Structural Interpretation of Azimuthal AVO for Natural Fracture Patterns in the Wind River Basin Wyoming

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Introduction
It has long been recognized that the presence of naturally occurring fracture networks can lead to unpredictable heterogenity within many reservoirs. Improved fracture detection can reduce this uncertainty, and recent efforts to apply the seismic method in this area have included post-processing 3-D seismic data in order to map changes in amplitude vs. aziumth (AVAZ) (e.g Lynn et al. 1996 and Gray et. al. 1999). The anisotropic nature of P and S wave velocities are then used to determine parameters such fracture intensity and fracture orientation. Two problems remain: (1) the simplfying assumptions used to determine the fracture parameters are inconsistent with engineering and geologic understandin of fracture networks, and (2) even if AVAZ data is supplying useful information, how can it be interpreted i.e. what do you expect the pattern of fractures to be?.

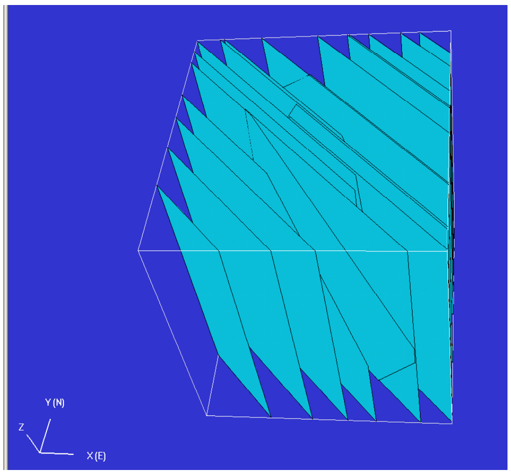
This talk addresses these issues by comparing AVAZ imagery for a field in the Wind River Basin with the field's structural geology. A Discrete Fracture Network (DFN) model constructed from the AVAZ imagery is then used to predict fracture-related flow in the reservoir, and compared to well tests to validate the model and the interpretation of the imagery.

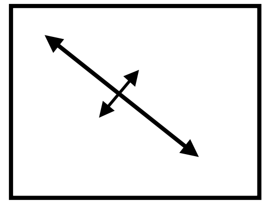
AVAZ theory
Many theories have been suggested to explain the relationship between directional changes in amplitude vs. offset as seen in seismic data as a function of changes in fracture intensity and orientation. However these theories are based on geophysical models of fracturing that are not consistent with either geologic or engineering models of fluid and/or gas flow in fractured reservoirs. For example, most geophysical models assume that all fractures are near vertical, and are locally oriented in a single dominant direction (Figure 1). Using these simplifications the AVAZ response has been used to predict average fracture orientation and intensity. However, geologic data indicates that fractures usually occur in multiple sets, and engineering models require that more than one fracture set occurs before fractures form networks capable of transmitting fluids. Simple variations from vertical sets (Figure 2) may change the orientation measured under the AVAZ approach, and it is uncertain what would be measured if multiple fracture sets are present (Figure 3).

Circle Ridge Study
As part of a U.S. Department of Energy Study a structural model of the Circle Ridge field in Wyoming was constructed (www.fracturedreservoirs.com). As part of this study a fully three-dimensional strain field (Figure 4) was calculated using three dimensional palinspastic reconstruction. Fracture patterns througout the field were also analyzed through image log and outcrop studies. Fracture occurance was shown to be consistent with the strain values derived from the reconstruction.

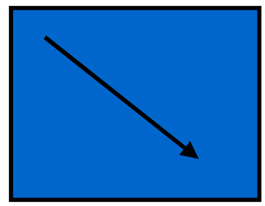
AVAZ Interpretation
Initial interpretation of AVAZ data in structural reservoirs has proven difficult as it was previously not clear weather trends occuring in the seismic data were caused by the natural fracture patterns or were an artifact of the processing. Within the AVAZ data bands of fracture orientation appear, which alternate between two dominant orientations. This polarity switching is consistent with the observations of strain bands at Circle Ridge demonstrating both the potential of the amplitude vs. approach, and the need to understand natural fracture geometry when interpreting this type of Data.

1.3.1.





Minimum and maximum AVO effect direction

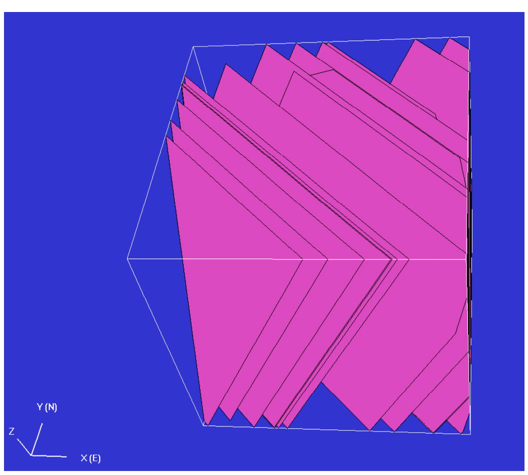


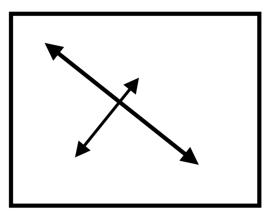
Vertical fractures Constant Orientation

AVAZ predicted orientation

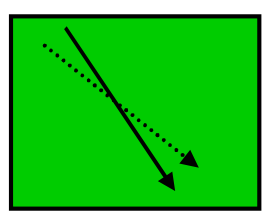
Fig 1 AVAZ response under single vertical fracture set.

