The Hodogram as an AVO Attribute

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INTRODUCTION

The use of hodograms in interpretation of AVO cross-plots is a relatively recent innovation (Keho, 2000). Often, when comparing models of attributes to the actual seismic attributes, we find that anomalous zones are much closer to the background trend than the model indicates. One reason for this concerns wavelet effects. The AVO hodogram takes wavelet effects into account and can better isolate anomalies that are otherwise difficult to distinguish from the background trend by calculating the angle (called the polarization angle) of the hodogram for the series of points.

METHODOLOGY

Because seismic data is bandlimited, reflections that are identified on a cross-plot do not come from a single point, but from a series of points that result when convolving a wavelet with the reflectivity sequence of the earth. Figure 1a shows a sample of the intercept and gradient amplitudes for a single reflector. As described by Keho (2000), when the two attributes are free of noise, the cross-plot of the amplitudes for the single interface maps onto a straight line (Figure 1b). Adding noise (random, phase, RMO, etc.) creates what many recognise as a hodogram, an apparently non-systematic curve (see Figure 1c-d). The hodogram will have a dominant angle, called the Polarization angle, which defines the dominant vector of the cross-plot for the single reflector. Often when cross-plotting AVO attributes derived from seismic data, some anomalies may reside on the edge of what would be defined as the background trend. These anomalies, however, will have a very different polarization angle from the rest of the background trend, providing another means to aid in the identification of AVO anomalies. This same calculation can be applied to real seismic data to create another attribute to which can be used as an aid to identify subtle AVO anomalies by the polarization angle of the hodogram.

The AVO cross-plot is compared to the AVO-hodogram results and corresponding attributes. Also, by using the hodogram, we can derive a filter that can be applied to AVO attributes to derive *enhanced* AVO attributes which better identify the anomaly. By analysing the angle of the hodogram derived in cross-plot space from a series of amplitudes (e.g. from a trough on the Intercept stack), it is possible to better distinguish AVO anomalies from the background trend. This cross-plot angle attribute can produce a variety of various attributes, including a polarization filter. This filter, when applied to the AVO attributes used to derive the hodogram, can produce a more recognisable AVO anomaly, providing a means of data-derived anomaly accentuation.

