Estimating impedance from PP and PS seismic data at the Ross Lake oilfield, Saskatchewan

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Abstract

A 3C-3D surface seismic data was acquired over Husky Energy's Ross Lake oilfield in south-western Saskatchewan. In the previous interpretation, a Vp/Vs map between horizon IHACM and RushLake was calculated by combining PP and PS travel time thickness maps. In this paper, the impedance inversions are performed on the post-stack PP and PS data. Dividing the average of the inverted P-impedance over a 8ms horizon-based time window by the average of the inverted S-impedance over the same window, we map the Vp/Vs with higher vertical resolution. The Vp/Vs value derived from impedance inversion is generally lower than the Vp/Vs derived from the time-thickness ratios. The impedance Vp/Vs and traveltime Vp/Vs values show promising anomalies.

Introduction

Husky Energy Inc.'s Ross Lake heavy-oil field is located in south-western Saskatchewan. Sand bodies of incised-valley channel systems, or possibly shore deposits, are developed in proximity to the Dimmock Creek member of the Cantuar formation of the Mannville Group in the lower-Cretaceous. These oil-saturated sands are the drilling targets.

A 3D multi-component seismic survey was conducted over this area by Veritas DGC in 2002. Veritas also processed the 3C-3D data from field edits through post-stack migrations of the vertical-, radial- and transverse-component volumes. Based on the vertical (denote as PP) and radial (denote as PS) migrated results, a preliminary interpretation has been offered by Xu and Stewart (2003 and 2004). They developed a promising Vp/Vs map that they interpreted as being a sand indicator. This map was created by combining PP and PS time thickness maps calculated between the IHACM and RushLake horizons that include the reservoir interval. This sand indicator map from the Vp/Vs value has been correlated with results from a horizontal well log.

In this paper, we employ a widely used seismic inversion package to invert the post-stack PP and PS volumes into impedance traces. We arrive at a Vp/Vs map by dividing the inverted P-impedance by the inverted S-impedance.

PP Data Inversion

Before designing the background velocity model for the inversion, the correlation between the logs at well 11-25 and the well site seismic trace is carefully checked using synthetic seismogram.

The P-impedance curve in well 11-25 is derived by multiplying the measured P-velocity log and the density log. To extend the P-impedance trace to the entire 3D area, 4 picked seismic horizons, which are the Viking, IHACM, RushLake and GravelBourg, respectively, are used to constrain the horizontal interpolation of the impedance log. Then, a 20Hz low-pass filter is applied to arrive at the low-frequency trend (Figure 1) that acts as the P-impedance model.

The P wavelet is next extracted from all the PP seismic traces excluding the edge traces. Then, a model-based inversion is performed to invert the PP seismic traces into P-impedance traces. Figure 2 shows the inversion result and notice that the inversion does find a low P-impedance area at the target zone (Inline 35-50 at about 1150ms).

PS Data Inversion

To accomplish the PS inversion, we make the simplifying and quite approximate assumption that the PS reflectivity is linearly proportional to the SS reflectivity. In reality, the relationship is more complicated and is dependent on the trace offsets comprising the stacked PS seismogram as well as the time-dependent incidence angle. Nonetheless, relative changes in the PS reflectivity over small depths may be highlighted by the approximate inversion procedure.

PS to PP horizon matching

The multi-component seismic data interpretation package is used for registering PP and PS events. The previous interpretation work revealed an event correlation between PP and PS data, by integrating well logs and offset-VSPs.

By the process of horizon matching, all the 4 annotated PS horizons are forced to match the PP time of same PP horizons (Figure 3). Therefore, the Vp/Vs of each trace between those events are obtained by this travel time adjusting.

Build S-impedance model

The PS data are now in the PP time at the 4 picked horizons, which means the same set of horizons in PP time used to create P-impedance mode should be to create the S-impedance model. The difference is that S-impedance model trace value comes from multiplying the S-velocity log and density log. Then, a low-pass filter is applied to the model to keep the initial model smooth (Figure 4).

The next step is to check the correlation between the PS synthetic log and PS seismic trace, and stretch or squeeze the logs if needed. The PS wavelet is then statistically extracted from all the PP-time PS seismic traces excluding the edge traces in the time window of 800ms – 1300 ms, assuming zero-phase.

Inversion

Two inversion techniques are investigated here: model-based and sparse-spike. In this case, there is no directly measured shear-wave log in well 11-25. So, the shear-velocity is derived using the first-arrival time picked from the vertical-source and horizontal-source zero-offset VSP traces to get an interval Vp/Vs, which is then multiplied by the measured P-velocity to get the S-velocity. So, this S-impedance model may not be perfectly correct. We found that the sparse-spike inversion seems to be less noisy than model-based inversion. We choose the sparse-spike inversion result as our final result (Figure 5).

