Abstract

The advantages of using converted-wave (C-wave) seismic data in hydrocarbon exploration have become widely accepted in recent years. Due to their sensitivity to anisotropy various new approaches have been introduced to estimate anisotropic parameters and correct this anisotropy. In this paper we promote the approach of using pre-stack time migration (PSTM). We have carried out an integrated analysis of the Alba 4C data to demonstrate how seismic anisotropy can be estimated from 4C seismic data and how such information can be used to improve subsurface imaging.

Introduction

The Alba Field is located about 225 km NE of Aberdeen in the UK sector of the North Sea. It is a high porosity Eocene sand reservoir sealed by shales. It is approximately 15 km long, 1.5-3.0 km wide and situated at a depth of ~2.0 km (MacLeod et al., 1999). The presence of polar anisotropy, or vertical transverse isotropy (VTI), is evident in the Alba 4C data and the effect must be taken into account for further improvements of the subsurface image. Here we show an approach of using pre-stack time migration to improve imaging (Dai, H., 2003; Li, X.-Y., 2003). Following this method the C-wave kinematic response is separated into a zero-dip response (moveout signature) for horizontally layered media and an all-dip response from a point scatterer (diffraction signature). The former controls the stacking process and the latter the PSTM. The moveout signature is determined by four parameters: the C-wave stacking velocity $V_{c2}$, the vertical and effective velocity ratios $\gamma_0$ and $\gamma_{\text{eff}}$ and the anisotropic coefficient $\chi_{\text{eff}}$. The diffraction curve is determined by five parameters: the vertical velocity ratio $\gamma_0$, the P- and S-wave stacking velocities $V_{p2}$ and $V_{s2}$, and their corresponding anisotropic coefficients $\eta_{\text{eff}}$ and $\zeta_{\text{eff}}$. There is a one-to-one link between the stacking and PSTM velocity models. Therefore, anisotropic imaging can begin with moveout analysis to build the stacking velocity model. This model can then be used as an initial model for PSTM. We will use the Alba 4C data to test this approach and to demonstrate how anisotropic parameter can be estimated and utilised for improved imaging. Constraints of the anisotropic parameters are obtained from the Alba VSP data for calibration and verification.

Real Data

The 4C data were acquired in 1998. For this work we have focused on one 2D shotline. The data show good signal-to-noise ratio, natural separation of P- and C-wave in the vertical and horizontal component and no leakage. Processing results from multiazimuth walkaway VSP data and wireline logs from deviated wells from the same region were available for model building.

Work Flow and Processing Results

First, we apply conventional processing to the data to estimate $\gamma_0$, which is needed before anisotropic processing can be performed. Secondly, we introduce a non-hyperbolic processing flow for both the vertical and horizontal components of the 4C data, which allows the estimation of the other three parameters by a semblance double scanning technique. Thirdly, we use these parameters to perform
anisotropic moveout correction and stacking which leads to improved stacked sections. Finally, the stacking model is used as an initial model for PSTM. Table 1 lists an example of picked anisotropy parameters $\chi$ and $\eta$ from C- and P-wave data for two selected near-surface events. Reference model values are calculated from available VSP data. We find that the anisotropic parameters derived from the C-wave data correspond well with the range of values seen in the VSPs. However, the P-wave parameters estimated from the surface data are much larger than the ones found from VSPs. As the parameter $\eta_{eff}$ is needed for PSTM model building we compare the values determined from P-wave data with those $\eta_{eff}$ calculated from C-wave data using the relation $\eta_{eff} = \chi_{eff}/(\gamma_0^2 - 1)$. We find that these calculated values correspond better with the VSP values.

<table>
<thead>
<tr>
<th>Event</th>
<th>Picked $\chi$</th>
<th>Model value $\eta$ from VSPs</th>
<th>Picked $\eta$ from P</th>
<th>Calculated $\eta$ from $\chi$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.45</td>
<td>0.017</td>
<td>0.163</td>
<td>0.01</td>
</tr>
<tr>
<td>2</td>
<td>0.34</td>
<td>0.023</td>
<td>0.35</td>
<td>0.009</td>
</tr>
</tbody>
</table>

Table 1: Anisotropy parameters estimated from real data. The model values are from VSP and well log data.

Figure 1 compares the final results of the non-hyperbolic C-wave stack (1a) and the C-wave PSTM (1b). Both sections are zoomed into the reservoir level. The events in the target zone (3.8-4.4s) have improved and are more continuous after PSTM than after stacking only.

![Figure 1](image1.png)

Figure 1: (a) C-wave non-hyperbolic stack and (b) PSTM focusing on the target interval of the Alba reservoir.

Modelling Study

In order to verify the processing results we carry out a forward modelling study. The model is based on three events in the overburden of the Alba field. Its properties are derived from the processing results of the VSP and surface data and are listed in Table 2.

