Migrating Fracture Attributes

Ye Zheng and David Gray - Veritas DGC, Inc.

CSEG Geophysics 2002

Abstract

Fractures are small cracks that occur when brittle rock is stressed to the point where it breaks. Zones of high stress frequently occur where the rock is bent the most, and therefore in places where seismic migration is most likely to be needed. Consequently, it is often important to be able to migrate fracture attributes derived from seismic data. Conventional pre- and post-stack migration methods are incapable of handling azimuthal variations in amplitude. However, they can be modified to do this, and then they can be used in positioning seismic fracture attributes. Some such time-migration methods are tested on a geologically complex data set over the Manderson Field in Wyoming, USA, for which well control for the fractures in the reservoir is available. All these migrations collapse zones of apparently high fracture intensity and move them closer to significant structural features, e.g. faults. The conclusion is that these migration methods can successfully move the fracture attributes to appropriate positions.

Introduction

Recent work has shown that open, fluid-filled, natural fractures can be detected in seismic data from **A**mplitude **v**ersus **A**ngle and A**z**imuth (AVAZ) analysis of P-wave 3-D seismic data using Rüger's (1996) AVAZ equation to derive the anisotropic gradient and its orientation (e.g. Gray et al, 1999, Hall et al 2000, Roberts et al 2001, Gray et al, 2002). Rüger's anisotropic gradient is closely related to the seismic 'crack density' (Lynn et al, 1996). Fractures usually occur where brittle rocks are stressed so much that they crack. Fractures are often observed in areas of significant geologic structure because the rocks fold (bend), fracture and fault (break) to accommodate the applied stress. Therefore, fractures are frequently observed in association with faults and folds, where migration of seismic data is required. Conventional migration methods mix the azimuthal components of the seismic data and therefore cannot be used for positioning of these seismic AVAZ fracture attributes. Existing pre-stack and post-stack time migration methods can be modified so that they account for azimuthal variations in amplitude and so are suitable for use with these attributes. These migration methods are applied to 3-D seismic data shot over the Manderson Field in Wyoming, USA, which has significant structural features and has had oriented analyses of the core from three wells within the area of the 3-D to indicate the size and orientation of the fractures in the reservoir. Results of the migrations show that zones indicating significant fracturing on the unmigrated results, observed in Gray and Head (2000), spatially collapse and move up-dip, in a fashion similar to the way the seismic stacked amplitudes do when they are migrated. The seismic fracture attributes also tie available well control for the fractures. This suggests that the migration methods used here are suitable for positioning these AVAZ fracture attributes.

Methods

Pre-stack

Traditional common-offset migration methods can be modified for use with azimuthal attributes by adding an azimuthal component to the method. By dividing the pre-stack input data into restricted azimuthal zones, which we call azimuthal cones, based on shot-receiver azimuth and performing amplitude-preserving common-offset migrations on each azimuthal cone individually, a pre-stack migration that conserves azimuthal variations in amplitude with offset can be performed. It has been shown that common-offset migration, when done properly, does preserve amplitudes (Gray, 1998). The pre-stack migrated azimuthal components can be recombined and the combined data set passed through the AVAZ analysis algorithm to create traces representing the anisotropic gradient and its orientation, which are used for the detection of fractures. Because the AVAZ analysis is run on the appropriately-positioned, recombined, azimuthally-restricted, pre-stack seismic gathers, the fracture attributes are also appropriately positioned.

Post-stack

Sections representing Rüger's anisotropic gradient are created by AVAZ analysis of the unmigrated seismic gathers. They are usually non-negative and therefore they may have significant low frequency components that may go as low as DC, so they are probably not suitable for migration directly. However, the anisotropic gradient and its orientation can be combined and treated as a vector and this vector may be transformed into two orthogonal directions, e.g. east-west (X) and north-south (Y). The transformed anisotropy trace data can then be input into traditional post-stack migration processes - if its bandwidth is similar to that of the stacked seismic data. Each of these X- and Y-anisotropy sections are migrated separately, then the migrated X- and Y-components of the seismic anisotropy are recombined and transformed back to create the migrated anisotropic gradient trace and a trace representing its orientation.

