# Can we extract fracture information from 3D marine streamer data?

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## Summary

Azimuthal $P$-wave AVO has been used successfully for characterising a variety of fractured gas reservoirs in land 3D data. Here we present a case study from the North Sea to demonstrate how fracture orientation can be estimated from 3D marine streamer data. The data include a 3D survey shot ten years ago using a two-streamer 3D boat. Super gathers are formed from the two streamers combined with crossed 2D lines from other vintage surveys to overcome the lack of azimuthal coverage. This gives rise to at least three azimuthal gathers for each CDP point along any particular crossed 2D line. The approach requires careful data processing to match the acquisition geometry, phase and amplitude characteristics of the 2D and 3D surveys. Azimuthal AVO analysis is then carried out for each CDP point along the crossed line. In this way, the lateral variation in fracture orientations can be determined, and the results agree with previous analysis of orthogonal 2D lines (Liu et al., 1999).


## Introduction

Fracture detection using P-waves instead of S-waves has attracted considerable attention in recent years (e.g. MacBeth, 1998; Leaney et al., 1999; Tsvankin and Lynn, 1999; Contreras et al., 1999). However, the application of P-wave fracture detection to marine data is a challenge because of the lack of azimuthal coverage in marine streamer surveys. 3D marine data are quite different from land 3D data in which most of the data are recorded with single or multi streamers which are parallel to each other, giving rise to a very narrow azimuthal coverage. This, to some extent, limits the application of azimuthal analysis of P-wave attributes for fracture detection.

In this paper, we examine the possibility to combine super gathers of 3D multi-streamer survey with crossed 2D lines from other vintage surveys to overcome the above problem. For 3D data acquired with multi-streamers, at least three-azimuthal gathers can be formed along the CDP points of any crossed 2D line. Applying the P-wave fracture detection method, the orientation information can then be calculated. This forms the basis of our scheme for extracting fracture information from 3D marine streamer data. A dataset comprising one 3D survey acquired with a two-streamer 3D boat and several crossed 2D surveys from the North Sea is used to illustrate this scheme.

## Study area and datasets

The Data were recorded over a salt-induced structure in the Central North Sea with intensive faulting in the area (Figure 1). The target is the Ekofisk and Tor formations in the Chalk sequence. The top and bottom of the target are at 3130ms and 3200ms two way time, respectively. The chalk sequence is approximately 200m thick and is known to be fractured. High hydrocarbon saturations are believed to be related to the fractured/fault zones.

There are total 88 swathes in the 3D data and each swath has two receiver lines, which are parallel to each other (Figures 2 and 3). In addition, there are ten 2D lines (Figure 1). These datasets were shot about ten years ago (Table 1). The azimuth of the 3D swathes is also parallel to the main fault system at the target depth. For such a dataset, initially it appears to be inadequate for azimuthal analysis for fracture detection, simply because of the lack of azimuthal coverages.

## Data processing

We utilise the multi-streamer configuration in the 3D survey to increase azimuthal coverage (Figure 2). Combined with a crossed 2D line, this will give rise to at least three azimuthal gathers at each CDP point along the crossed 2D line. The goal of our processing is to prepare the data at each CDP point for azimuthal analysis. Firstly, we need to locate those surface points with at least three azimuthal observations. Secondly, we should be able to sort the data into super gathers that contain traces from the same CDP point. Afterwards, we can apply azimuthal analysis of P-wave attributes to these super gathers. For the same super gather, there may be many offset distributions. The fracture strike is calculated for each offset distribution and the averaged result of all offset distributions is defined as the strike for the CDP point.

To fulfill the above goals, we develop the following three-match processing scheme. The first match is the geometry match which matches the coordinate values from the navigation files to their corresponding traces. This proves to be very time consuming for vintage datasets because of possible missings in shots or navigation data. The second match is the CDP bin match between the 2D and

Table 1: The acquisition parameters of the 2D and 3D marine data

| | Shot Interval (m) | Receiver Interval (m) | Traces /Shot | Date | Shots | Size (GB) | Record Length (ms) | Sample Rate (ms) |
|---|---|---|---|---|---|---|---|---|
| 2D | 26.6/50 | 13.3/25 | 240/120 | 1989 | 10,000 | 10 | 7000 | 2 |
| 3D | 50 | 25 | 240 | 1989 | 50,000 | 56 | 7000 | 2 |

3D surveys. This is also time consuming, due to variations in acquisition geometry among different 2D lines and between the 2D and 3D surveys. This process contains several steps: for example, coordinate assignment, boundary searching, header value manipulation, etc. Figure 4 shows an example of such super gathers. The third match is the data match which deals with time shifts and source wavelets difference among these vintages surveys, and Figure 5 shows an example.

