Identifying vertical productive fractures in the Narraway gas field using the envelope of seismic anisotropy

Dragana Todorovic-Marinic[1], Glenn Larson[2], David Gray[1], Greg Soule[2], Ye Zheng [1] ,Jean Pelletier[2]
[1]Veritas DGC, Calgary, Alberta, Canada, [2]Devon Canada Corp., Calgary, Alberta, Canada,

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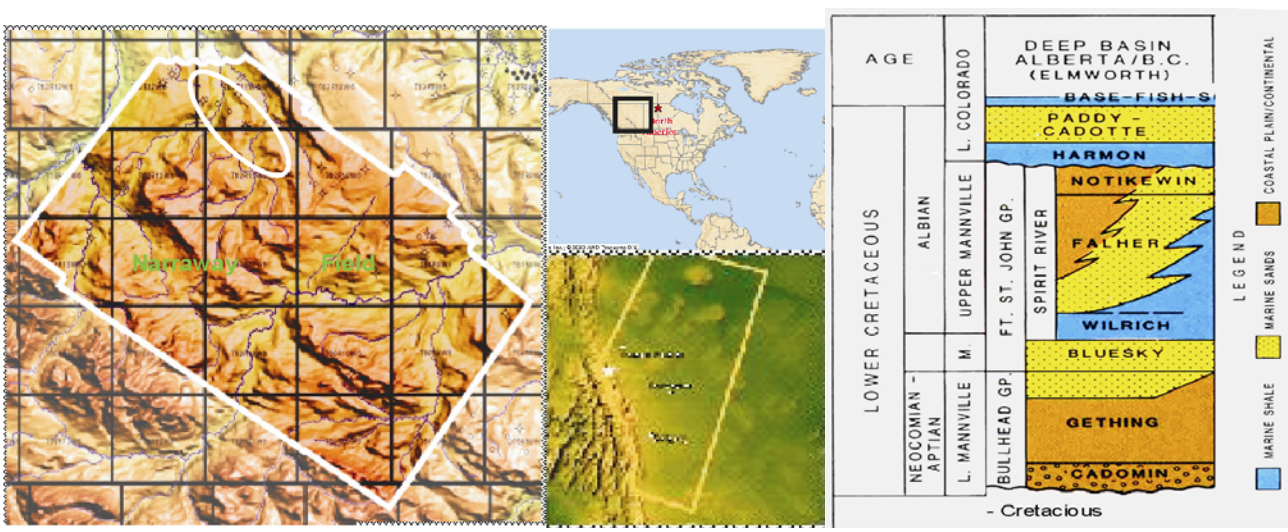
Summary

This paper summarizes recent progress towards the goal of identifying productive vertically aligned fractures, cracks or micro-cracks in gas reservoirs using surface seismic data. Our results demonstrate that identification and interpretation of fracture trends can be more accurate by exploiting a new seismic attribute, the envelope of the anisotropic gradient, in an integrated interpretation approach. The method was applied to the Narraway gas field located on the leading edge of the Foothills Disturbed Belt in Northwest Alberta, where intersecting the fracture trends with the borehole is key to achieving a commercial well. The data are analysed to test for a relationship between the fracture density and orientation as indicated by the attribute and the actual well performance, core and logs. Commercial wells were drilled based on the results of this work, thereby validating the applied methodology.



Introduction

Fractures are of great interest for hydrocarbon production. They can either hurt or help production depending on the nature of the reservoir being explored. Knowledge of their distribution and orientation can be critical to exploration success. Vertically aligned fractures, cracks or micro-cracks are known causes of Horizontal Transverse Isotropy (HTI). This type of anisotropy often has a horizontal axis aligned with open vertical fracturing that trends parallel to the maximum horizontal stress and normal to the minimum horizontal stress. It is increasingly recognised (e.g. Gray et al, 2002, Gray et al, 2003) that HTI anisotropy has a strong effect on the seismic amplitude. This can be measured by fitting the parameters of the P-wave Amplitude Versus Angle and Azimuth (AVAZ) equation of Rüger (1996) to surface seismic data. The outputs are seismic attributes that contain different information that may be relevant to the fracturing. The P-wave reflectivity is the response of the rock to compression by the seismic wave and provides information on the rock's lithology and fluid content. The S-wave reflectivity is the response of the rock to shearing by the seismic wave and is comprised primarily of information about the lithology. The anisotropic gradient is closely related to fracture 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 orientation of the fractures in the reservoir.

