Characterization of Heavy Oil Reservoir using Vp/Vs Ratio and Neural Network Analysis

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Summary

The north-eastern corner of Alberta contains an estimated 200 billion cubic metres of bitumen. Working interest partners Nexen Inc. and OPTI Canada Inc. hold rights to oil sands leases covering over 80,000 hectares in the Athabasca Oil Sands Region. The focus of this study is the southern portion of the Long Lake lease located approximately 40 km southeast of the City of Fort McMurray. The lease area is roughly 25,000 hectares and contains over 8 billion barrels of bitumen in place.

It is well known, especially for heavy oil projects, that the Vp/Vs ratio is a good lithology discriminator. In this paper we provide Vp/Vs ratio volumes based on (i) deterministic prestack inversion and (ii) neural network analysis. From the prestack inversion the following volumes are estimated: P-impedance, S-impedance, density and Vp/Vs. The inversion approach accounts for the petrophysical relationship that exists in the logarithmic domain between: (1) P-impedance and S-impedance and (2) P-impedance and density.

Neural network estimation of reservoir properties has proven effective in significantly improving accuracy and vertical resolution in the interpretation of the reservoir. Neural network analysis is performed on logs and pre- and post-stack seismic attributes. The Vp/Vs ratio volume from prestack inversion compared well with the similar volume obtained from neural network analysis. The latter results are sharper and offer more details in identification of the sand and shale within the heavy oil reservoir of Long Lake South.

Introduction

The Oil Sands reservoir related to the Long Lake South (LLS) Project is contained within the McMurray Formation, which is the basal unit of the Lower Cretaceous Mannville Group. The McMurray Formation directly overlies the Subcretaceous Unconformity, which is developed on Paleozoic carbonates of the Beaver Hill Lake Group, and overlain by the Clearwater and Grandrapids Formations of the Mannville Group.

The study area (Figure 1) is located along the axis of the McMurray Valley system, which was localized by the dissolution of underlying Devonian evaporates, creating the preferred depositional fairway for the Lower Cretaceous McMurray sediments. The most significant bitumen reservoirs within the McMurray Formation are found within the multiple channels that represent lowstand system tracts, incised into the regional, prograding parasequence sets that represent highstand system tracts. During sea level rise, these incised channel systems were filled with a transgressive estuarine complex, consisting of sandy to muddy estuarine point bars. In the Long Lake area, the McMurray Formation is dominantly composed of these multiple, sand rich, fluvial and estuarine channels, which are incised into each other and stacked along a preferred path of deposition. This preferred path is aligned north-northwest to south-southeast in the Long Lake area (Long Lake Project, 2006).

Depending on their size and configuration, non-reservoir shale bodies can impede steam chamber growth and fluid drainage within a SAGD production process. Distinguishing between reservoir and non-reservoir using a conventional seismic interpretation approach has proved ambiguous. However, petrophysical analysis has determined that Vp/Vs and density are key discriminators between sand and shale. Therefore deriving a Vp/Vs and density volume from seismic data is a useful and important objective.

It is well known and accepted by the industry that inversion is a necessary step in imaging and interpreting the reservoir and there is a continuous struggle to improve the resolution of the inverted volume. Depending on the seismic data and the number of wells available, a Vp/Vs ratio volume can be obtained from: (i) traveltime measurements on the vertical and radial components of the multicomponent records (Lines et al., 2005), (ii) AVO analysis and simultaneous inversion using only the PP component (Dumitrescu et Lines, 2006), or (iii) joint inversion of the PP and PS (registered in PP time) poststack seismic data (Dumitrescu et Lines, 2007). In this project, prestack seismic data was processed through a model-based prestack inversion algorithm to produce P-impedance, S-impedance, Vp/Vs and density volumes.

