Fracture detection using marine streamer data: a case study


Summary

Fractures can provide conduits for fluid flow and knowledge of their distribution and orientation can be critical to hydrocarbon production. Here we present a case study from the North Sea to demonstrate how fracture strike and intensity can be estimated using conventional 2D streamer data selected from repeated surveys of different vintages. The data include four 2D lines intersecting at a wellbore with sonic logs. The area is relatively flat with dips less than three degrees. Three techniques are used to characterizing the fractures. These include azimuthal analysis of the interval moveout, NMO velocity and AVO gradient, combined with the application of a genetic algorithm for the inversion of the fracture parameters. The results of NMO velocity and AVO gradient analysis for the bottom target event are consistent with those of interval moveout analysis and show a strike direction of about North 10 degrees East and 5% intensity.

Introduction

Recent work on P-waves has opened a new era of more inexpensive acquisition for fracture detection when compared with multicomponent shear-wave surveys. These include azimuthal P-wave AVO (Lynn et al., 1996; MacBeth et al., 1997; Malik et al., 1998), and azimuthal variations in P-wave NMO velocity (Tsvankin, 1997), and interval moveout (Li, 1997). Here we apply these P-wave techniques to a dataset from the North Sea with four intersecting 2D lines.

The four lines have been acquired at different times over a 15 year period. Three lines are 2D surveys and one line is part of a large recent 3D survey. These lines intersect at the position where a well was drilled and density and velocity logs are recorded for depths up to 3200m (Figure 2). These marine seismic data are of high quality and should allow a reliable detection of any fracturing and a good comparison of the various techniques for fracture detection.

Study area

The study area is in the Norwegian sector of the Fife field in the Central North Sea. The primary reservoir is sandstone but additional reserve has been found in the chalk sequence. The chalk sequence is known to be fractured (MacBeth et al., 1997). The log data (Figure 2) shows that the overburden is a uniform sequence of claystone similar to the nearby area studied by Mackertich (1996). The local area around the well is very flat with dips less than 3°. This offers an ideal setup for the fracture detection from P-wave data.

Data processing

Only conventional data processing is applied to the data. The essential steps include gain control to maintain the relative amplitudes, velocity analysis, NMO stack, well tie and horizon correlation to identify the top and bottom of the reservoir for subsequent anisotropy analysis.
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At the cross point, the velocity spectra show consistent forms (Figure 3). This confirms that lateral structural variations are small. After NMO stack, a comparison between the log synthetics and the stacked section is carried out to identify the top and bottom of the reservoir. The correlation is very good, and the area of interest is the thin layer just above the sharp velocity and density increase at a depth of about 2800m (Figure 4).

![Figure 3. Velocity spectra of the CDP gathers at the well location for all four lines.](image)

Azimuthal interval moveout analysis

The azimuthal variation of the interval travel time shows elliptical variation and allows the estimation of the fracture strike and intensity (Li, 1997). Here we pick the travel time of the top and bottom of the target events and fit ellipses to the interval times. A simple genetic algorithm (GA) is used to obtain the best fitting ellipse (Kühnel, 1998).

The top and bottom events and the picked travel times for lines 1 and 2 are shown in Figures 5 and 6. The smoothed interval times for all lines and an example of the best fitting ellipse are shown in Figure 7, indicating the fracture strike direction at about North 10 degrees East with about 5% azimuthal anisotropy.

![Figure 5. Left: CDP gather at the well location for line 1. Right: Picked travel time for the top and the bottom of the target zone.](image)

![Figure 6. Same as Figure 5 but for line 2.](image)

![Figure 7. The smoothed interval travel times together with the best fitting ellipse calculated from the inversion results.](image)

NMO velocity

In order to verify the result from the analysis of interval travel time, a similar analysis is applied to the NMO velocities of the four lines. Grechka and
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Tsvankin (1998) showed that the azimuthal variation of the NMO velocity for a TIH medium is always an ellipse and the orientation of the axis indicates the fracture strike.

<table>
<thead>
<tr>
<th>$v_{NMO}$</th>
<th>Line 1</th>
<th>Line 2</th>
<th>Line 3</th>
<th>Line 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Top</td>
<td>2068</td>
<td>2061</td>
<td>2038</td>
<td>2065</td>
</tr>
<tr>
<td>Bottom</td>
<td>2144</td>
<td>2193</td>
<td>2177</td>
<td>2110</td>
</tr>
</tbody>
</table>

Table 1: NMO velocities in m/s for the top and the bottom of the target.

The azimuthal variation in the NMO velocity for the top of target is very small (Table 1), indicating an azimuthally isotropic overburden. In contrast, there is an azimuthal anisotropy using the interval velocity of a target at a depth of 2810 m. A minimum thickness of 2810 m is required for a reliable estimation of the azimuthal anisotropy using the interval velocity of a target at 2810 m two-way time.

To summarize, the analysis of stacking velocity for the bottom event yields consistent results with interval moveout analysis. The fracture strike is about North 10° East, with about 5% azimuthal anisotropy.

**AVO analysis**

As shown by Rüger (1996), the azimuthal variation of the AVO gradient follows a $\cos(2\phi)$ variation. Thus the strike direction can be determined by the best fit of the function of $A + B\cos(2\phi)$ to the AVO gradient, and $\phi$ is the fracture strike.

The AVO gradient can be calculated from the picked amplitudes (Figures 8 and 9), after a normalization by the zero-offset amplitudes. Theoretically, zero-offset amplitudes from horizontal reflectors must be the same at the well position for all lines. We first apply this procedure to the top event of the target and the results are unstable, since the azimuthal variation is small.

Sayers and Rickett (1997) and MacBeth et al. (1997) show that azimuthal AVO response from the bottom of a fracture layer is often more significant than the response from the top. Following their examples, we use the top event as a calibration point to normalize the amplitude of the bottom event, in order to compensate for the overburden effects.

**Figure 8.** Left: CDP gather at the well location for line 3. Right: Picked amplitude for the top and the bottom of the target zone.

**Figure 9.** Same as Figure 8 but for line 4.

**Figure 10.** The normalized amplitude for the bottom of the target versus the squared sine of the incidence angle at the reflector. a) Line 1, b) Line 2, c) Line 3 and d) Line 4.
After this normalization, a significant variation in the AVO gradient is revealed (Figure 10). Except line 4, lines 1, 2 and 3 show a good AVO response (Figure 10). Figure 11 shows the results of the best fitting cos 2φ function for the four AVO gradients. The fracture strike is given at about North 10 degrees East, which is in very good agreement with the results from the kinematic analysis.

![AVO Gradient vs Profile Angle](image)

**Figure 11.** The best fitting cosine to the AVO gradients of the reflections from the bottom of the target.

Conclusions

We have shown that fracture orientation can be estimated from intersecting 2D marine seismic surveys. The application of the different techniques to the real data yields consistent results and improves the reliability of the estimations. Depending on the thickness of the target zone and the complexity of the overburden, the results from AVO and interval velocity analysis should be viewed with some cautions. In our case, NMO velocities of the top event show almost no azimuthal variation, and analysis is carried out for the bottom event. AVO analysis is also focused on the bottom of target while the top of target is used as a calibration horizon for compensating any overburden effects on amplitude variation. The fracture strike is determined at about North 10 degrees East with about 5% intensity.

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References


