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AVO Crossplotting I: Processing and Calibration Considerations

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Introduction

Amplitude Variation with Offset (AVO) is a valuable tool for extracting fluid and lithology information from seismic data. Crossplotting AVO attributes can yield qualitative and quantitative measures of any given AVO anomaly relative to background trend rocks. Seismic processing and gather calibration (or lack thereof) can have a significant effect on the behavior of the data populations being interpreted in AVO crossplot space. Rotating intercept/gradient crossplot slopes (what Gidlow and Smith (2003) call the fluid factor angle, and Foster et al. (1997) the fluid line) observed in seismic data can often be directly attributed to the difficulty inherent in preconditioning gathers for AVO analysis. In this paper I will review the theoretical expectations regarding AVO crossplot behavior, the role of seismic gather calibration (or lack thereof), and the value of various compensating methods. Best practice procedures are stressed throughout the discussion. This paper is a shortened version of a recent CSEG Recorder article (December 2008).

Processing for AVO / Calibration

Cambois (2000) defines a processing workflow meant to be AVO friendly simply as “any sequence that makes the data compatible with Shuey’s equation” (or various other Zoeppritz approximation methodologies). *True Amplitude*, *Preserved Amplitude*, and *Controlled Amplitude Controlled Phase (CACP)* are a few examples. Many of these workflows include deterministic and/or statistical corrections calculated by incorporating well logs and/or geologic models. These workflows may comprise larger amplitude corrections, such as geometrical spreading and absorption (Q), or more subtle ones, like angle of emergence and array corrections. Typically these workflows apply time and offset variant corrections in an attempt to compensate for the earth filter. Several authors have discussed at length the difficulties inherent in this process, including Cambois (2001) and Bachrach; Kozlov and Ivanova; Landro and Stavos (2006).

Processing workflows like the one described by Ramos (1998) highlight the need to compare and contrast the AVO behavior after every processing step. Qualitative and quantitative evaluation involving the amplitudes of our primaries is performed to determine if any gradient responses have been altered. Gather difference plots are an interpreter’s best friend when maintaining quality control. Some QC methods need to be more sophisticated in order to quantify any possible changes. For example, the difference of a gather pre- and post-spectral whitening cannot be used because the frequency content of the primaries has been altered too dramatically. In these cases it is necessary to crossplot the AVO attributes, before and after the process to test the response on known population outliers.

The goal of these true amplitude flows is to restore the amplitude (and phase) response to a point where geologic meaning can be inferred. It is important to understand that the gradient behavior (as a function of time) is dependent upon the processing applied to that data. All background trend rocks have amplitudes that decay as a function of offset. In other words, positive intercepts have negative gradients, while negative intercepts have positive gradients (For the sake of simplicity I am generalizing to only include consolidated rocks, not rarer low velocity regime background rocks which can have amplitudes which can increase in magnitude with offset). The rate at which these gradients decay can be very much affected by the processing applied, especially when offset varying applications are present. The first check when quality controlling CDP gathers is to verify that the majority (i.e. non-anomalous) of the reflection events do indeed decay. This decay should be noticeable over the angle of incidence range of 0-40 degrees, and then the amplitudes can sharply increase again as they approach the critical angle. *Note:* this means that for shallow data the amplitude decay will happen relatively quickly over a given offset range compared to the decay that will be more gradual deeper in the section over the same offset range. Another way of expressing this is: as time increases the angle of incidence range decreases.

A common misunderstanding is to assign a correlation between the rotating intercept/gradient crossplot slope observed in seismic data and the rotating background trends as described by Castagna and Swan (1997). This is discussed at length in my follow-up 2009 CSEG presentation titled *AVO Crossplotting II: Examining Vp/Vs behavior*. Despite our attempts, most processing flows do not fully account for all of the complex earth filtering of the data. Apparent rotations in crossplot space (static or time variant), measured on real data, may actually be telling us more about how much residual earth compensating corrections are still required rather than representing actual geologically meaningful Vp/Vs trend variations. The issue is further complicated when the effects of noise are considered, as discussed by Cambois (1998). Signal-to-noise ratio (S/N) issues tend to broaden the intercept and gradient (I/G) reflectivity points within crossplot space into oval distributions (Simm et al., 2000). This seismic noise acts to further blend the background trend lines together into a singular cloudy trend. Therefore, since depth dependent fluid angle variations are typically small in compacted basins, and often embedded within seismic noise, larger temporal windows can be brought into AVO crossplot space when searching for AVO anomalies.

Alternative Calibration/Interpretation Techniques

What can be done if time and resources are insufficient to apply a calibrated AVO workflow prior to an AVO analysis? There are many common practices that provide viable workarounds to the calibration uncertainty issue. One of the most well known approaches is the Geogain methodology, introduced by Gidlow et al. (1992). In this approach a Fluid Factor stack is calculated by subtracting the intercept attribute (the P-wave reflectivity – denoted R_p or $\Delta I/I$) by a scaled version of the gradient attribute (the S-wave reflectivity – denoted R_s or $\Delta K/K$) (equation 1).

