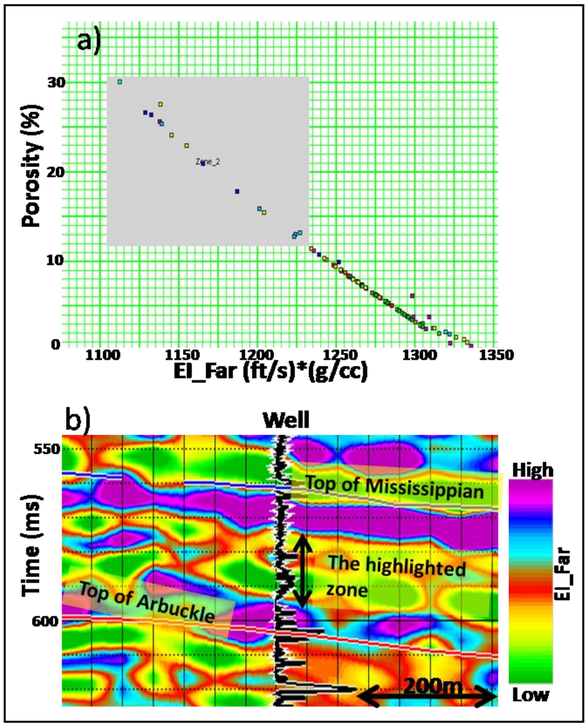

Figure 4: (a) Cross plot between EI far and porosity log from well. (b) EI far section through the well. The highlighted zone in the cross plot is shown in the EI section.

Correlation of EI with porosity from core

One of the wells nearby the study area has been cored and different petrophysical parameters have been measured in the laboratory. Porosity and permeability were calculated using helium gas at three different confining pressures: 800, 1500 and 3000 psi. An attempt has been made to understand the relation between the elastic impedance with porosity measured on core samples from the same chert reservoir.

Figure 5 shows the cross plot between EI log measured at 40^0 angle and the porosity measured on the core plugs. The plot indicates that high porous chert has low elastic impedance and vice versa.

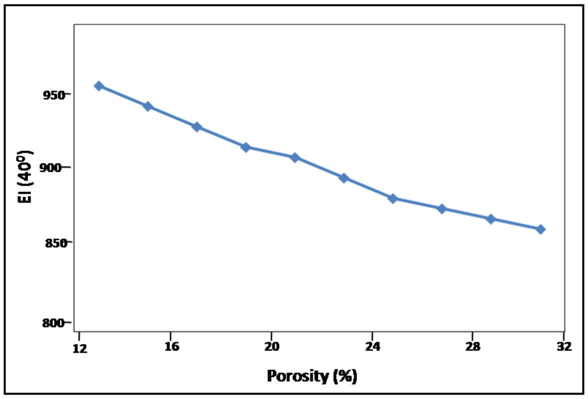

Figure 5: Plot between elastic impedance log and porosity measured from core plugs.

AVO inversion for Lame rock parameters

Reservoir properties can be defined in terms of fundamental rock parameters such as incompressibility and rigidity. Goodway et al. (1997) suggested the use of Lambda-Mu-Rho analysis to extract lithology and pore fluid information from seismic and well log data. Impedance reflectivities are related to Lame parameters of incompressibility (λ) and rigidity (μ) by the relationships $\lambda\rho = Zp^2 - 2Zs^2$ and $\mu\rho = Zs^2$, where ρ is bulk density. Lambda-Rho is a sensitive indicator of water versus gas saturation and Mu-Rho is used to help determine pure rock fabric or lithology.

A standard AVO method is used to compute estimates of P-wave and S-wave reflectivities directly from pre-stack data. These two datasets are then inverted, using model based inversion technique to generate both P and S impedance volumes. After deriving the P and S impedance volumes, we estimated the Lame parameters, Lambda-Rho and Mu-Rho, which can be related to fluid and rock properties.

Cross plotting is widely used in AVO analysis, because it facilitates the simultaneous and meaningful evaluation of two attributes. 2D/3D AVO plotting will help for better interpretation of different attributes for different rock types with different fluid saturations (Chopra et al, 2003).

