Envelope of Fracture Density

Dragana Todorovic-Marinic*
Veritas DGC Ltd., Calgary, Alberta, Canada
dragant@veritasdgc.com

Dave Gray, Ye Zheng
Veritas DGC Ltd., Calgary, Alberta, Canada

Glenn Larson and Jean Pelletier
Devon Canada Corporation, Calgary, Alberta, Canada

ABSTRACT

This paper demonstrates that interpretation of fractures can be improved by using the envelope of the fracture density. It has been shown that open, fluid (or gas) filled fractures can be identified through the use of the AVAZ method (Gray et. al, 1999). The technique, based on the Azimuthal Amplitude vs. Incident Angle and Azimuth (AVAZ) equation of Rüger (1996), is modified to output attributes that are useful in the identification of fractures. One of the attributes is the estimated anisotropic gradient, which is closely related to fracture density (Lynn et. al, 1996), provided certain assumptions are met. Thus the anisotropic gradient is often an estimate of the fracture density.

The envelope of a seismic attribute is often used to highlight certain features of the data that are not as easily seen in the raw attribute. The fracture density attribute has small values that have the appearance of high frequency vertical discontinuities at and near zero crossings in the seismic gather. Using the envelope of the fracture density instead of the fracture density attribute itself allows for identification of whole geobodies more clearly, which improves the fracture interpretation. The other advantage of this approach is the phase insensitivity of the new attribute that allows for data whose phase is impossible or difficult to determine to be analyzed for fractures.

INTRODUCTION

Fractures are of great interest for hydrocarbon production. They can either hurt or help depending on the nature of the reservoir being explored. Therefore, the knowledge of their distribution and orientation can be critical. Vertically aligned fractures, cracks or micro-cracks are known causes of HTI (Horizontal Transverse Isotropy) anisotropy. This type of anisotropy has a horizontal axis aligned with open vertical fracturing that tends to be parallel to the maximum horizontal stress and normal to the minimum horizontal stress. It is increasingly recognised (e.g. Gray et al, 2002) that HTI anisotropy has a strong effect on the seismic amplitude. The effect is seen as azimuthal variations in the amplitude of seismic data at long shot-receivers offsets. This can be measured by fitting the parameters of the P-wave AVAZ equation of Rüger (1996) to seismic amplitude data. Rüger's method can be modified to output attributes that may be useful in the identification of fractures between the wells. The outputs that we prefer are: Estimated P-wave Reflectivity, Estimated S-wave Reflectivity, Estimated Anisotropic Gradient and Estimated Azimuth of Anisotropic Gradient. These attributes are useful because they all contain different information that may be relevant to the fracturing. The P-wave reflectivity is the response of the rock to its compression by the seismic wave and includes information on the rock's lithology and fluid content. The S-wave reflectivity is the response of the rock to its shearing by the seismic wave and is comprised primarily of the information about the lithology. The Anisotropic Gradient is closely related to crack density i.e. to the magnitude of the differential horizontal permeability (Lynn et al. 1996). The Azimuth of the Anisotropic Gradient is the strike of the fractures in a HTI medium and therefore, if the reservoir meets this HTI criterion, then it is the strike of the fractures in the reservoir.

In this paper we present a new seismic attribute: the Envelope of the Anisotropic Gradient. In particular our results demonstrate that this new seismic attribute contain information that can provide a more accurate estimate of reservoir characteristics. The envelope is generated by following the method prescribed by Taner et al, 1979. The method is tested on both synthetic data and seismic data over the Pinedale Anticline field in Western Wyoming.

SYNTHETIC TESTS

A synthetic gather with a zero phase Ricker wavelet is created using Rüger's (1996) equation. Figure 1 shows the synthetic gather and the model. The reflection interface is an AVO Class I type interface (Rutherford and Williams, 1989) with positive intercept (A) and negative gradient (B). The fracture orientation is set to 45 degrees and the fracture density is positive. Figure 2 shows the stacked trace, model and the results of fracture detection for the model and for a 90-degree phase shift of the gathers. The next model created has three layers, an isotropic overburden on top of an anisotropic layer with an underlying isotropic layer, resulting in two anisotropic interfaces: one for the top of the anisotropic layer and the second for the bottom. From the results of the synthetic tests, one can find that detected fracture density are not totally independent of the phase of the data.

