PS and PP AVO Analysis; A Multi-component Seismic Case Study for the Long Lake Oil Sands Project

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ABSTRACT

Summary

In this paper, three-component 3D data from the Long Lake Project (Nexen/OPTI synthetic oil joint venture) in North-East Alberta are analyzed. The Long Lake Project uses the commercially proven Steam Assisted Gravity Drainage (SAGD) process for extraction of raw bitumen. The goal of integrating multi-component data analysis is the identification of lithologies and barriers to steam. This is one of the first such converted-wave (PS) AVO projects presented in Canada.

The analysis included: comparison between the PP and PS migrated stack registered in PP time; comparison between PP AVO rigidity reflectivity and PS AVO rigidity and density reflectivity; and comparison betweeen inverted PP and PS AVO attributes registered in PP time.

The PS radial component section is of good quality, with many coherent reflections correlating well to those of the PP vertical component. The converted-wave section, however, has a much lower bandwidth than the vertical component section.

Careful analysis of the vertical component seismic gathers at the zone of interest shows measurable variation in amplitude with offset. PP AVO, based on the Gray et al (1999) equation was done and allowed estimation of the incompressibility and rigidity components based upon variations in reflection amplitude of the PP component.

In addition, converted-wave AVO, based on Aki and Richards (1980) equation, was done and allowed estimation of the rigidity and density components based upon variations in reflection amplitude of the PS component.

Special attention was paid to registration of the PS seismic section from PS time to PP time. PP seismic sections were compared with corresponding PS seismic section registered in PP time.

PS and PP AVO Analysis

Inversion of the PP AVO rigidity reflectivity was compared with inversion of the PS AVO rigidity and density reflectivities. The inverted rigidity results indicated that both PP and PS components provide complementary information about the lithology of the reservoir.

Data Available for the Project and Registration in PP-time

Veritas acquired a 3D seismic survey for Nexen/OPTI at Long Lake (Figure 1) in 2002 using VectorSeis^{TM} digital, three-component geophones. This survey was undertaken to obtain detailed information within the McMurray Fm. oil sands. Historically, conventional P-wave data has been used with some success.
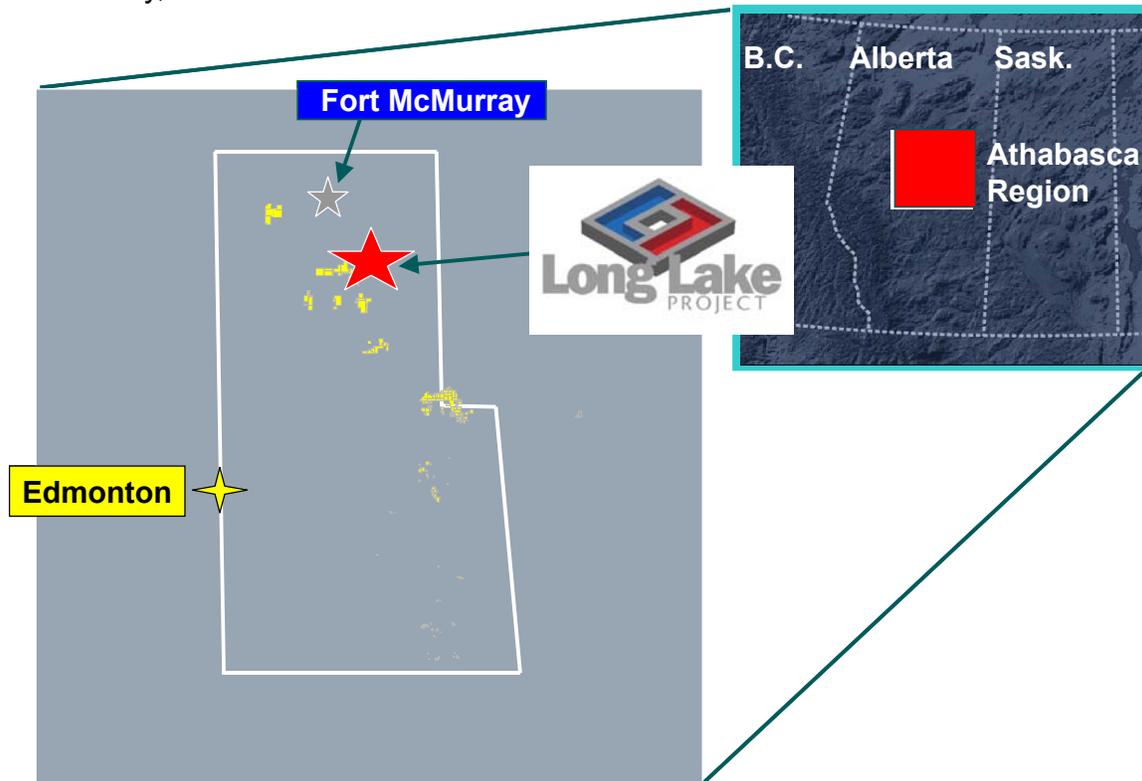