Vp/Vs Calculation

Now we have two 3D volumes of the inverted P-impedance and S-impedance. Ideally, the Vp/Vs volume can be derived by dividing the P-impedance by the S-impedance. However, the PP and PS time registration remains as a problem: by horizon matching, we only force PS time equal to PP time along the 4 horizons. All the time points between horizons are not necessarily correspondent, until we have a very accurate Vp/Vs at each spatial point and at each sampled time, which is actually what we want to achieve.

Therefore, an average value over a certain time window is perhaps more reasonable. By checking the horizon slices of the inverted P-impedance, we notice that a 8ms window centered at the 14ms above RushLake horizon is a relative good size window, which is used to get the RMS average of the P-impedance. The RMS average of inverted S-impedance is also calculated in the same 8 ms window.

Then, the Vp/Vs map is manipulated by dividing the average P-impedance by the average S-impedance. The comparison of the impedance-derived Vp/Vs and travel time-derived Vp/Vs is shown in Figure 6. Also keep in mind that using the impedance method, the Vp/Vs is an average over 8ms (PP time) window, meanwhile, the Vp/Vs from travel time is an average over 40~50 ms (PP time) window.

Some observations from these two Vp/Vs maps are:
1. Overall, the impedance-derived Vp/Vs map has a lower Vp/Vs value, which ranges from 1.5 ~ 2.3 with reservoir sand about 1.6~1.7, than the traveltime Vp/Vs, which ranges from 1.7~ 2.6 with reservoir sand about 2.15~2.25.

2. The low-Vp/Vs strip at the left part of traveltime Vp/Vs map disappears on the impedance Vp/Vs map.
3. The size of the sand body looks more areally extensive on the impedance Vp/Vs map.
4. The sand body has an eastern direction extension on both impedance Vp/Vs and traveltime Vp/Vs maps.

Discussion

Inversion is a data-driven process. When we look at the data, above IHACM and below RushLake horizon, the PP and PS data are correlated in terms of their seismic characters. Between these two horizons, where the zone of interest lies, the PP data show several events. In contrast, PS section has only one wide, low-frequency, low-amplitude peak. This difference is sufficient to create the discrepancy between PP and PS inversion.

At the well location, in the zone of interest, the PP seismic trace shows a good correlation with PP synthetic. However, the PS seismic trace doesn't show such a nice correlation with the PS synthetic seismogram (figure 7). We hope to improve the imaging and frequency content in the future interpretive-oriented PS data re-processing.

Conclusion

The PP data inversion indicates that the oil-bearing sand body has a lower P-impedance compared with surrounding formation. In contrast, PS data inversion shows the sand has a bit higher S-impedance. The Vp/Vs value derived from impedance inversion is generally lower than the Vp/Vs derived from the time-thickness ratios. The impedance Vp/Vs and traveltime Vp/Vs values show promising anomalies.

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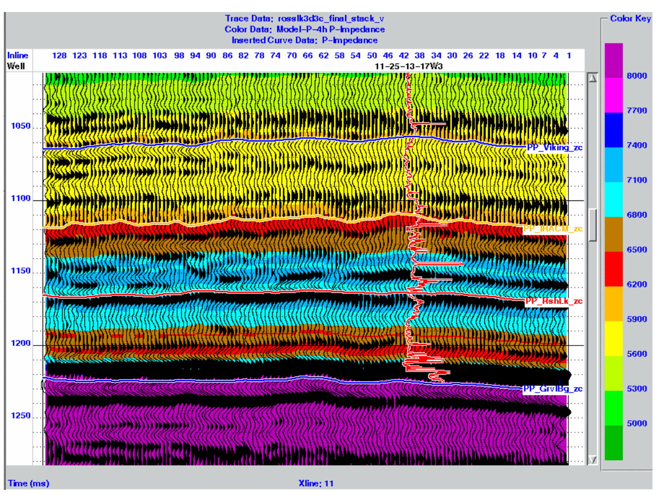

FIG. 1. The P-impedance model with P-impedance log inserted.

