Summary

Over the past ten years, there has been a continuous increase in the use of 3D P-wave data for fracture characterization. In this study, we analyze P-wave azimuthal anisotropy in three 2D OBC (Ocean-Bottom-Cable) lines combined with a patch of 3D OBC data from the Clair Field, in the UK continental shelf (UKCS), in order to assess how seismic anisotropy can help improving fracture characterization in this field. The three 2D OBC lines are at 45-degree angle with each other, intersecting at a well position, and overlaps with the 3D survey. Analysis of the P-wave amplitude and velocity at the intersecting point shows significant azimuthal variation. P-wave interval velocities show about 10% variation in azimuth and the orientation is at N94°E, agreeing with previous studies. The 2D and 3D results are consistent at the intersecting point, and the joint analysis of 2D and 3D data increases the spatial coverage and improves the accuracy, further confirming the potential for using azimuthal variations of P-wave attributes for fracture detection.
Introduction

The Clair Field is located about 75km west of Shetland on the UK Continental Shelf (UKCS) with a water depth of 140 m, and is regarded as the last remaining giant field to be developed in the UKCS with current estimated hydrocarbon volumes in place exceeding 4 billion barrels. The field comprises of a Devonian/Carboniferous fractured reservoir beneath a Base Cretaceous unconformity (Coney et al. 1993) with an oil column about 600m. Studies on oriented core and field analogue data indicate that the Clair reservoir contains a complex variety of fracture types, orientations and scales. Successful production from the field is very much dependent on the ability to characterize the fracture system.

To achieve this goal, a series of seismic initiatives were taken to evaluate the use of seismic anisotropy for improving fracture characterization. The first initiative was the acquisition of a multi-azimuth walkaway VSP in October 1996 to investigate if the azimuthal variations of seismic P-wave attributes may aid in fracture analysis (Horne et al. 1998). This leads to a feasibility study of using crossed 2D and 3D surveys from repeated vintages to map fracture orientation and density (Smith and McGarry 2001), and they successfully correlated the fracture density measured from velocity anisotropy to flow rates in producing wells. However, the intersecting points from these vintage surveys are very sparse. A 3D wide-azimuth OBC data set were then acquired in 2002. Before that, three 2D OBC lines coinciding with the walkaway VSP were acquired in May 2000, serving as a feasibility test for the 3D OBC survey. In this study, a patch of the Clair 3D OBC data is used for P-wave AVD (Attribute Versus Direction) analysis, and the results are analyzed jointly with the 2D results at the intersecting point.

Data acquisition and characteristics

The three lines of 2D OBC data were acquired in May 2000 using three Nessie-4 multi-component cables deployed on the seabed. The azimuths of the three 2D OBC lines are: North-South (Line A), N45°E (Line B) and N135°E (Line C), and intersecting at well 206/8-9Y (Figure 1a). The cables were 6 km long with receiver arrays every 25 m, giving 240 channels in total. Each array consisted of 7 hydrophones (P), and 21 orthogonal geophones (X, Y, & Z), hence a recorded channel group consisted of 7 receivers (P, X, Y, or Z). Shot spacing using a single array is 25 m for all lines, and CMP spacing for the 2D lines is 12.5 m with a nominal fold of 120.

Figure 1. Acquisition geometry of the Clair (a) 2D OBC lines, and (b) 3D OBC survey.

The 3D data were acquired with the same cable system in 2002 using the patch geometry where the sail lines are orthogonal to the receiver cables in order to obtain a wide azimuth coverage. Four cables are used with a cable separation of 480m, and sail line separation of
240m. Total four patches were acquired and the patch we analyzed coinciding with the 2D survey (Figure 1b). The patch shooting gives a good azimuth coverage. Figure 2 shows the offset-azimuth distribution of a CMP super gather from the 3D data. The horizontal axis denotes offset values, and the vertical axis denotes azimuth values. It shows that the data have a wide azimuth distribution that meets the requirement for fracture detection using P-wave data.