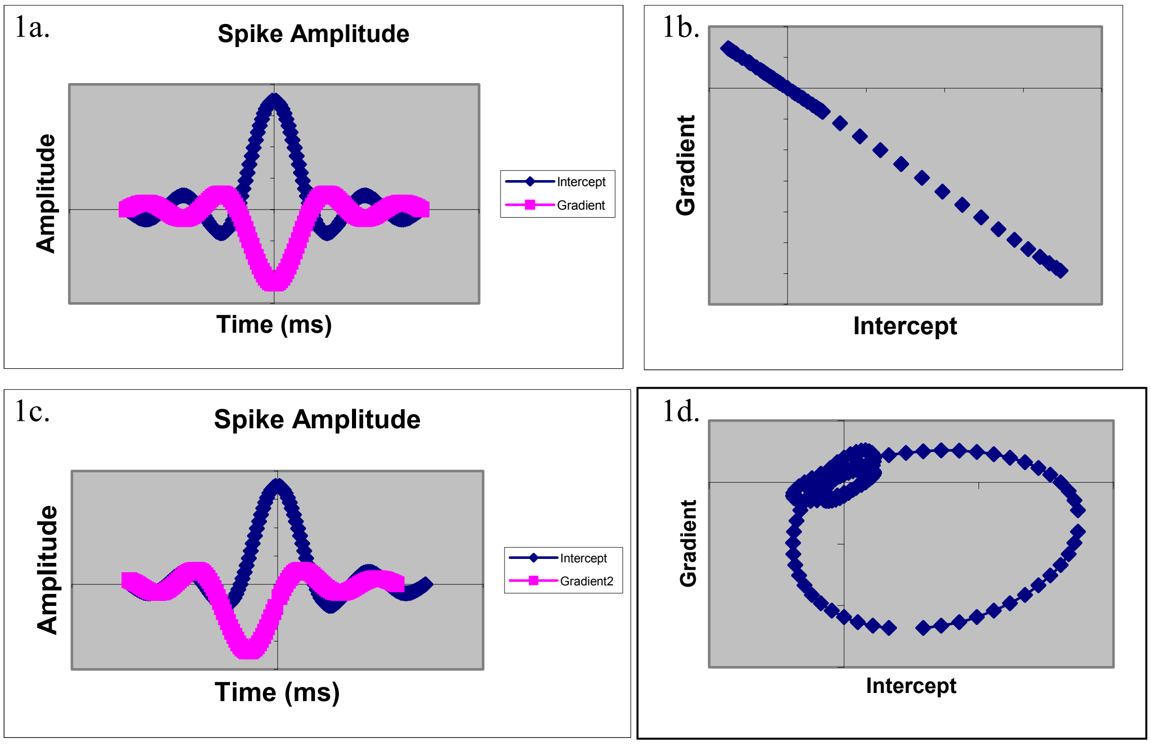

Figure 1a. Plot of Intercept and Gradient. Figure 1b. Cross-plot of Intercept and Gradient for a single reflector falls along a straight line when there is no noise associated with the amplitudes. Figures 1c-d show a sample hodogram resulting from a cross-plot where the absolute maximum Gradient occurs at a different time than the maximum Intercept (from Keho, 2000).

Synthetic Data

A simple example is shown below to describe the relationship between AVO-hodograms and traditional cross-plots. In this example, two attributes were created for each of 4 CMP locations. Each attribute contains a spike at 500 ms with an amplitude for each trace described in Table 1. The synthetic amplitudes for each attribute are then cross-plotted and the hodogram calculated for each point.

A background trend is defined as described in the cross-plot above and indicates those points with a polarization angle of +45 degrees. The two points lying off of this background trend are at –45 degrees. It is easy to identify the "anomalous" points in this instance with synthetic spikes. However, is this same response as recognisable for bandlimited data? Bandlimited data results in a true hodogram plot for each reflector as the hodogram is made up of points from the wavelet side-lobes. The angle of the cross-plot trend (polarization angle) side-lobes is highly dependant upon the window used to calculate the hodogram.

CDP	X	Y
1	1	1
2	1	-1
3	-1	-1
4	-1	1

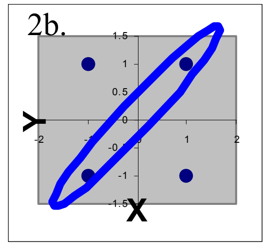

Figure 2a: Synthetic amplitudes for each attribute for 4 synthetic CMP locations. 2b describes the cross-plot for these points. The oval defines what could be the background trend for the cross-plot.

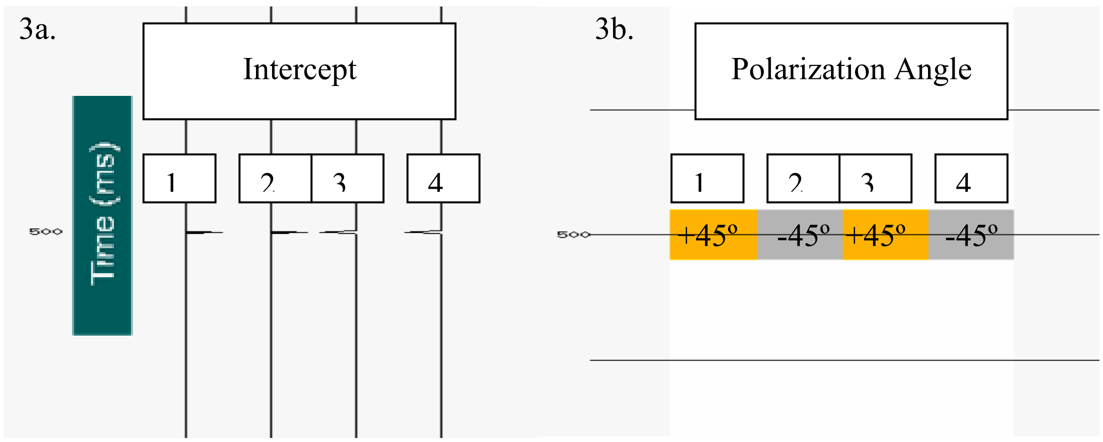

Figure 3a. Spike amplitudes on Intercept and Gradient from Figure 1a above result in the polarization angle described in Figure 3b. CMP numbers are noted above each trace.

