# 3-D Seismic in Identifying Spatially Variant Fracture Orientation in the Manderson Field, Wyoming*

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## Abstract

Oil is produced from the Manderson Field, in Wyoming's Big Horn Basin, from a fracture system with possible significant lateral connectivity; therefore, characterizing the fractures in this field is of great importance. Amplitude Versus Offset (AVO) analysis of azimuthally restricted seismic data is used to determine the orientation and density of fractures at selected locations corresponding to well sites in the Manderson Field. The result of this analysis is compared to fracture strike analysis from oriented cores for three wells.

## Introduction

The Manderson Field in Big Horn Basin, discovered in 1951, is located on a sharp, asymmetric, northwest-plunging anticline. It produces oil and gas from Pennsylvanian, Permian and Cretaceous horizons, although the Permian Phosphoria is the most productive zone. It is a complex interval consisting of a thick unit of medium-to-thick bedded, fractured carbonate.

Purchased by KCS Mountain Resources in 1995, the field showed several wells with cumulative production in excess of original oil-in-place estimates. Low matrix porosity, production history and strong pressure support suggest that oil is produced from a fracture system with significant lateral connectivity. Four oriented cores and one Formation Micro-Imager (FMI) log were taken by KCS between 1996 and 1998. Analysis of fractures in the cores and the FMI show varied fracture orientations at different wells within the field.

A 3-D seismic survey was undertaken in 1996 to improve structural definition of the reservoir. The survey was reprocessed in 1998 to further improve structural characteristics--and to detect those, fractures that strongly influence production.

## Method

The seismic data from the Manderson 3-D was acquired over a full 360 degree azimuthal range--a suitable candidate for the test of measurements of azimuthal anisotropy from pre-stack seismic data using seismic AVO techniques. This method examines differences in the AVO response with respect to azimuth to predict the primary fracture strike and the relative density of cracks.

The Manderson 3-D covers the locations of three wells for which oriented cores have been analyzed for fracture azimuth. This experiment is to determine whether fracture strike and fracture density can be determined from 3-D seismic data in the Manderson Field. The requirements for this analysis are full azimuthal coverage in the 3-D seismic (excluding the edges) and sufficient source-to-receiver offsets to measure significant differences in azimuthal AVO effects in the zone of interest in the Phosphoria carbonate at 1,200-1,400 meters (approximately 6,700 feet).

The five locations chosen for these tests are centered on the wells 4333P, 34-28P, 34-18P, 42-24P and 1218P. Well 43-33P is the most productive well in the field, and wells 34-28P, 34-18P, and 42-24P have fracture strike analysis. Well 42-24P was abandoned shortly after drilling, without achieving commercial production.

A modification of the AVO method of Lynn et al. (1996) is used to estimate the fracture strike and density at these locations. The theory behind this method is that the acoustic velocity of shear waves in a fractured medium is faster parallel to the fractures than perpendicular to them. This is known as shear wave birefringence (Figure 1). Figure 1 also shows how the AVO gradient is related to the shear-wave impedance. So AVO in a fractured zone should show the largest difference between values parallel and perpendicular to the dominant fracturing direction.

The primary direction of the anticlinal fold axis is 140 degrees (Figure 2). The most dominant fracture direction may be expected to be parallel and perpendicular to the fold axis at 140 degrees or 50 degrees, respectively. The AVO azimuthal analysis uses eight azimuth ranges centered on 5, 27.5, 50, 72.5, 95, 117.5, 140 and 162.5 degrees. Because each range is a 22.5 degree azimuthal cone, the error associated with any estimated fracture strike is ±11.25 degrees. These orientations, starting at 5 degrees, are based on the estimate of the primary direction of the anticline. They give complete coverage of all possible fracture strike directions.

## Examples

Azimuthal differences in AVO response are shown in the change in amplitudes with shot-receiver offset as shown in the boxes in Figure 3. These amplitudes are larger at long offsets in the gather on the left than the one on the right.

The fracture azimuth predicted by the seismic data falls within the range of values estimated from the oriented core (Table 1). This azimuth appears to be the average value for the open fractures. For example, the strike orientation rose diagram for the open fractures of the 34-28P well (Figure 4) shows three significant strike directions, at 0, 60 and 105 degrees. If all these fracture strikes are averaged then 84 degrees is the expected response.