Experiments

The above migrations are applied to the 3-D seismic data shot in 1996 over the Manderson Field in Wyoming, which was used in Gray et al (1999). This field is in is a highly structured area in Wyoming's thrust belt and is geologically complex. The field produces oil and gas from a Permian-age, medium- to thick-bedded, fractured carbonate of low matrix porosity. It is part of an asymmetric, NW-plunging anticline, which is faulted in the deeper part of the section (Figure 1), including in the reservoir zone. There is also faulting in the reservoir running in an EW direction, which complicates the stress field and hence the fracturing in the reservoir. Oil and gas production is significantly enhanced when natural fractures are encountered in the reservoir. The results of the migrations of the AVAZ fracture analysis are expected to conform to structure, as did the unmigrated results in Gray and Head (2000), and observed zones of high crack density are expected to collapse and move up-dip, as do seismic amplitudes when they are migrated.

Results

The migrated anisotropic gradient traces, which can be considered to be estimates of the crack density (Figure 2), show similar structural features to the migrated stack (Figure 1) and zones of high anisotropy appear to have collapsed and moved up-dip (as migration is expected to do), closer to significant structural features like the faults (Figure 3). The latter result is particularly encouraging as zones of intense fracturing are expected to occur more frequently in areas where the rock has been bent more. Zones like the top of the anticline, the inflection point on the flanks of anticline, and areas near faults are where these criteria are met. The zones of more intense fracturing indicated by Rüger's anisotropic gradient also better conform to the major structural features after the migrations. Particularly notice the better conformance of zones of apparently high intensity fracturing to the EW fault. This fault can be seen in the swirls in the contours on the SW part of the section (Figure 3). The migrated results also tie independent oriented core analyses, which indicate fracture strike and intensity in the reservoir, from three wells in this field (Gray et al, 1999). The high intensity fracturing also remains bed-bounded, which is as observed by Gray and Head (2000) for the unmigrated data, and is consistent with observations of this formation in outcrop at Zeismann Dome, 10 miles to the SE of the field, as described in Gray and Head.

Conclusions

Various conventional migration methods, with modifications that allow them to account for variations in amplitude with azimuth, are applicable for positioning seismic fracture attributes. Instances of such pre-stack and post-stack time migration methods have been shown to be appropriate and work effectively to position seismic fracture attributes from a highly structured area. It has been shown that the results of these migrations collapse zones of high fracture intensity observed in the unmigrated sections and move them up-dip and closer to major structural features, where fractures are expected to occur and that these results tie other geologic information for this reservoir.

References

Gray, F.D., Chen, T. and Goodway, W.N., 1998, 3-D AVO and migration: Geo-Triad '98 Abstracts, 157-158; 68th Annual Internat. Mtg., Soc. Expl. Geophys., Expanded Abstracts, 234-235.

Gray, F.D., Head, K.J., Chamberlain, C.K., Olson, G., Sinclair, J. and Besler, C., 1999, Using 3-D Seismic to Identify Spatially Variant Fracture Orientation in the Manderson Field, SPE Paper 55636 presented at the 1999 SPE Rocky Mountain Regional Meeting.

Gray, F.D. and Head, K.J., 2000, Fracture Detection in the Manderson Field: A 3-D AVAZ Case History: The Leading Edge, Vol. 19, No. 11, 1214-1221

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.

Hall, S., Kendall, J.M., Barkved, O. and Mueller, M., 2000, Fracture characterization using P-wave AVOA in 3-D OBS data, 70th Ann. Internat. Mtg: Soc. Of Expl. Geophys., Session: RC 1.3, 1409-1412.

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.

Roberts, G., Wombell, R., Gray, D., Al-Shamsi, A., Suwaina, O., Ajlani, G., Ebed, A. and Al-Kaabi, M., 2001, Estimation of fracture orientation, offshore Abu Dhabi, Expanded Abstracts of the 63rd EAGE Conference and Technical Exhibition.

