

Heavy Oil Reservoir Characterization using Vp/Vs Ratios and Spectral Decomposition

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Summary

It is well known, especially for heavy oil projects, that Vp/Vs is a very good lithology discriminator. In this paper we provide a Vp/Vs ratio volume based on AVO analysis and simultaneous inversion using only the PP component. The new results are compared with the previous results based on the traveltimes measurements on the vertical and 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.

We performed AVO analysis followed by simultaneous inversion on pre-stack time migrated gathers in order to derive P-impedance, S-impedance, density and Vp/Vs 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 Vp/Vs ratio estimates. Additional rock properties, such as rigidity and incompressibility were derived from P-impedance and S-impedance (Goodway et al., 1997).

The Vp/Vs volume from simultaneous 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 volume, based on simultaneous inversion produces Vp/Vs ratio values with a vertical resolution of 2ms (sampling rate) whereas the previous results from travel times 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.

In this project we applied spectral decomposition (discrete Fourier transform) to the AVO attributes P- and S-wave impedance reflectivities to better predict changes in lithology and flow barrier. The spectral decomposition amplitude and phase spectra volumes show structural geologic features and the limits of the reservoir.

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 processed by Sensor Geophysical Ltd. as part of a different CHORUS project.

The estimated Vp/Vs variations based on travel time have been used successfully in mapping oil sands in heavy oil reservoirs. Now, we use AVO analysis and simultaneous inversion to estimate the Vp/Vs ratio and some other attributes (rigidity, incompressibility, density) that are very useful in lithology discrimination.

Spectral decomposition (discrete Fourier transform) generates amplitude and phase maps tuned to specific frequencies. The resulting spectral amplitude maps can aid in identifying structural bodies and estimating bed thicknesses whereas the resulting phase maps help to define lateral stratigraphic discontinuities. Together, the amplitude and phase related interference phenomena allow mapping of the local rock variability within the 3-D surveys (Partyka, 1999).

Method

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

Simultaneous inversion analyzes pre-stack 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

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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 Vp/Vs volumes.

Results

P-wave impedance reflectivity (AVO Rp), 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).

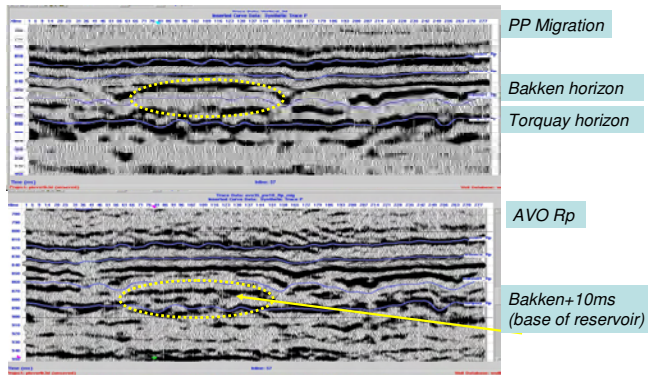


Figure 1: Comparison between PP-migration (top) and AVO Rp (bottom) showing higher resolution on the AVO Rp.

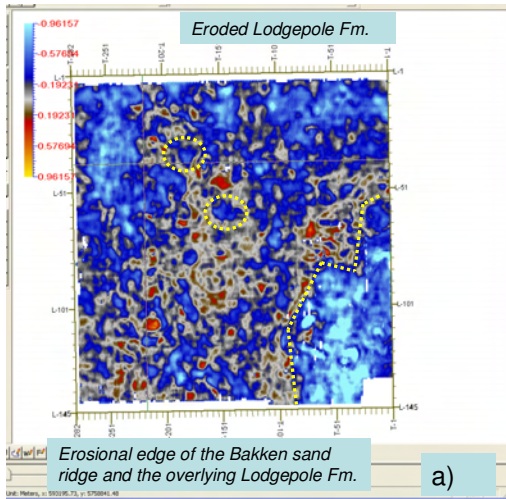


Figure 2a: Horizon slice of the AVO Rp at Bakken+2ms.

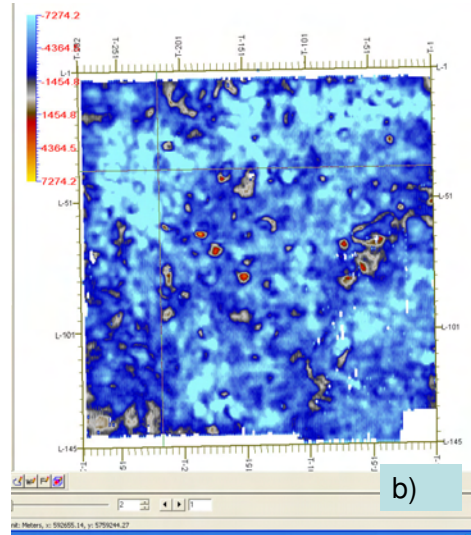


Figure 2b: Horizon slice of the Migration at Bakken+2ms.

