

P301

## Heavy Oil Reservoir Characterization Using Vp/Vs Ratios from Multicomponent Data

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### SUMMARY

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Vp/Vs is a very good lithology discriminator especially for heavy oil projects. We provide two Vp/Vs ratio volumes based on (i) simultaneous inversion on prestack PP data and (ii) joint inversion of PP and PS poststack data. The new results are compared with the previous results based on the traveltimes measurements on the PP and PS components (Lines et al., 2005).

The area for this project is a heavy oil field (oil sands of the Devonian-Mississippian Bakken Formations) near Plover Lake, Saskatchewan.

The Vp/Vs volume from simultaneous and joint inversion compared very well with the similar volume obtained from a previous study. The Vp/Vs results for the Sparky/Waseca-Torquay interval show similar general features. The new volumes, based on simultaneous and joint inversion produces Vp/Vs ratio values with a vertical resolution of 2ms whereas the previous results from traveltimes are just averaged over 60 ms. The new results are sharper and offer more details in identification of the sand and shale. Integrating the P-wave and the converted wave seismic volumes we obtained a better definition of rock properties, since converted wave data should add significant information to the conventional P-wave interpretation.

## Summary

It is well known, especially for heavy oil projects, that  $V_p/V_s$  is a very good lithology discriminator. In this paper we provide two  $V_p/V_s$  ratio volumes based on (i) AVO analysis and simultaneous inversion on prestack PP data and (ii) joint inversion of PP and PS (registered in PP time) poststack data. The new results are compared with the previous results based on the traveltimes measurements on the PP (vertical) and PS (radial) components of the multicomponent records (Lines et al., 2005).

The area for this project is a heavy oil field (oil sands of the Devonian-Mississippian Bakken Formations) near Plover Lake, Saskatchewan. In this study we analysed Nexen's 3D-3C seismic survey, acquired by Veritas DGC and processed by Sensor Geophysical.

From the simultaneous inversion on prestack time migrated PP gathers we derived P-impedance, S-impedance, density and  $V_p/V_s$  volumes. 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. It provides a significant improvement over separate inversions of the two AVO attributes P- and S-wave impedance reflectivity, particularly for  $V_p/V_s$  ratio estimates. Additional rock properties, such as rigidity and incompressibility were derived from P-impedance and S-impedance (Goodway et al., 1997).

The above mentioned petrophysical relationship were used for the joint inversion of PP and PS (registered in PP time) poststack data. 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  $V_p/V_s$  volume from simultaneous and joint inversion compared very well with the similar volume obtained from a previous study. The  $V_p/V_s$  results for the Sparky/Waseca-Torquay interval show similar general features. The new volumes, based on simultaneous and joint inversion produces  $V_p/V_s$  ratio values with a vertical resolution of 2ms (sampling rate) whereas the previous results from traveltimes are just averaged over 60 ms (Sparky – Torquay interval). The new results are sharper and offer more details in identification of the sand and shale. As expected by integrating the P-wave and the converted wave seismic volumes we obtained a better definition of rock properties, since converted wave data should add significant information to the conventional P-wave interpretation.

## Introduction

The Plover Lake Oil Sands Project, conducted by Nexen Inc., is located in Saskatchewan, Canada. Oil sands of the Devonian-Mississippian Bakken Formation are found in NE-SW trending shelf-sand tidal ridges that can be up to 30 m thick, 5 km wide and 50 km long. Overlying Upper Bakken shales are preferentially preserved between sand ridges. The Bakken Formation is disconformably overlain by Lodgepole Formation carbonates (Mississippian) and/or clastics of the Lower Cretaceous Mannville Group (Mageau et al., 2001).

The 3D-3C seismic dataset was acquired by Veritas DGC using the VectorSeis® digital multi-component recording system over an 8 square kilometer surface area. On the project we used one well with a dipole sonic log, and out of 100 logged wells, only 29 had sonic, density and GR logs. The migrated structure stack for the PP (vertical) component was produced by Sensor Geophysical Ltd. as part of a different CHORUS project.

The estimated  $V_p/V_s$  variations based on traveltimes have been used successfully in mapping oil sands in heavy oil reservoirs. Now, we use (i) AVO analysis and simultaneous inversion of PP prestack data, and (ii) joint inversion of PP and PS (registered in PP time) poststack data, to estimate the  $V_p/V_s$  ratio and some other attributes (rigidity, incompressibility, density) that are very useful in lithology discrimination.

