Vp/Vs Ratio of a Heavy Oil Reservoir from Canada*

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Abstract

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 travel time 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 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.

Introduction

The Plover Lake Oil Sands Project, 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 multicomponent 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.

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 (Zp), S impedance (Zs) and density 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. In this project, the regional rock property trends were derived from logs, over the interval Waseca-Torquay and are presented in Figure 1. 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 2). 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 3b). None of these features can be identified on the horizon slice of the migrated volume (Figure 3a).

The same structural features are highlighted in Figure 4, which shows the same horizon slice, but of the Vp/Vs volume from simultaneous inversion (a) and from the Mu-Rho (rigidity) volume (b). 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 with the ones obtained from traveltime (Figure 5), they both indicate the same anomalous areas, although the Vp/Vs values derived from inversion are generally lower than Vp/Vs derived from traveltime-thickness ratios. The inversion-based estimates appear to have higher vertical resolution when compared with the ones from traveltime.

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.

Acknowledgements

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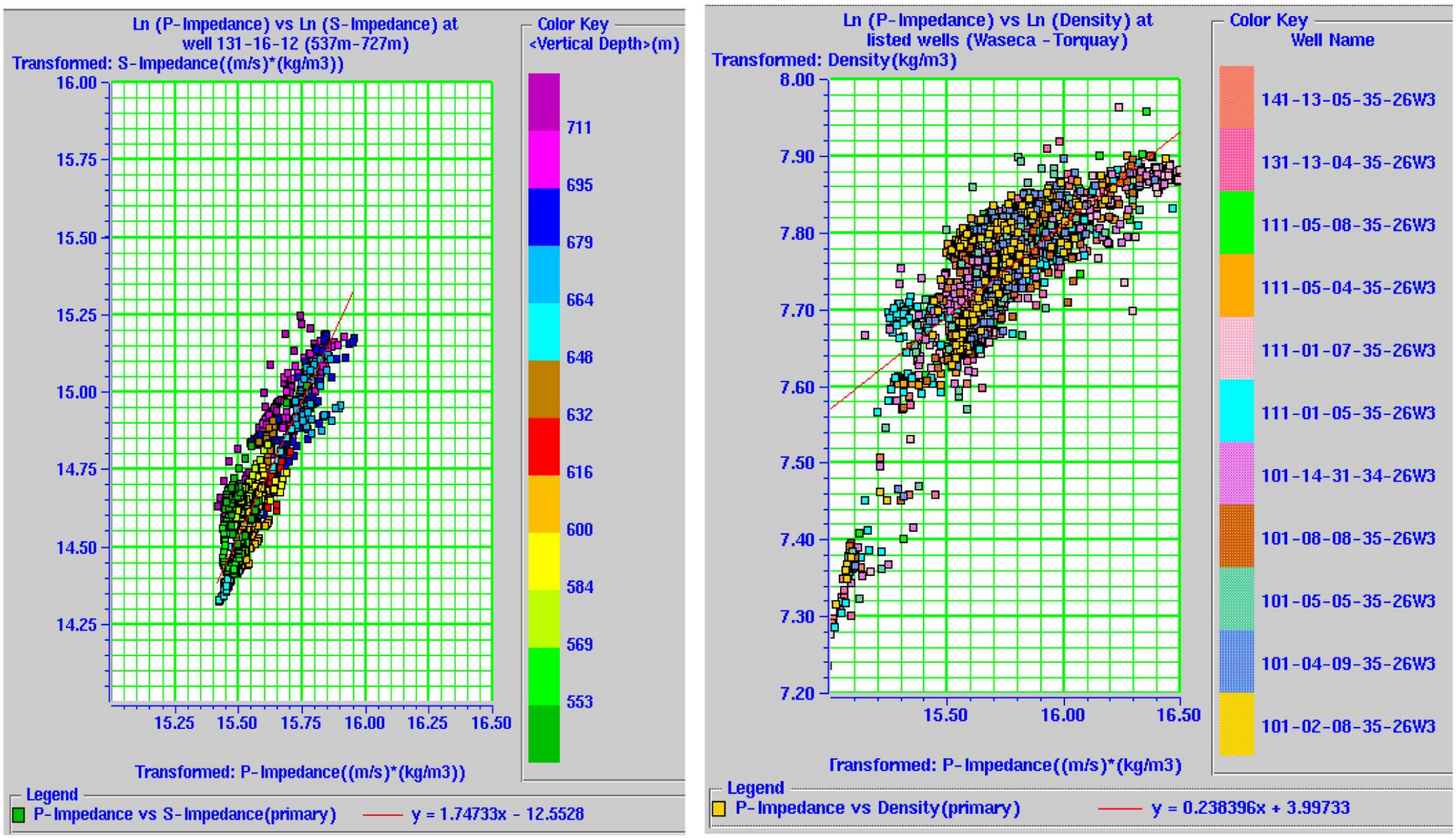

Figure 1. left: relationship between ln(Zp) and ln(Zs) based on one dipole well: ln(Zs)=1.74*ln(Zp)-12.55; right: relationship between ln(Zp) and ln(Density) based on 11 wells: ln(Density)=0.23ln(Zp)+3.99.