Envelope of Fracture Density

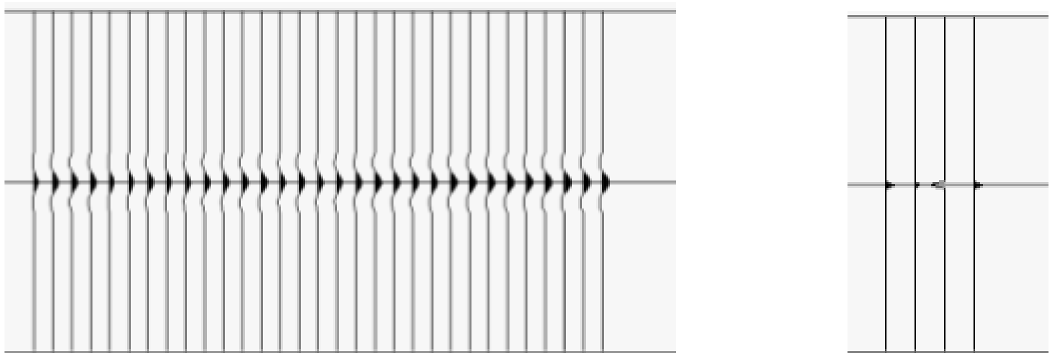

Figure 1: Gather (left) and model (right) for fractured AVO Class I interface.

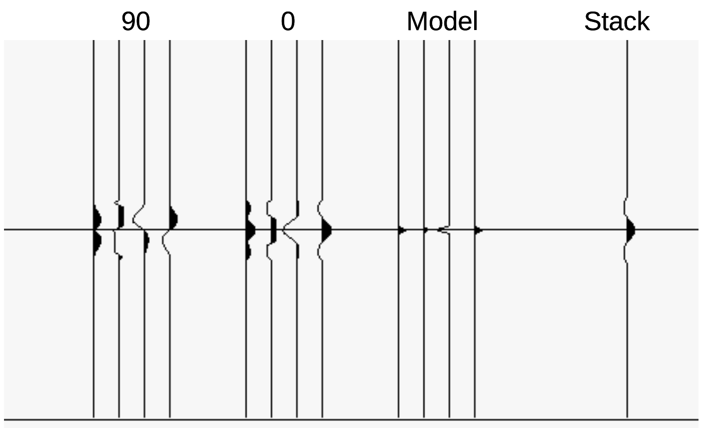

Figure 2: Results of AVAZ analysis for fractured AVO Class I interface shown in Figure 1. Compare the results to the model for both 0 and 90 degree rotations.

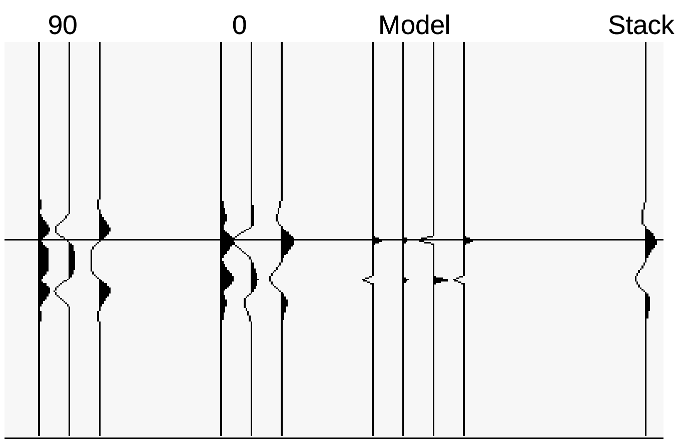

Figure 3: Results of AVAZ analysis for fractured AVAZ two-layer model.

ENVELOPE OF FRACTURE DENSITY

Figure 4 shows envelopes of the fracture density calculated for both zero-phase and 90-degree rotations of the input gathers. Both are the same, indicating that the envelope of the fracture density is independent of the phase of the seismic data.

