Stabilizing the AVO Gradient

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Summary

A technique to reduce the noise in AVO gradient data is presented. This filtering technique is a post-processor to a traditional AVO fit. It has its roots both in time windowed AVO (Ratcliffe & Adler, 2000), and also in hodogram technology (Keho et al., 2001). Both of these approaches utilize the principle that, for noise-free data, we expect a constant relationship between the intercept A, and gradient B for each point in the wavelet associated with a discrete reflection event. In B vs. A crossplot space these points would plot along a trajectory passing through the origin and characterized by a specific angle, which we call $\chi$, and measure anti-clockwise from the positive A axis.

While hodogram technology uses this relationship to generate attributes for the identification of AVO anomalies, and time-windowed AVO uses it to aid with velocity picking in class II territory, the output of our new technique is an improved AVO gradient volume. The approach can therefore be used as a pre-processor for traditional AVO crossplotting (e.g. Castagna & Swan, 1997), or to precondition data for elastic impedance inversion of the intercept and gradient volumes (Whitcombe et al., 2002). This technique has been successfully applied to many data sets.

Introduction

AVO gradients are notoriously noisy. Their statistics are well understood (Spratt et al., 1993). Typically AVO gradients can be an order of magnitude more noisy than the intercept attribute. This has put many people off using gradients.

Extended Elastic Impedance theory (Whitcombe et al., 2002) demonstrates how the ‘Elastic Impedance’ of a gradient trace may be determined, and how many other elastic attributes (e.g. shear modulus, shear impedance, Lame’s constant, $\lambda$, bulk modulus and Poisson’s ratio) can be determined by inverting linear weighted combinations of A and B. These elastic attributes can alternatively be obtained by inverting weighted combinations of near and far offset stacks. This alternative at first looks attractive as near and far stacks have more similar noise characteristics than A and B volumes. However, the noise problem does not go away: A weighted combination of far minus near stacks produces a volume with very similar noise characteristics as the B volume. By working directly with B, we are better exposing the noise in the system at an early stage, and can then attempt to suppress the noise prior to generating linear combinations for EI or EEI inversion. This approach should therefore provide better quality data than using linear combinations of near and far angle stacks.

Another advantage of using intercept and gradient is that the statistics of the AVO fit can be generated and preserved as a quality measure during subsequent analysis. This is particularly relevant now that full pre-stack time migration prior to AVO is readily available: The AVO gathers are in their final migrated position and the AVO fit parameters do not need migrating into a final interpretation position.

Theory

Before describing the process, we will first consider a B vs. A crossplot for an AVO fit through gathers containing pure random noise and no geological signal. The gathers were simulated to a maximum angle $\theta$ of 30 degrees, with an average $\sin^2 \theta$ of 0.11. The stack of these data can be recovered exactly using the relationship stack = A + 0.11 B. Several authors (Simm et. al., 2000; Whitcombe et al., 2002) have noted the relationship between $\chi$ and $\theta$, namely:

$$\tan \chi = \sin^2 \theta$$

(1)

Figure 1: Intercept-gradient crossplot from gathers containing only noise. This noise shows up as correlated noise on the A and B crossplot. This correlation can be removed by rotating from the A, B coordinates to the stack and ortho-stack directions.
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Using this relationship we determine an angle $\chi$ of 6.3 degrees for the stack direction, and therefore an angle of $\chi = 96.3$ degrees for the ‘ortho-stack direction’. We see from figure 1, that the stack direction aligns with the direction of minimum noise, while the ortho-stack direction aligns with the direction of maximum noise on the crossplot.

Our filtering approach utilizes the fact that, for a noise free, discrete reflection event, each time sample through the wavelet shows the same relationship between A and B (figure 2), characterized by the angle $\chi$.

We will be carrying out linear regressions of the (A, B) data in order to fit noisy data with a model, and hence reduce the noise. Within the linear regression process, residuals are minimized in the Y direction, while data are untouched in the X direction. The x-axis is therefore chosen in the direction of the stack, and the y-axis chosen in the direction of the ortho-stack. We therefore first rotate our data $A$, $B$ to $A^1$, $B^1$, where $A^1$ aligns with the stack direction and $B^1$ aligns with the ortho-stack direction.

