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Constraining a 3D anisotropic tomography inversion with hundreds of well ties – A Canadian Oil-Sand case history

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Summary

This Canadian oil sands case history demonstrates how developments in depth imaging technologies enable accurate tying of the 3D seismic image of the subsurface to several hundreds of wells. The resulting Anisotropic Pre-stack Depth Migration provided a better-focused and better-positioned subsurface image, as well as Offset Vector Tile gathers for subsequent inversion work.

Introduction

The results of a 2013 depth imaging pilot project that is part of a larger feasibility study for an oil sands seismic survey were published in the CSEG Recorder (Charles et al, 2014). The job flows that were established in the pilot project were enhanced and extended to the entire seismic coverage of the commercial SAGD project area. Over the lifecycle of the field development, many vertical wells have been drilled in the area to delineate and assess the quality of the resource. In fact, there are more than 800 vertical wells within the seismic coverage area that can be utilized to tie the subsurface image, and more than 160 horizontal well pairs from SAGD pads.

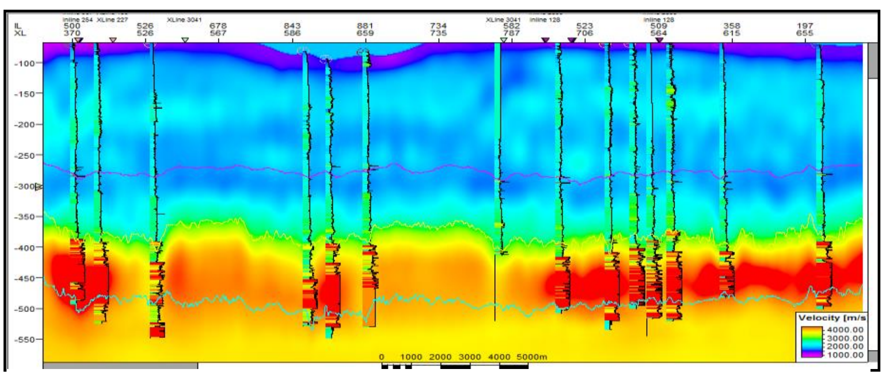

Figure 1: *Final APSDM velocity traverse with sonic velocity for the deep wells. There is a good correlation between the well velocities and the tomography model. The sonic logs were not used to constrain the model.*

In this abstract we will describe in more detail how we carried out depth imaging on the project. A newly acquired 3D walkaway VSP at the north boundary of the seismic coverage area was used to derive the initial anisotropy parameter estimations using different methods, including the slowness polarization inversion (Home and Leaney, 2000). The depth imaging process started with a velocity model built from the near surface refraction tomography velocity model and PSTM velocity field. Because the data are rather low resolution and relatively sparse for such a shallow target, and because different shooting directions were used over the years, we decided to regularize the data using 5D interpolation onto a common grid, i.e. we emulated a new and perfectly regular seismic field acquisition experiment. Beside the regularization, we refined the workflow that was used in the pilot project. The initial velocity model was iteratively updated first through isotropic tomography, then through a Vertical Transverse Isotropy (VTI) tomography flow, and last with a Tilted Transverse Isotropy (TTI) tomography flow. Diverse regularization schemes were adopted to help control the tomography updates that included: steering filters, well constraints, bounds, and simultaneous multi-parameter updates (Woodward et al, 2008, Bakulin et al, 2009, Zdraveva, O, et al, 2011).

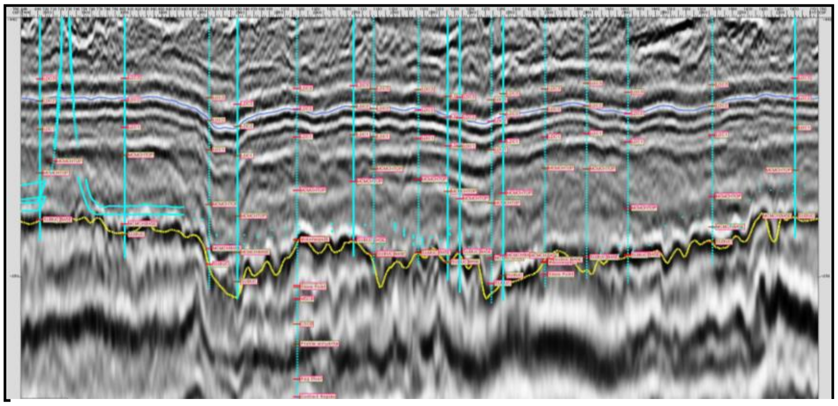

Figure 2: *Final A-PSDM image that shows well ties with both vertical and horizontal well pairs and a deep well. Several horizontal well pairs are running in the direction that is orthogonal to the picture.*

The final Anisotropic Pre-Stack Depth Migration provided a better focused image and generated Offset Vector Tiles gathers optimized for subsequent inversion work.