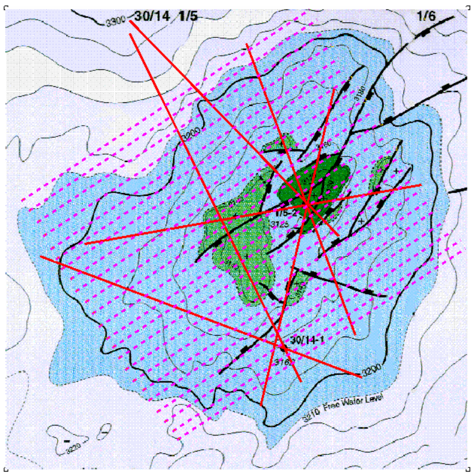


**Figure 1**. Depth map of the target (Ekofisk). The dashed lines show the shot direction of the 3D swathes, and the solid lines show the crossed 2D lines. There are total 88 swathes which are parallel to each other and ten 2D lines across the 3D area.

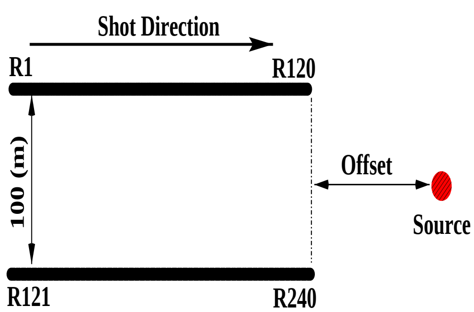


**Figure 2**. Streamer configuration of the 3D survey. It was a two-streamer 3D boat with 240 receivers on each streamer.

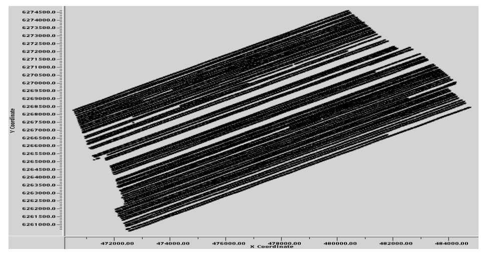

**Figure 3**. Regional coverage of the 3D survey. There are 88 swathes separated by 100m from each other.

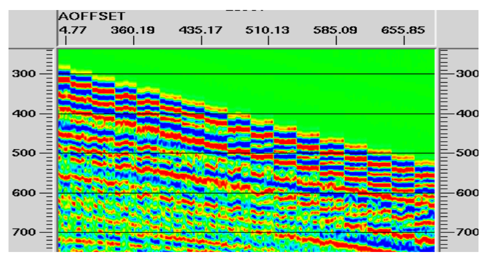


**Figure 4**. A windowed display of a super gather of the combined 2D and 3D surveys. Common-offset traces with different azimuths show constant first break times, and the attribute analysis will be performed on these common-offset traces.

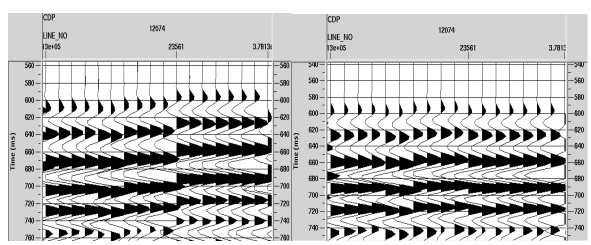

**Figure 5**. Left - the super gather without data matching. Right - the super gather after data matching.

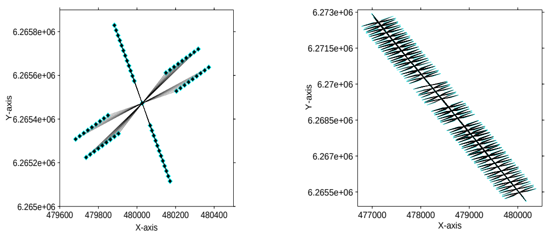


**Figure 6**. Azimuth distribution analysis. Left - the distribution for a given CDP. Right - the distribution for all CDPs along a crossed 2D line

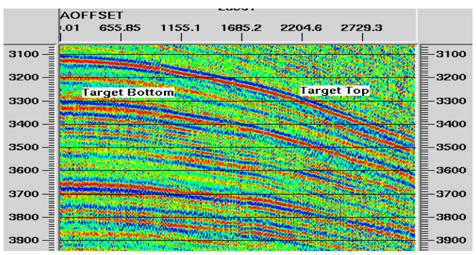


**Figure 7**. The top and bottom reflections from the target as identified in the super gather of the combined 2D and 3D surveys.