To test this, we create two spikes (450ms and 500 ms), apply a bandpass filter and repeat the procedure described for the synthetic described in Figure 2, above. The spike in all 4 models have an amplitude of +1 for each attribute and the spike at 500 ms uses amplitudes described in the table above. Using an 8/12-60/80 Hertz Ormsby-filter, we find that the result is identical to that seen in the wide-band case, at the time of our reflectors, however where the side-lobes combine significantly different results occur. By increasing the window used to calculate the hodogram polarization, we can decrease the noise present in the result. This however does not come without some cost. If we increase the size if the window to include several reflectors, we risk contaminating the true polarization with an average from several layers. Also, the larger the window, the more an anomalous reflector will contaminate the calculated hodogram above and below the reflector, due to smearing. The window size used should be tested extensively so as to provide the least noise and smearing possible.

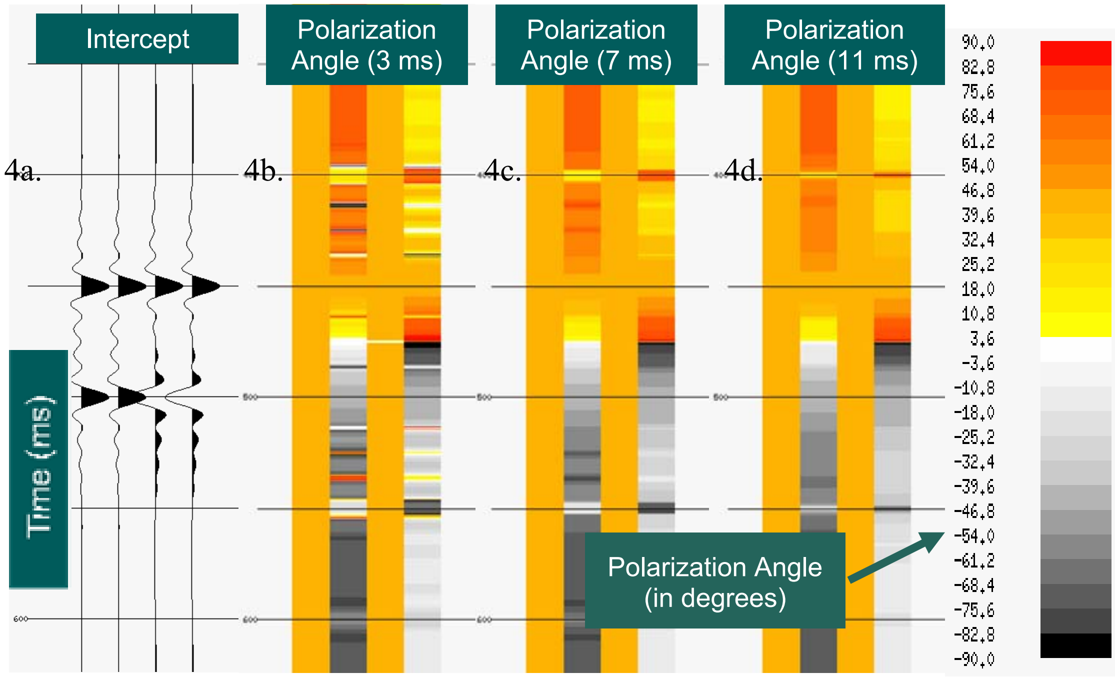

Figure 4. Resultant polarization angles calculated with different size calculation windows. 4a shows the intercept traces. Figures 4b-d, show the resultant polarization angle using windows of 3 ms, 7 ms and 11 ms respectively. Small windows result in a noisy result, large windows provide more stability but more smearing.

Field Data

How does the method respond to real geology? Using real well log data, two synthetics were created using the hydrocarbon-saturated case and a brine-saturated case, via Gassman fluid substitution. After careful petrophysical analysis of the well log data, offset-synthetics were created from which AVO attributes (e.g. intercept & gradient) were extracted. Figure 5 shows the well logs and basic interpretation. Two synthetic cases were modeled from the same well. Case 1 is for the in-situ fluid (brine) and case 2 used Gassman fluid substitution for the gas case. Figure 6 shows the offset synthetics for the 2 cases described. The top of the reservoir exhibits a Class III anomaly when gas-saturated and a Class I when brine saturated (Rutherford & Williams, 1989). The AVO polarization angle calculated readily shows the top and base of the gas-saturated interval, providing information about two attributes within one volume (similar to Fluid Factor, product stack, etc). The polarization angle for each synthetic is shown in Figure 7. We can readily see how anomalous the top and base of the reservoir are for this sand.

