

Estimating impedance from PP and PS seismic data, a case study from Western Canada

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Summary

A 3C-3D surface seismic data was acquired over Husky Energy's Ross Lake oilfield in south-western Saskatchewan. In the previous interpretation, a V_p/V_s 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 V_p/V_s with higher vertical resolution. The V_p/V_s value derived from impedance inversion is generally lower than the V_p/V_s derived from the time-thickness ratios. The impedance V_p/V_s and traveltimes V_p/V_s 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 in 2002. 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 V_p/V_s 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 V_p/V_s 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 V_p/V_s map by dividing the inverted P-impedance by the inverted S-impedance.

PP Data Inversion

PP data inversion is carried out using a model-based method. 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 from the well 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 initial P-impedance model for inversion.

The P-wave 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 of one line and notice that the inversion does find a low P-impedance block at the target zone (marked by a black ellipse).

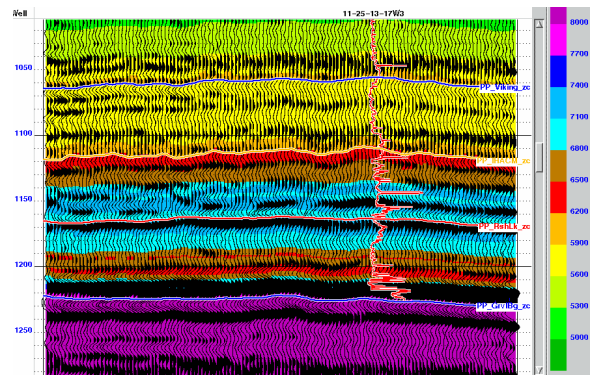


Figure 1. The P-impedance model with P-impedance log inserted.

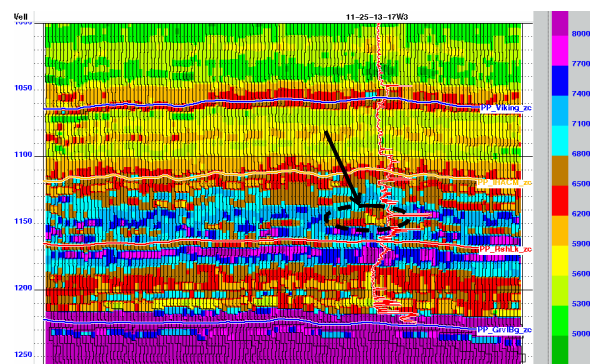


Figure 2. Results of the model-based P-impedance inversion

PS Data Inversion

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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.

The work flow for PS inversion is: 1. PS-to-PP horizon matching. 2. Build the S-impedance model 3. Extract PS wavelet from PS data in PP-time. 4. Invert the PS data.

PS-to-PP horizon matching

The first step is to convert the PS data from PS time into PP time, by matching PS event to the same PP event. Integrated with well logs and offset-VSPs, the previous interpretation work revealed an event correlation between PP and PS data. After the horizon matching, all the 4 annotated PS horizons are forced to 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.

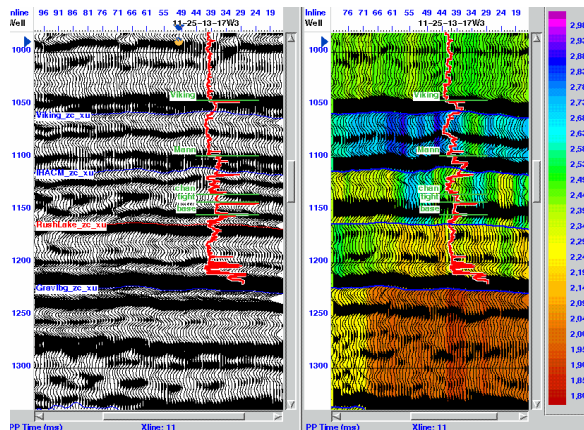


Figure 3. PP data (left) and PS data (right) after horizon-matching, in PP time. The P- and S-impedance curves from well log are also shown (in red)

Build S-impedance model

The PS data are now in PP time. 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, for the purpose of further quality control. The benefit of horizon matching is that we can use previous P-impedance model as the S-impedance model except replacing the P-

impedance value by the S-impedance. Then, a low-pass filter is applied to the model to keep the initial model smooth (Figure 4).

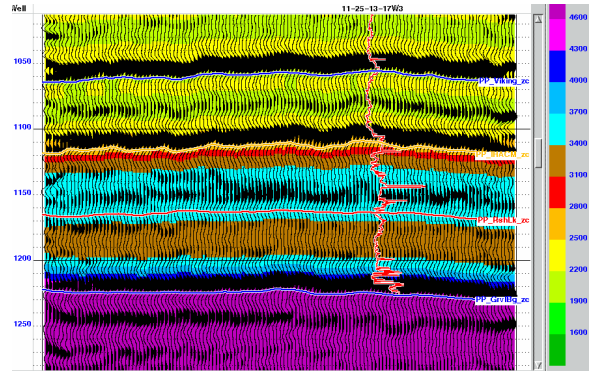


Figure 4. The S-impedance background initial model.

PS wavelet

The PS wavelet is then statistically extracted from all the PP-time PS seismic traces in the time window of 800ms – 1300 ms, excluding the edge traces.

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).

