C-wave anisotropic imaging using PSTM: a case example from the North Sea

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Abstract

In this paper we present the results from an anisotropic C-wave Pre Stack Time Migration (PSTM) of a 2D line acquired over the Lomond Field, North Sea. The key processing steps are model building prior to PSTM and model updating during PSTM. Four parameters are required to define the model: C-wave short-spread velocity, \( v_{cn} \), the vertical and the effective velocity ratios, \( \gamma_0 \) and \( \gamma_{eff} \), and the anisotropic parameter \( \chi_{eff} \). C-wave velocity and \( \chi_{eff} \) can be updated using inverse NMO on Common Image Points (CIPs) obtained from PSTM. The final results are very good. Comparing them with results from a more “conventional” isotropic PS-DMO plus Post Stack Migration demonstrates great improvement in the image quality.

Introduction

The Lomond Field, in the Central North Sea, is an excellent area to test C-wave processing tools: it has a complex structure, dominated by a salt-induced anticline fractured on top, large gas effects, due to the escape of gas from the fractured reservoir, and it has a strongly anisotropic (VTI) overburden of laminated shales.

We present here the results of an anisotropic PSTM processing sequence applied to the inline component from a 2D 4C line acquired over the Lomond Field. We apply a Kirchhoff PSTM based on a Double Square Root equation (DSR) (Dai and Li, 2003). The DSR is fully defined by four parameters: the C-wave short-spread velocity, two velocity ratios and one anisotropic parameter. These parameters can be extracted by non-hyperbolic processing of C-waves. Their correct definition, that is, the model building, is the crucial step of the processing sequence. This model can then be updated during PSTM; more on this procedure can be found in Dai and Li (2003). The PSTM approach has a double advantage over the more “conventional” PS-DMO plus Post Stack Migration sequence: it does not require CCP binning and only needs limited information from P-waves.

Parameterization

We define here the four parameters required for the PSTM: \( v_{cn} \), \( \gamma_0 \), \( \gamma_{eff} \) and \( \chi_{eff} \). \( v_{cn} \) is the C-wave short-spread velocity, \( \gamma_0 \) is the vertical velocity ratio, \( \gamma_{eff} \) is the effective velocity ratio, which takes into account the effects of layering, and \( \chi_{eff} \) is the C-wave anisotropic parameter (Li and Yuan, 2001). Equations (1) (2) and (3) (Thomasen, 1999) explain the link between the different velocity ratios. \( v_{pn} \) and \( v_{sn} \) are the P and S short-spread velocities while \( v_{p0} \) and \( v_{s0} \) are the P and S vertical velocities. The expression for \( \chi_{eff} \) is shown in equation (4):

\[
\gamma_{eff} = \frac{\gamma_0^2}{\gamma_0} \quad (1) \quad \chi_{eff} = \eta_{eff} \gamma_0 \gamma_{eff}^2 - \zeta_{eff} \\
\gamma_{s} = \frac{v_{pn}}{v_{sn}} \quad (2) \quad \text{with } \eta_{eff} \text{ and } \zeta_{eff} \text{ given by:} \\
\gamma_{0} = \frac{v_{p0}}{v_{s0}} \quad (3) \quad \eta_{eff} = \frac{1}{8t_{p0}v_{pn}} \left( \sum_{i} V_{pni}^4 (1 + 8\eta_i) \Delta t_{p0i} - t_{p0} V_{pn}^4 \right) \\
\zeta_{eff} = \frac{1}{8t_{s0}v_{sn}} \left( \gamma_0 V_{sn}^4 - \sum_{i} V_{sni}^4 (1 + 8\zeta_i) \Delta t_{s0i} \right) \quad (4) \quad (5) \quad (6)
\]
Model Building

$\gamma_0$

A raw $\gamma_0$ is estimated from event correlation between the P and C stacked sections (pseudo-zero offset) using the ratio of the arrival times, $t_{p0}/t_{c0}$. The event picking in the Lomond field is shown in Figure 1b. $\gamma_0$, as expected, is higher in the shallow part, where sediments are unconsolidated, and decreases with depth. At the reservoir ($t_{p0} = 2.2$ s.) $\gamma_0$ is about 2.8 (Figure 1c). The effects of the gas cloud are noticeable on the $\gamma_0$ profile.

![Figure 1](image1.png)

Figure 1: (a): P-wave stack. The area affected by the gas is circled in black; we can notice amplitude dimming and pull-down effects. (b): event correlation, P-stack on the left and C-stack on the right. Five events were correlated. (c): average $\gamma_0$ in P-time. At the target ($t_{p0} = 2.2$ s.) $\gamma_0$ is about 2.8.