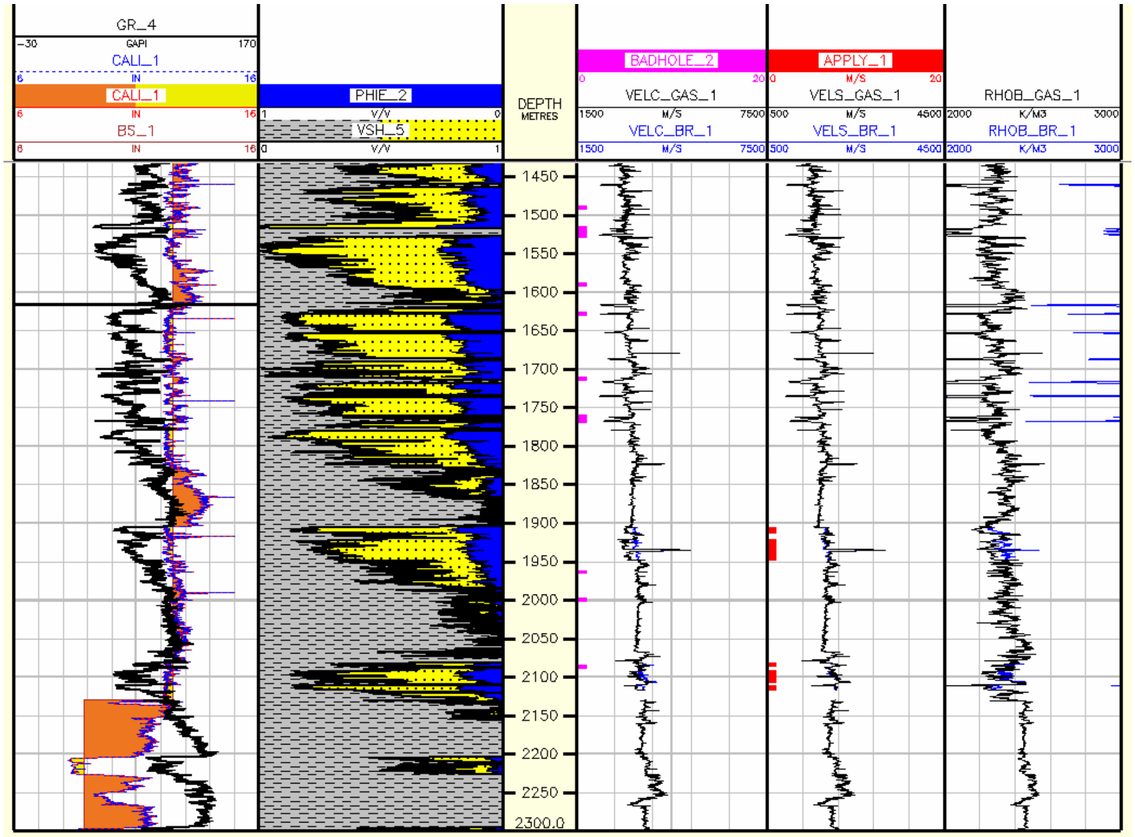

Figure 5. Log data and analysis. Zone of fluid substitution indicated by red "flags". Track 1 shows Gamma Ray and Caliper logs, Track 2 shows formation evaluation, tracks 3-5 show curves for brine-saturated and gas-saturated for Vp, Vs & density respectively.