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

Figures

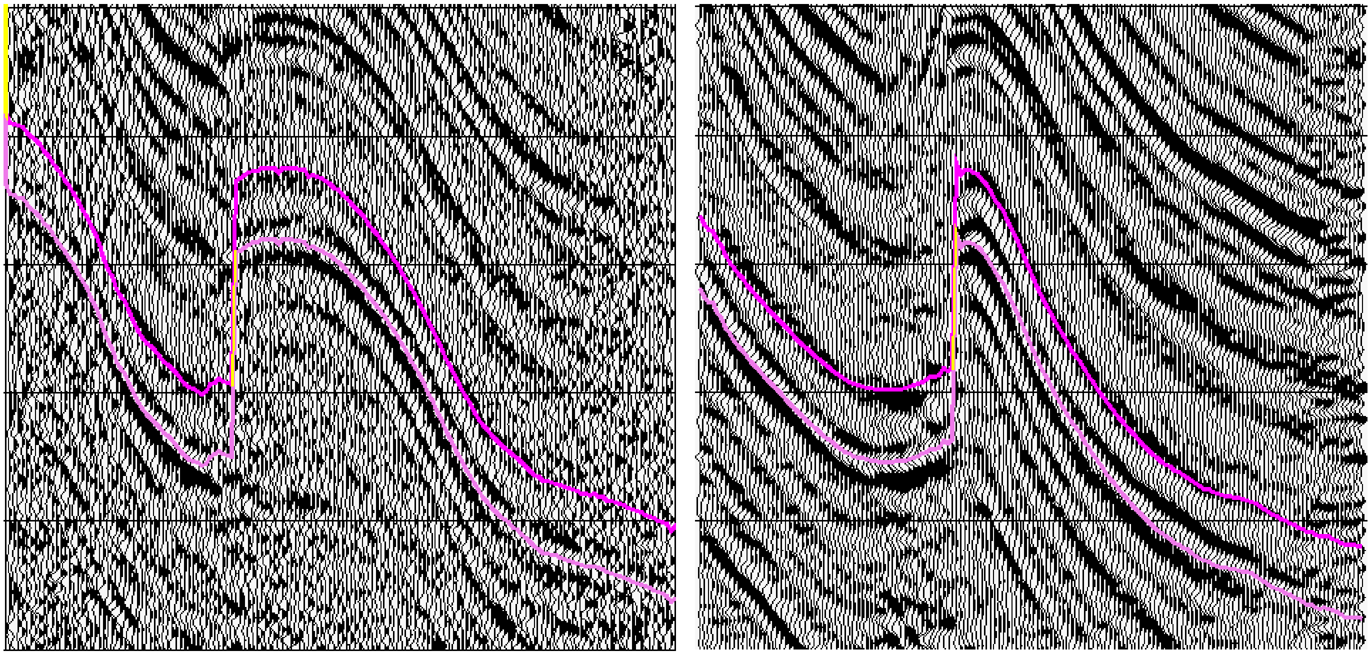

Figure 1: The structure stack, shown on the left, and the migrated stack, on the right, give an idea of the structure in the area. The major structural feature is a steep-sided, NW plunging anticline, the center of which is faulted in the deeper part of the section, including at the reservoir level. There is also a smaller, E-W trending fault that appears to influence and complicate the fracture pattern in certain areas.