Method

The new seismic attribute, the envelope of the anisotropic gradient, is generated following the method described by Todorovic-Marinic et al, 2003. 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 anisotropic gradient attribute has small values that have the appearance of high-frequency vertical discontinuities at zero crossings in the seismic gather. Using the envelope of the anisotropic gradient instead of the anisotropic gradient itself allows for identification of fracture swarms more clearly, which improves the fracture interpretation. The other advantage of this approach is that the new attribute is insensitive to phase, so data with phase that is difficult to determine can still be analyzed for fractures. Conventional seismic attributes, the envelope of the anisotropic gradient, well performance, logs and core information are interpreted together to characterize the Narraway fractured reservoir.

Application to Real Data

The methodology was applied on the multi-client Copton3D seismic dataset, which covers the Narraway anticline, an area of ongoing commercial interest. These data have been shot and processed for AVAZ compliance and have had AVAZ analysis performed on them. The Narraway field is located on the leading edge of the Foothills Disturbed Belt in Northwest Alberta, Canada and east of the Muskeg/Huguenot surface thrust fault (Figure1). Figure 2 illustrates the Cretaceous stratigraphy of the region. The reservoir sections consist of beach sand trends of the Cretaceous FahlerG and Cadotte formations. The main horizon of interest in this study is the base of Falher formation**.** The Cretaceous section forms a broad anticline cored by a thrust fault which carries Paleozoic strata in the hanging wall. The sand trends intersect the anticline at Narraway. To the east of the structural belt, the Fahler conglomerate is productive, but not the low-permeability sandstone intervals. The conglomerate deposits are absent at Narraway, therefore intersecting the fractures in the sandstone is key to achieving a commercial well. The two reservoir units have tested as high as 1 Mm3/d (35 mmcf/d) in wells with both porous sandstone and effective fracture development (Figure 4).