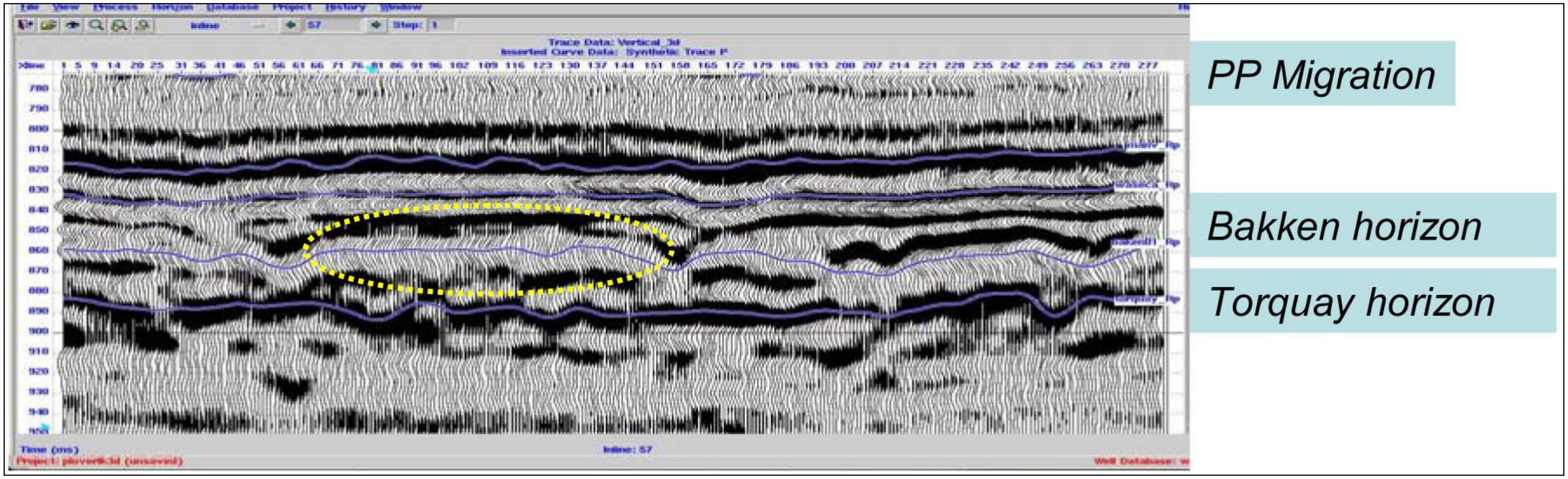

Figure 2. Comparison between PP-migration (top) and AVO Rp (bottom) showing higher resolution on the AVO Rp.

