Estimating and compensating for anisotropy observed in PS data for a Heavy Oil reservoir
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Summary
Shear-wave anisotropy in the Quaternary and upper Cretaceous section can be significant over heavy-oil reservoirs in Alberta. Compensation for the overburden shear-wave splitting improves the PS data used for reservoir characterization of the deeper targets. We illustrate both the analysis and compensation of splitting for a recently acquired 3-C dataset. The correction is applied using a layer-stripping approach to distinguish overburden effects from possible reservoir-level anisotropy.

Introduction
Extra-heavy oil development in Alberta has been a significant driver for multi-component 3D seismic acquisition in recent years to meet expansion plans and for time-lapse surveys for monitoring of thermal processes. Recent surveys commonly use 3-component sensors; the costs of 3C surveys have dropped to the point where they are now comparable to the single component programs.

The converted wave (PS) data acquired in the 3C-3D surveys has several potential applications in heavy oil developments, such as: identification of shale volume through Vp/Vs ratio analysis, tracking temperature changes in 4D surveys, and fracture identification by shear wave splitting. Shale volume is a particularly important parameter for heavy oil recovery processes as shale units act as barriers or baffles to steam movement, which reduces the recovery factor.

The PP data for the shallow (300 to 600 m depth) heavy oil targets is generally good to excellent quality with broadband (250hz) signal recovery using small (1/8 to ¼ kg) dynamite charges. However, the PS data quality varies significantly with some areas having very poor PS data and other areas having PS data equal to or better than the PP data. Poor PS areas are characterized by shallow layers with high shear absorption (Q = 1 to 10), high Vp/Vs ratios (5 to 8), and large lateral variations (up to 200 ms) in shear statics.

While solving the statics problem is probably the most important issue in processing the PS data, another feature of the near surface is that it can have significant azimuthal anisotropy, which needs to be accounted for and removed in order to improve the PS stack and to enable azimuthal analysis for the deeper target levels. Where azimuthal anisotropy is present, the shear waves split into fast and slow polarizations and PS reflections are found on both the radial and transverse components. In the past, PS data processing concentrated on mainly the radial trace or, in situations where the shear splitting was substantial, the data was further processed and rotated into PS1 (fast) and PS2 (slow) directions, typically choosing just one dominant angle for the fast shear direction and using that for rotating the entire survey.

While deeper formations have a fairly consistent maximum horizontal stress, forming a regional NE trend that is oriented parallel to thrust directions in the Rocky Mountains, we have found that shallower geologic units can have a very different set of lateral stresses and can exhibit significant amounts of splitting and azimuthal variations. The near surface sediments of northern Alberta have been extensively modified in the past 12 million years due to erosion by glacial action and large valley incisions. The present day minimum stress direction tends to be oriented towards the areas of deepest erosion by these features.

Method
Shear-wave splitting can be detected and analyzed using multi-azimuth data after initial rotation to the radial (parallel to source-receiver azimuth) and transverse (orthogonal to source-receiver azimuth) orientations. Figure 2 shows horizontal component data from a single CCP superbin, taken from a 3-component single sensor dataset acquired over heavy oil in Alberta. Each trace is a
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Figure 2: Radial (a) and transverse (b) data before and after layer stripping through overburden. Each display shows a set of traces, from within a single CCP superbin, stacked into 10° azimuth sectors, as annotated on top of the displays. The left side of each display shows original data. The right side shows result after correction for splitting estimated at the base Cretaceous horizon, around 700ms.

Each gather is rotated to the S1-S2 coordinate system, and is summed using an optimal stacking method to generate S1 and S2 traces. These traces are correlated to determine the total time delay between S1 and S2 signals. Then a time-variant shift, linearly interpolated between centers of analysis windows, is applied to the S2 shear wave to align it with the S1. This realignment compensates for the splitting effect and allows recombination of the split waves into new radial and transverse datasets. In the ideal case, the result would be that all of the transverse signal would be reassigned to the new radial data, leaving only noise on the transverse component. An indication of the quality of anisotropy estimation is the similarity between S1 and S2 records after correction, which is measured by the value of the cross-correlation peak.

The scheme may be applied in a layer stripping fashion to account for changes in the orientation with depth. In this case the center of the previous analysis window serves as the reference time for the time-delay measurement.
Results

This method was used to analyze the full dataset. The analysis initially was performed assuming a single layer from surface to the top of Devonian at about 700ms. The results are shown in figure 3, including: (a) the estimated S1 orientation; (b) the time delay between S1 and S2 – an indication of anisotropy intensity; and (c) the value of the cross-correlation peak between S1 and S2 – an indication of confidence in the estimation. It is observed that there is significant spatial variability in both the direction and degree of anisotropy. This suggests that factors other than simple regional stress are having a significant influence on the anisotropy. Secondly, the correlation coefficient is highly influenced by known acquisition difficulties, such as two lakes where shear wave transmission is blocked, and an area of unconsolidated dunes, which led to very poor data.

Subsequently the analysis was repeated (not shown) assuming two layers, one from surface to approximately 400ms, and a second from 400ms to 750ms. After analysis of the first layer, the azimuth and time delays were spatially filtered with median filtering, and a mask of the poor data areas was created from the correlation coefficient. This mask was used to zero the anisotropy in these areas. The data were “layer-stripped” to generate new radial and transverse data. These were then used to perform analysis for the deeper layer. The results of this two-stage layer stripping are shown in figure 4. The initial radial and transverse stacks are shown in (a) and (b). The new radial and transverse stacks after both layers have been corrected are shown in (c) and (d). Note the improved continuity and S/N of the radial data after layer-stripping, as highlighted by the ellipses. An important confirmation of the correction is the reduction in signal on the transverse data, as signal is being transferred onto the radial at each step.

Conclusions

PS data has potential benefits for characterization of extra-heavy oil (bitumen) reservoirs which are a crucial resource for unconventional hydrocarbons. Overburden azimuthal anisotropy with significant spatial variability causes shear-wave splitting effects that must be addressed to utilize the PS data optimally. Weaker anisotropic effects can be observed in the heavy oil reservoir itself. We have applied a prestack splitting analysis technique to each CCP superbin, and used the results to remove the anisotropic effects with a layer-stripping approach. The results are shown to be improvements in the quality of the stack image after each layer of splitting correction.

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Figure 4: Effect of layer stripping on stacked data, for radial data (a, c), and transverse data (b, d). The original radial and transverse is shown in (a) and (b). The data in (c) and (d) are the radial and transverse data after applying anisotropy estimates for three separate window (shallow, mid level, and deep). Improvements are observed in the radial data continuity as indicated by the ellipses in (c). On the transverse component stacks we see gradual reduction in coherent signal as the energy is transferred to radial, as indicated by the ellipse in (d).

References


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