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Elastic Attribute Generation From 3 Points Elastic Inversion

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Abstract

The concept of Elastic Inversion (EI) has been generally accepted over the last few years in the exploration and production environment. EI reconstructs elastic attributes, such as Poisson's ratio, V_p/V_s ratio and other attributes using angle stack AVO data. This paper discusses a 3-point elastic inversion method.

As its name suggests the 3-point inversion needs three impedance values at each location for calculating various elastic attributes. First, three angle stacks are calculated and inverted individually to reflectivity impedances using standard seismic software. The three resulting reflectivity impedances are associated with angle-dependent elastic impedance by Connolly's (1999) formula. Unfortunately, this EI formula is strongly dimension-dependent, which makes application of it difficult since it predicts very large values of EI for small angels and small values of EI for large angles.

In 2002 Withcombe derived a dimensionless version of Connolly's formula. It contains quantities V_p, V_s and ρ normalized by the background (average) values of V_p, V_s and ρ. The background values are derived either from the mudline or from existing logs. We obtain stable results using a slightly modified version of Whitcombe's and Connolly's formulae. Here, we present and discuss real-data results on a Frio reservoir.

The Elastic Inversion Concept

Elastic Inversion reconstructs elastic attributes, such as V_p/V_s ratio, Poisson's ratio and other attributes using angle stack AVO data. First, three angle stacks are calculated, e.g. at near (5-15 degrees), middle (15-25 degrees) and far angles (25-35 degrees). Next, each of these angle stacks is inverted to reflectivity impedances, using standard seismic software. The following method is used to associate the three resulting reflectivity impedances with angle dependent elastic impedance.

According to Connolly (1999), Elastic Impedance EI depends on angle θ :

$$EI = (V_p)^{1+\sin^2\theta} (V_s)^{-8K\sin^2\theta} (\rho)^{1-4K\sin^2\theta}$$

where V_p is p-wave velocity, V_s is s-wave velocity, ρ is density and K is empirically calibrated constant.

Unfortunately, Connolly's EI formula is strongly dimension-dependent, which makes application of it difficult since it predicts large values of EI for the small angles and small values of EI for large angles. Whitcombe (2002) derived a dimensionless version of the EI formula:

$$EI = V_{po}\rho_o \left(\frac{V_p}{V_{po}}\right)^{1+\sin^2\theta} \left(\frac{V_s}{V_{so}}\right)^{-8K\sin^2\theta} \left(\frac{\rho}{\rho_o}\right)^{1-4K\sin^2\theta}$$

which contains quantities V_p, V_s and ρ normalized by the background (average) values of V_{po}, V_{so} and ρ_o. This is the formula used for this elastic inversion. Assuming that K=2, and taking the logarithm of EI and rearranging the terms, we have:

$$\ln(EI) - \ln(V_{po}\rho_o) = \ln\left(\frac{V_p\rho}{V_{po}\rho_o}\right) + \sin^2\left(2\ln\frac{V_pV_{so}}{V_sV_{po}} - \ln\frac{V_p\rho}{V_{po}\rho_o}\right)$$

As can be seen, the log of EI linearly depends on $\sin^2\theta$. Therefore, parameters of a linear trend to log-EI could be converted to $\frac{V_p}{V_s}$ ratio:

$$\ln(EI) - \ln(V_{po}\rho_o) = R + \sin^2 G$$

$$\frac{V_p}{V_s} = \frac{V_{po}}{V_{so}}\exp(G+R)/2$$

Assuming background values $\frac{V_{po}}{V_{so}}=2.5$, and $\ln(V_{po}\rho_o) = mean(\ln EI)$.

Seismic example

The Frio reservoir is a stratigraphically trapped sand and shows a large drop in acoustic impedance when gas saturated. This results in a typical bright spot around the gas reservoir. However, amplitude alone does not seem to define the limits of the gas sand sufficiently and elastic attributes were calculated.

Figure 1 shows an amplitude horizon map at the top of the Frio reservoir. Around well-2 amplitude anomalies are present, which are most likely caused by the gas. However, this figure does not clearly show the extent of the reservoir.

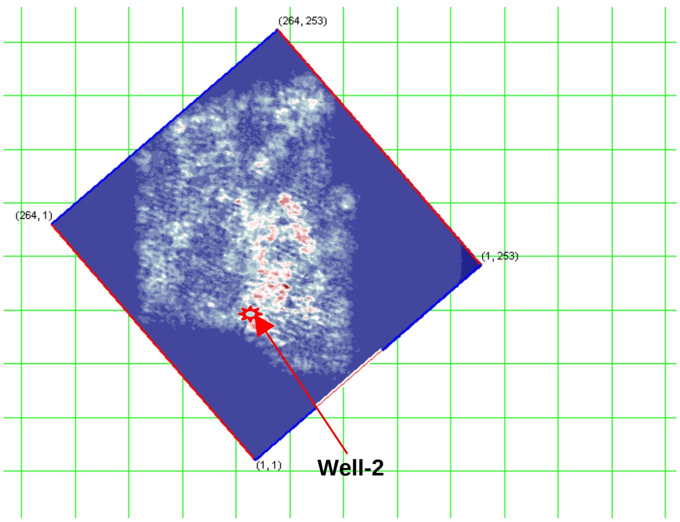

Figure 1: Amplitude map at top of Frio sand.

Figure 2 displays the elastic attribute Poisson's ratio. For the calculation of this map, the same horizon and same time window as for the amplitude map were applied. This figure shows more details then figure 1. For example, around the well location there are low Poisson's ratio values.