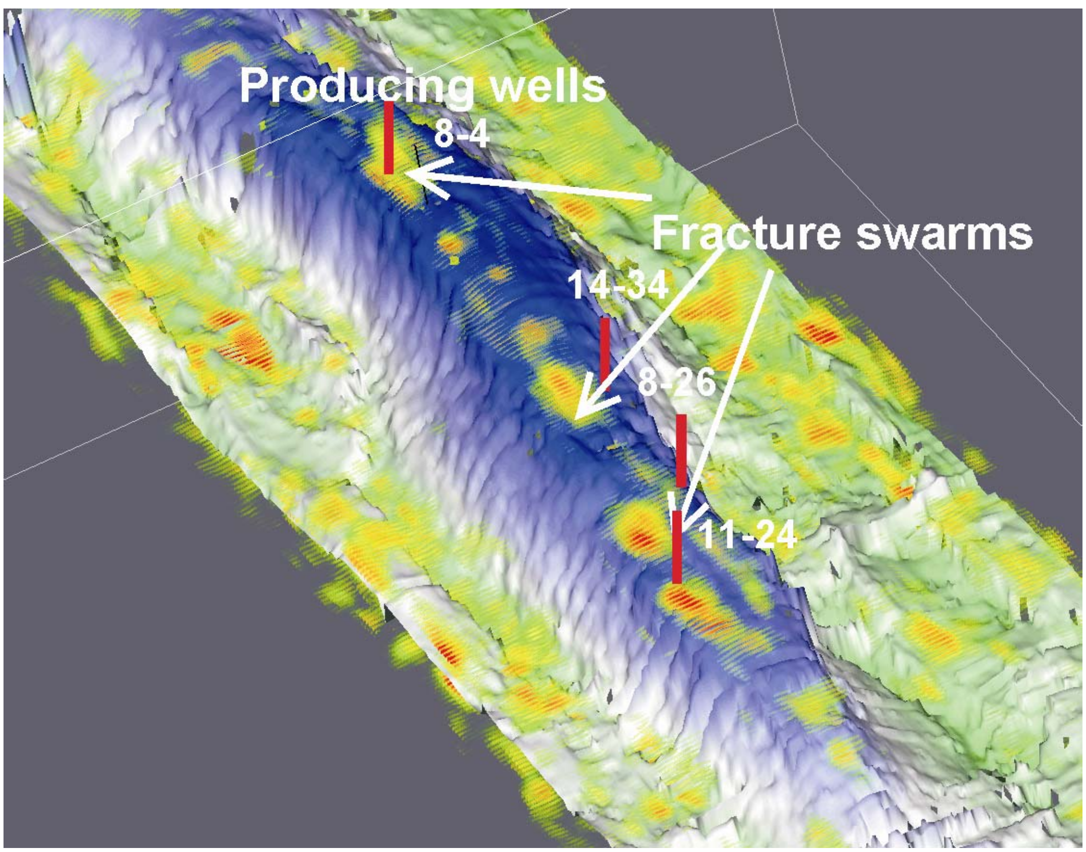


Figure3: Time structure of the bottom of the reservoir (blue and white) overlaid with fracture swarms (red and yellow) and wells that are known producers. Initial production of the wells from north to south was 0.7 Mm3/d (24 mmcf/d) at 8-4, 0.08 Mm3/d (3 mmcf/d) at 14-34, 0.06 Mm3/d (2 mmcf/d) at 8-26, and 1 Mm3/d (35 mmcf/d) at 11-24.

Results

The AVAZ analysis over this field reveals the presence of fractures that are related to well productivity. Figure 3 shows the Fahler time structure surface co-rendered with fracture swarms identified by the envelope of the anisotropic gradient. The two producing wells, 8-4 and 11-24, with high initial production rates intersect or are in the vicinity of these fracture swarms. These wells were drilled before the fracture study was initiated. The analysis suggests that there are other areas along the structure that may be conducive to zones of high fracture intensity and higher well productivity. The fracture swarms identified by the envelope of the anisotropic gradient occur toward the backlimb of the structure, but not at the hinge. Also, their intensities are not consistent along strike, indicating that fracture-strain relationships vary. These variations may be related to the evolution of the structure, and perhaps more than one phase of deformation has occurred.

In Figure 4a the anisotropic gradient has a high-frequency vertical discontinuity that is caused by small values at zero-crossings in the seismic gathers. The envelope of the anisotropic gradient (Figure 4b) eliminates these vertical discontinuities and establishes where there is a vertical continuity in the fractures. As a result, a multitude of events have resolved themselves into one distinct fracture swarm. This significantly increases the estimates of the reservoir for this well.

Figure 5b shows that the fracture swarms identified by the envelope of the anisotropic gradient are correlated to sand proportions. This correlation may be caused by sands being more brittle than surrounding shales and therefore more prone to fracturing. In Figure 5a the correlation between the fracture swarms identified by the anisotropic gradient and sand proportion is less clear. The envelope of the anisotropic gradient allows identification of fracture swarms more clearly, which can then be correlated to the sands.

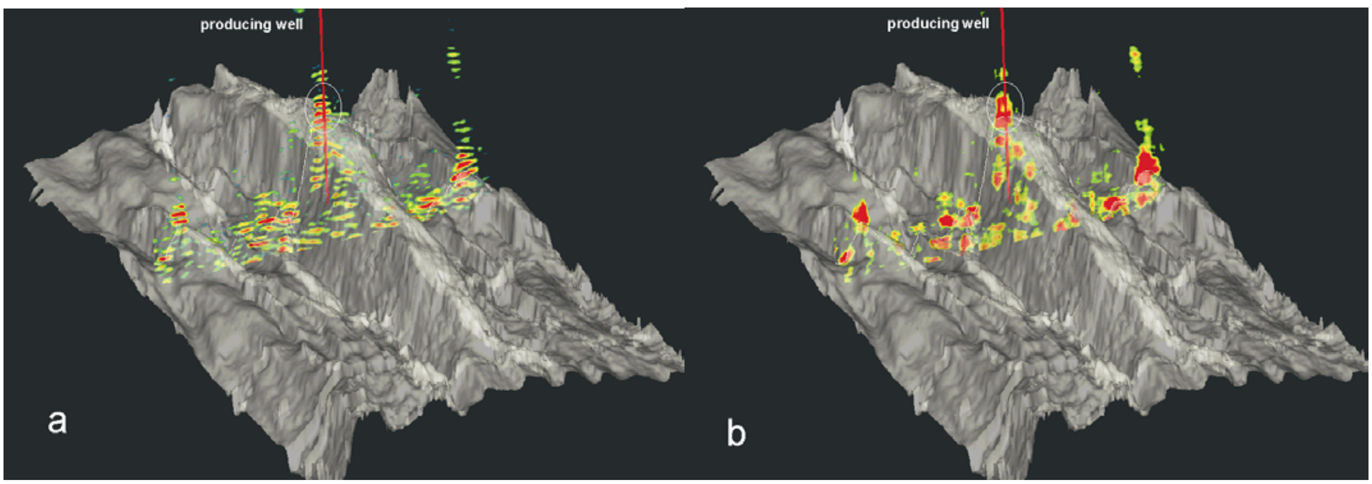
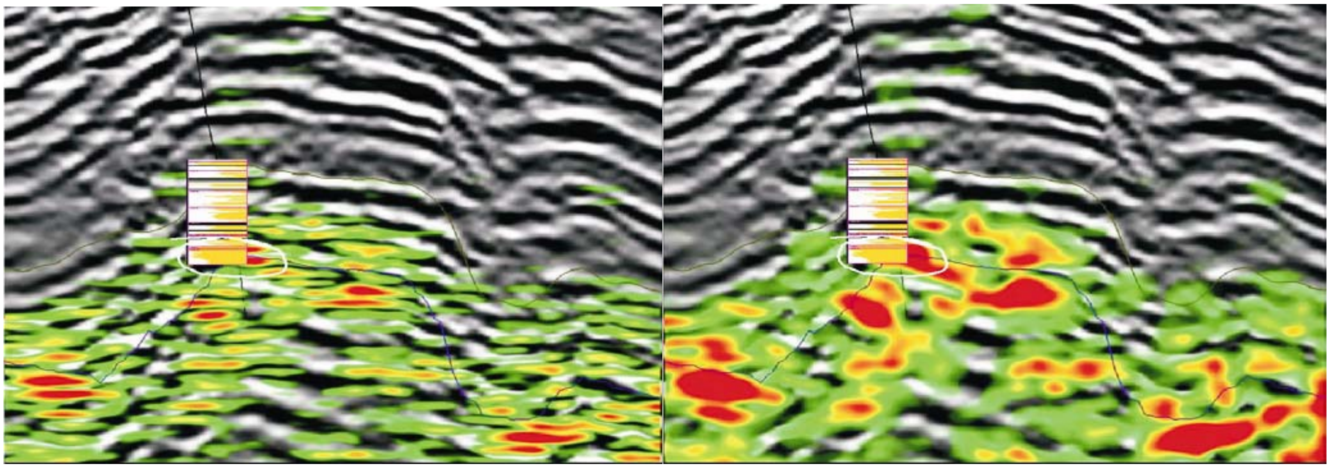