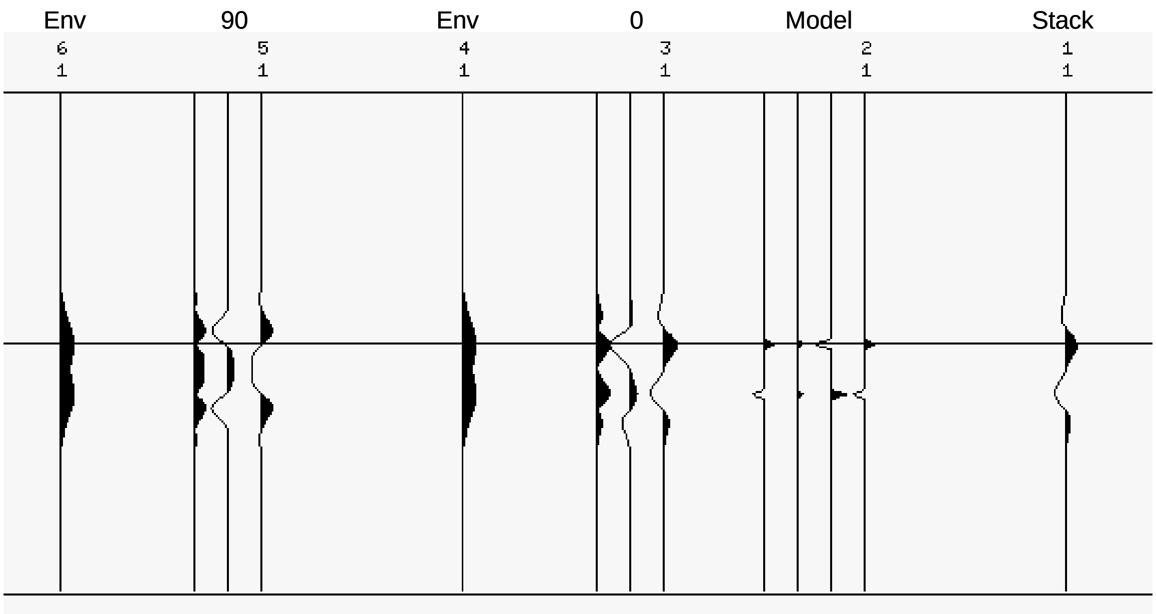

Figure 4: Envelope of the fracture density (Env.) is independent of the phase of the data.

REAL DATA

Two multi-client seismic datasets were used in the analysis: the Pinedale Anticline 3D and the Copton 3D, both shot by Veritas. These data have been processed for AVAZ compliance and have had AVAZ analysis performed on them (Gray et al, 2002). The results shown in Figure 5 are from a cross-line intersecting the new Riverside 4-10 well that has produced 696 MMCF in the six months ended January, 2003. Production in this well comes from the entire interval from the upper horizon to the bottom of the well. This corresponds well to the crack densities as measured by seismic that show that the reservoir is fractured over most of this interval. The crack densities shown in Figure 5 have high frequency vertical discontinuities that are caused by zero-crossings in the seismic gathers. The envelope of the crack density, shown in Figure 6, eliminates these vertical discontinuities and establishes where there is vertical continuity in the fractures. This can be seen along the track of the Riverside 4-10 well, where a multitude of events between the two deepest horizons in Figure 5 have resolved themselves into 4 distinct geobodies in Figure 6