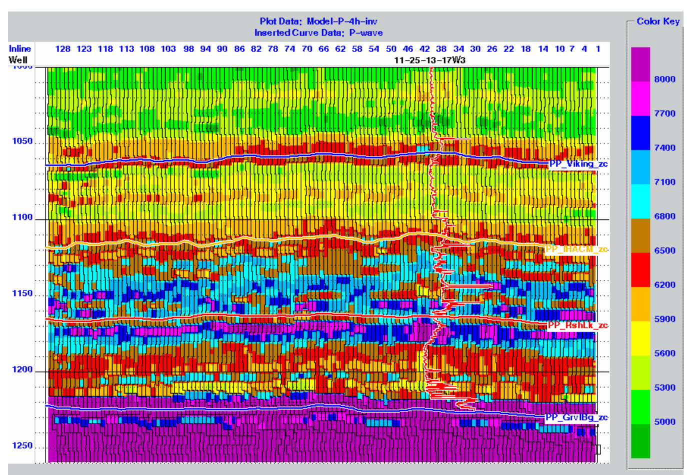

FIG. 2. Results of the model-based P-impedance inversion

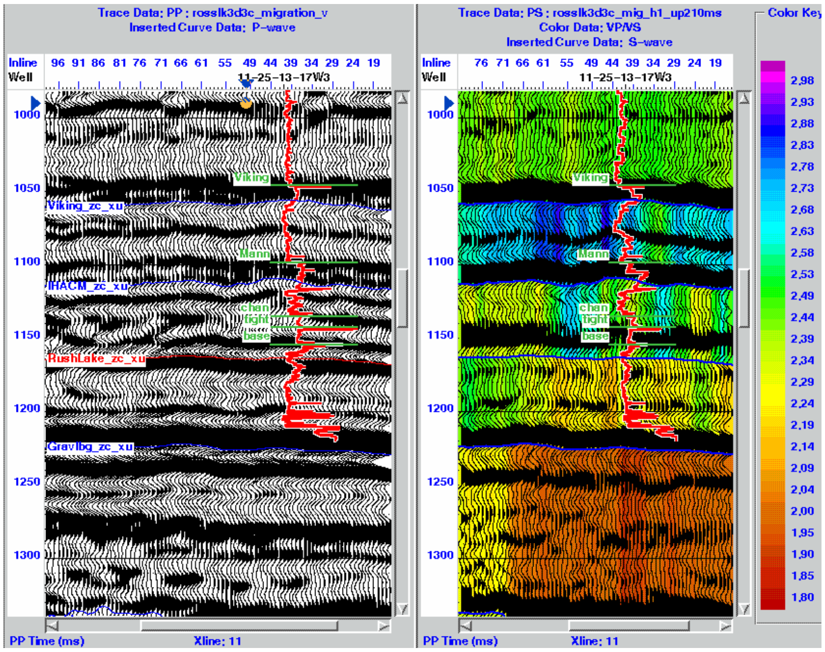

FIG. 3. PP data (left) and PS data (right) after horizon-matching.

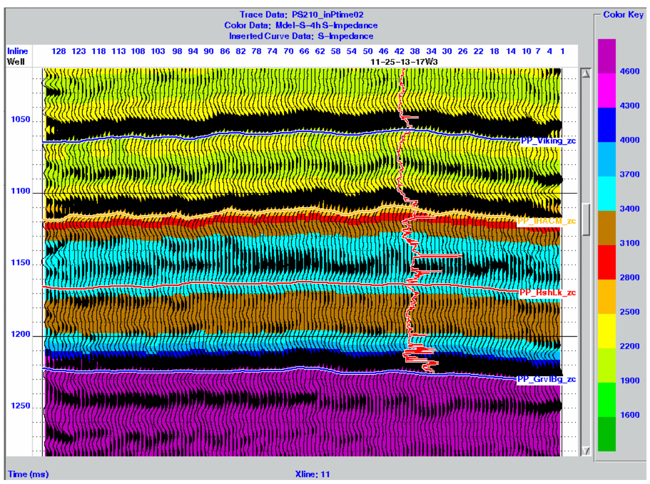

FIG. 4. The S-impedance background model.

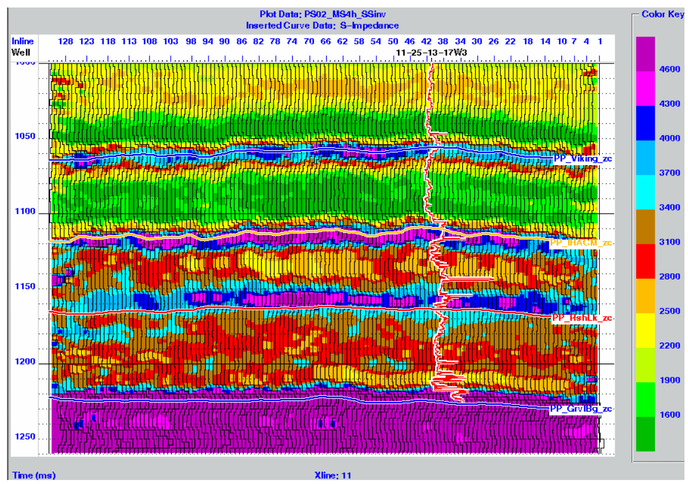

FIG. 5. The inversion result of PS data.