Figure4 a: The Anisotropic Gradient (Fracture density) from an inline intersecting the well that is known producer. b: The Envelope of Anisotropic gradient from the same inline intersecting the well

Conclusion

The objective was to find an attribute that more clearly identifies the boundaries of fractured zones within a reservoir. The envelope of the anisotropic gradient appears to meet this criterion. It eliminates the high-frequency horizontal striping characteristic of the anisotropic gradient by eliminating effects due to small amplitudes near zero-crossings in the section, and more clearly defines fractured swarms. 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 phase affects the AVAZ calculation. The primary application of this technology is in reservoirs where near-vertical fractures with a preferred alignment are the principal source of HTI anisotropy and the dominant contributor to fluid flow. High fracture densities indicated by the envelope of the anisotropic gradient coincide with better well performance in FahlerG reservoir sands of the Narraway anticline. This approach could be applied to any surface 3D seismic data recorded with wide azimuth.



a b

Figure5: Correlation between fracture density and sand proportion: White corresponds to -shale, yellow to -sand, and black to -coal; (a) Anisotropic gradient , (b) Envelope of anisotropic gradient.

Future Work

Future work with the Copton 3D data set will use additional constraints from known rock and fracture properties in order to determine the orientation (Zheng at al. 2004) of the fractures.Furthermore, the envelope of the anisotropic gradient from this data set will be used for integrated fractured reservoir characterisation where a neural network will be applied to combine seismic-based fracture detection with porosity, lithology and structural attributes (Boerner at al. 2003). This will be utilized to predict the best fracture indicator for this reservoir.

Acknowledgement

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References

[1] 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.

[2] Gray, F.D., Boerner,S., Todorovic-Marinic, D. and Zheng, Y., 2003, Analyzing fractures from seiesmic for improved drilling success, World Oil, Vol. 224, No. 10

[3] 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.

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

[5] Todorovic-Marinic, D.,Gray,F.D., Zheng, Y.,Larson, G. and Pelletier, J. Envelope of Fracture Density, 2003, Technical Abstracts of the Joint CSEG/CSPG Convention

[6] Gray, D 2004, Elastic Impedance and Anisotropy, submitted for 2004 EAGE Annual Mtg

[7] Zheng,Y., Todorovic-Marinic,D. and Larson, G., Fracture detection (AVAZ): ambiguity and practical solution, Submitted to CSEG convention 2004

[8] 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