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Integration of Well Logs and Seismic Data for Prediction of Elastic Properties in a Heavy Oil Sand Reservoir: Manitou Lake, Saskatchewan

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Summary

Wells logs and seismic data were used to estimate elastic properties in a heavy oil sand reservoir. Previous studies have shown that there is little change in the P-wave velocity at the sand/shale interface, while the shear-wave velocity increases significantly from 800 to 1300 m/s. Post-stack inversion results show the importance of the frequency bandwidth of the data, with the PS inversion resulting in a smoothed impedance estimate. In general, V_p/V_s values lower than 2.15 have been determined to indicate sand reservoirs, and within the target zone densities lower than 2250 kg/m^3 further indicate sands.

Introduction

The estimation of elastic parameters, such as shear wave velocity and density, has become crucial for reservoir characterization, especially in cases where the P-wave information leads to ambiguous results. Nonetheless, the promise of converted-wave data usually has some of its own challenges, such as lower frequency content than the P-wave data, and the difficulty in correlating the P- and S-wave data sets to ensure consistent interpretations of the horizons of interest. However, with recent improvements in acquisition and processing of multicomponent data, the more recent converted-wave studies have proven useful for fluid and lithology estimations.

The Manitou Lake oilfield is located in west central Saskatchewan, approximately 50 km southeast of the city of Lloydminster. Production in this field comes mainly from channel facies of the Colony and Sparky B members of the Cretaceous Mannville group. In this area, the Colony sand member has been extensively explored using conventional seismic techniques, with bright spot anomalies on the amplitude maps being the main tool to delineate the sand channels. Royle (2002) used AVO and post-stack attributes to extract fluid and lithology information from seismic and well log data, in an attempt to better delineate the reservoir channels. However, previous studies in this area have shown similarities in the P-wave impedance response between the prospective channel sands and the non-productive shales, as well as a direct correlation between lithology and the Vp/Vs value (Soubotcheva and Stewart, 2006; Quijada and Stewart, 2008),

Rock Properties

The data from the Manitou Lake oilfield used in this project includes a suite of logs from two wells (A11-17 and C07-16), as well as a 3D-3C seismic survey acquired by Kinetex. Inc in February 2005. Quijada and Stewart (2008) evaluated the petrophysical properties using wireline data from this field, and showed that the Vp/Vs value appears to give the best differentiation with regards to lithology, with sands having a Vp/Vs value lower than 2.15. Also, the P-wave velocity shows almost no change at the sand/shale interface, and is more affected by the saturating fluid. Density values overlap significantly between sands and shales (See Figure 1A) over the complete interval of the logs (100-600 m); however, within the target zone, density is also a good lithological indicator, with densities lower than 2250 kg/m3 indicating sands, and higher values corresponding to shaly sands and shales (Figure 1B).