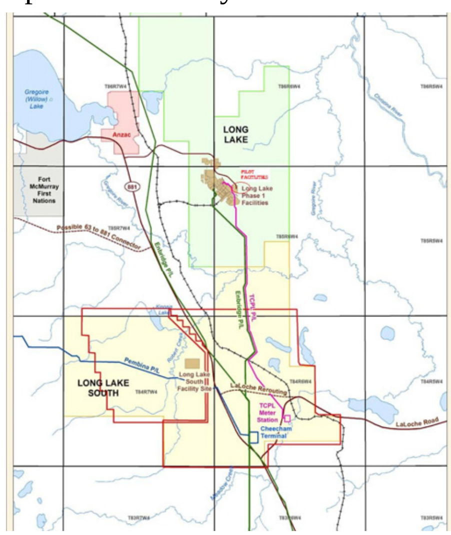

Figure 1. Map showing the Long Lake South area, Alberta, Canada

Neural network analysis (NNA) is used for estimating new seismic volumes by integrating well information and existing seismic volumes (e.g. deterministic inversion results). For this project, we estimated Vp/Vs ratio volume and used it successfully in mapping oil sands in heavy oil reservoirs. We present estimated Vp/Vs results from (i) prestack inversion, and (ii) neural network analysis.

Method

The LLS Project includes 3-D seismic and approximately 50 logged and cored wells over a 50 square kilometre surface area. The 3-D seismic was acquired in 2005 using the Sercel digital multi-component recording system. Out of 42 wells with dipole sonic logs only 31 were used in the NNA. Petrophysical analysis was performed on all the wells in order to provide a trustworthy set of logs for inversions and neural network analysis.

Prestack inversion estimates P-impedance (Zp), S-impedance (Zs), Vp/Vs and density (Dn) volumes. It uses the fact that the basic variables Zp, Zs and density are coupled by two relationships which should hold for the background “wet” trend. The regional rock property trends for this area are derived from log data within the Wabiskaw and Devonian interval.

Joint inversion is based on an extended conjugate gradient technique, which starts from an initial low frequency model of P-wave velocity, S-wave velocity and density. As the program iterates, it improves the fit between the recorded seismic traces and model-based synthetic traces by locally modifying the P-impedance model together with local deviations of the relationship between P-impedance, S-impedance and density.

The neural network was used in an effort to account for non-linear relationships between logs and seismic after first testing the linear multi-attribute method alone. Neural network analysis has four steps: 1. perform a multi-attribute step-wise linear regression and its validation, 2. train neural networks to establish the nonlinear relationships between seismic attributes and reservoir properties at well locations, 3. validate results on the wells withheld from the training, 4. apply trained neural networks to the 3D seismic data volume. The NNA was performed for 31 wells and eight seismic volumes (PSTM stack, AVO-derived P-wave and S-wave reflectivity, Fluid Factor, P-wave impedance, S-wave impedance and Vp/Vs from inversion and Density from a previous NNA) and a seven-point operator. Using the ranking process available within the software and after checking the errors, we selected the attributes for training the network.

Results

Deterministic inversion and neural network analysis are applied to the LLS 3D, a heavy oil reservoir in NE Alberta, in an attempt to get a better definition of the bitumen sand and to better differentiate between gas sands and shale in the McMurray Formation.

In this paper we discuss how neural network analysis for estimating Vp/Vs volume improved the results from deterministic inversion (Figure 2). Vp/Vs results obtained from the two inversions are comparable but it is easy to observe that NNA results are less noisy and better connected to the geology.

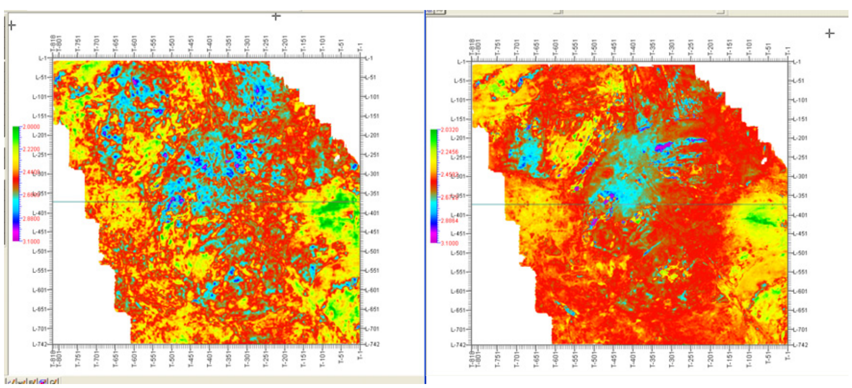

Figure 2: Horizon slice at McMurray+7ms on Vp/Vs volume obtained from (left) prestack inversion and from (right) neural network analysis.