We take a moving time window and within each window perform a best-fit linear regression through the data (Figure 3). This models the expected linear relationship between B and A (and therefore $B^1$ and $A^1$) in the window. We use this model to predict a new $B^1$ value, $B^1_{\text{model}}$, from the $A^1$ value for the sample at the center of the window.

Figure 4 illustrates the application of the process to the random noise shown in figure 1. We used a moving window of 5 samples, and this has decreased the scatter in the ortho-stack direction to 66% of its original value. Greater noise attenuation would be achieved by using a longer time gate.

**Limitations**

The main limitation of the process is that if the geology is varying rapidly along the time axis, the relationship between A and B (i.e. $\chi$) can also change rapidly. This variability of $\chi$ can be investigated from log data. Note, however, that for a stack of thinly bedded sand-shale layers, where all the sands have identical properties, and all

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**Figure 2:** (Adapted from Keho et al, 2001). This illustrates the expected behavior of all the samples in the wavelet associated with a discrete event characterized by positive A and B reflection coefficients (the peak of the event is described by the red circle). This example shows the noise free case.

We take a moving time window and within each window perform a best-fit linear regression through the data (Figure 3). This illustrates the filtering process. 5 data points in a time window are input into the process (blue points). A linear regression is carried out using these points. The central point in the window is then replaced by the linear model prediction (red point). The time window slides down by one sample and the process is repeated.

We repeat this operation for all samples in the trace, sliding the window down a sample at a time. We then back-rotate the $A^1$, $B^1_{\text{model}}$ into new A and B data. While the A data is changed by the process, most of the noise suppression happens on the B data. Note that the stack is preserved through this process.

Figure 4 illustrates the application of the process to the random noise shown in figure 1. We used a moving window of 5 samples, and this has decreased the scatter in the ortho-stack direction to 66% of its original value. Greater noise attenuation would be achieved by using a longer time gate.
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the shales have identical properties, $\chi$ will remain constant. The time window should be set to minimize ‘smoothing through geology’. In practice we tend to choose a relatively short time window (approximately half the dominant period of the signal), but also include samples from adjacent inlines and xlines. For steeply dipping structures we extract neighboring traces along the dominant dip of the data. In practice we are looking for the smallest ‘box’ of data that will deliver an improved and adequate gradient attribute, without ‘smoothing the geology’.

Data pre-conditioning prior to gradient stabilization

It is well recognized that gradient data are sensitive to velocity errors. This is well accepted by the authors, who regard a high lateral frequency velocity fields, with grids of 50m*50m or better a pre-requisite for AVO analysis (McKenzie, 2004).

Keho et al (2001) demonstrated that NMO stretch disrupts the linear relationship between A and B. We have found it beneficial to apply spectral balancing to offset planes prior to applying gradient stabilization.

We often additionally apply noise suppression to the gathers, and routinely apply a robust AVO fit, which automatically rejects outliers prior to the AVO fit for A and B.

Data examples

Figures 5 and 6 show the input and output sections respectively for a N Sea example. It can be seen that significant noise reduction has been achieved for the gradient section. This has delivered better interpretability. The event alignments between the intercept and gradient sections have also been improved. This is particularly beneficial when going on to generate linear combinations of the two volumes for lithology and fluid discrimination.

Conclusions

The technique described allows noise suppression to be targeted at the noisiest direction in the AVO space. This provides light noise reduction to the intercept data and heavier suppression to the gradient data. The resulting gradient data are more interpretable and better temporally aligned to the intercept data.

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References


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Figure 5: Intercept and gradient sections from a N Sea data set, input into filtering process.

Figure 6: Intercept and gradient sections output from the filtering process. A moving window \((t, IL, XL) = (5,5,5)\) was used. Note the noise reduction and resultant improvement in interpretability of the Gradient section. Note also that the intercept section is little changed by the process.