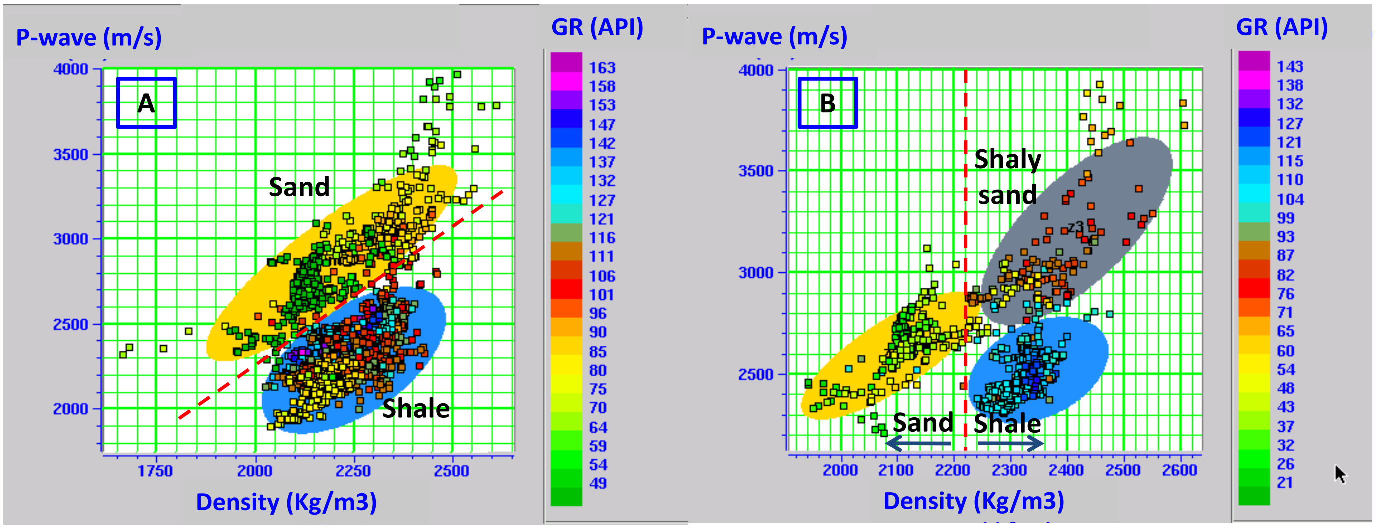

Figure 1: P-wave velocity versus density crossplot for well C07-16. Colorbar indicates GR values. (A)Crossplot for the complete depth interval of the log; (B)Crossplot within the target zone (500-600 m)

Forward modeling

Three modeling approaches were used to predict elastic logs (Vp, Vs and Density): Gardner's density velocity relationship, log response modeling (Crain, 1986) and Kuster and Toksöz (1974). Calculations for Gardner were done using a least square fit on each zone defined in Figure 1A, and using the GR log as a lithology constrain, with values higher than 70 API corresponding to shales and lower values to sand. The log response equation models the rocks as having four major components that contribute to the log reading (e.g. water, hydrocarbon, shale and matrix). It results in accurate estimations within the deeper section; however, it requires significant input from the interpreter, including curves for shale volume, effective porosity and water saturation. Finally, Kuster-Toksöz' formulation for composite media was evaluated assuming a velocity linearly increasing with shale volume. Results from the modeling are generally very good within the deeper section; however, for depth shallower than 350 m it is possible to note a divergence between the model and original velocity logs, suggesting there is a significant change in the elastic properties at this depth.

Seismic Inversion

A model-based inversion of the PP and PS seismic volumes was evaluated to estimate P- and S-impedance values. The amplitude spectrum of the extracted wavelets (Figure 3) shows the significant difference in bandwidth between the two seismic volumes, while the PP bandwidth extends from 10 to 110 Hz, the PS frequency band is between 5 and 40 Hz.