Envelope of Fracture Density

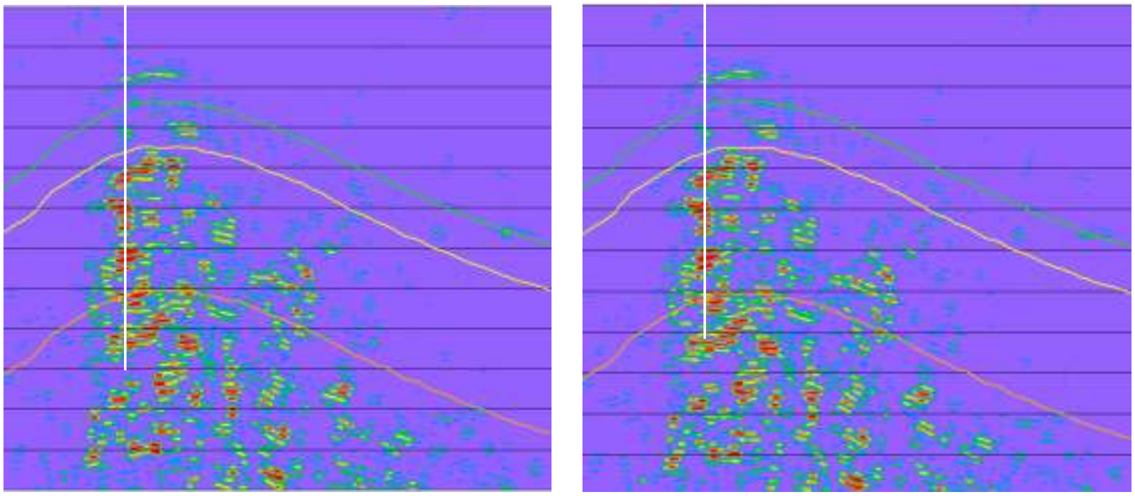

Figure 5: Estimates of the crack density from the AVAZ technique derived from zero-phase data (left) and 90 degree rotated data (right) around the location of the Riverside 4-10 well (hotter colours indicate higher crack densities).

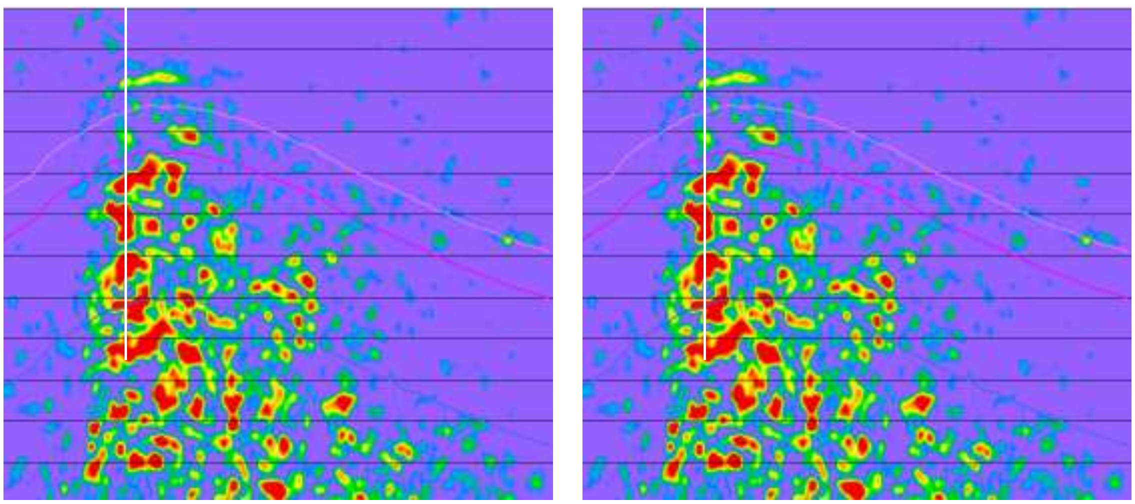

Figure 6: Envelope of the crack density around the location of the Riverside 4-10 well from the zero-phase data (left) and from the 90 degree rotated data (right) (hotter colours indicate higher crack densities).

The second example from the Copton 3D covers a portion of the Narraway field. The Narraway field is located on the leading edge of the Foothills Disturbed Belt in Northwest Alberta and outboard of the Muskeg/Huguenot surface displacement. The reservoir sections consist of beach sand trends of the FahlerG and Cadotte formations. The trends are draped over the Narraway anticline where tests as high as 30 mmcf/d have been attained by targeting the intersection of porous sand trends with fracture development. Intersecting the fracture trends is key toward achieving a commercial well. AVAZ analysis over this field reveals the presence of fractures, which may be related to well productivity. The results shown in Figures 7 and 8 are from an inline intersecting "well X", which is a known producer.