Fig. 1: Base map of the Long Lake Project Area

The PP vertical component was processed by Veritas GeoServices Ltd. using a conventional P-wave processing flow which achieved frequencies upwards of 140 Hz. The PS radial component was processed using a converted-wave processing flow resulting in a 5 to 60 Hz frequency bandwidth.

PP and PS synthetic seismograms (from 8 dipole sonic logs and many more conventional sonic logs) were tied to both the vertical and the radial component sections. The key seismic horizons are Clearwater, McMurray and Devonian (*Fig. 2*). All the seismic sections presented are oriented NE-SW along one of the Long Lake Project's pilot horizontal well pairs.
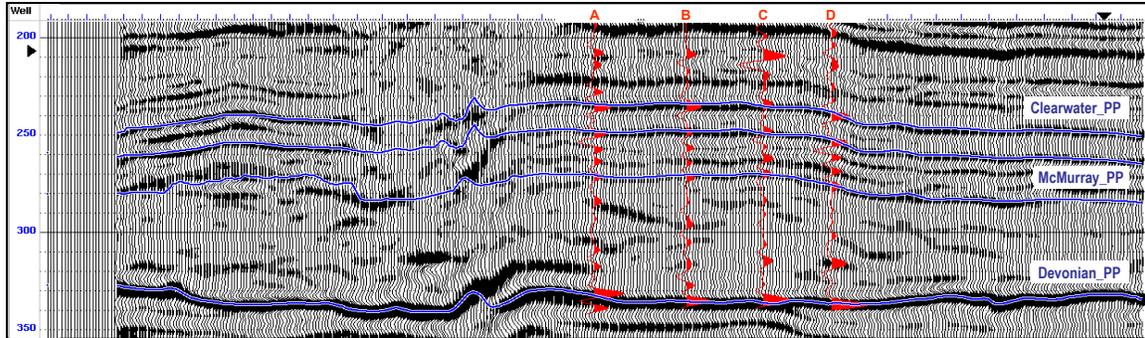
Fig. 2: PP migrated stack (in PP time; inserted in red are the synthetic traces)

In order to register the PS section from PS time to PP time Clearwater, McMurray and Devonian events were picked on both the PP and PS seismic sections. The registration of the PP and PS seismic sections was done using the ProMC software (Hampson-Russell) which facilitated horizon matching between the PP and the PS volumes. Figure 3 shows the PS migrated stack registered in PP time.
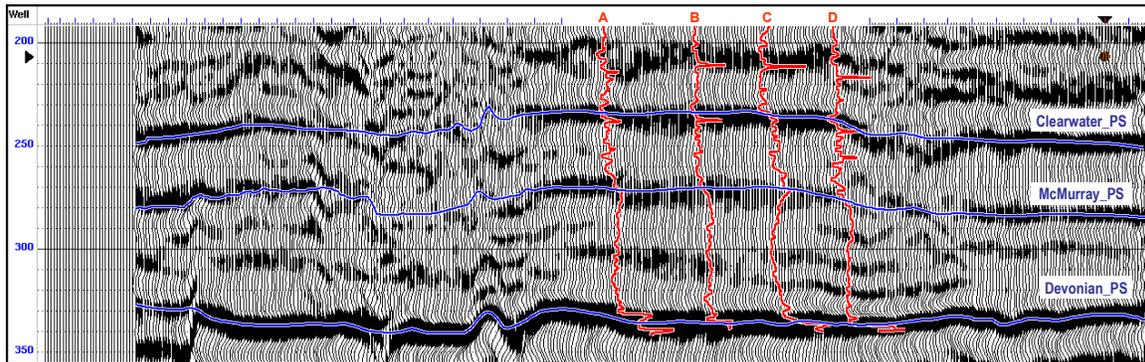