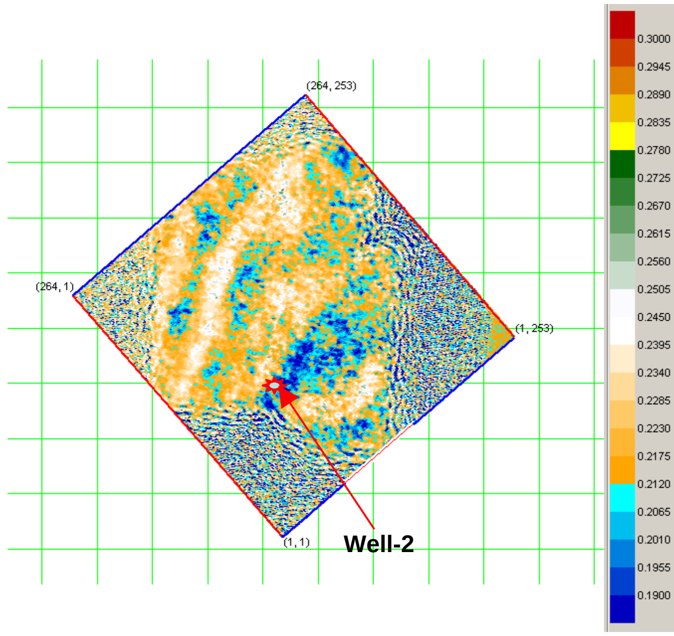

Figure 2: Poisson's ratio elastic attrbiute map, top of Frio formation.

Figure 3 shows a lambda/mu horizon map. Although, this attribute still displays an anomaly around the producing well-2, it does not show the possible extent of the gas field as clearly as the Poisson's ratio map.

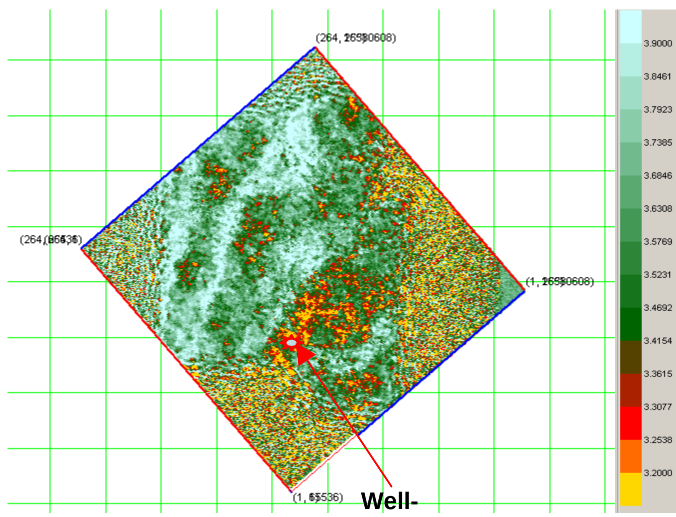

Figure 3: Lambda/mu elastic attribute map, top of Frio formation.

Figure 4 displays the acoustic impedance, calculated using the same formulas as for the elastic attribute calculation. In this scenario, the acoustic impedance does not resolve the gas reservoir very well.

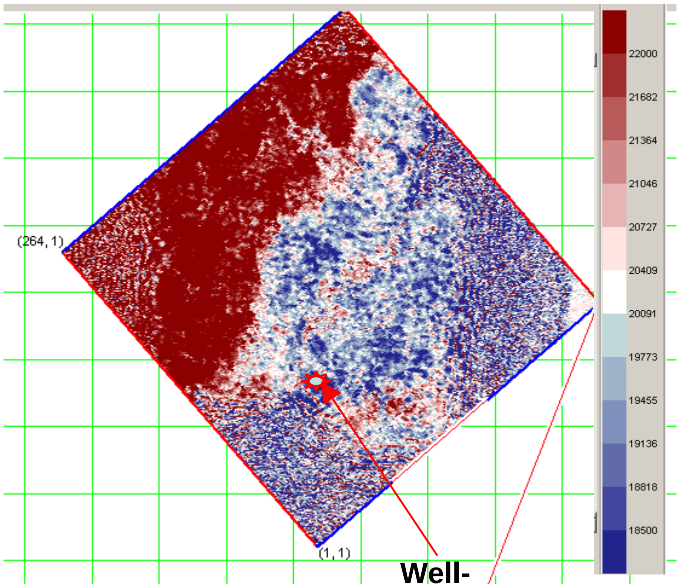

Figure 4: Acoustic impedance at the top of the Frio gas reservoir.

Conclusions

A practical application of the modified Whitcombe's and Connolly's formulae shows very encouraging results over a known and explored gas field in the Frio formation. The widely used approach for calculating elastic attributes designed by Connolly in 1999 has the disadvantage of needing a scaling factor for each angle stack. Even with this scaler, it is extremely difficult to calculate realistic elastic attribute values. Therefore, until recently, elastic attributes such as the Poisson's ratio could be used for predicting hydrocarbons but for example not for porosity calculation. With the new approach for calculating elastic attributes, which does not rely on difficult normalization processes, much more realistic values for the attributes can be extracted. This opens a door for usage of these attributes in more complex reservoir studies, such as porosity predictions or even flow simulations.

References

Connolly, P., 1999, The Leading Edge, Elastic Impedance, pg. 438-452.

Whitcombe, D.N., 2002, Geophysics, Elastic Impedance Normalization, pg. 60-62.

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