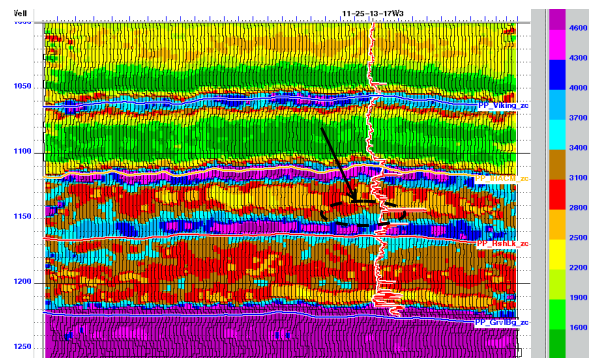


Figure 5. The inversion result of PS data.

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Vp/Vs Calculation

Now we have the inverted P-impedance volume and S-impedance volume. Ideally, the Vp/Vs volume can be obtained 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 considered 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 proper 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.

Post-stack PS data has been commonly used for normal interpretation. To get S-impedance from PS data, the better way is to do it in the pre-stack stage, which reveals the S-reflectivity by considering offsets or incident angles. This will be the future work.

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.

Acknowledgements

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References

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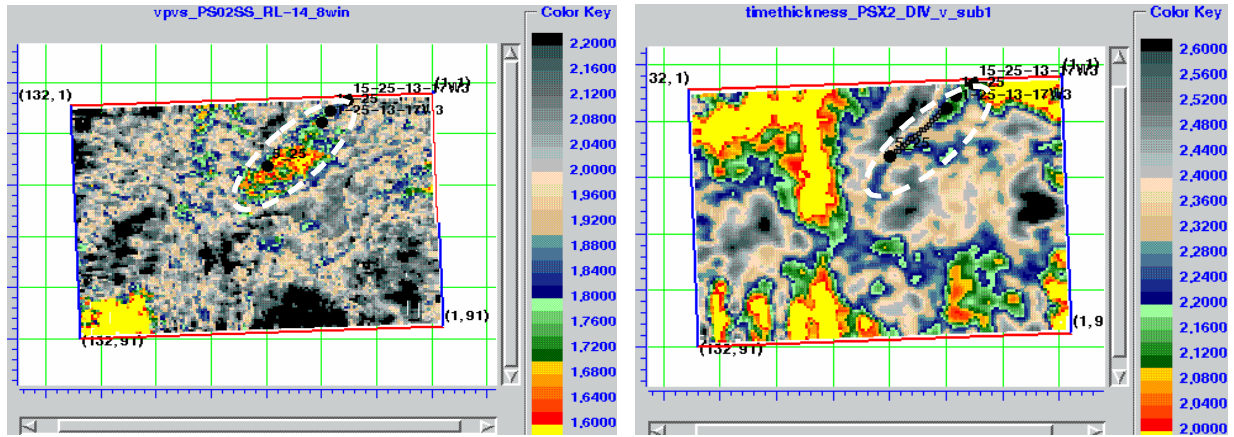


Figure 6. Comparison of Vp/Vs derived from impedance (left) and Vp/Vs derived from time-thickness ratios (right).

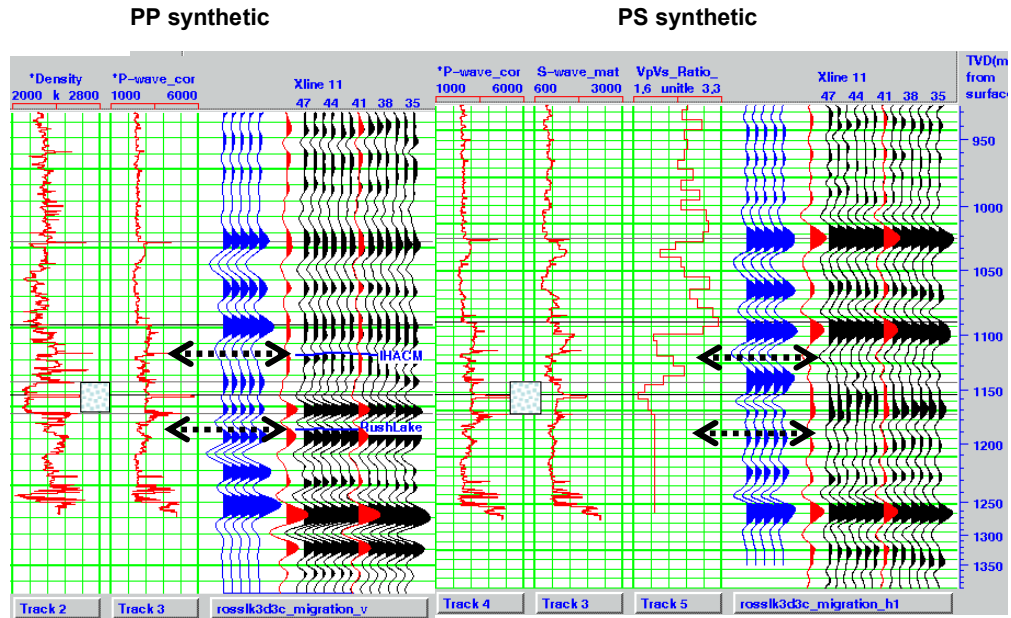


Figure 7. Logs, synthetic seismogram and seismic traces of PP (left) and PS data (right). The white block shows the reservoir sand.