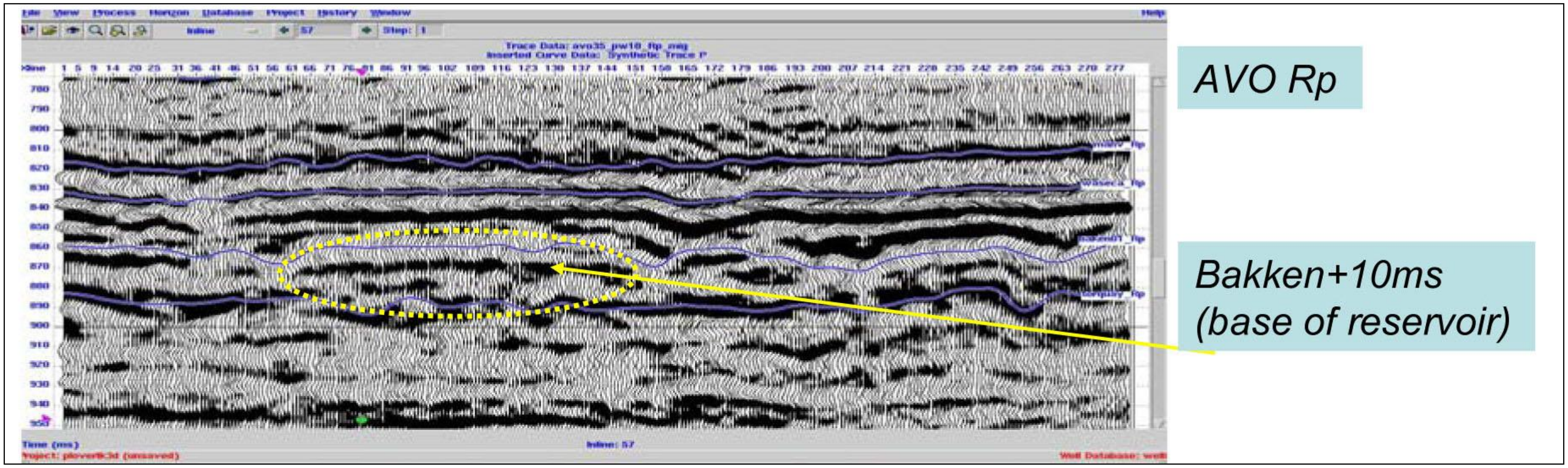

Figure 3. Horizon slice of the (a) AVO Rp and (b) Migration at Bakken+2ms.