Figure 3 is a typical moveout-corrected supergather from the 3D data sorted in offset. The target horizon is below the base Cretaceous between 1400 and 1800ms. The maximum offset of the original data is around 3000m, but there is no useful information in the far offset traces at the target horizon due to interferes with the refracted arrivals. The effective offset for the target layer is less than 2000m, as indicated by the blue lines in Figure 3. This reduction in usable offset-range needs to be taken into account during acquisition design and data processing. Furthermore, there are significant multiple reflections present in the data due to the hard seabed. This will also compromise the result to some extent, especially for the target layer, where the primary reflections are relatively weak. Therefore, a careful processing procedure is required to attenuate the multiple and increase the signal to noise ratio in order to condition the data for azimuthal analysis. Further improvement in the data quality shall be very useful for successful fracture detection with the AVD method.

Azimuthal NMO velocity analysis

Azimuthal analysis is first carried out at the intersection point of the 2D OBC data. Amplitudes and traveltimes were picked for the event at 1.4s corresponding to the Base Cretaceous. The section down to the Base Cretaceous represents the overburden. The NMO velocity in the overburden shows weak azimuthal variation of 3-5%, which is within the error margins of conventional velocity analysis (Figure 4a), and there is no clear preferred direction; the interval velocity shows 10-15% variation with a clear fast direction at N94°E (Figure 4b). We binned the 3D data into six narrow azimuths, and the corresponding velocity ellipse shows 5-10% variation at the east direction (N90°E, Figure 4c). The 2D and 3D data agree with each other very well, and they are also in agreement with previous studies using streamer data (Smith and McGarity 2001). However, the AVO gradient in the overburden shows abnormal variations of more than 100%, and the direction is along N45°E, coinciding with the direction of Line B. This highlights the uncertainties associated with the amplitudes. More careful analysis is required for the amplitudes. Traveltime and velocity attributes may be more appropriate.
Analysis of azimuthal stack panels in the 3D data

For a low to high impedance contrast, the reflection coefficient along the fracture strike should be larger than the reflection coefficients along any other direction, whilst the reflection coefficient along the fracture normal should be the smallest. Figure 5 displays the azimuthal stack panels in six azimuth directions in order to examine the variations of the stacked amplitudes. The stack section in the east direction (90°) shows the strongest reflection event, and should denote a fracture strike along the east direction. In the north direction (0°), the event is the weakest one, which denotes the fracture normal direction. This result agrees with the result obtained from azimuthal NMO velocity analysis. Both azimuthal NMO velocity and azimuthal stack display approximately a fracture strike in the east direction.

Estimated fracture distribution from the 3D data

Figure 6a shows the fracture distribution obtained from the analysis of the top reflection amplitude. The colour indicates the fracture density. From the analysis carried out at the intersecting point, we have already known that the amplitude analysis is less reliable, and the results need to be interpreted more carefully. Figure 6b shows the fracture information derived by the AVO gradient. The distribution shows clear stripes parallel to the OBC lines,
indicating the effects of the acquisition footprint. This is consistent with previous findings regarding the use of the AVO gradient (Li et al. 2003). Figures 6c displays the results from the interval travel time, showing relatively stable fracture distribution trend. These results are consistent with the results at the intersecting point as shown in Figure 4.

Conclusions

The Clair 3D OBC data have a good offset-azimuth coverage, but refractions after the first arrival limited the effective offset range for azimuthal analysis. Only the data within the offset of 2000m can be reliably used for azimuthal attributes analysis. Thus, in OBC data acquisition, merely increasing the offsets is not good enough, and the effective offset range for the target horizon must be taken into account. The data also contain some strong multiples, which have in turn reduced the reliability of the results obtained from the amplitude analysis. Both analyses of azimuthal stacking velocities and azimuthal stack panels reveal a fracture orientation striking at the east direction. This agrees with the results of VSP and 2D OBC data analysis in the area. Furthermore, the anisotropy in the overburden above the Base Cretaceous is weak. This represents a very favourable setup for the use of seismic anisotropy for characterizing fracture distribution in the Clair field.

Acknowledgements

We thank the Clair Partners (BP, Chevron, ConocoPhillips, Shell and Amerada Hess) for providing and permission to show the Clair 2D and 3D 4C data. We thank Sue Fowler and John McGarrity of BP for useful discussion. This work is funded by the Edinburgh Anisotropy Project (EAP) of the British Geological Survey, and is presented with the approval of the Executive Director of British Geological Survey (NERC) and the EAP sponsors.

References


Figure 6. Fracture density and strike distribution from azimuthal attribute analysis: (a) amplitude; (b) AVO gradient; (c) interval travelt ime.