The Elastic Impedance Inversion Method And Its Application In SLG Gas Field

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Summary

The acoustic impedance (AI) differences between gas-sand and shale are very small in SLG gas field of Western China. Therefore the lithologic prediction solely by AI inversion will lead to multi-solution problem. Ni proposed a new elastic impedance (EI) calculation method (Ni, 2003) to deal with the seismic inversion and the prediction of lithology and fluid. In this paper, we compared this method with BP EI method in Jason commercial package; we concluded that our method has better liquid recognitions ability on inverted profiles.

Introduction

SLG gas field is the major gas supplier for China’s famous project of “transport the natural gas from the West to the East”. In SLG area, the AI differences between gas-sand and shale are very small. Therefore the lithologic prediction solely by AI inversion will not resolve the uncertainties. The inversion method using S-wave becomes very popular in this area.

The EI (Connolly, 1999) is an inversion technique, which combines AI with pre-stack AVO inversion technologies and uses the angle stack data with different incidence angle. Whitcombe (Whitcombe, 2001) proposed a method of AI-GI (Gradient Impedance) crossplot as an aid to analyze the distribution of lithology and fluid. Inspired by AI-GI crossplot method, we use the crossplots analysis of EI-AI with different incidence angle to select the suitable seismic angle stack data for EI inversion. We also considered them as a guide to predict the lithology and fluid distribution. Since different EI calculation methods make different results, we used both methods (Ni and Jason BP’s methods) to calculate EI. Then, we inverted the seismic data and predicted the lithology and fluid based on EI-AI crossplots using the EI from both methods. Crossing well Su20 of Line 557 in SLG area was used to illustrate our methodology.

Methodology

Based on the EI research made by Connolly (Connolly, 1999) and Whitcombe (2002), Ni (Ni, 2003) proposed the following EI equation:

$$EI(\theta) = V_{p0}(\frac{V_p}{V_s})^{\sin^2(\theta)}$$

where $\theta$ is incidence angle; $V_p$ is P-wave velocity; $V_s$ is S-wave velocity; $p$ is density; and $K= V_p^2/V_s^2$, is a constant from the average of adjacent layers.

Three reference constants $V_{p0}$, $V_{s0}$, and $\rho_0$ are used to ensure that the EI calculations from different angles are with the same scale as the AI calculations. $\tan(\beta) = \sin(\theta)$, and $\beta$ is a independent variable. The norm $p$ is a real number greater than 0. When $\beta=90^\circ$, $EI=AI$; $\beta=0^\circ$, $EI=GI$ (Gradient Impedance), in which the EI is the same as the term B in AVO equation $R=A+B\sin^2\theta$.

Like AVO response analysis by crossplot of gradient B vs. the interception A from AVO Equation, we can research the lithology and fluid distribution by the crossplot of AI as X axis and GI as Y axis. Since we can’t get seismic data when $\beta=90^\circ$, we used the EI values when $\beta$ is less than $90^\circ$ in EI-AI crossplots. We did EI inversion based on the crossplot and then predicted the distribution of lithology and fluid with the help of well logging and drilling data.

Case Studies

Well Su20 is a gas well in SLG gas field. S-sonic data was measured in this well. The well encounters four gas anomalies in Shihezi Group of upper and lower Permian series. Among four gas anomalies, two of them were interpreted as gas formations and the other two were interpreted as gas-water formations. In this area, the Gamma logging has a good correspondence with lithology distribution. Generally, Gamma value greater than 100gAPI corresponds to shale, Gamma value between 50-100gAPI indicates sand, and Gamma value less than 50gAPI may be saturated sand. Based on above facts, we made the AI-GI crossplot based on the statistical data in upper and lower Permian series of well Su20. Figure 1 shows the crossplot. From this figure, we can conclude:

1) In X-axis direction, the AI difference between sand and shale is small; so is the difference between gas formation and gas-water formation. The maximum difference is less than 2000m/s*g/cm$^2$. This will lead to obviously uncertainty for lithology prediction only by the conventional AI inversion.

2) By combining AI and GI, we can draw two orthogonal projection lines: Lithology projection line and fluid projection line. In lithology projection line direction, the GI difference between sand and shale is more than 3000m/s*g/cm$^2$. In fluid projection line direction, the GI difference between good gas formation (HC=2.62, R=25.65) and shale is also more than 3000m/s*g/cm$^2$, the difference between bad gas formation (HC=2.39, R=8.88) and shale is small. So the projection line resolutions are much better than the resolution of AI.