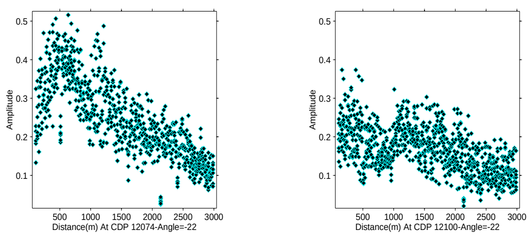


**Figure 8**. Variations of amplitude with offset for a given azimuth. Left - CDP 12074; right - CDP 12100.

## Azimuthal AVO analysis

We have utilised the multi-streamer configuration in the 3D survey to increase azimuthal coverage. As shown in Figure 6, the azimuthal coverage decreases sharply as offset increases. The key question to be addressed is that whether sufficient azimuthal variations in P-wave attributess can be observed to perform a reliable analysis? For this, we will focus on azimuthal AVO analysis, since azimuthal velocity and moveout analysis often require longer offset coverage than AVO analysis. This is aided by the presence of strong and coherent reflection events from the top and bottom of the target (Figure 7).

Firstly, the amplitudes at all offsets at the top target interface are picked up, and traces with offset separation less than 10m are summed together. To check the amplitudes, Figure 8 shows the amplitude variation with offset for different CDPs at a given azimuth, and Figures 9 and 10 show the amplitude variation with CDP points at a given offset for different azimuthal directions.

Secondly, we use the following equation for azimuthal AVO analysis:

$$F(\theta,\ \phi) = A(\theta) + B(\theta)\cos 2\phi, \tag{1}$$

where $F(\theta,\ \phi)$ represents the $P$-wave amplitude, $\theta$ is the incidence angle, $\phi$ is the azimuthal angle measured from the fracture strike, and $A(\theta)$ and $B(\theta)$ are azimuthally invariant coefficients. We use the least-square method to calculate the three parameters for different offsets. For each offset distribution, a set of A, B and $\phi$ are calculated and the results are averaged over all offsets for a given CDP (Figure 11).

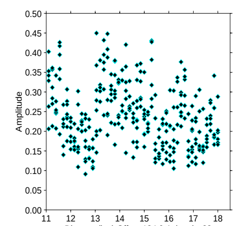


**Figure 9**. Amplitude variations with CDP points at a given offset for azimuth at -22 degrees.

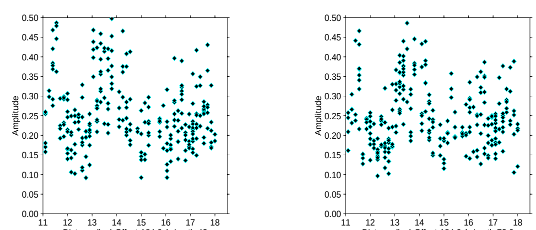


**Figure 10**. Amplitude variations with CDP points at a given offset for azimuths at 43 (left) and 73 (right) degrees.

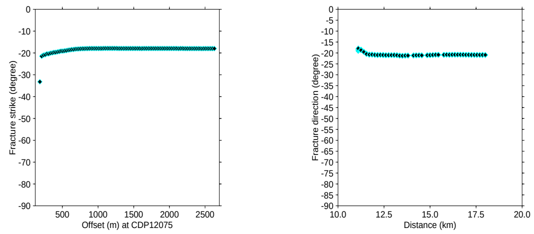


**Figure 11**. Results of azimuth AVO analysis. The fracture orientation calculated for each offset distribution for a given CDP (left) and the fracture orientation for each CDP along a given crossed 2D line (right).

## Discussion and conclusions

We have evaluated the possibility of using 3D marine streamer data for determining the fracture orientation. Careful processing is required to match the acquisition geometry and compensate for variations in time shifts and source signatures. For this, we have proposed a three-match scheme: geometry match, CDP bin match and data match. The result from this case study is very encouraging, and reveals good potential for further applications to modern 3D marine surveys with wider-azimuthal coverage and improved data quality.

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