Envelope of Fracture Density

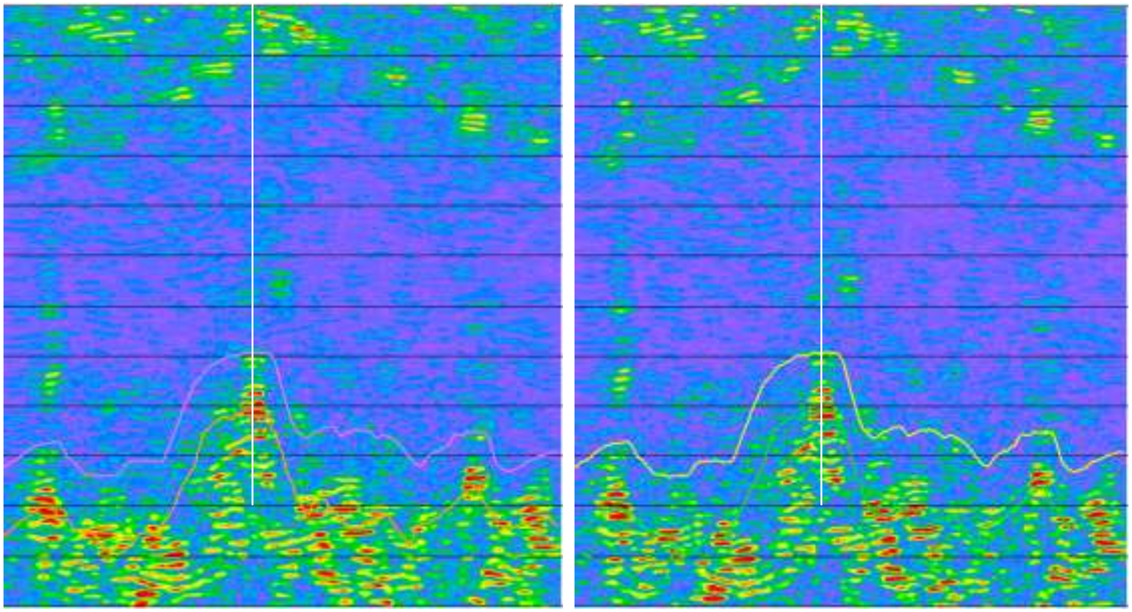

Figure 7: Estimates of the crack density from the AVAZ technique derived from zero-phase data (left) and 90 degree rotated data (right) around the location of the well X (hotter colours indicate higher crack densities).