## Method

The AVO analysis was performed with Fatti's equation on prestack time migrated gathers using angles up to 29 degrees. The resulting AVO attributes are P-wave and S-wave impedance reflectivities.

Simultaneous inversion analyzes prestack gathers to derive P-impedance ( $Z_p$ ), S-impedance ( $Z_s$ ) and density volumes. It uses the fact that the basic variables  $Z_p$ ,  $Z_s$  and density are coupled by two relationships which should hold for the background "wet" trend.

In this project, the regional rock property trends were derived from logs, over the Waseca-Torquay interval. The two background relationships assure some coupling between physical properties estimated by the simultaneous inversion. The results are P-impedance, S-impedance, density (based on the relationship with P-impedance) and  $V_p/V_s$  volumes.

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.

## Results

P-wave impedance reflectivity (AVO  $R_p$ ), the attribute calculated from AVO analysis, compares very well with the migrated vertical component stack, showing even more details within the Bakken reservoir (Figure 1).

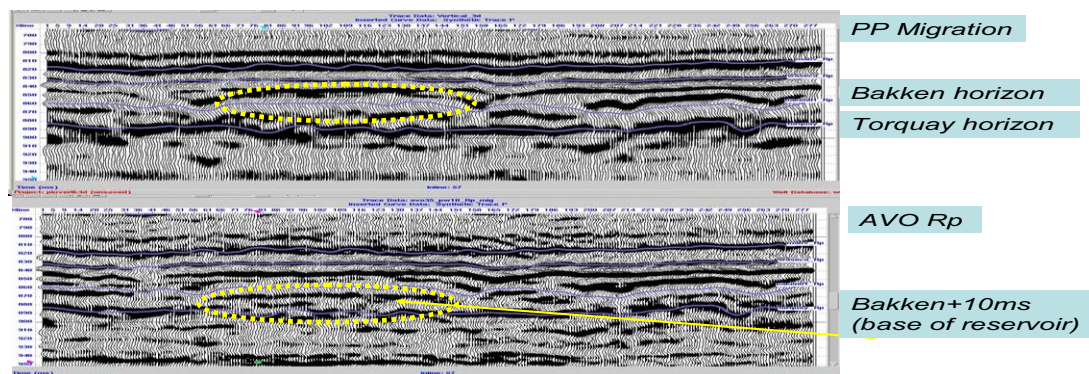


Figure 1: Comparison between PP migrated stack (top) and AVO  $R_p$  (bottom) showing higher resolution on the AVO  $R_p$

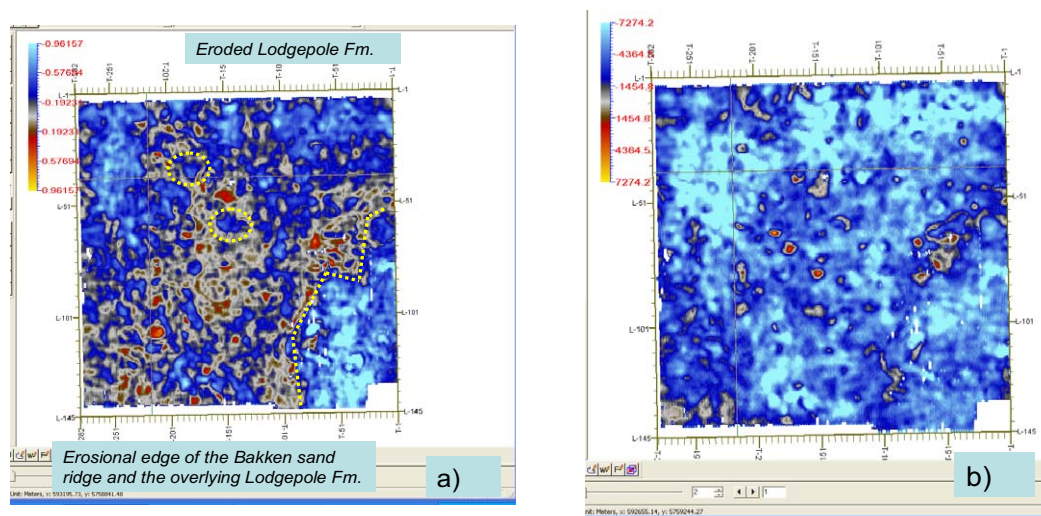


Figure 2: (a) Horizon slice of the AVO  $R_p$  at Bakken+2ms, (b) Horizon slice of the Migration at Bakken+2ms

Very interesting structural features, like the erosional edge of the Bakken sand ridge and the overlying Lodgepole formation, can be identified on the SE corner of the horizon slice of the AVO Rp (Figure 2a). None of these features can be identified on the horizon slice of the migrated volume (Figure 2b).