The average fracture strike (Figure 5) is a useful value, because the largest volume of open fractures will be encountered by drilling horizontally perpendicular to this average fracture direction. Well 43-33P is the most prolific well in the Manderson Field, and it has the largest value of crack density. Wells 34-28P, 34-18P and 42-24P indicate that there may be correlation between crack density and open fracture aperture. Combine this with the high value observed for well 43-33P, and crack density appears to have some correlation with open fracture aperture.

There appear to be two predominant fracture strikes indicated by the azimuthal AVO analysis: one at 90-110 degrees follows the east-west faulting direction seen in Figure 2, the other at 230-170 degrees follows the fold axis of the anticline. All measurements are performed on the unmigrated seismic data.

The values derived from these data may be map-migrated to correctly position the detected fracture strikes and crack densities. A window from the top Phosphoria to 10 milliseconds below is used. The average value for this zone is shown on the map.

## Conclusions

Fracture strike and crack density are estimated from the seismic AVO response. The seismic AVO results show consistent fracture strikes and crack densities at the test locations, implying that these values are robust. The most predominant estimated fracture strikes at these locations coincide with the major geologic features in the area, a correlation that makes sense from a geologic standpoint. The fracture strikes derived using AVO agree with the average fracture strikes determined from oriented cores. Crack density may correlate with average fracture aperture, and it generates significantly higher values at the location of the most prolific wells in the Manderson Field.

It is important to note that this AVO method probably finds the average fracture direction. If the fractures have different aperture or spacing in different directions, then the seismic may find a weighted average. Far example, if fractures at 0 degrees are 0.1mm thick and fractures at 60 degrees are 0.2mm thick, then the weighted average is 40 degrees.

## Reference


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.


## Figures and Table

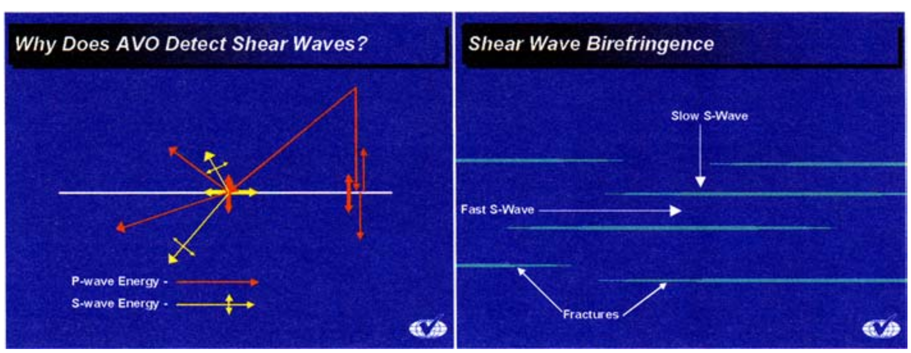


Figure 1. Shear wave birefringence: velocity in fracture is faster along it than at right angles to it.