Anisotropic Velocity Model Updates

During the model building tomography update iterations, about 800 wells were used for the well tie analysis. We saw a reasonable mis-tie distribution for the caprock marker, but some greater mis-ties at the top of the Devonian unconformity were difficult to explain. We identified approximately 80 mis-ties that were larger than 10 meters. Through a detailed analysis we determined that some of these misties were due to differing geological interpretation and inherent geological complexity. Indeed, in the presence of collapsed features, it may be difficult for the geologist to pick with certainty the clastic–carbonate contact, especially in the vicinity of, or within, a sinkhole.

Based on the analysis above, it was decided to use different weighting schemes for each mis-tie distribution category. The large mis-ties were weighted loosely in the well constraint tomography velocity update initially. Considering the uncertainty of the well tops and the horizons picked on fuzzy reflection events, this prevented the tomography from introducing unrealistically large velocity perturbations that negatively impacted the small mis-ties in the neighboring wells.

To further reduce the mis-ties, we also updated not only the velocity, but also the anisotropy parameters. Bounded simultaneous multi-parameter tomography updates of velocity, delta and epsilon were used on the carbonates as the anisotropy used for the carbonate layer was a best guess beyond the depth of the 3D walkaway VSP.

Conclusions

The described anisotropic pre-stack depth migration processing flows provided substantial imaging improvements over pre-stack time imaging. The newly derived subsurface image tied more than 800 vertical wells in the clastics and in the carbonates very accurately with a mis-tie standard deviation error that is less than 2m (the Devonian unconformity is at a measured depth of about 300m). This was achieved with a workflow that was specifically tailored to this type of data.

Although this workflow used the PSTM velocities for the construction of the initial velocity model for depth imaging, we wonder whether time domain imaging adds much value. It's the position of the authors that it may be more accurate, as well as more efficient from a timeline and cost perspective, to go straight to depth imaging. Depth is a more natural domain for geomodeling, well planning and monitoring, reservoir flow simulation, etc. The vertical time to depth conversion routinely done within the industry does not results in the level of accuracy that depth imaging provides as illustrated in this paper.

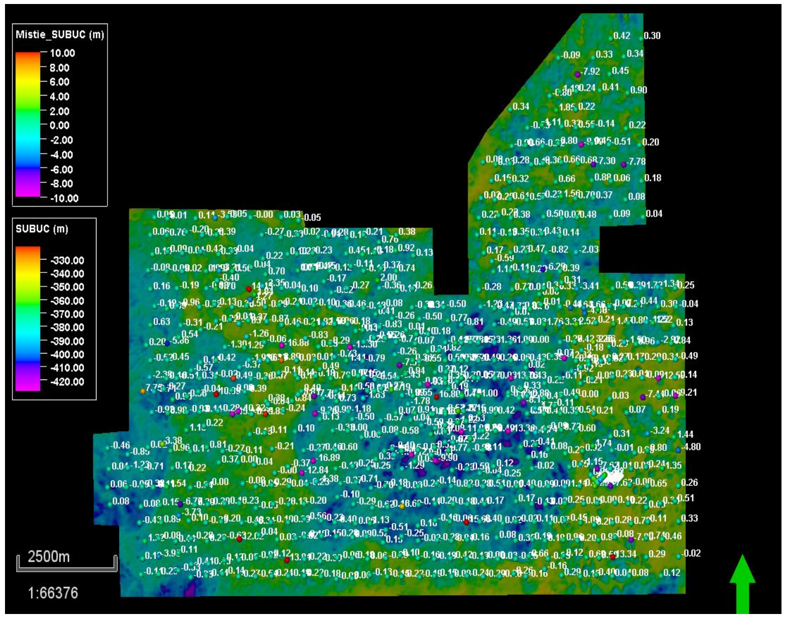

Figure 3: *Final Anisotropic Migration Well mis-tie distribution at the Devonian unconformity.*

We have also shown that it is now feasible to constrain depth imaging with hundreds of well ties. However, these constraints need to be carefully validated, as we found that despite the great efforts, with the large number of wells, it is very difficult to identify all inconsistencies or errors in geological well tops during depth imaging.

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