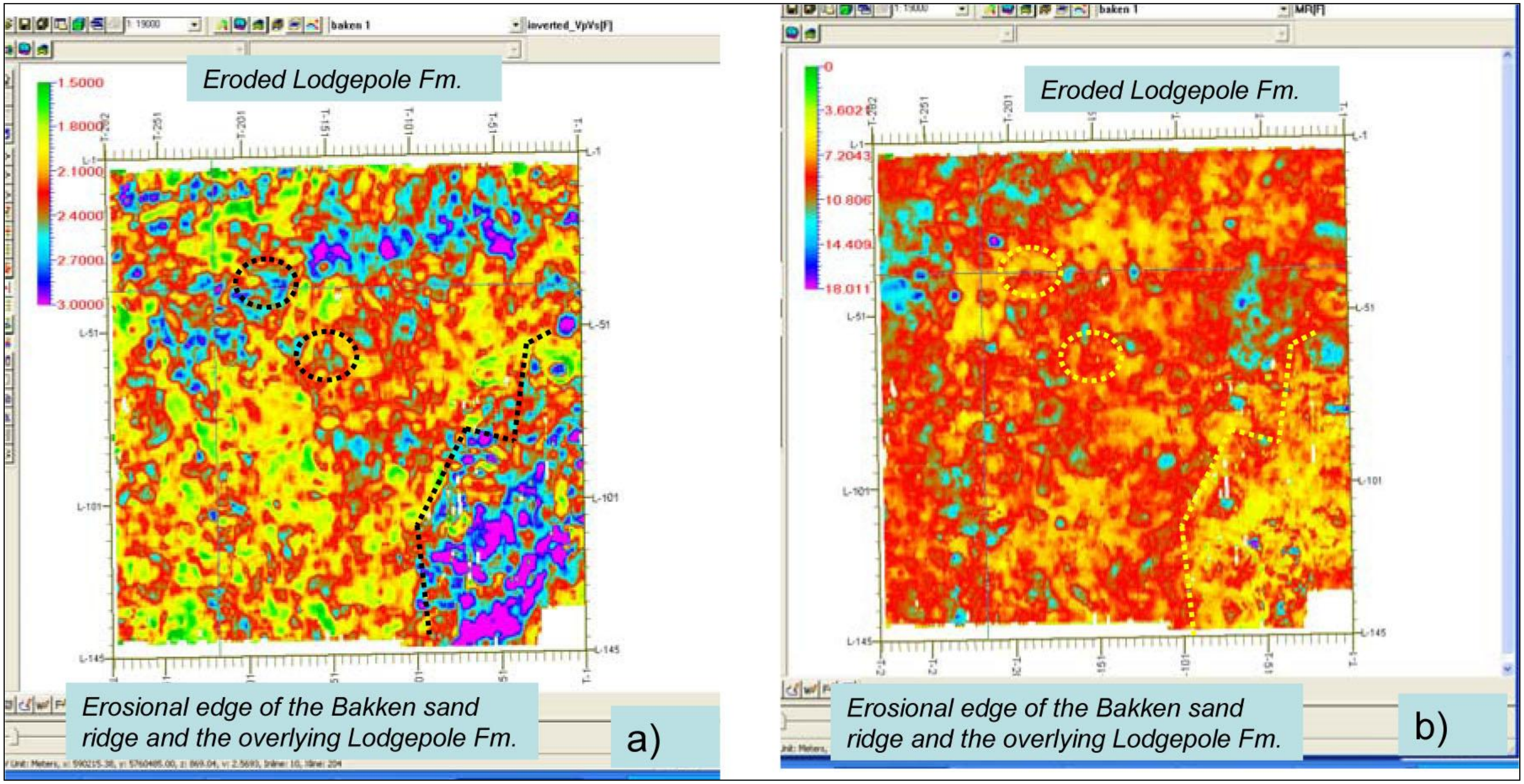

Figure 4. Horizon slice of the (a) Vp/Vs and (b) Mu-Rho at Bakken+2ms.

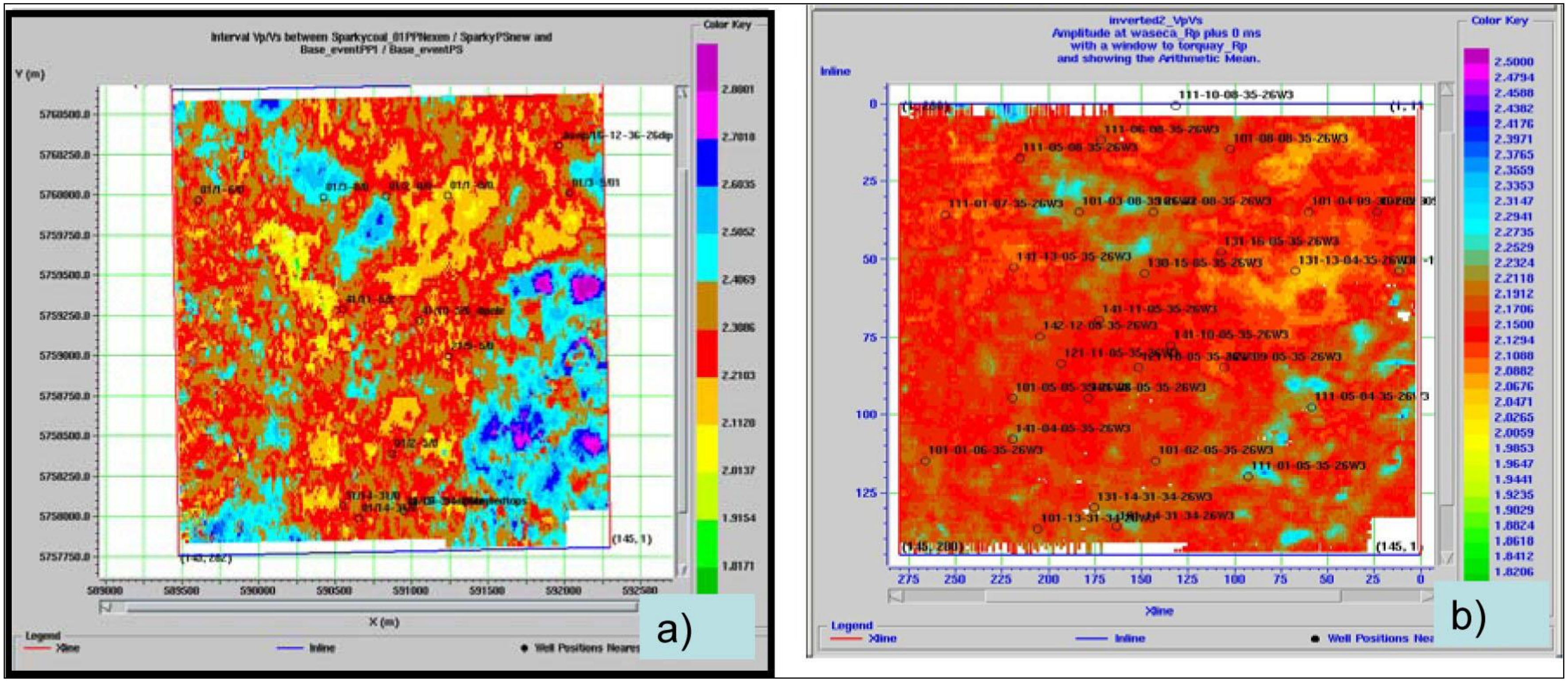

Figure 5. (a) Average Vp/Vs for interval Sparky-Torquay (Lines, et al., 2005) and (b) average Vp/Vs for interval Waseca-Torquay from simultaneous inversion.