1.3.1.





Minimum and maximum AVO effect direction

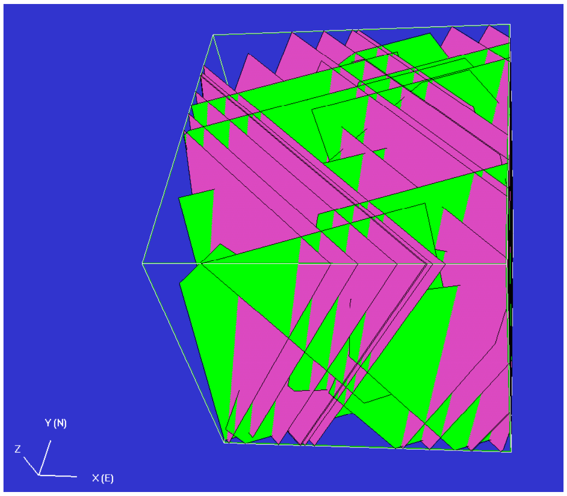


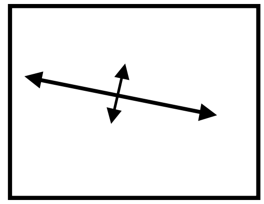
Fracture 20 degress from vertical Constant Orientation

AVAZ predicted orientation

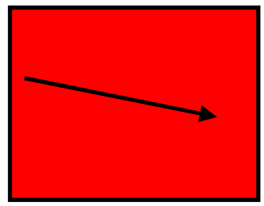
Fig2. Effect non-vertical fractures on AVAZ interpretation. Interpreted strike rotates from AVAZ interpreted strike due to changes in dip.

1.3.1.





Minimum and maximum AVO effect direction



Two sub vertical sets

AVAZ predicted orientation

Fig 3. Effect of multiple sets maybe to produce an average orientation

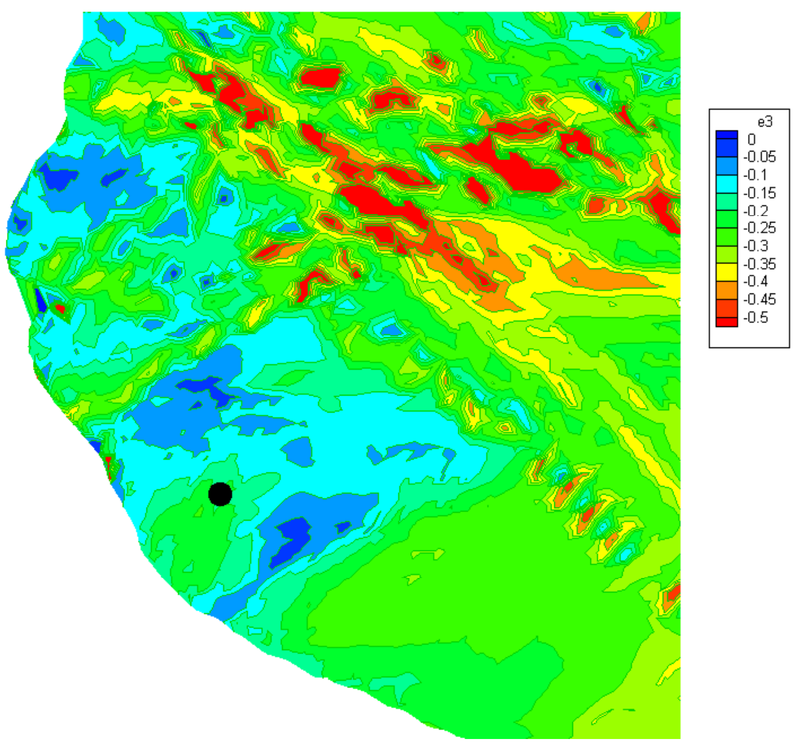


Fig 4 Strain values from three-dimensional reconstruction over the overthrust block at Circle Ridge field, Wyoming.

References

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

Gray, F.D., Head, K.J., Chamberlain, C.K., Olson, G., Sinclair, J. and Besler, C., 1999, Using 3D Seismic to Identify Spatially Variant Fracture Orientation in the Manderson Field, SPE Paper 55636; 1999 Canadian SEG meeting abstracts, 59-63; AAPG Explorer, 20, 9.