Fig. 3: PS migrated stack registered in PP time (inserted in red are the sonic logs)

PP and PS AVO Analysis

Many equations have been used over the last 15 years for conventional PP AVO, all of which work in a similar manner. This project utilised the Gray et al (1999) equation which allows any meaningful Vp/Vs ratio to be used as a constraint. The Gray method recasts the AVO equations of Aki and Richards into a form that is preferable for direct rock property estimation. The calculated AVO attributes are incompressibility (Lambda) and rigidity (Mu or shear modulus) reflectivity.

PS AVO calculates AVO attributes from PS seismic gathers. It is based on the AVO equation of Aki and Richards (1980), which describes the PS gather amplitudes as a function of shear velocity reflectivity and density (Rho) reflectivity. Modified equations (Gray, 2003) were used to calculate rigidity and density reflectivity.

In a comparison of rigidity reflectivity from PP and PS AVO, the rigidity reflectivity from PS AVO has fewer but more continuous events than rigidity reflectivity from PP AVO. Positive events on the rigidity reflectivity from the PS AVO section

correlates well with the "shaly" zones identified on the Gamma Ray (GR) logs from vertical observation wells.

The density reflectivity from PS AVO looks very similar to the rigidity reflectivity section (from the PS AVO). Higher density "shaly" zones on the inserted density logs correlate well with positive events on density reflectivity.

Inversion of AVO attributes

While AVO analysis examines the properties of the interfaces between layers, inversion is the critical process to convert data from reflectivity to interval rock properties.

For this project, model based inversions of the rigidity and the density reflectivity were conducted to obtain rigidity and density rock properties. Direct inversion reduces the noise levels as is expected from statistical theory (Gray, 2002).

Amplitude inversions were model based (blocky constrained) using STRATA (Hampson-Russell) software. Rigidity and density models, fulfilling the role normally played by the impedance model, were built. The rigidity and density models were built based on logs and horizons. The second step in the process was inversion itself, from AVO derived reflectivity to rock property.

Figure 4 and Figure 5 compare the rigidity obtained from inversion of PP and PS AVO reflectivity. The rigidity section was registered in PP time. Frequency content aside, the two rigidity sections are quite similar, increasing confidence in PS derived AVO attributes. From the interpreter's point of view the PS derived rigidity inversion does a better job distinguishing the variations in the McMurray reservoir. Figure 6 shows the density section obtained from inversion of the PS AVO attribute registered in PP time. Qualitatively the density inversion was quite successful at depicting zones of good reservoir and poor reservoir, including the boundaries that separate them. These different reservoir correlate well with the posted GR logs. Quantitatively, however, the results were not as succesful. Work continues to deal with these discrepancies.
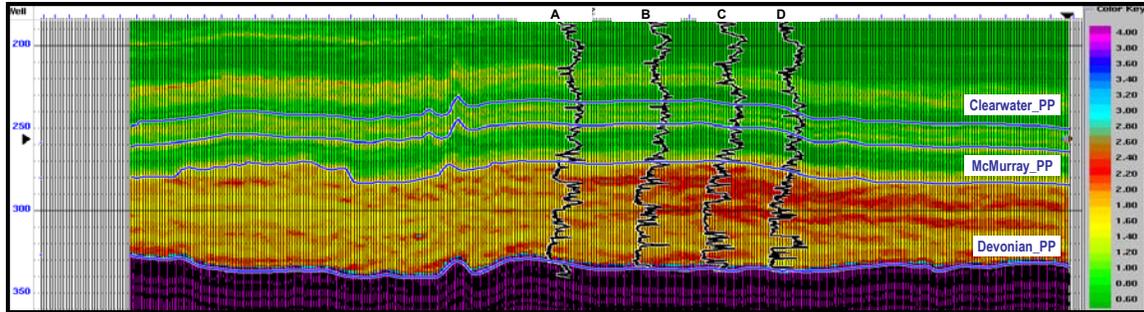
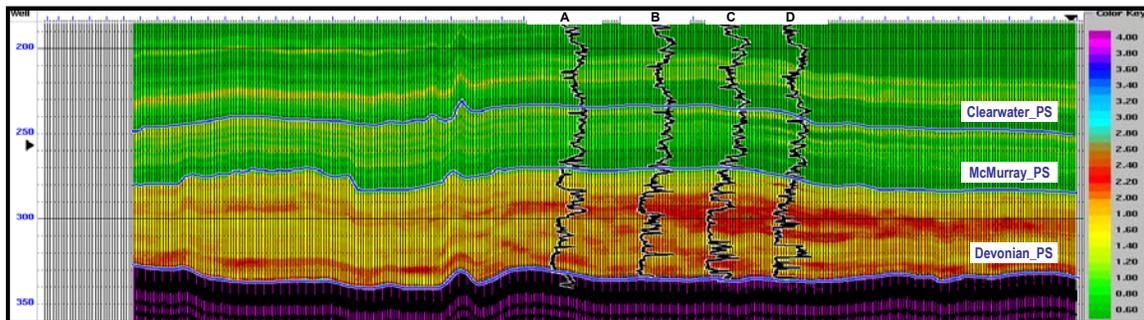*Fig. 4: Rigidity from inversion of PP AVO reflectivity (inserted logs are GR)*