<table>
<thead>
<tr>
<th>depth [km]</th>
<th>$V_{p0}$ [km/s]</th>
<th>$V_{s0}$ [km/s]</th>
<th>$t_{p0}$ [s]</th>
<th>$V_{p2}$ [km/s]</th>
<th>$t_{p2}$ [s]</th>
<th>$V_{s2}$ [km/s]</th>
<th>$\eta_{eff}$</th>
<th>$\chi_{eff}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.66</td>
<td>1.8</td>
<td>0.4</td>
<td>0.733</td>
<td>1.844</td>
<td>2.017</td>
<td>0994</td>
<td>0.0034</td>
<td>0.421</td>
</tr>
<tr>
<td>1.37</td>
<td>2.0</td>
<td>0.9</td>
<td>1.443</td>
<td>1.968</td>
<td>3.161</td>
<td>1.222</td>
<td>0.042</td>
<td>0.346</td>
</tr>
<tr>
<td>1.73</td>
<td>2.3</td>
<td>1.1</td>
<td>1.756</td>
<td>2.054</td>
<td>3.644</td>
<td>1.316</td>
<td>0.078</td>
<td>0.348</td>
</tr>
</tbody>
</table>

Table 2: Parameters for the three-layer model based on three anisotropic overburden events from the real data.

Figure 2 displays one CDP (2a) and one ACP (2c) gather from the 4C data set and Figure (2b) and (2d) show the respective synthetic seismograms computed with the reflectivity method. We test if the modelled traveltimes resemble the ones in the real data by plotting calculated traveltimes on the seismograms for the three chosen events. The traveltimes curves are computed from the model parameters and muted according to the range of validity of the traveltimes approximations (Li et al., 2003, Alkhalifah, 1997). For all three events the calculated traveltimes of both the P- and C-wave fit
the events very well for small offsets. For large offsets, the first and second event show good agreement for both wave types. The third one is hardly visible on the C-wave data. However, it can be seen on the P-wave.

![Figure 2](image1.png)

**Figure 2:** Comparison of real data and synthetic seismograms for three events from the Alba data set and its model. Traveltime curves are printed on top of the selected events. (a) Z-component of real data, (b) of synthetic study, (c) X-component of real data and (d) of synthetic study.

Again, we estimate the anisotropic parameters by semblance double scanning for both P- and C-wave synthetic data. The picked values and their errors compared to the model values are listed in Table 3. The first layer shows the largest errors possibly due to a large velocity ratio $\gamma_0$. Furthermore, parameter estimation is influenced by amplitude and phase changes for the events of layer 1 and 2 of the C-wave and event 1 of the P-wave, which leads to increased errors. In principle, the synthetic modelling study of the three events of the overburden from Alba confirms the findings from the real data. The traveltimes can be matched with the model and the parameters estimated from the synthetic data are in the same range as the ones obtained for the real data.

![Table 3](image2.png)

**Table 3:** Picking results from synthetic data using a double scanning technique.

**Evaluation with borehole data**

Interval velocities $V_{p0}$, $V_{s0}$ and Thomsen parameters $\varepsilon$ and $\delta$ gained from VSP data can be used to calculate the corresponding RMS and effective parameters. We use these quantities to evaluate the parameters obtained from surface data processing. Figure 3 shows the comparison of RMS-velocities from C-waves and P-waves as well as of the anisotropy parameter $\eta$. The P-wave RMS-velocities show the best agreement with each other. C-wave velocities from VSP and surface data results differ by about 0.4 km/s at an arrival time of 2 seconds and by 0.25 km/s for an arrival time of 3.5 seconds.

![Figure 3](image3.png)

**Figure 3:** Comparison of velocities (a) $V_{p2}$, (b) $V_{c2}$ and anisotropy parameters (c) $\eta$ gained from surface and VSP data.
Taking the obtained velocity and depth information from the VSP data into account we can obtain $\eta_{\text{eff}}$ values in the C-wave time domain. Figure 3c compares $\eta_{\text{eff}}$ obtained from VSP results with values calculated from the C-wave parameter $\chi_{\text{eff}}$ and values estimated directly from P-wave data. The VSP results give the smoothest curve. $\eta_{\text{eff}}$ obtained from C-wave data lies in the same range as values from the VSP data while the P-wave $\eta_{\text{eff}}$ is generally larger. This result confirms our earlier result that calculated $\eta_{\text{eff}}$ values from the C-wave parameter $\chi_{\text{eff}}$ match the actual medium properties than $\eta_{\text{eff}}$ estimated from P-wave data. In summary, comparing results from VSP data and surface data we find that especially the P-wave velocities match very well while there are differences for the C-wave. For the anisotropic parameter $\eta_{\text{eff}}$, however, there is better agreement if it is derived from C-wave data than from P-wave data.

**Conclusion**

We have presented an integrated study on imaging and model building of the Alba data. Evaluating the results by comparing VSP and surface data with synthetic modelling we find that the P-wave velocity matches very well with the VSP data whilst there are considerable differences for the C-wave velocity. In contrast, the anisotropic parameter from the C-wave data matches better with the VSP data than the corresponding parameter from the P-wave data does. A reason for this could be an error in event correlation. Furthermore, Leaney et al., 2001, found estimated values of $V_z$ in deviated wells to be significantly too high, so that some form of calibration would be required. We have verified the processing results from the surface data by a modelling study for 3 chosen events from the overburden. The travelt ime curves from the model match the real data reasonably well. We conclude that the synthetic study confirms that calculated $\eta_{\text{eff}}$ from C-wave parameter $\chi_{\text{eff}}$ is closer to the $\eta_{\text{eff}}$ values obtained from VSP data than the values determined directly from P-wave data.

**Acknowledgements**

The authors thank the Alba partnership (ChevronTexaco, BP, Conoco, Petrobras, Statoil, Total and Unilon/Baytrust) for permission to show the data. This work was supported by the Edinburgh Anisotropy Project (EAP) of the British Geological Survey, and is published with the approval of the Executive Director of BGS and the EAP sponsors.

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