$v_{cn}$ and $\gamma_{eff}$

$v_{cn}$ is obtained by short-spread velocity analysis on Asymptotic Common Conversion Point (ACCP) gathers. Given $v_{pn}$ (from P-wave processing) and $v_{cn}$ we can calculate $\gamma_n$ and $\gamma_{eff}$ using equation (2) and (1). The results are shown in Figure 2. From left to right we have $v_{pn}$, $v_{cn}$ and $\gamma_{eff}$. Due to high apparent C-velocity introduced by the presence of dips (Figure 2b) the $\gamma_{eff}$ field shows very low values, even below 1 in the areas affected by strong dip. In the middle of the section $\gamma_{eff}$ is about 1.5-1.6. $\gamma_{eff}$ can also be determined using a velocity independent procedure, based on imaging principles: the CCP-scanning technique (Audebert et al., 1999). With this technique we search for the value of $\gamma_{eff}$ giving the least lateral shift between the positive and negative offset stacks. Figure 3 shows the results of the CCP-scanning technique applied at the reservoir area of the Lomond data, the values of $\gamma_{eff}$ used are: 1.25, 1.50, 1.75 and 2.00. For each quadrant of Figure 3 the positive stack is at the top, the negative stack at the bottom. If we focus our attention on the top of the salt dome, the correct value of $\gamma_{eff}$ is about 1.50. This result is in good agreement with the central part of the $\gamma_{eff}$ field calculated using velocity information.

![Figure 2](image2.png)

Figure 2: (a): P-wave DMO velocity field, (b): C-wave DMO velocity field and (c): $\gamma_{eff}$ in PP time.
\( \chi_{\text{eff}} \) is calculated from residual long offset moveout correction on ACCP gathers, using the three-term equation presented by Li and Yuan (2001). The \( \chi_{\text{eff}} \) fields for the positive and negative offsets are shown in Figure 4. We can notice that \( \chi_{\text{eff}} \) has quite high values (up to 1.60) and that it tends to follow the geological structure. This consideration leads us to believe that the presence of dips has effects on the calculation of \( \chi_{\text{eff}} \) (Mancini et al., 2003).

**PSTM in practice**

After the initial model building on ACCP gathers, \( v_{cn} \) and \( \chi_{\text{eff}} \) can be updated during PSTM. The procedure is explained in Dai and Li (2003): a reverse NMO is applied to selected Common Image Points (CIPs) after PSTM, obtaining inverse NMO(INMO)-CIPs. Applying the inverse NMO to the CIPs removes the effects of the non-hyperbolic component of the velocity. Dai and Li (2003) show that the velocity picked on the Inverse NMO CIPs tends to converge to the correct value of the migration velocity after few iterations. Often one pass of velocity updating is adequate, but in more difficult areas more iterations may be needed. Figure 5 is an example of this procedure: from left to right we have ACCP 880 after non-hyperbolic NMO, CIP 880 after the first PSTM run, the INMO-CIP gather and CIP 880 after the second run of PSTM. The sharpness of the image at around \( t_{\text{c0}} = 5.0 \) s. is greatly improved. This CIP does not need further velocity update.

The full PSTM image is shown in Figure 6a. The image quality is very good, with great definition of the horst structure forming the top of the Lomond Field. In Figures 6b and 6c we show the detail of the reservoir area for the PSTM flow and for a more “conventional” isotropic PS-DMO + Post Stack Migration sequence. This sequence is limited to the near offsets, with hyperbolic velocity analysis before and after PS-DMO (Mancini et al., 2002). At the target the improvements in the overall continuity and, in particular, in the lateral positioning of the faults defining the horst after PSTM are noticeable. Above the reservoir the use of the full offset range introduces some noise, which deteriorates the continuity of the events. In this part of the data a time-variant mute can probably improve the results.
Figure 5: From left to right: ACCP 880 after anisotropic NMO, CIP 880 from PSTM first run, INMO-CIP 880, CIP 880 after PSTM second run.

Figure 6: (a): C-wave PSTM; (b): zoom-in of the target area (after PSTM); (c): zoom-in of the target area after PS-DMO+Migration

Conclusions

We have shown here the results from an anisotropic C-wave PSTM sequence applied on a 2D line acquired over the Lomond Field. Prior to PSTM we need to extract four key parameters required in the process. $\gamma_0$ is given by a raw event correlation, $\gamma_{\text{eff}}$ can be obtained from velocity information and/or using the CCP-scanning technique, $v_{cn}$ and $\chi_{\text{eff}}$ are extracted during long-offset velocity analysis on ACCP gathers. These parameters can be updated during PSTM. The final image is a great improvement compared with the results from the more “conventional” PS-DMO + Migration flow.

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Reference


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