Figure 2 shows AI-GI crossplot based on real data with the same depth range in Figure 1. Although the dispersion degree of real data in Figure 2 is very large due to measure...
error and random noise, the aforementioned conclusion is still tenable. Generally, AI is effective on lithology inversion and is the technique most commonly used at present. However, the AI inversion has some limits in lithology and fluid resolutions. In this case, the EI inversion technique based on incidence angle stack data will help to improve the interpretation results.

From EI-AI crossplots, we can determine the incidence angle based on the target formation data and then extract the angle stack. The angle stack will then be used for inversion. Figure 3 shows 8 EI-AI crossplots with different incidence angles (10, 20, 25, 30, 40, 50, 60, and 70 degrees for crossplots 1–8) from Su-20 within the depth interval of 3086-3655m. The formations covered in this interval include the Shiqianfeng group of Upper Permian series, Shihezi group of Upper and Lower Permian series, Shanxi group and Taiyuan group of Lower Permian series, and Majiagou group of Lower Ordovician series.

On Figure 3, the clusters with higher impedance belong to carbonate reservoir in Majiagou group of Lower Ordovician series and the clusters with lower impedance belong to clastic reservoir in Permian series. In Permian clastic reservoir data, it is hard to discriminate lithology and fluid types unless the incidence angle is larger than 40°. However, the quality of stacking data is affected by the incidence angle. The larger the incidence angle is, the less reliable the stacking data will be.

The similar characteristic of lithology and fluid distributions in well Su-20 was also found in well Su-21 and Shan-210 based on S-sonic and other logging data.
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This means that the characteristics of lithology and fluid distributions are common features. Based on above analysis, we conclude that the EI inversion can be used to predict the distribution of lithology and fluid. Due to the limitations of seismic data, we selected the 25° angle stack and we should only do the inversion for target zone.

An EI calculation method called BP EI method is provided in Jason commercial package. The calculation method comes from Connolly formula. We developed an EI calculation method based on an adjustable norm. We compared two methods using real data.

Figure 5 shows the inverted result of line 557 crossing well Su20. In this figure, the color legends of three profiles are all the same. We can see that EI provides more information than AI. In the target area, the shale has relative high impedance and the gas and gas-water sands have lower impedance.

Figure 6 shows the sand distribution predicted based on EI25° inversion using our proposed EI method. The clusters of every type of lithology are concentrated in its own area and can be clearly identified.

Figure 7 shows the distribution of gas sands and Figure 8 shows the distribution of gas water sands based on our proposed EI25° inversion. It is significant that parts of gas sands are located on the top of gas water sands.

Figure 9 shows the result from BP EI method in JASON package. In this case, the lithology distribution is very dispersive and it is difficult to separate one type of lithology from other type of lithology.

Figure 5 Comparison of AI and EI25° of Line 557

The upper section is AI, the middle one is EI25° by Jason BP method, and the bottom one is EI25° by our proposed method. The black curve in the middle of these three sections is gamma log in Su20.

Figure 6 the prediction sand in Line 557 by proposed EI25°, the area with circle in left corresponds to the black zone on the bottom EI inverted profile.

Figure 7 the gas prediction in Line 557 by proposed EI25°. The area with circle in left corresponds to the black zone on the bottom EI inverted profile.

Conclusions

AI inversion is a popular technique for lithology prediction. However, the technique has low lithology resolutions when the AI values of shale and sand formations are close or overlapped. The AI-GI crossplot based logging data can be used to determine whether the AI technique has good lithology resolutions for target reservoir. AI-EI crossplots are helpful to choose suitable incidence angle stack data for EI inversion. Furthermore, we can effectively identify the distribution of lithology and fluid based on the AI and EI integrating results. The case study in this paper shows the feasibility of this methodology.

References


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Figure 8 Line 557 gas-water prediction by proposed EI25°, the area with circle in left corresponds to the black zone on the bottom EI inverted profile.

Figure 9 Line 557 inversion result by BP EI25° method in Jason. The black area in (d),(e), and (f) correspond to the circle in (a),(b), and (c) respectively. Since the distribution of sand on Al-EI crossplot is dispersive, it is difficult to differentiate sand from shale.