

Fracture analysis on prestack migrated gathers: A physical modeling study

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Summary

Fractures are often associated with geologic structures. If seismic fracture analysis is applied to unmigrated CMP gathers in highly structured areas, energy can be mispositioned thereby affecting the accuracy of the analysis. In highly structured areas, it is important to prestack migrate data before performing fracture analysis. One approach to do so is to run prestack migration for several different azimuthally restricted gathers separately.

Geometry irregularity is a problem for migration of seismic data acquired on land. When migration is applied to an azimuthally restricted gather, this irregularity can be even more severe. In this paper, area weighting is used to compensate for the geometry irregularity. Tests of these concepts on a physical modeling dataset are performed and good results are achieved.

Introduction

Many papers have been published on fracture analysis using extracted seismic amplitude variation with angle and azimuth (e.g. Gray et al, 1999, 2002, Hall et al, 2000, Roberts et al, 2001). The analysis is based on Rüger's (1996) equation to derive the anisotropic gradient, which is closely related to crack density (Lynn et al, 1996). In this method, AVO analysis is extended to AVAZ (**A**mplitude **V**ersus **A**ngle and **A**zimuth) to obtain crack density and orientation, along with AVO intercept and gradient.

Fractures often occur in highly structured areas, bringing a challenge to extracting fracture information from the amplitudes of unmigrated P-P reflection data (Zheng and Gray, 2002). The energy in unmigrated CMP gathers is smeared over a Fresnel zone and mispositioned down-dip. To place the crack density and orientation in the correct position and eliminate the dip effect, prestack migration should be incorporated into the AVAZ processing. In this paper, we illustrate the procedure using prestack time migration.

A test on physical modeling data shows that the crack density is better imaged on the AVAZ output on the prestack migrated gathers than on the unmigrated CMP gathers.

Method

Conventional prestack migration mixes all azimuths of the seismic data, preventing the use of AVAZ analysis on migrated gathers. To preserve the azimuth information of the seismic data, we can modify the migration workflow and divide the migration input gathers into several sub-volumes. Each sub-volume only contains traces with acquisition shot-receiver azimuths that are in a certain restricted range. Migration is applied to each sub-volume individually. Assuming that the seismic ray path is restricted to the plane defined by the shot, receiver and image

locations, the acquisition azimuth is the same as the subsurface azimuth at the image point. The migrated sub-volumes are then combined together to form a complete set of migrated gathers that preserve the variation in amplitude with azimuth.

For most land seismic data, the acquisition geometry is irregular, and sampling in offset and azimuth is not uniform. After being divided into sub-volumes, the offset sampling will be even less uniform. Special treatment is needed to preserve amplitudes and compensate for the geometry irregularity. Area weighting (Zheng et al, 2001) is a good method for this purpose.

The combined, migrated, azimuth and amplitude preserved gathers are least-squares fitted to the Rüger's equation by an AVAZ algorithm to create traces representing AVO intercept, AVO gradient, crack density and orientation. Since the seismic energy is focused prior to the AVAZ, the positioning of the output attributes is correct; therefore AVAZ on the migrated gathers will give good estimates of crack density in the correct position.

Model composition and data acquisition

A physical modeling experiment has been conducted by CNPC Geophysical Key Lab. The model consisted of three layers. The first and third layers are isotropic. The second layer is azimuthally anisotropic. The fast P and S wave direction is along the X-axis (90° azimuth), and the slow P and S wave direction is along the Y-axis (0° azimuth). P and S wave anisotropy is about 20%. At the base of the anisotropic zone, there are two milled out structures, a dome and a thrust fault (Figure 1). The model was submerged in water at an equivalent depth of 1470 m. The modeling scale is 1:10,000. The equivalent thickness of the first layer is 495 m; the second layer 602 m; and the third layer 690 m. The height of both dome and thrust fault is 200 m.

A wide-azimuth P-wave reflection survey was shot and recorded at the water surface (Wang and Li, 2003). There are 1040 shots in total. The receiver patch is 12 lines x 64 receivers. The shots are located in the center of the receiver patch. Both shot and receiver intervals are 50 m. The natural CMP bin size is 25 x 25 m². The normal fold is 48. The minimum offset is 200 m and the maximum is 2122 m. The equivalent depth of the bottom of the fractured layer is 2564 m; the equivalent depth of the top of the two structures (dome and thrust fault) is 2354 m. At each CMP location, the offset and azimuth coverage is fairly good, except that there is no acquisition azimuth on the east-west direction, because of the limitation of the modeling device.

Since both shots and receivers are on the surface of the water, only PP waves were recorded. There might be some interbed converted waves in the recordings, but they are not the interest of this paper. Figure 2 is a raw record with Automatic Gain Control (AGC) applied in order to show all reflections. Clearly, there are four primary reflections, the water bottom, the top of the fractured layer, the bottom of the fractured layer, and the bottom of the model. There are also some multiples and possibly interbed converted waves.

Data processing and interpretation

For processing, the input gathers were divided into eight azimuthal cones. Each cone is 22.5° wide. For example, the first cone contains the traces whose shot-receiver azimuths are in the range from -11.25° to 11.25° and from 168.75° to 191.25°. Area weighting (Zheng et al, 2001) was applied to the data of each cone prior to migration to compensate for the irregularity of the acquisition geometry. Then prestack time migration was applied. After migration, the migrated gathers from the eight cones were merged together to form amplitude and azimuth preserved gathers.