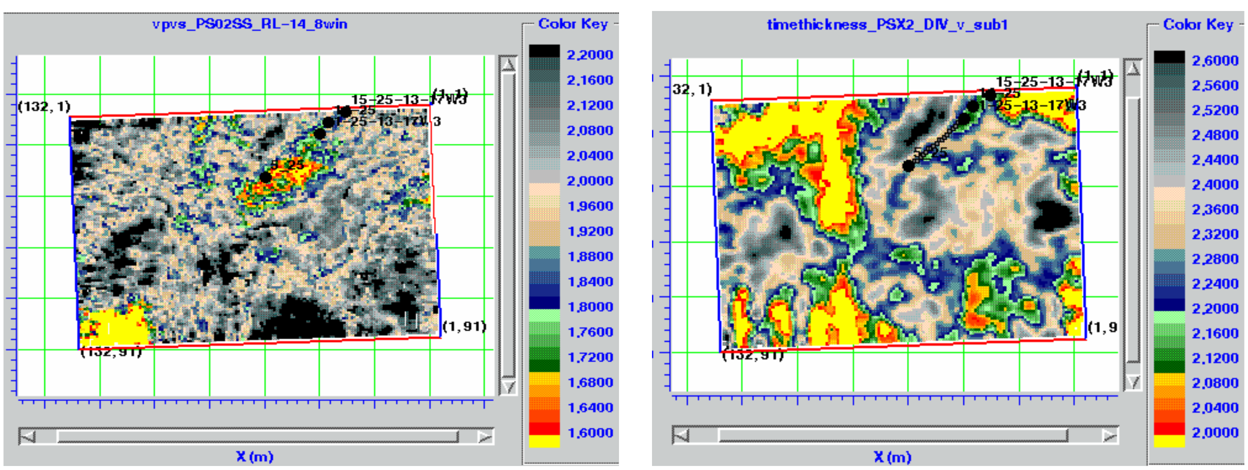

FIG. 6. Comparison of Vp/Vs derived from impedance (left) and Vp/Vs derived from time-thickness ratios (right).

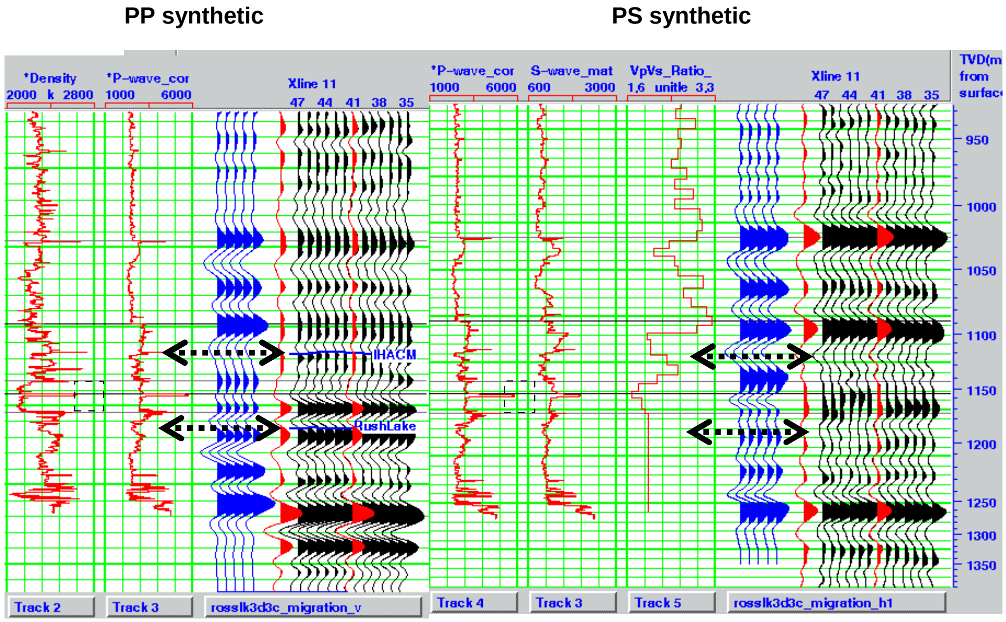

FIG. 7. PP and PS synthetic seismograms and seismic traces.

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