Very interesting structural features, like the erosional edge of the Bakken sand ridge and the overlying Lodgepole formation, can be identified on the 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). The same structural features are highlighted in Figure 3a and 3b which shows the same horizon slice, but of the Vp/Vs volume from simultaneous inversion (a) and from the Mu-Rho (rigidity) volume (b).

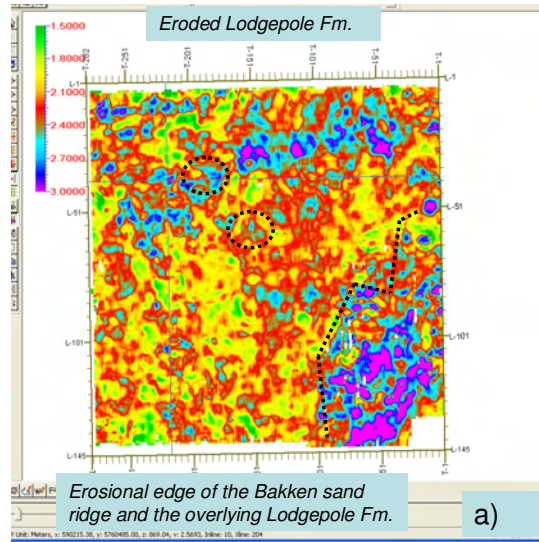


Figure 3a: Horizon slice of the Vp/Vs at Bakken+2ms.

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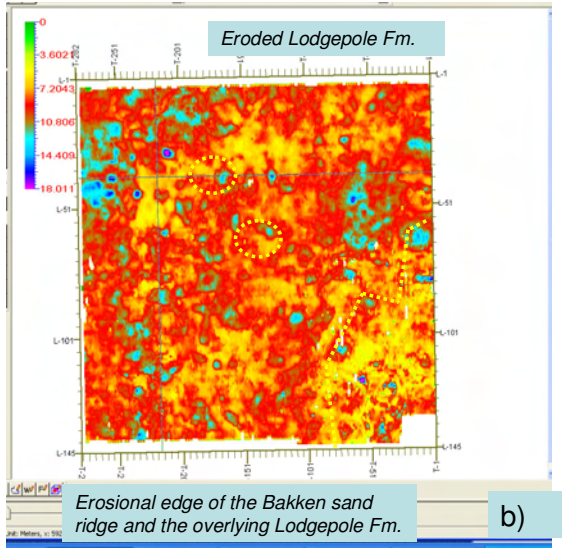


Figure 3b: Horizon slice of the Mu-Rho at Bakken+2ms.

Since sandstones have larger S-wave velocities, and hence lower Vp/Vs ratios than shales, Vp/Vs maps are good indicators of the sand and shale distribution. Rigidity is also a very good physical property that differentiates between shales (low rigidity) and sands (higher rigidity). There is a good agreement between the horizon slices of the two physical properties derived from inversion.

Now, if we compare the Vp/Vs maps generated from inversion (Figure 5) with the ones obtained from traveltimes (Figure 4), they both indicate the same anomalous areas, although the Vp/Vs values derived from inversion are generally lower than Vp/Vs derived from traveltimes-thickness ratios. The inversion based estimates appear to have higher vertical resolution when compared with the ones from traveltimes.

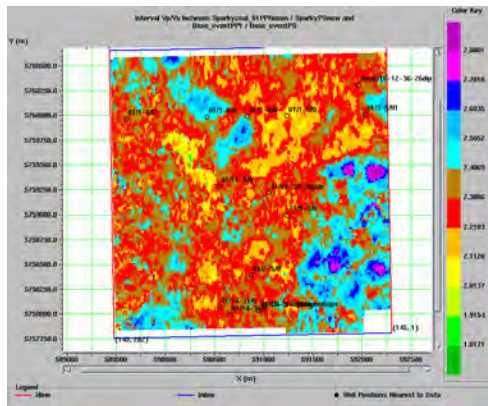


Figure 4: Average Vp/Vs for interval Sparky-Torquay as derived from traveltimes (Lines, et al., 2005).

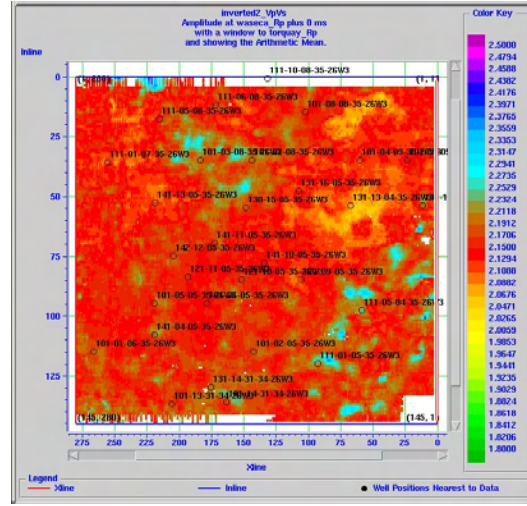


Figure 5: Average Vp/Vs for interval Waseca-Torquay from simultaneous inversion.