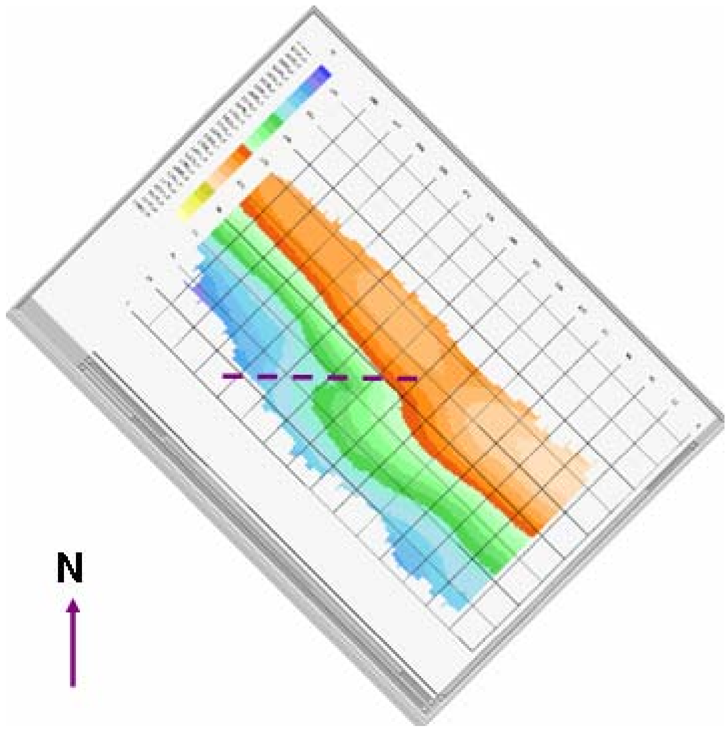


Figure 2: Time structure of the Phosphoria. The orientation of the anticline is 140 degrees. Notice the structure indicating later faulting at 90 degree azimuth, marked by the dashed line running diagonally across the center of the display.

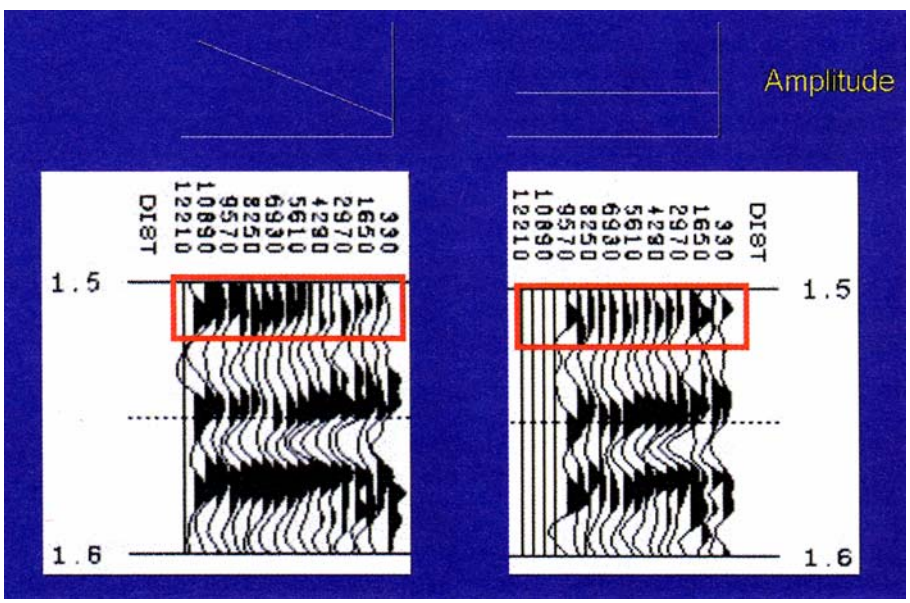


Figure 3: Azimuthally restricted prestack seismic gathers for orthogonal azimuths at the same location. The amplitudes in the box in the gather at left increase with increasing shot-to-receiver distance (from right to left), while the corresponding amplitudes in the orthogonal gather (right) have no change in amplitude. This difference is used to indicate the fracture direction and to estimate the fracture density.

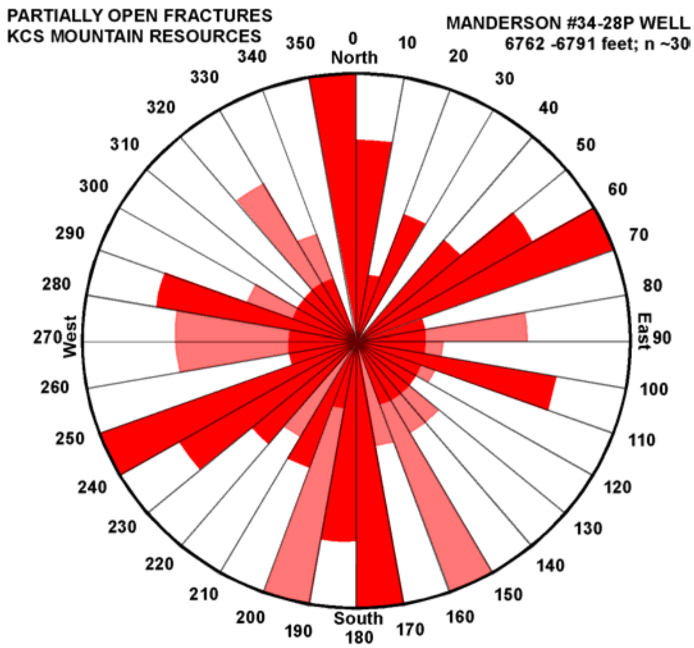


Figure 4: Strike orientation rose diagram for partially open fractures from the strike analysis from the oriented core for the 34-28P well.