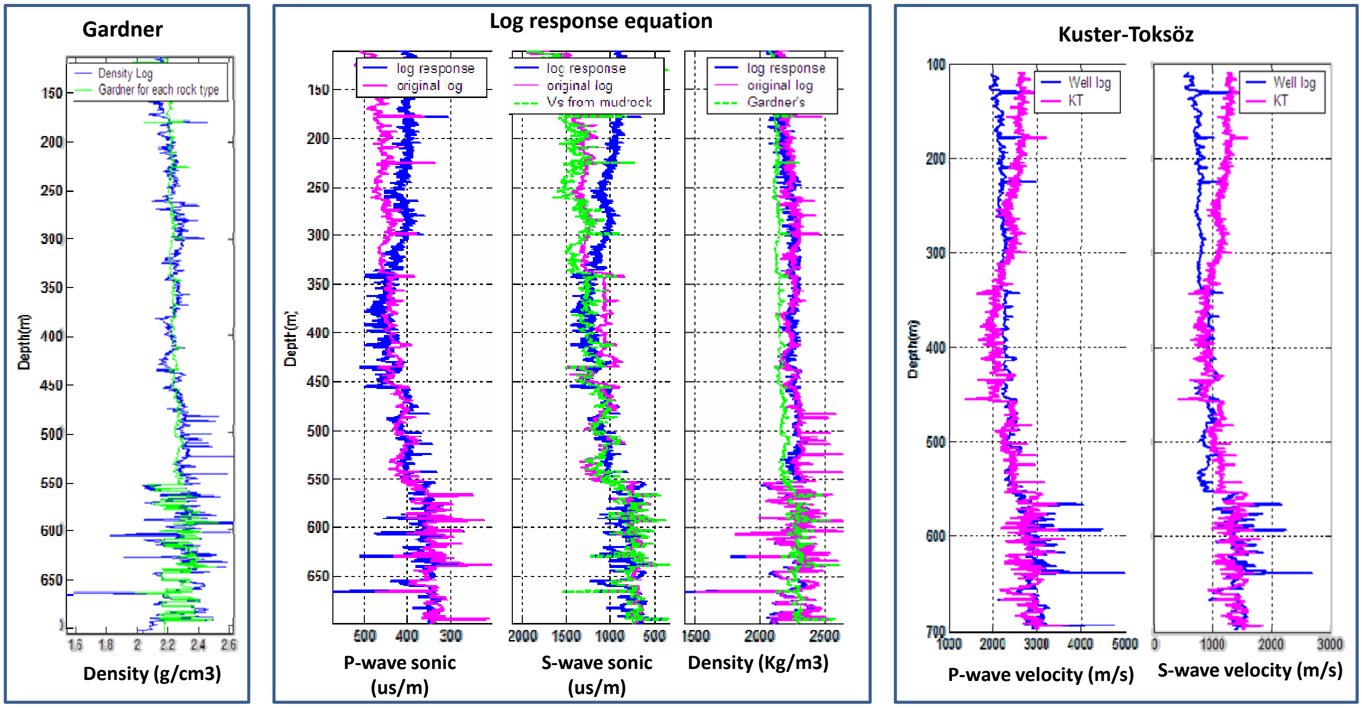

Figure 2: Predicted elastic logs using Gardner, log response modeling and Kuster and Toksöz formulation.

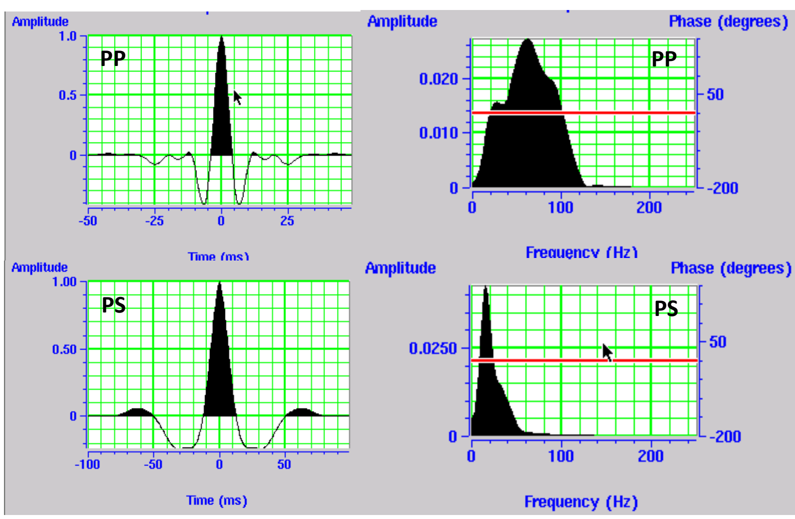

Figure 3: Extracted wavelet from the PP and PS seismic volumes, and their corresponding amplitude spectrum.

Figure 4 shows the results from the inversion analysis at well A11-17, with the red line indicating the inverted result and the blue line showing the original log. In both cases there is very good correlation (more than 97%) between the synthetic generated from the inverted result and the actual seismic data However, note the smooth character of the PS inversion result, due to the much lower frequency content of the PS data. Figure 5 shows the P- and S-impedance estimates inverted from the PP and PS volume. Note the low P-wave impedance anomaly associated to the top if the Colony and its limited lateral extent, suggesting it is related to the productive sand channel in this well. In this case, even though the P-wave velocity does not change significantly at the top of the channel, the decrease in density is large enough to generate a significant decrease in the P-impedance. There is no evident change in the S-impedance at the top of the Colony on the inverted section.