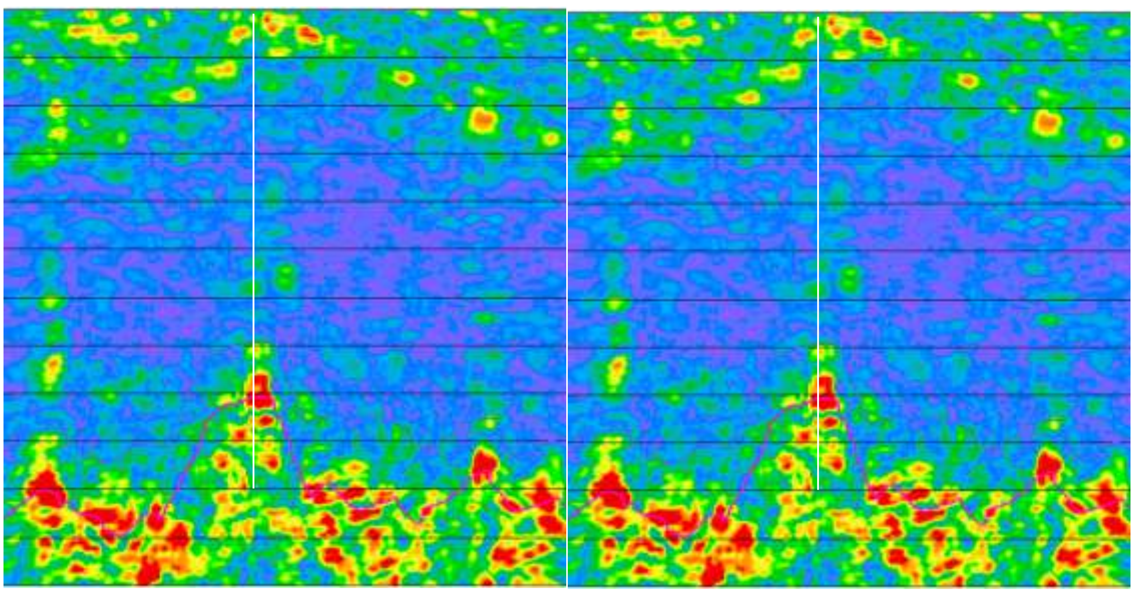

Figure 8: Envelope of the crack density around the location of well X from the zero-phase data (left) and from the 90 degree rotated data (right) (hotter colours indicate higher crack densities).

FRACTURED RESERVOIR CHARACTERIZATION

The Pinedale Anticline is located in Sublette County, southwestern Wyoming. The reservoir section is over 5,000 feet thick and composed of interbedded sands and shales deposited by a fluvial/alluvial system (Law and Spencer, 1989). The reservoir rocks have moderate porosity ranging from 8-12%. Matrix permeabilities are very low and on the order of microdarcies. Evidence for the presence of natural fractures comes from the high production rates seen in some of the wells. Therefore it is assumed that intersecting a connected fracture system is requirement for profitable wells. So fractured reservoir characterization requires a good understanding of the spatial distribution of fracture density.

A 3D seismic survey was acquired over the anticline and processed using AVAZ analysis to estimate the intensity and orientation of fracturing.

In order to predict fracture intensity within a reservoir, a neural network is used to combine seismic based fracture detection (from AVAZ method) with well and structure data that have traditionally been used for such analyses. Seismic attributes (P-wave Coherency, S-wave Coherency, P-Impedance, S-Impedance) and attributes from AVAZ analysis (Anisotropic Gradient, Azimuth of Anisotropic Gradient, Envelope of Anisotropic Gradient, P-wave Reflectivity, S-wave Reflectivity) are combined with 3D geologic model attributes (porosity, lithology and structural attributes) to predict fracture intensity. The four-month cumulative production provides a good estimate for EUR and it is used as the fracture indicator (Boerner et al.,2003). We had good well data for 19 wells within the area of interest. The attributes are ranked according to their correlation with the fracture indicator, and a subset of variables is selected as an input into the neural network for the prediction of the fracture indicator.

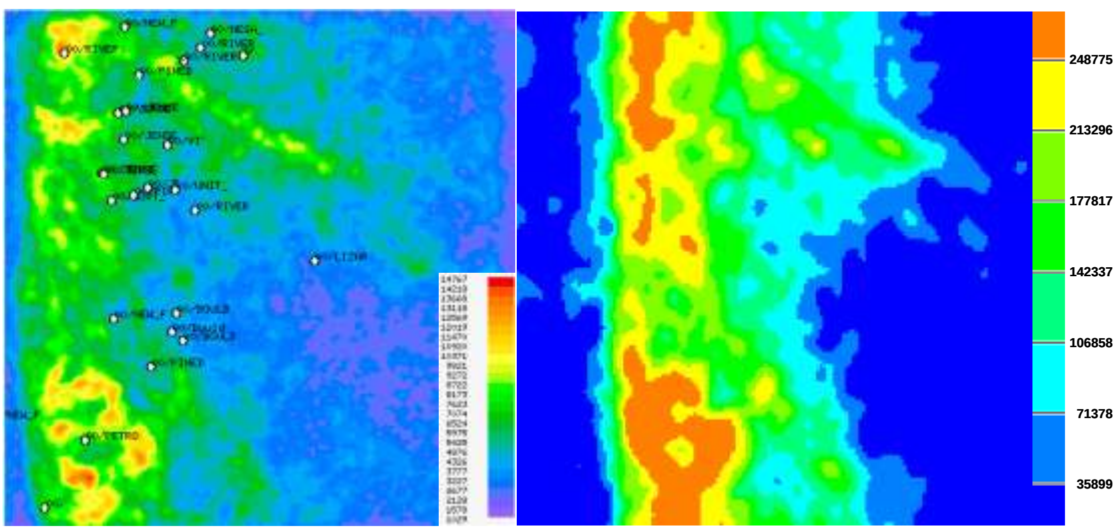

Figure 9: On the left is a Map of average Fracture Density Envelope between Upper Lance and Mesaverde horizons overlaid with wells. On the right is a SureFrac estimate of the four-month cumulative production based on existing wells and seismic attributes, the most important of which is the Fracture Density Envelope.