Figure 3 shows results from simultaneous inversion on prestack PP data in comparison with results from joint inversion of the poststack PP and PS data.  $V_p/V_s$  results obtained from the two inversions are comparable but it is easy to observe that joint inversion results are less noisy and better connected to the geology.



Figure 3: Horizon slice at Bakken+2ms on  $V_p/V_s$  volume obtained from (a) simultaneous inversion on prestack PP data and from (b) joint inversion of poststack PP and PS data.

Since sandstones have larger S-wave velocities, and hence lower  $V_p/V_s$  ratios than shales,  $V_p/V_s$  maps are good indicators of the sand and shale distribution. There is a good agreement between the horizon slices of the two physical properties derived from inversion.

Now, if we compare the  $V_p/V_s$  maps generated from simultaneous inversion on prestack PP data (Figure 4b) with the ones obtained from traveltimes (Figure 4a), they both indicate the same anomalous areas, although the  $V_p/V_s$  values derived from inversion are generally lower than  $V_p/V_s$  derived from traveltimes-thickness ratios. The inversion based estimates appear to have higher vertical resolution when compared with the ones from traveltimes.

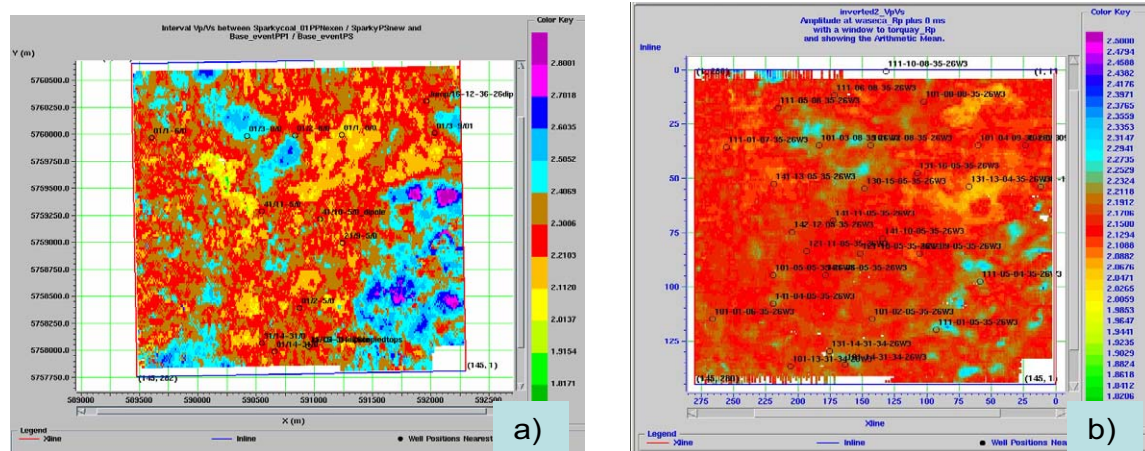


Figure 4: (a) Average  $V_p/V_s$  for interval Sparky-Torquay as derived from traveltimes (Lines, et al., 2005); (b) Average  $V_p/V_s$  for interval Waseca-Torquay from simultaneous inversion on prestack PP data.

## **Conclusions**

From this study we can formulate the following conclusions:

- P-wave impedance reflectivity shows more details when compared with the migrated stack, opening a perspective for future interpretation.
- Vp/Vs results calculated by the two inversion methods are based on the two regional relationships derived from petrophysical analysis.
- Vp/Vs results obtained from simultaneous inversion on prestack PP data are noisier than results obtained from joint inversion of PP and PS poststack data (mainly because of poor quality of gathers).
- Vp/Vs maps are very similar with the rigidity maps - both being very good lithology discriminators.
- Vp/Vs results for the Sparky/Waseca-Torquay interval show the same general features as previously presented by Lines, et al., (2005).
- integrating converted-waves and PP data we can get more accurate physical properties volumes that can help the interpretation.

## **References**

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