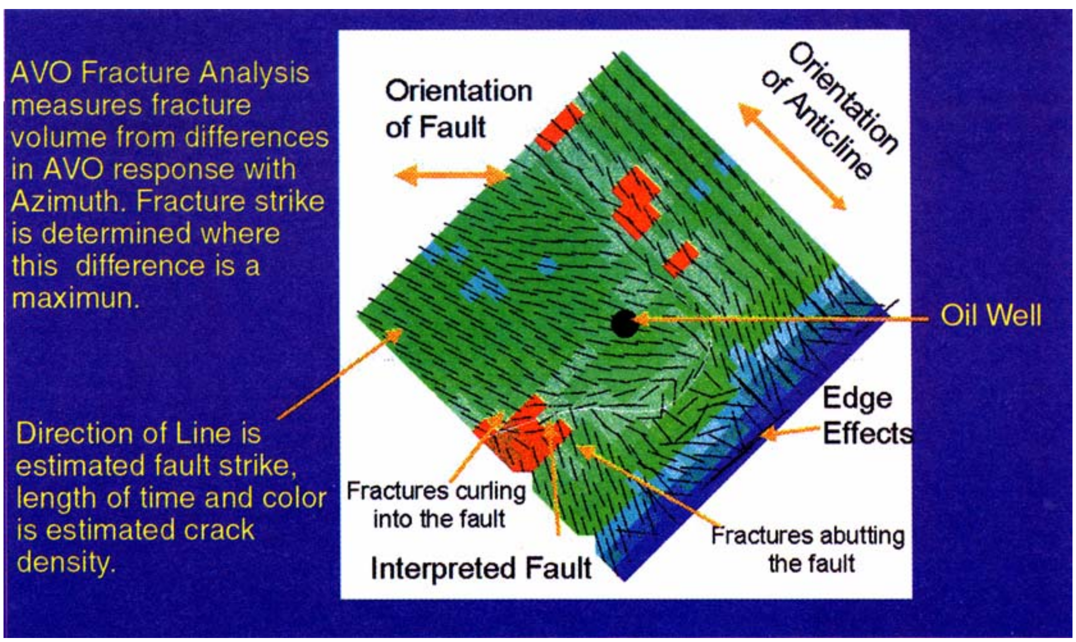


Figure 5: Estimated fracture strike and crack density in the Phosphoria derived using seismic AVO at the 43-33 well location, plus interpretation. The fracture strike distribution is far more complex than was originally anticipated; its interpretation appears to be geologically reasonable with most fracture orientations paralleling the major geologic features: the anticline (140 degrees) and the fault (90 degrees). The high values of crack density on the lower right side of the figure are due to edge effects.

| Fracture Analysis Manderson Field | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Location | | | Seismic | | Oriented Core | | | | |
| Well | Row | Column | Azimuth | Density | Strike | Range | Vol (mm/m) | Aper (mm) | Comments |
| 43-33P | 45 | 93 | 100° | 1.5 | No Core | No Core | No Core | No Core | Most Prolific Well |
| 34-28P | 81 | 107 | 115° | 1.1 | 83 | 33 | 19 | 0.12 | Poor Well |
| 34-18P | 218 | 111 | 100° | 0.5 | 127 | 29 | 5 | 0.04 | Good Well |
| 42-24P | 227 | 65 | None | None | No Fracs | No Fracs | 0 | 0 | Tight |
| 12-18P | 253 | 111 | 100° | 0.6 | No Core | No Core | No Core | No Core | Moderate Well |

Table 1. Comparison of seismic AVO fracture strike analysis to strike analysis from oriented core.