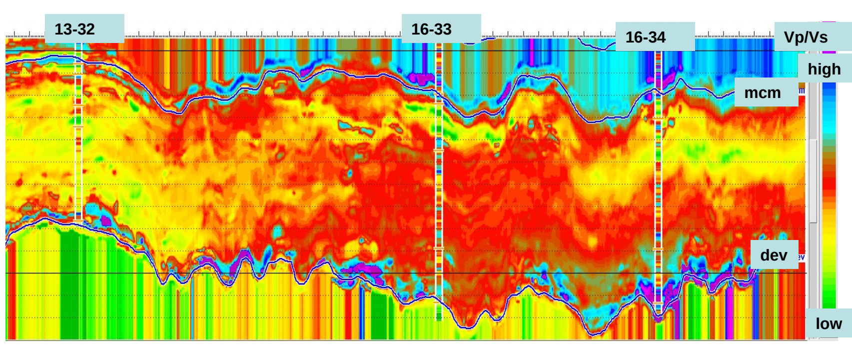

Figure 3: Vp/Vs results at one line from the 3-D. Inserted in color are the Vp/Vs logs. All the wells tie this line within a 50 m projection distance.

The data used for estimating the Vp/Vs volume are Vp/Vs logs, AVO attributes and inversion results. These attributes have been ranked on their ability to predict the Vp/Vs logs and the highest ranking attributes are then fed into a neural network to generate estimates of the Vp/Vs throughout the 3-D volume. There is a high cross-correlation (0.87) between actual and predicted Vp/Vs for all the wells in the study area. Figure 3 shows the Vp/Vs results on a seismic line within the 3-D where we projected wells within 50 m distance. Vp/Vs is a useful property in differentiating gas sand (lowest values), bitumen sand (mid values) and shale (highest values).

It is a good idea to compare the physical property maps with maps obtained from other attributes, such as semblance. In Figure 4 we present a comparison between Vp/Vs map and semblance on a horizon slice at 10 ms below McMurray. Semblance is an attribute calculated from the prestack time migrated stack and is a good indicator of structural features.

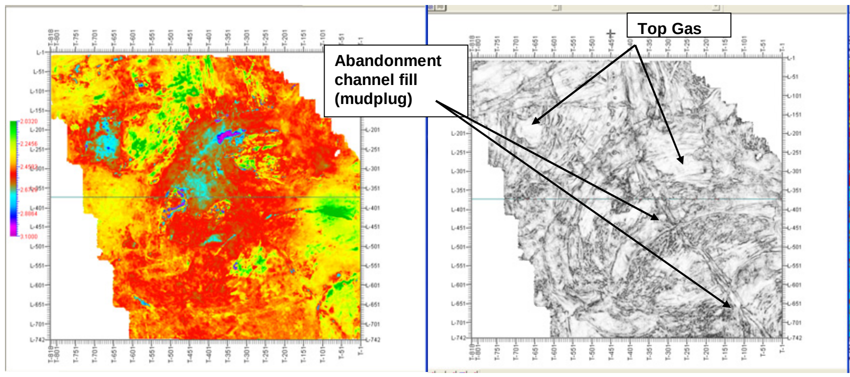

Figure 4: Horizon slice at McMurray+10 ms of the (left) Vp/Vs results from neural network analysis and (right) semblance.

Conclusions

We presented a case study for improving the resolution of a Vp/Vs volume (obtained from deterministic inversion) by using neural network analysis. The derived neural network results show strong correlation with the target logs, both at training well locations and for the rest of the wells suggesting that rock properties can be accurately estimated with neural network analysis when deterministic inversion results are used as external attributes in training the network.

The results of this analysis correlated well with recent drilling making the neural network analysis part of the workflow for future projects. Utilizing the Vp/Vs and density volumes computed with neural network analysis minimizes the uncertainty in gas sand, bitumen sand and shale identification thereby contributing to optimal horizontal well placement. This will in turn have the ultimate effect of increased production and economic efficiency.

Acknowledgements

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