Envelope of Fracture Density

Driver	Rank
FractAL_Envelope.xyz_map	0.75
FractAL_Density.xyz_map	0.74
S_Coherance.xyz_map	0.59
Top_TK_Depth.xyz_map	0.50
Mid_Lance_Depth.xyz_map_SLP_EW	0.46
P_Coherance.xyz_map	0.44
Lower_Lance_Depth.xyz_map_CRV_NWSE	0.42
Top_TK_Depth.xyz_map_SLP_NESW	0.28
Mid_Lance_Depth.xyz_map_CRV_EW	0.24
InvertedData.xyz_map	0.10

Table 1: The fracture density (FractAL_Density) and its envelope (FractAL_Envelope) are the attributes ranked by SureFrac™ as being most important in predicting the production in this reservoir. Their close ranking is probably due to the estimates being averaged over the entire producing interval from the Upper Lance to the Mesaverde.

CONCLUSIONS

The objective is to find an attribute that more clearly identifies the boundaries of fractured zones within a reservoir. The envelope of the crack density appears to meet this criterion. It eliminates the high frequency vertical striping characteristic of the AVAZ crack density measurement by eliminating effects due to small amplitudes near zero-crossings in the section and more clearly defines fractured geobodies. Another advantage is that the method is independent of the input phase of the data and therefore can be used in areas where the phase of the seismic data is uncertain, which is important, since the phase affects the crack density measurement. In order to ascertain the orientation of the fractures, additional information is required on their orientation. The primary application of this technology is in reservoirs where near-vertical fractures with a preferred alignment are the dominant contributor to fluid flow.

ACKNOWLEDGMENT

We would like thank Devon Canada Corporation, Veritas Land Surveys and Time Seismic for allowing us to present these results. We also thank Veritas' Reservoir Studies Group for their continuous support.

REFERENCES

Boerner, S., Gray, D., Zellou, A., Todorovic-Marinic, D. and Schnerk, G. ,2003,. Employing neural networks to integrate seismic and other data for the prediction of fractures intensity. Abstract submitted to 2003 SPE Annual Technical Conference and Exhibition.

Gray, F.D., Roberts, G. and Head, K.J., 2002, Recent Advances in Determination of Fracture Strike and Crack Density from P-Wave Seismic Data, The Leading Edge, Vol. 21, No. 3, pp. 280-285.

Gray, F.D., Todorovic-Marinic, D. and Lahr, M., 2002, Seismic Fracture Analysis on the Pinedale Anticline: Implications for Improving Drilling Success, Expanded Abstracts of the 72nd SEG Annual Meeting.

Law, B.E. and C.W. Spencer, 1989, Geology of tight gas reservoirs in the Pinedale Anticline area, Wyoming, and the Multiwell Experiment site, Colorado: U.S. Geological Survey Bulletin 1886.

Lynn, H.B., Simon, K.M. and Bates, C.R., 1996, Correlation between P-wave AVOA and S-wave traveltime anisotropy in a naturally fractured gas reservoir, The Leading Edge, 15, 8, 931-935.

Rüger, A., 1996, Reflection Coefficients and Azimuthal AVO Analysis in Anisotropic Media, Doctoral Thesis, Center for Wave Phenomena, Colorado School of Mines.

Rutherford, S.R. and Williams, R.H., (1989), Amplitude-versus-offset variation in gas sands, Geophysics, Vol. 54, No. 6, pp. 680-688.

Taner, M.T., Koehler, F. and Sheriff, R.T., 1979, Complex seismic trace analysis, Geophysics, Vol. 44, No. 6, pp. 1044-1063.