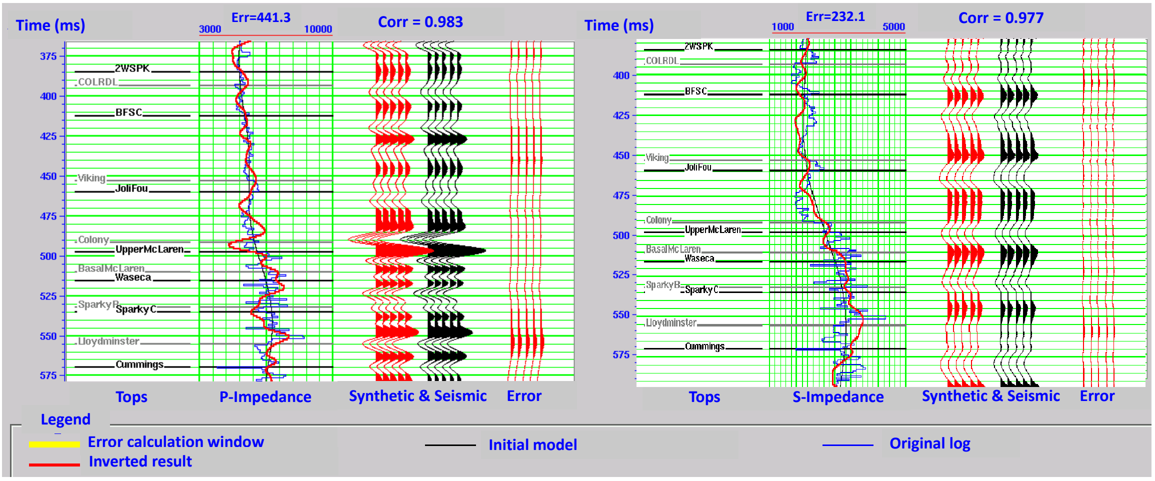

Figure 4: PP and PS inversion analysis at well location A11-17.

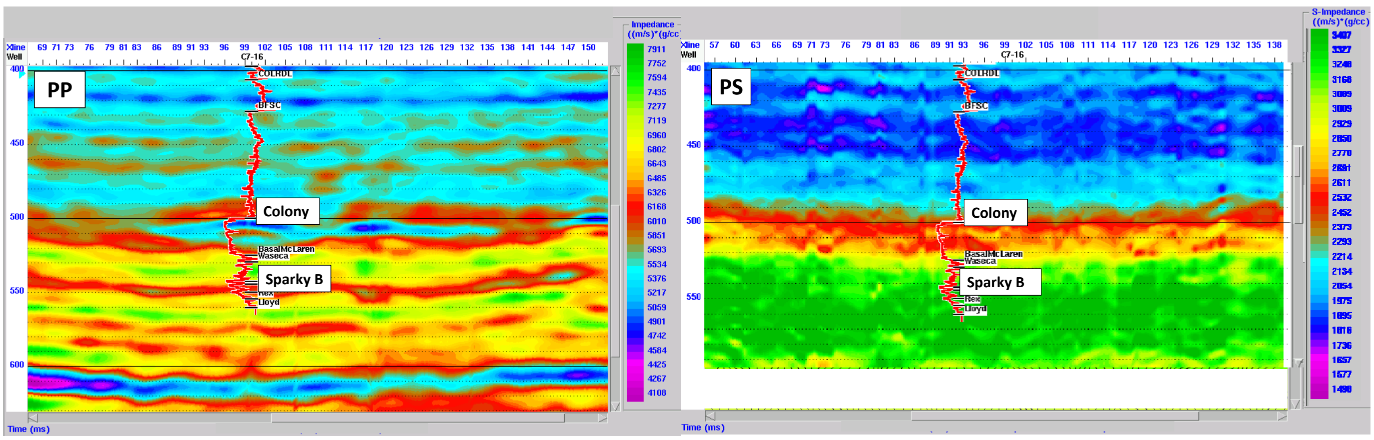

Figure 5: P- and S-wave impedance estimates from the mode-based inversion of the PP and PS seismic volumes.PS traces overlain on PS inversion result

Conclusions

Shear-wave velocity appears to be the best lithological indicator in the area, showing a change of 500 m/s at the sand/shale interface. Within the target zone, densities lower than 2250 kg/m^3 corresponds to clean sands, while shaly sands and shales have densities between 2250 and 2600 kg/m^3. Applying empirical relations, such as Gardner and the mudrock line, resulted in accurate estimations of elastic properties as long as a local fit was used to estimate the parameters. The post-stack inversion results show the problems encountered when the frequency bandwidth of the PS dataset is significantly lower than that of the PP data, highlighting an issue affecting converted-wave interpretation.

Acknowledgements

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