Spectral decomposition

Spectral decomposition (SD) opens the door to a non-traditional approach to seismic interpretation. It can be used qualitatively to reveal stratigraphic and/or structural edges as well as relative thickening and thinning. Spectral decomposition refers to any method that produces a continuous time-frequency analysis of the seismic trace.

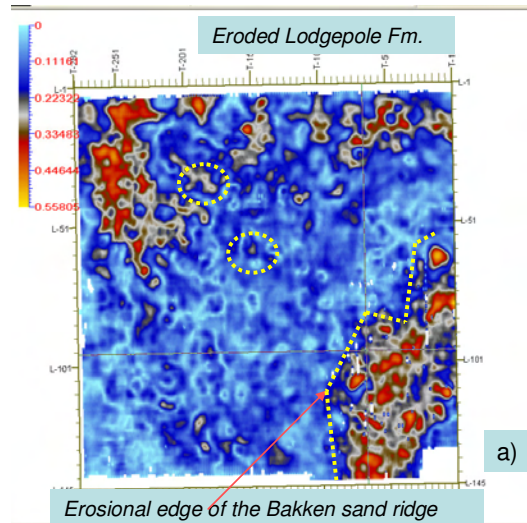


Figure 6a: Horizon slice of the SD AVO Rp for 50 Hz at Bakken.

Spectral decomposition was applied to the AVO attributes the P- and S-wave impedance reflectivities to better predict changes in lithology and fluids. We present horizon slices (at Bakken) from the SD AVO Rp at 50 Hz (Figure 6a) and

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SD AVO Rs at 50 Hz (Figure 6b) that show structural geologic features (e.g. erosional edge of the Bakken) and the limits of the reservoir distribution.

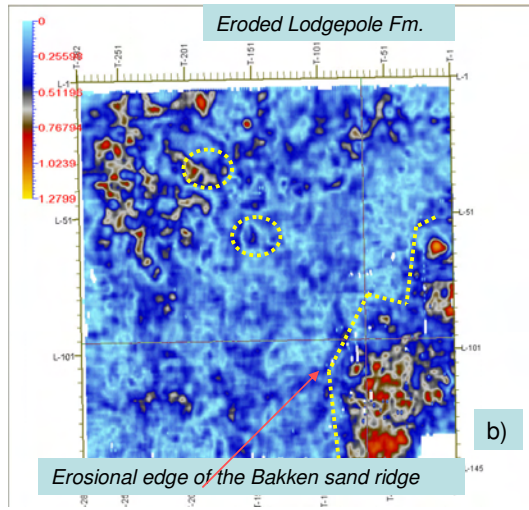


Figure 6b: Horizon slice of the SD AVO Rs for 50 Hz at Bakken.

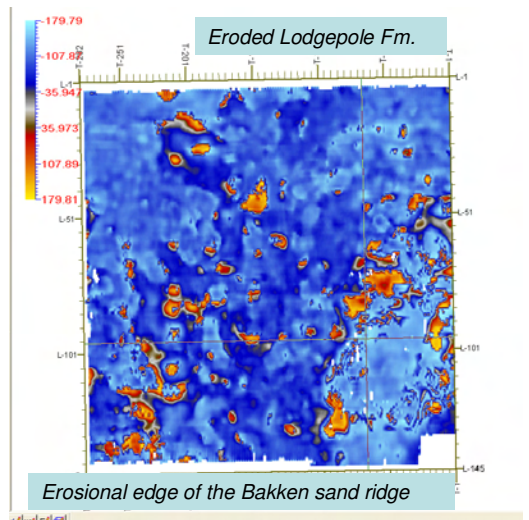


Figure 7: Horizon slice of the SD AVO Rp phase for 50 Hz at Bakken.

Figure 7 is an example of phase spectra of the AVO Rp at 50 Hz presented on a horizon slice at Bakken. Phase spectra respond to lateral discontinuities via local phase instability. Amplitude and phase maps from spectral decomposition identified the structural bodies and stratigraphic edges that are overlooked in the full bandwidth display. The usability of the spectral decomposition mapping technique as an interpretation tool for defining the geology has been proven by these maps.

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 calculated by simultaneous inversion is based on the two regional relationships derived from petrophysical analysis.
- 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).
- Utilizing AVO and inversion minimizes uncertainty in sand and shale identification, thereby contributing to optimal well placement.
- The amplitude and phase related interference phenomena allow interpreters to quickly and efficiently quantify and map local geology variability within the 3-D surveys.

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EDITED REFERENCES

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