We plot the results of Lambda-Rho ($\lambda\rho$) with Mu-Rho ($\mu\rho$) colored with porosity within the Mississippian interval from the well. The chert reservoir facies which have good porosities (> 24%) show low values of $\lambda\rho$ and $\mu\rho$ on the cross plot. Limestone which has 1-5% of porosity show high $\lambda\rho$ and $\mu\rho$ values on the cross plot. The highlighted zone is shown in respective logs in the well.

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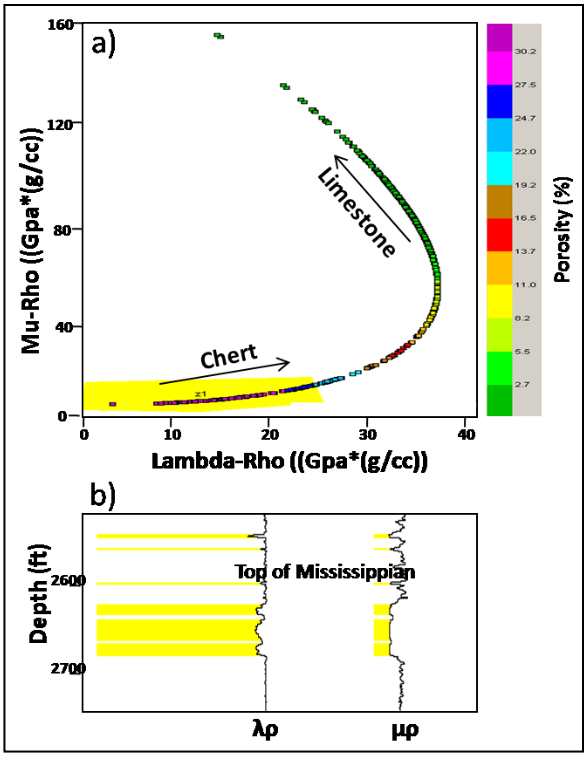

Figure 6: (a) Cross plot between Lambda-Rho and Mu-Rho with porosity as colored b) The highlighted yellow zone is shown in the well logs of λρ and μρ.

Fluid substitution model

The Vp, Vs and density logs have been re-generated using 3 phase fluid model. We considered the three phases of fluids: oil (10%), gas (30%) and brine (60%). Elastic impedance logs were generated using the fluid substituted logs. The EI logs calculated for near angle (7^0) and far angle (37^0) are shown in the Figure 7.

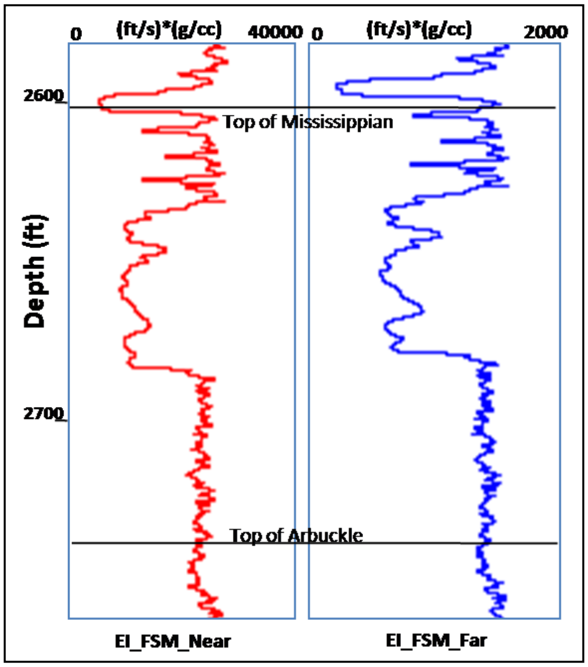

Figure 7: Fluid substituted EI logs generated for near and far angles from the well.

Conclusions

Rock properties can be derived from inversion of AVO stacks. These results greatly reduce the ambiguity for determination of lithology and fluid content. The AVO inversion methods such as elastic impedance inversion and LMR inversion have been used to characterize the Mississippian chert reservoir from north-east Oklahoma. Sweet spots of cherts, which have more than 20% of porosity have been identified from pre-stack seismic data using AVO inversion methods. Elastic impedance results have been correlated with porosity seen on logs and cores. Cross plotting has further helped to identify the better reservoir facies.

Acknowledgments

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EDITED REFERENCES

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