Fig. 5: Rigidity from inversion of PS AVO reflectivity (registered in PP time; inserted logs are GR)
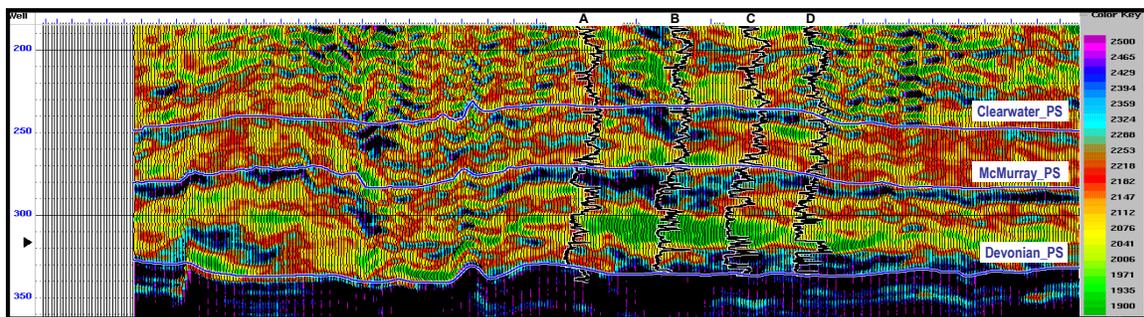

Fig. 6: Density from inversion of PS AVO reflectivity (registered in PP time; inserted logs are GR)

Conclusions

By correlating synthetic PP and PS data with seismic sections at well locations several events have been identified on both PP and PS reflectivity sections (Clearwater, McMurray and Devonian) allowing for accurate registration of PS data and display of PS data in PP time. The PP and PS migrated stacks compare favourably and correlate well for major events although PP data show higher vertical resolution. In particular the top McMurray is much better imaged on PS data than PP data (due to the much larger impedance contrast on shear wave data compared with compressional wave impedance).

PS and PP AVO Analysis

Gray's methodologies were applied to calculate PP AVO rigidity reflectivity and also PS AVO rigidity and density reflectivity. Strong correlation exists between "shaly" lithologies and positive events on PS derived density and rigidity reflectivity. Barriers to steam and non (or poor) reservoir lithologies are much better defined on PS derived rigidity than PP rigidity. In a way PP rigidity reflectivity suffers from "too great a bandwidth" by way of too many weaker, less continuous high frequency events masking the basic geologic character evident on the PS data. The PS AVO attribute data does a much better job distinguishing reservoir from non-reservoir.

Model based inversion techniques inverted the reflectivity stacks to the interval rock properties; incompressibility (from PP AVO), rigidity (from both PP and PS AVO) and density (from PS AVO). The inverted rigidity results indicate that both PP and PS components provide important and complementary information about the reservoir. Also, the incompressibility and density estimates provide additional interpretive value. Good correlation exists between the GR logs and the rigidity sections, suggesting that rigidity can be used for sand/shale discrimination.

References

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