Equation 1

$$\Delta F(t) = \frac{\Delta I}{I}(t) - g(t)\frac{\Delta K}{K}(t)$$

The smoothed time-variant and spatially-variant scalar, g(t), is applied to the gradient attribute post AVO extraction. This scalar initiates a rotation in crossplot space whereby one-to-one correlated R_p and R_s points cancel out and all uncorrelated points (i.e. anomalous **fluids** and/or lithologies) are highlighted in the **fluid factor** attribute. Buried in the g(t) scalar are both the mudrock line contribution (Smith and Gidlow, 1987) as well as the seismic calibration term. This calibration term is often misinterpreted as a geologically induced crossplot rotation. Since all the low frequency time-variant background trends have been collapsed onto a one-to-one line (45 degrees) crossplotting the intercept attribute along with the scaled gradient attribute provides the interpreter with the ability to crossplot larger time windows. *Note:* This assumes that the processing induced time-variant gradients (i.e. time variant rotations in crossplot space, or “residual calibration”) are comparable to the low frequency g(t) scalar trend. For example, if the ΔF scalar design window is too large not all of the time-variant fluid angle rotations may be removed, but too small a window could rotate anomalous data populations (i.e. potential reservoirs) into the background trend. Despite being able to bring in larger windows this does not mean that vertical (temporal) windowing is necessarily preferred to horizontal (spatial) windowing. Evaluating a formation across a large horizontal crossplot window is the preferred way of inferring lateral facies/fluid variability as rock properties may be changing too rapidly with depth for fair comparisons to be made. Each reservoir has its own unique noise, structural, and/or lithologic elements and several crossplot trial and error iterations may be required to best illuminate anomalous population outliers. The Geogain methodology, and others fashioned after it, can produce results comparable to having performed a calibration to a set of gathers (when parameterized correctly).

One of the best ways to ensure the optimum calibration of seismic data is to perform an inversion (Cambois, 2001). During the inversion process the seismic reflectivity data is scaled to match the well log reflectivity, therefore anomalous time-variant gradients are also scaled appropriately. Furthermore, interpreting inversion crossplots may be easier as a result of adding the time-variant low frequency log trends to the data. Overlapping data trends present in AVO reflectivity space are now separated into discrete geologic intervals. This is the benefit of moving from a differential property (changes of one quantity relative to another) into a layer property.

Finally, there is much literature devoted to developing more sophisticated attribute displays derived from AVO crossplot space. The Fluid Factor stack represents the perpendicular distance of anomalous data points relative to the background trend. More complex segregation techniques (ex. color scheme manipulations, 3D crossplotting) have produced stack and/or map representations of fluids, porosity, and lithology – just to name a few. While these approaches have merit, the key thing to remember is that these attributes can be automated and may not always represent the true nature of what is happening with the data. Any crossplot derived, or crossplot related, attribute should always have an associated crossplot displayed alongside of it. This requirement is as fundamental as evaluating the gathers that have produced any stack/AVO/inversion related anomaly. When dealing with these attribute choices remember that sometimes less is more. Why not simply interpret the crossplot space itself, while simultaneously highlighting the fluid, porosity, and lithology populations/trends in one pass, rather than dealing with a myriad of attribute sections which require cross referencing in order to tell the whole story?

Conclusion

It is important to understand how calibrated the seismic data is beforehand when performing crossplot analysis. Background trend rotations observed in the seismic, as a function of time/depth, are typically not representative of the local geology. The AVO fluid angle experiences dramatic variations only in extremely low velocity environments, often producing polarity shifts in the AVO gradient. The calibration process can be difficult; however, simple and effective alternatives are available. For most datasets, applying an AVO friendly processing flow and a time-variant fluid factor correction after AVO extraction is a practical workaround to a rigorous calibration process. Finally, although it may be tempting to skip the AVO crossplot analysis altogether to perform an inversion (the ultimate form of calibration) it is important to be cautious and not trust the inversion implicitly. Any anomalies identified by an inversion analysis should always be confirmed in AVO crossplot space as well as reviewed on the input gathers themselves to rule out other, less geologically driven, causes.

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References

Bachrach, R.; Kozlov, E., Ivanova, N.; Landro, M., and Stavos, A., 2006, *Expert Answers*, CSEG RECORDER, October 2006, 9-15.

Cambois, G., 1998, *AVO attributes and noise: pitfalls of crossplotting*, EAGE, Abstract 2-14.

Cambois, G., 2000, *Can P-wave AVO be quantitative?*, The Leading Edge, Society of Exploration Geophysicists, 19, 1246-1251.

Cambois, G., 2001, *AVO processing: Myths and Reality*, CSEG RECORDER, March 2001, 30-33.

Castagna, J. P., and Swan, H.W., 1997, *Principles of AVO crossplotting*, The Leading Edge, Society of Exploration Geophysicists, 17, 337–342.

Foster, D. J., Keys, R.G., and Schmitt, D. P., 1997, *Detecting subsurface hydrocarbons with elastic wavefields, in* Chavent, G., Papanicolaou, G., Sacks, P., and Symes, W., Eds., Inverse problems in wave propagation: Springer-Verlag.

Gidlow, P. M., and Smith, G. C., 2003, *The fluid factor angle*, 65th Annual Conference and Exhibition, EAGE, Extended Abstracts, E27.

Gidlow, P.M., Smith, G.C., and Vail, P.J., 1992, *Hydrocarbon detection using fluid factor traces: A case history*, SEG/EAEG Summer Workshop, 78-79.

Ramos, A., 1998, *AVO processing calibration*, The Leading Edge, Society of Exploration Geophysicists, 8, 1075-155.

Simm, R., White, R., and Uden, R., 2000, *The anatomy of AVO crossplot*, The Leading Edge, Society of Exploration Geophysicists, 19, 150-155.

Smith, G., and Gidlow, P. M., 1987, *Weighted stacking for rock property estimation and detection of gas*, Geophysical Prospecting, EAGE, 35, 993–1014.