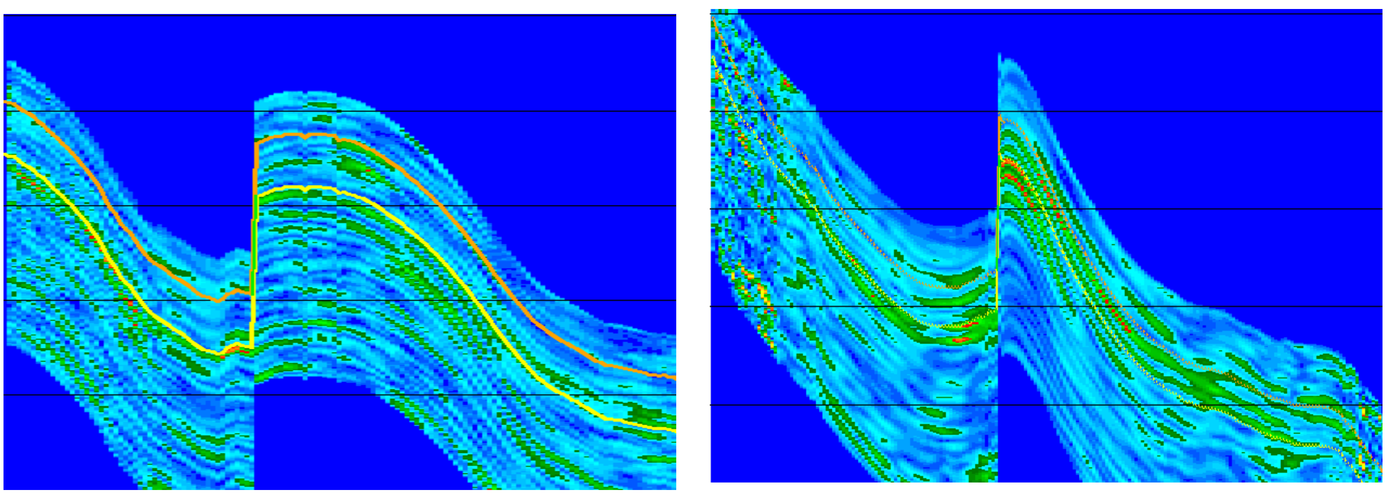

Figure 2: The unmigrated estimated crack density volume is shown on the left and the estimated crack density calculated from AVAZ analysis on the pre-stack, common-offset migrated gathers is shown on the right. Significantly, the zones of high intensity fracturing (reds and greens) continue to follow the structural trend in the migrated version, which has changed appreciably due to the migration, providing evidence that this migration methodology is moving the estimated seismic anisotropy correctly.

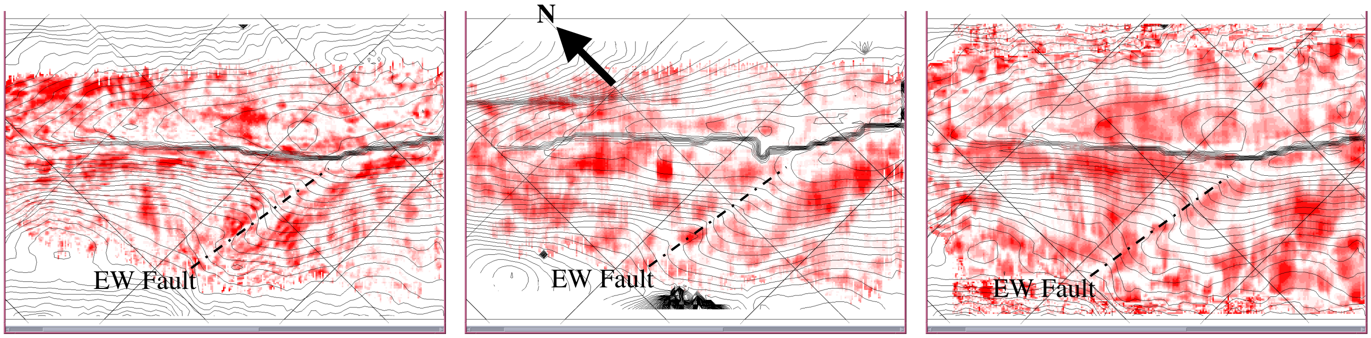

Figure 3: On the left is a map of the estimated crack density output by the post-stack migration of the AVAZ results. The center of the Figure shows the unmigrated estimated crack density, and on the right is the estimated crack density derived from the pre-stack, common-offset migrated gathers. All maps show the average seismic anisotropy, which is also an estimate of the crack density, through a 10ms thick zone of the producing, Phosphoria formation. Deeper red indicates zones of higher crack density. A fault runs NW-SE along the axis of the anticline. It is down-thrown to the NE. A second, smaller fault runs E-W and is indicated on each of the maps. Zones of complex fracturing appear to be associated with the interaction of the E-W and NW-SE faults.