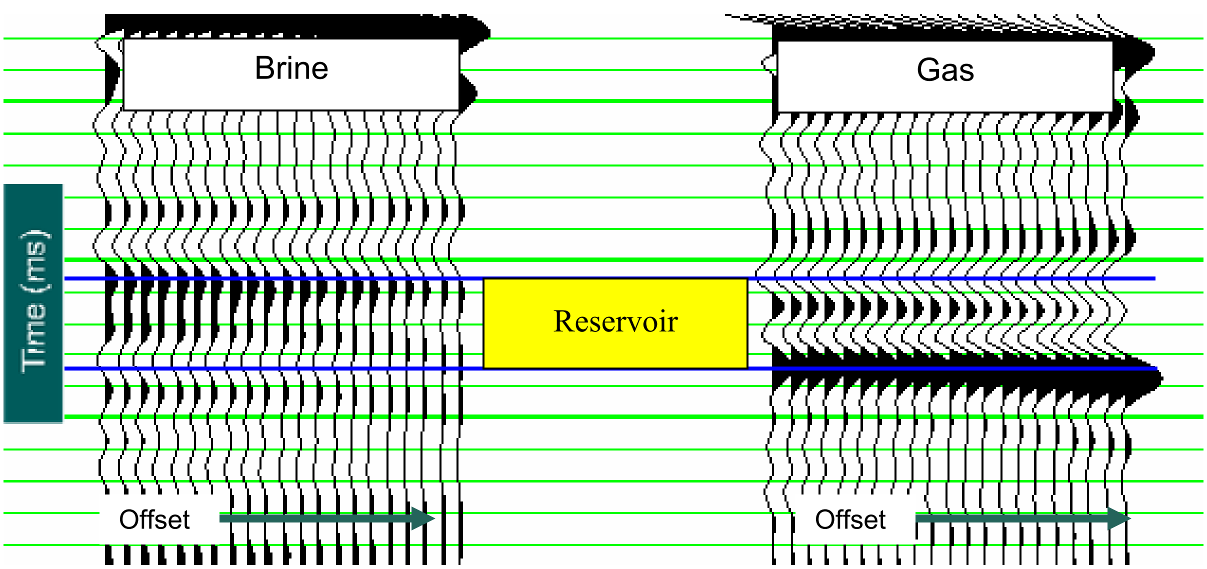

Figure 6. Offset synthetics for the upper sand (1900 m) for both the Brine saturated and gas saturated cases.

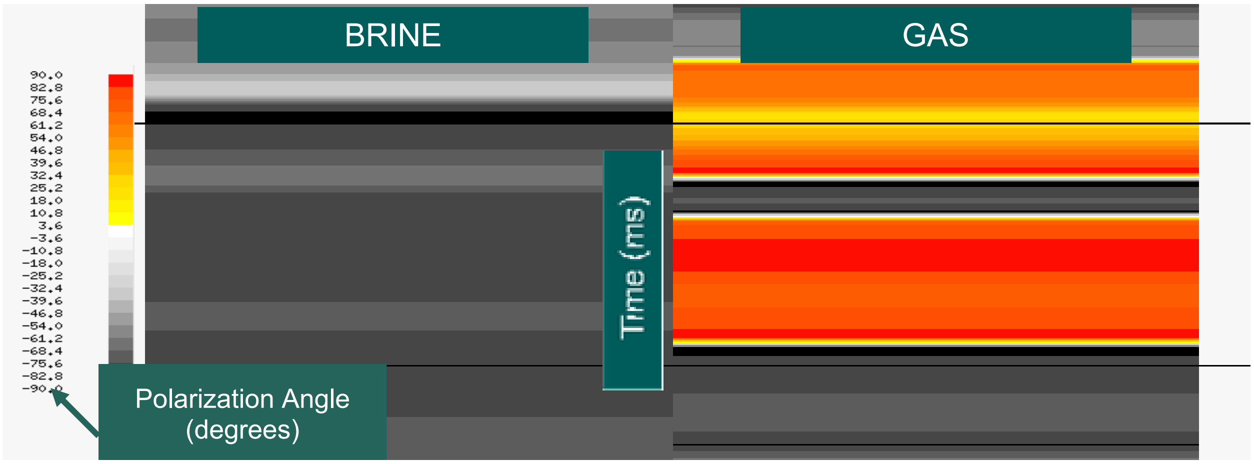

Figure 7. Polarization angle for both brine and gas saturated sand. Both the top and the base of the reservoir are readily identifiable in the case of the gas saturated sand.

Discussion

It has been a well established fact (Castagna, 1998) that in order to gain maximum benefit of AVO attribute analysis, multiple attributes must be used in concert, either via cross-plot or some other methodology. AVO hodograms provide a methodology by which a single attribute reveals information about multiple attributes. Polarization angle provides a simple method for identifying anomalies that would otherwise be difficult to locate using traditional cross-plot analysis. Models of hypothetical and real geology show the value of hodograms, and this method can similarly be applied to real seismic data for any pair of attributes, including:

- Intercept versus Gradient,
- Near stack versus Far stack,
- P-wave reflectivity versus S-wave reflectivity,

Care must be taken to ensure that an optimum calculation window is used to maximize the reliability of the results. Specifically, it is necessary to balance the noise versus the “smearing” so that the results are interpretable.

Acknowledgements:

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References:

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