AVAZ analysis was applied to the prestack migrated gathers. Ideally, AVAZ measures azimuthal anisotropy on the top and the bottom of the fractured zone. Figure 3 shows a line of the estimated crack density, and Figure 4 shows a

line of the estimated crack orientation, both were detected from the prestack migrated gathers, on the same section shown in Figure 1 (b). As a comparison, Figure 5 shows the estimated crack density detected from the unmigrated CMP gathers on the same line as in Figure 3. In these three figures, the wiggle traces are AVO intercept. The overlaid color represents the crack density or orientation. The crack density in Figure 3 is in the correct location on both the top and the bottom of the fractured layer. On the other hand, in Figure 5, only on the top of the fractured zone, the crack density from unmigrated CMP gathers is correct, but on the bottom of the fractured layer, around the structures, it appears on the incorrect position.

The crack orientation of the model is 90°. Figure 4 shows that the estimated crack orientation is around 90° (red) or 0° (blue). Because of the ambiguity in the estimated crack orientation (Zheng et al, 2004), the estimated orientation is either correct or off by 90°. By modulating this ambiguity, in this example AVAZ on the prestack migrated gathers gives the correct crack orientation. Additional information is needed in order to determine if the result from AVAZ is parallel or perpendicular to the strike direction of the fracture.

Conclusions

Fractures often occur in highly structured areas. The structures introduce smearing through the Fresnel zone and mispositioned reflected energy. Gathers that preserve amplitude and azimuth are created by applying prestack migration to a set of azimuthally restricted gathers and then recombining them. The fracture analysis results should then not be affected by the artifacts caused by geologic structures. Geometry irregularity and amplitude preservation must be addressed as part of the migration process.

A physical modeling test has shown that the crack density and orientation determined from the prestack migrated gathers are more accurate than those from the unmigrated CMP gathers.

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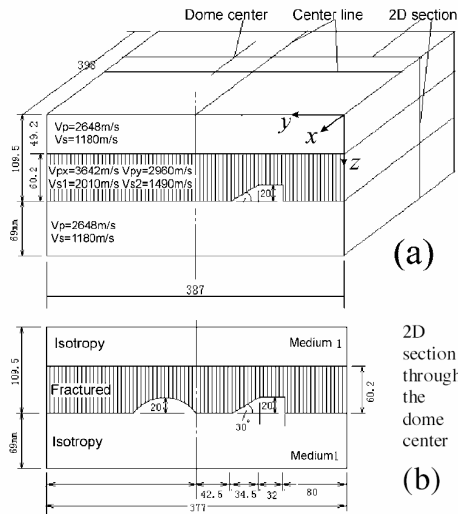


Figure 1. (a) 3D view of the model. (b) A 2D section through the center of the dome. There are two structures at the bottom of the fractured layer, a dome and a thrust fault. The modeling scale is 1:10,000. (after Wang and Li, 2003)

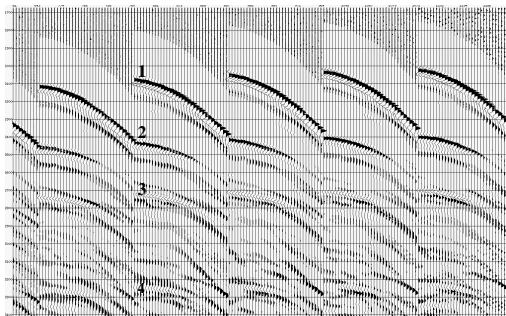


Figure 2. A raw record with AGC applied. Four primary reflections are clearly shown. (1) the water bottom; (2) the top of the fractured layer; (3) the bottom of the fractured layer; and (4) the bottom of the model.

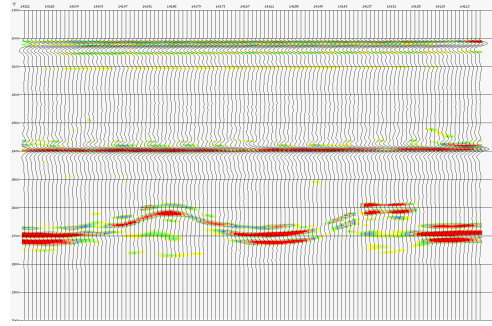


Figure 3. The crack density (color) detected from prestack migrated gathers is overlaid on the AVO intercept (wiggles). Red color indicates high crack density.

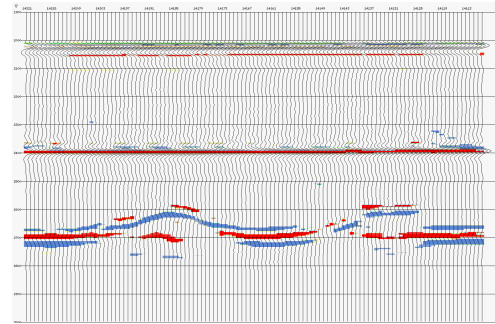


Figure 4. The crack orientation (color) detected from prestack migrated gathers is overlaid on the AVO intercept (wiggles). Red color indicates azimuth around 90° and blue 0° .

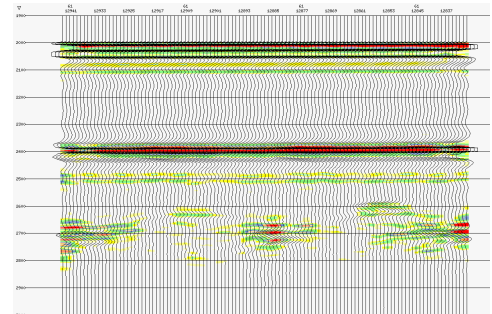


Figure 5. The crack density (color) detected from unmigrated CMP gathers is overlaid on the AVO intercept (wiggles). Red color indicates high crack density.